National Park Service
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Natural Resource Program Center

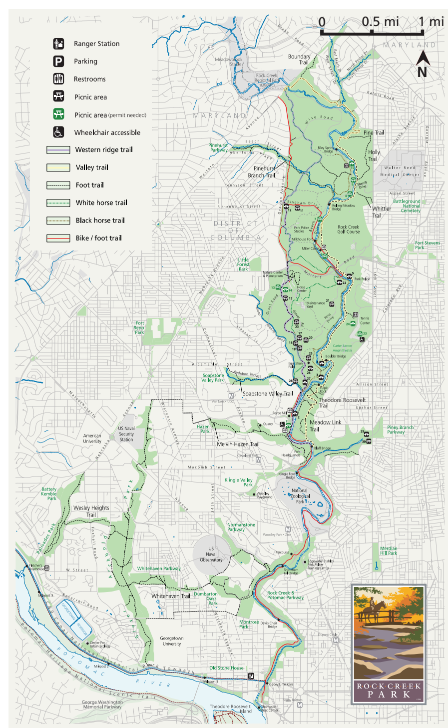
Rock Creek Park Natural Resource Condition Assessment

National Capital Region Network

Natural Resource Report NPS/NCRN/NRR—2009/109

The 11 parks of the NPS National Capital Region Network are shown in red.

The DC-VA-MD region and Potomac River. Map: Google™.



Rock Creek Park. Map: NPS.

ON THE COVER

Aerial photo of Washington, D.C. on the left and Rock Creek Park on the right. Photo: Tom Paradis.

Rock Creek Park Natural Resource Condition Assessment

National Capital Region Network

Natural Resource Report NPS/NCRN/NRR—2009/109

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May 2009

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National Park Service
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Fort Collins, Colorado

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NPS 100011, May 2009

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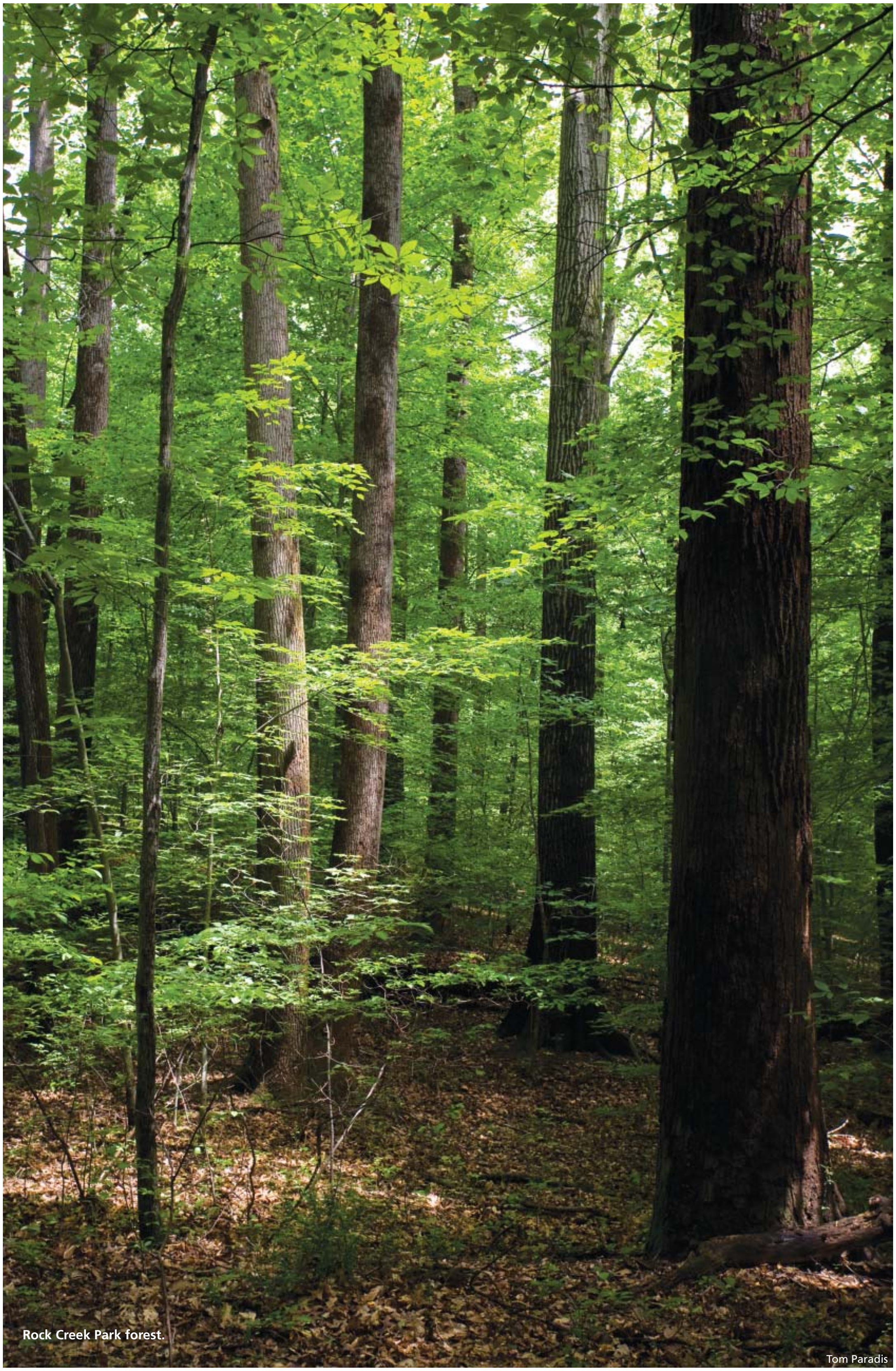

Rock Creek Park forest.

Tom Paradis

Executive Summary

Background

Rock Creek Park, established in 1890, is one of the largest urban natural parks in the world and provides both recreational and ecological benefits to millions of visitors. Even though the park is 81% forested and has extensive stream and wetland habitat, it nevertheless faces many ecosystem challenges as a consequence of its urban surroundings. The park is located at the downstream end of an urban watershed, with some tributaries of Rock Creek surrounded by more than 75% impervious surface.

In June of 2006, scoping efforts were initiated to compile existing natural resource data. Important sources of information used in this report include the products of short-term research studies, long-term monitoring, baseline inventories, and mapping. Inventory and monitoring 'vital signs' monitoring commenced within Rock Creek Park in 2003. This program provided the core data utilized in this natural resource condition assessment.

Rock Creek Park provides a wealth of natural resource values, largely resulting from the maintenance of forest and wetland habitats. The secondary growth forest, dominated by mixed beech and oak communities, functions as a regional refuge for forest dwelling bird species which have been showing regional declines. The large forest area also adds value to remnant forest patches surrounding the park, allowing for ecological connectivity between these fragments. Seep and spring habitats have been almost eliminated regionally with increased development, so the existence of these water resources in the park provides increasingly important habitat for native fauna and flora. Since being established, the park has provided a natural oasis for millions of visitors in the Washington D.C. area to enjoy.


Lisa Florkowski

A woodland footbridge over Rock Creek.

Rock Creek Park's natural resources are challenged by multiple regional and local stressors. Air pollution from power plants, industry and vehicle emissions result in reduced air quality through large regions of the central eastern seaboard of North America. The urban Rock Creek Park is therefore subjected to high ozone and atmospheric deposition, potentially impacting flora, fauna and park visitors. Watershed wide urbanization and development result in challenges to water quality and quantity. Increased nutrients, pollutants and flashiness of river flow can result in impacts to wetland flora and fauna as well as stream bank erosion, respectively. Locally, Rock Creek Park has very high visitation and therefore has increased pressure to develop new paths and facilities would that potentially stress the connectivity of natural habitats.

Sewage outfalls following rain events sends pollution to park streams, as this sign on zoo grounds forewarns.

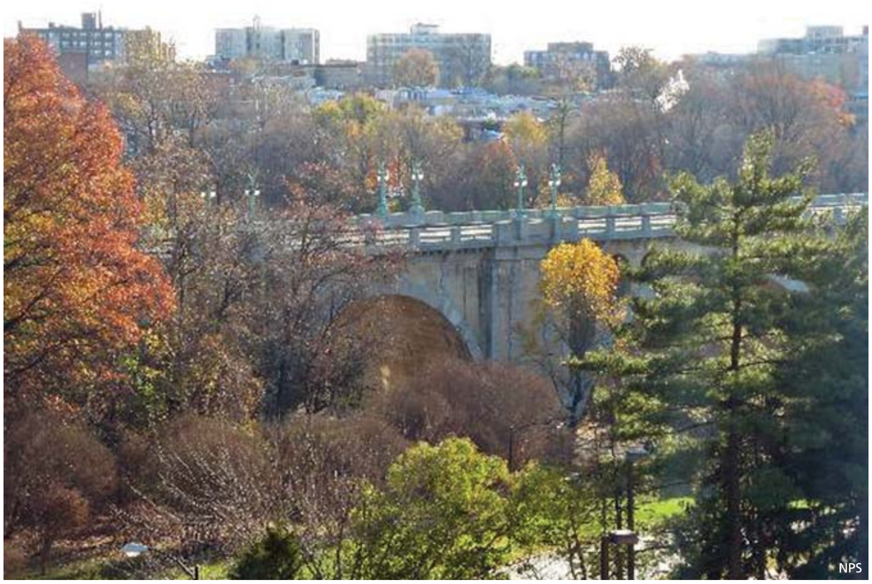
Natural resource condition assessment

Assessment of natural resource conditions within Rock Creek Park was carried out using two synthetic frameworks. Both were based on categories that addressed key structural and functional aspects of the ecosystem. The first framework was an ecological monitoring framework based on the Inventory and Monitoring vital signs categorization of metrics. These 29 metrics were synthesized in four categories: **Air Quality**, **Water Quality**, **Biodiversity**, and **Ecosystem Pattern and Processes**. The second framework focused 21 metrics in the three dominant habitat types present within Rock Creek Park, **Forest Habitat** (81% of the area), **Wetland (Inland) Habitat** (2% of the area) and **Artificial-terrestrial Habitat** (17% of the area). The synthetic assessment of condition was based on a comparison of available data collected between 2000 and 2008 to justified ecological threshold values. The assessment was then presented in a conceptual framework of desired to degraded condition.

Posted fencing protects a sensitive amphibian breeding area from people off trails and pets off leashes, but poor water quality can threaten their viability as well.

Ecological monitoring framework

The ecological monitoring framework showed that, within the park, **Air Quality** was generally in degraded condition, **Water Quality** was highly variable but generally good, **Biodiversity** was generally fair, and **Ecosystem Pattern and Processes** were generally good. In good condition according to indicators included: percent cover of forest habitat, percent impervious surface within park boundaries, amphibian occupancy, the presence of important forest interior bird species, and the lack of forest insect pests. Stream water quality showed mixed results. While several stream parameters (temperature, pH, dissolved oxygen concentration, and physical habitat) were found to be in good condition, other chemical components (salinity, nitrate concentration, total phosphorus concentration) seldom met threshold standards. Total phosphorus, in particular, was exceptionally high and always exceeded acceptable concentrations. Other areas of concern included native seedling regeneration, white-tailed deer densities, invasive exotic species, and several components of air quality (ozone concentration, particulate matter concentration, and mercury deposition). Decline in water quality, air quality, and stormwater management usually indicate regional or watershed changes rather than processes within the park boundaries alone.



This view across Rock Creek Park illustrates the periodic breaks in forest cover as the park is intersected by roads and bridges, and fragmented by urban and suburban development.

Recommendations based on habitat monitoring framework

The habitat monitoring framework showed that, within the park and in general, **Forest Habitats** (Biodiversity and Ecosystem Pattern and Processes metrics) were assessed to be good, **Wetland (Inland) Habitats** were fair (Water Quality and Biodiversity metrics), and **Artificial-terrestrial Habitats** were degraded (Biodiversity, Ecosystem Pattern and Processes, and Air Quality).

Forest Habitats (81%) have high overpopulation of deer, resulting in overgrazing of vegetation and limited regeneration of native seedlings as well as negative impacts upon diversity and abundance of forest interior dwelling bird species and increased road collisions. It is recommended to implement deer population control measures to reduce the current population, 26 deer km^{-2}. Another challenge to Forest Habitats was the presence of exotic plants (including shrubs and trees) currently over 16% by area. It

A white-tailed deer hesitates before crossing a winding, sometimes busy park road.

Tom Paradis

LEFT: Mile-a-minute (*Persicaria perfoliata*), one of the fast-growing, exotic plants the park works to control, reaches for the tree tops.

RIGHT: A volunteer holds an American robin (*Turdus migratorius*) as part of the joint National Park Service and the National Geographic Society's May 2007 BioBlitz, a 'snapshot' of biodiversity in Rock Creek Park.

Tom Paradis

Ryan Valdez, DCNature.com

is recommended to emphasize early detection of these species, continue controlling them when detected and clearly prioritize control strategies based on characteristics such as relative invasion and expansion rates of different species. Forest Habitats within Rock Creek Park were found to be intact and to act as an important refuge for forest interior dwelling birds and potentially for other fauna such as amphibians. It is recommended to maintain forest connectivity and reduce forest fragmentation by minimizing stressors such as dumping, roads, structures, trails, and fires.

Wetland Habitats (2%) within Rock Creek Park are challenged by elevated nutrient concentrations and salinity, resulting in negative impacts on stream flora and fauna and potential reduction of visitor experience. It is recommended that road salting should be managed to further reduce impacts to streams and that nutrient reduction strategies should be implemented. Increased storm driven river flow and resultant bank erosion were also identified as concerns.

Artificial-terrestrial Habitats (17%) within the park are a highly visible and highly utilized visitor use habitat but are poorly characterized in terms of ecosystem value. To improve future assessments and better identify management needs within this habitat, it is recommended to implement monitoring such as soil compaction and invasive exotic species presence in these areas, as well as develop inventories of some key insect species. The assessment of this habitat also highlighted the poor air quality and therefore the need for regional partnerships and education to improve air quality.

A seasonal wetland, habitat to a variety of flora and fauna, begins to dry up in Rock Creek Park.

With a summer picnic and soccer game, park visitors enjoy the artificial-terrestrial habitat of mowed lawns within Rock Creek Park.

Data gaps

Many aspects of park resources are well understood, however some data on important aspects of flora and fauna, as well as inputs and stressors, are still required. Data gaps and research needs identified during the assessment include the quantification of groundwater inputs and especially a better characterization of the water quality and biotic integrity of the many seeps and springs within the park. The sources of nutrients and salt are poorly defined (though clearly a challenge); tracer studies and identification of point and diffuse sources both within and outside the park as well as the development of nutrient budgets would address this data gap. Other important areas for further in-depth research include a better understanding of invasive exotic species and forest regeneration under high deer grazing pressure, especially the potential benefits of exclosures as well as a better understanding of potential barriers to plant and animal dispersal among forest patches as they become increasingly fragmented in the park and the park surroundings. An improved understanding of local air quality would be helpful to downscale regional data; park data could be used to calibrate air quality transport and depositional models to achieve this goal. Finally, another need is an accounting of inner-basin water transfers and coordination with regional agencies and stakeholders to maintain water quantity by reducing flows and reducing flow variability.

Rock Creek Park staff and scientists review results of species survey.

Applicability of the natural resource condition assessment

The synthesis and frameworks presented in this report have the potential to include monitoring data directly in a park adaptive management cycle of conceptualization, implementation, evaluation, and communication. One of the challenges or data gaps that became apparent in the process of synthesizing available data was the disparity between the scales of available data and the scales of required management questions or needs. However, the identification of relevant ecosystem metrics that are sensitive and measurable and the development of relevant threshold values mean that the presented synthetic frameworks (ecological monitoring-based and habitat-based) can be applied to the collection of monitoring data and answering specific within-park management questions.

Conclusions

Rock Creek Park was determined to have very high regional ecological value, supporting large intact areas of forest habitat, bird and amphibian communities, and increasingly rare seeps and springs. While the high deer population is the largest internal threat to the natural resource condition of the park, the impact of invasive exotic species and automobile traffic are equally significant. However, the natural resource value of Rock Creek Park is mainly threatened by regionally poor air quality and inadequate stormwater management in a highly developed urban and suburban watershed. This suggests that the strengthening of local and regional partnerships is essential if Rock Creek Park is to be maintained as an ecological oasis in an urban landscape.

NPS

Artificial-terrestrial habitats within Rock Creek Park can provide natural resources as well as recreational value.


Built in the 1820s, Peirce Mill is the last extant 19th century gristmill in D.C.

The Library of Congress

Chapter 1: Introduction

A historical, political, and programmatic context to the Rock Creek natural resource condition assessment.

History of Rock Creek Park

Rock Creek Park was established in 1890 as one of the first federal parks. When the park was established, it was on the edge of a growing city and was already a favorite area for rural retreat in the nation's capital. The park was established at a significant time in the development of what would later become the National Park System (Mackintosh 1985).[1] In 1872, Yellowstone was reserved as the first national park by Congress, "dedicated and set apart as a public park or pleasure ground for the benefit and enjoyment of the people." This language is significant because the legislation for Rock Creek Park adopted language from the Yellowstone Act. The protective prescription for Rock Creek, modified only slightly from that of Yellowstone, called for regulations to "provide for the preservation from injury or spoliation of all timber, animals, or curiosities within said park, and their retention in their natural condition, as nearly as possible." (Ch. 1001, 26 Stat 492).

As the first park situated in the nation's capital, Rock Creek Park has a long and rich history. Peirce Mill is perhaps Rock Creek Park's most prominent historic feature. Situated on the west bank of Rock Creek, Peirce Mill is the only one of several 19th century mills still standing. The park commission acquired the mill property in 1892. The mill continued to grind corn and grain until 1897, when its main shaft broke. Today, the mill serves as a reminder of the park's importance to local commerce and trade.

Rock Creek Park would serve as a convenient and welcome respite for many prominent visitors, including U.S. Presidents. Best remembered among them is Theodore Roosevelt, who commented on the park in his 1913 autobiography (Roosevelt 1913):

"While in the White House, I always tried to get a couple hours' exercise in the afternoons—sometimes tennis, more often riding, or else a rough cross-country walk, perhaps down Rock Creek ... Often, especially in the winters and early springs, we would arrange for a point to point walk, not turning aside for anything—for instance, swimming Rock Creek or even the Potomac if it came in our way. Of course under such circumstances we had to arrange that our return to Washington should be when it was dark, so that our appearance would scandalize no one. On several occasions we thus swam Rock Creek in the early spring when the ice was floating thick upon it. We liked Rock Creek for these walks because we could do so much scrambling and climbing along the cliffs."

Old wooden foot bridge, Rock Creek Park, Washington, D.C., ca. 1930.

NPS Archive

[1] Several historical details used in this report about Rock Creek Park have been excerpted from the excellent administrative history written by an NPS employee, Barry Mackintosh, in 1985.

Woodrow Wilson also enjoyed Rock Creek Park during his presidency, especially for walks while courting Edith Boiling Galt, who would become his second wife. The significance of the park's forest to Wilson is best evidenced by an event when the Office of Public Buildings and Grounds undertook to remove numerous dead trees, mostly blighted chestnuts. Hundreds were sold to private cutters for telephone and telegraph poles. President Wilson was unconvinced that only blighted trees were removed and complained,

> *"I do not profess to be a forester, but the great majority of trees that I have noticed laying prostrate in the park are certainly sound. I know a sound tree when I see it inside the bark. Moreover, in one part of the park a whole plantation of young pines have been cut down and it made my heart ache to see it."*

The natural resources of Rock Creek Park have suffered from multiple environmental assaults since the park's inception. Dr. E.P. Meinecke, a natural scientist on the National Park Service staff, recorded his views on Rock Creek Park in 1934:

> *"The strongest impression I get is that of disappointment. I have every reason to expect, in a large city, the capital of the Nation, a Park representing that which is best in American landscape art, designed to serve a large and growing number of its inhabitants as a place of recreation and refuge from the turmoil and heat of the city. I find instead a curious mixture of more or less futile attempts at landscaping and of wild or rather unkempt growth, haphazardly developed, of amateurish attempts at embellishment side by side with crudest neglect … There is at present, little pleasure to be gained from visiting the creek itself … The water is dirty and the smell of decaying filth is anything but agreeable."*

He attributed much of this problem to an inadequate storm sewer gate in Piney Branch, which in heavy rain let raw sewage into the stream.

The primary feature of Rock Creek Park—the creek itself—would continually face assaults over time by its urban and suburban surroundings. In 1922, designated children's bathing places were identified as subject to very high fecal contamination, traced to sewage from Bethesda and Kensington, Maryland. Further, the volume of stream flow had become a matter of increasing concern in the 1920s. By 1929, the U.S. Geological Survey and the Federal Water Pollution Control Administration had conducted detailed studies to monitor water quality in the creek. A stream gauge was installed and two reservoirs

An August 1933 hurricane caused extensive flooding and erosion to the streambeds of Rock Creek Park.

(Lakes Needwood and Frank) were built upstream in Montgomery County in the 1960s by the Soil Conservation Service (the gauge and reservoirs still exist).

In summary, Rock Creek Park has served as a stalwart, though frequently beleaguered, jewel in the nation's capital for 119 years. It is one of the largest natural urban parks in the world and faces immense challenges in providing recreational benefits to millions while striving to protect and preserve the ecological processes and natural resources of its streams and forests.

Mission, goals, and context

There are two important mandates that broadly direct the natural resources protection and management of Rock Creek Park: the 1890 enabling legislation, and the National Park Service Organic Act of 1916 ("Organic Act", Ch. 1, 39 Stat 535). The "Organic Act," which established the National Park Service (NPS), provides the primary mandate for natural resource protection within all national parks. It states,

> *"the Service thus established shall promote and regulate the use of Federal areas known as national parks, monuments and reservations ... by such means and measures as conform to the fundamental purpose of the said parks, monuments and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."*

Consequently, chief among Rock Creek Park's environmental mandates is to preserve scenery and the natural and cultural resources of the park. Any visitor activities associated with enjoyment can occur only to the extent that they do not impair the scenery and the natural and cultural resources for future generations.

The General Management Plan for the park (NPS 2006), a guide and planning document that is subject to change and modification, provides details of what resource conditions the park considers significant and fundamental to the enabling legislation and management of the park. The NPS defines the most fundamental criteria for which the park is managed as follows:

- preserve the flow of water in Rock Creek;
- prevent the pollution of Rock Creek and the Potomac River; and
- preserve forests and natural scenery in and around Washington, D.C.

Transportation corridors, such as this Washington D.C. trolley bridge (ca. 1930) over Rock Creek, have challenged the park's natural resources for many decades.


NPS

INTRODUCTION

The following significant statements recognize the important features of the park:

- *Rock Creek Park is one of the oldest and largest naturally managed urban parks in the United States.*
- *The park contains approximately 1,754 acres of valuable plant and wildlife habitat, providing protection for a variety of native species within a heavily urbanized area.*
- *Rock Creek Park encompasses a rugged stream valley of exceptional scenic beauty with forested, natural landscapes and intimate natural details, in contrast to the surrounding cityscape of Washington, D.C.*
- *Rock Creek Park's forests and open spaces help define the character of the nation's capital.*

Rock Creek Park is therefore an urban park that has been established to preserve and maintain a natural environment within an urban landscape. The natural resources cited as fundamental or significant are primarily forested and riparian habitats. Thus, we gave specific attention to these habitats during the condition assessment process.

Rock Creek Park has always provided recreational respite from city life, as illustrated by these picnickers, ca. 1940.

Natural resource condition assessment

In the 2003 Federal Appropriations Act, U.S. Congress instructed and funded NPS to assess environmental conditions in watersheds where National Park units are located. Park managers currently face threats from nutrient enrichment, exotic species, air and water pollution, stormwater, and urban development. The Watershed Condition Assessment (WCA) program was established to help NPS better address stressors and management issues at park, watershed, or regional scales. Chief among the goals of the WCA program is to disseminate information gained via Natural Resource Condition Assessments (NRCA) and to provide a basis for actions that reduce or prevent impairment of park resources.

The Natural Resource Condition Assessment proposed here will:

- use existing information sources to evaluate the condition of park natural resources;
- identify current or potential stressors to park natural resources;
- identify information gaps or inventory and research needs; and
- provide data-based management recommendations.

Information used in the assessment is multidisciplinary (e.g., biology, ecology, water chemistry, hydrology, etc.) and from a variety of sources, including NPS, other federal agencies, state and local agencies, organizations, and individual researchers. The NRCA is divided into three descriptive components: natural resources, current and potential stressors, and a multi-scaled condition assessment. Practical limits to this assessment include a reliance on existing and readily usable data (i.e., no new data collection), and a park-wide scope to the assessment. Watershed-level interpretation was made whenever practical. However, such broad-scale inference was not always possible (or warranted) given the constraints described.

The WCA program has adopted the goal of completing NRCAs for 270 national parks by the end of fiscal year 2014. Rock Creek Park was selected as the first pilot for a condition assessment in the National Capital Region in 2006. The timeline for the completion of all 11 natural resource parks in the National Capital Region is as follows: MONO, MANA, ANTI (2007-2010), PRWI, CATO, HAFE, upper CHOH (2009-2013), NACE, GWMP, WOTR, and lower CHOH (2011-2014).[2] The approximate level of funding per park is $44,000 and it is anticipated that NRCAs will be duplicated at each park on an eight-year continual rotation.

Literature cited (Chapter 1)

Ch. 1001, 26 Stat 492. An act authorizing the establishing of a public park in the District of Columbia. 51st U.S. Congress, September 27, 1890.

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Mackintosh, B. 1985. Rock Creek Park: An administrative history. U.S. Department of Interior, National Park Service, Washington, D.C.

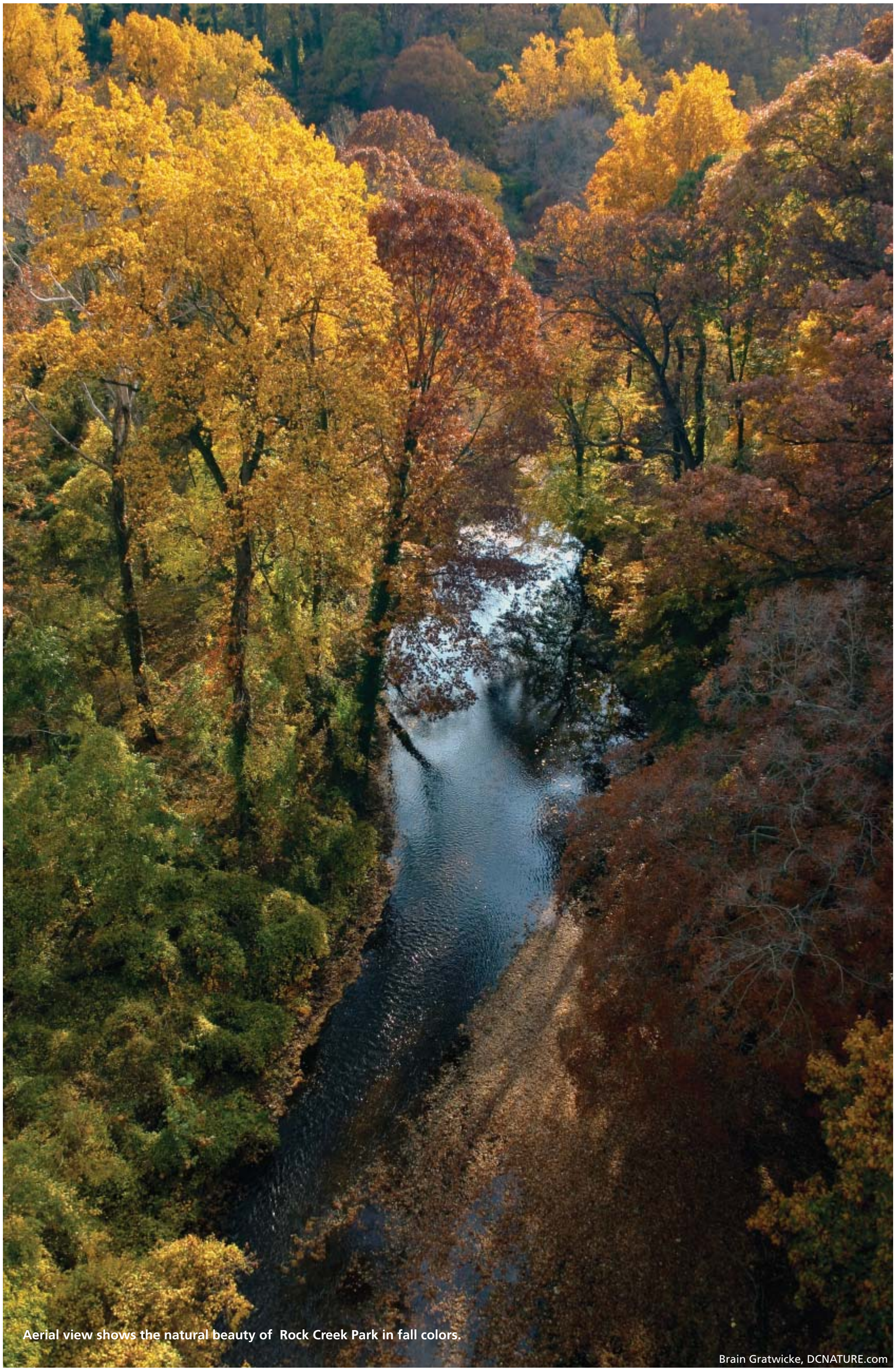
NPS. 2006. Draft general management plan/environmental impact statement: Rock Creek Park and the Rock Creek and Potomac Parkway. U.S. Department of Interior, Washington D.C.

Roosevelt, T. 1913. Theodore Roosevelt: an autobiography. MacMillan & Co., New York, NY.


The Library of Congress

Historic Milkhouse Ford was one of at least a half-dozen natural creek crossings in the early 1900s in Rock Creek Park.

[2] Park name acronyms are listed in Appendix Table B.6.


Aerial view shows the natural beauty of Rock Creek Park in fall colors.
Brain Gratwicke, DCNATURE.com

Chapter 2: Natural Resources

A summary of key data available on the natural resource values within Rock Creek Park.

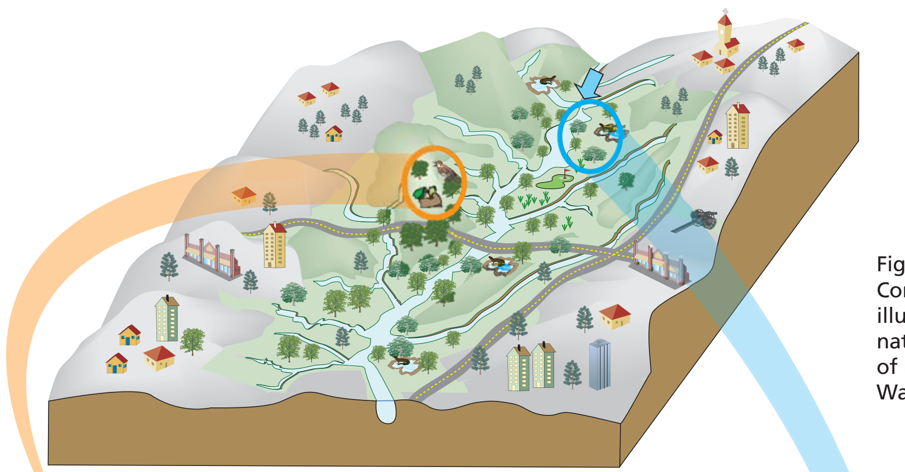
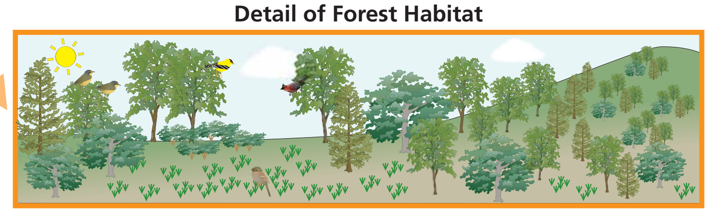


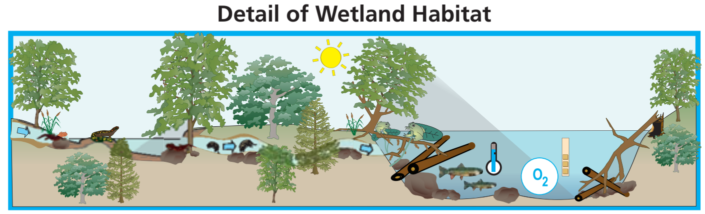
Figure 2.1. Conceptual diagram illustrating the key natural resources of Rock Creek Park, Washington, D.C.

Detail of Forest Habitat



Rock Creek Park has high forest cover dominated by mixed beech-oak forest with patches within and outside the park that can support sensitive forest-dwelling bird species .

Detail of Wetland Habitat



Rock Creek has generally high dissolved oxygen with reduction in summer months, and an adequate acid neutralizing capacity and buffered stream waters . Shading keeps park waters cool year-round , and the logs , pools, and riffles of stream habitat maintain diverse amphibian communities. Abundant springs and seeps support significant and rare fauna .

Introduction

Rock Creek Park provides natural habitat for many plant and animal species as well as a recreational retreat for residents in the Washington D.C. area (Figure 2.1). For more than a century, Washington, D.C. has grown to the point that the park no longer resides on the edge of the city, but within the city suburbs. The park maintains a wealth of natural resources that are enjoyed by millions of visitors each year. For the last 15 years, approximately 300,000 visitors per year have used the trails within Rock Creek Park for biking, hiking, jogging, or picnicking and around two million visitors per year have stayed within the park for at least half an hour (NPS Public Use Statistics Office[3]).

Data collection

Geospatial data (GIS) scoping began in September 2006 in conjunction with projects predating this effort (Dennison 2005). Data were exchanged and compiled through a series of meetings with staff from Rock Creek Park, the NPS Center for Urban Ecology (CUE), National Capital Region Network, and the Maryland Biological Stream Survey. In addition, GIS data were obtained from federal, state, and local web portals, such as EPA STORET, USGS NWIS, USGS Seamless Server, and the USDA Geospatial Data Gateway.

Data scoping workshop at the NPS Center for Urban Ecology.

Initial scoping for legacy datasets was conducted during a meeting in June 2006 at CUE. Attendees included scientists from NPS, local, and federal government, and academia (Appendix Table B.4).

Geology

The Rock Creek watershed contains a geologic feature called the Fall Line, which marks the east-west boundary between two physiographic provinces: the Piedmont and the Coastal Plain (Figure 2.2). The Piedmont Plateau underlies the western portion of the park and is characterized by exposed metamorphic rocks, rolling terrain, and fast flowing streams. The Coastal Plain is flatter, has few rocky outcrops, and has slower-moving streams (CH2m Hill 1979).

Soils

The soils within Rock Creek Park reflect, in part, the characteristics of the physiographic provinces running through the park (Figure 2.3). Soils found in the Piedmont Plateau areas (e.g., Brandywine Association) exhibit characteristics of moderate permeability, availability, and water holding capacity. These soils also tend to be moderately to severely erodible. Soils of the Coastal Plain (e.g., Sassafras-Chillum Association) contain relatively more gravel and sand, are well drained, and more acidic (CH2m Hill 1979).

[3] *http://www.nature.nps.gov/stats/*

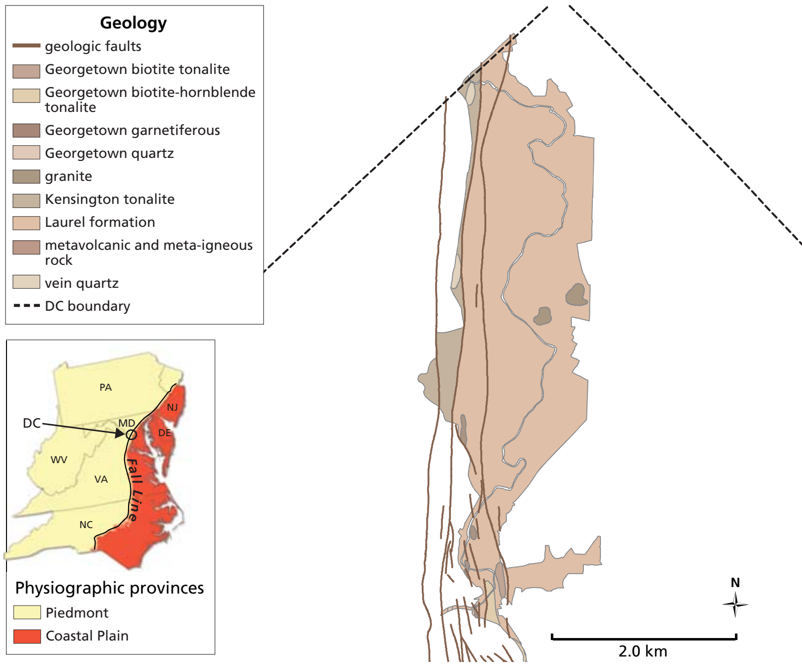


Figure 2.2. GIS data layer[4] of geologic faults and bedrock geology for Rock Creek Park, Washington, D.C.

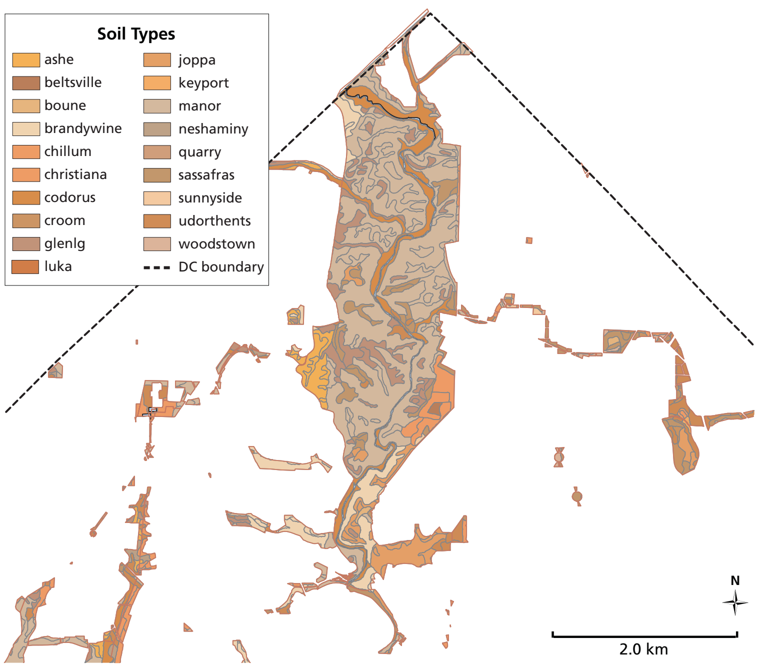


Figure 2.3. GIS data layer[5] of soil types found in Rock Creek Park, Washington, D.C.

[4, 5] NCRN I&M

Habitats

Using the International Union for the Conservation of Nature definitions[6] (IUCN 2007), we considered three predominant ecological habitat types within Rock Creek Park. These were: **Forest Habitat**, **Wetland (Inland) Habitat**, and **Artificial-terrestrial Habitat** (Figure 2.4). These habitats are transitional between the two physiographic provinces represented within the park, as Rock Creek Park runs along the topographic break separating the Piedmont Plateau (to northwest of park) and the Atlantic Coastal Plain (to southeast of park) provinces. We recognize that many ecological classification systems exist, many of which are based on vegetation communities (Anderson et al. 1998, Grossman et al. 1998) or land cover (Anderson et al. 1976). We chose a classification system that is at a high level of classification to permit comparisons to other systems (i.e., formation class or Anderson level one) while also being appropriate to data collection density.

Forest Habitat

Forest habitats constitute the majority of Rock Creek Park, covering approximately 81% of the park's 1,754 core acres (Figure 2.4), and are monitored at a series of sites (Figure 2.5). The park is dominated by a mixed beech *(Fagus grandifolia)* and oak (*Quercus* spp.) community (Figure 2.6). Though establishing legislation for the park identifies "timber" as an essential resource to the park, NPS policies require consideration of a broader ecological context and therefore consider "timber" to mean not just individual trees, but the interrelated plant and animal populations that form the forest community as well (NPS 2006). The forest at Rock Creek Park is comprised entirely of secondary growth, the majority of which is more than 100 years old. Activities prior to the park's establishment in 1890, such as timber cutting, farming, and Civil War clearing, removed much of the original forest. A few large oaks still living in the

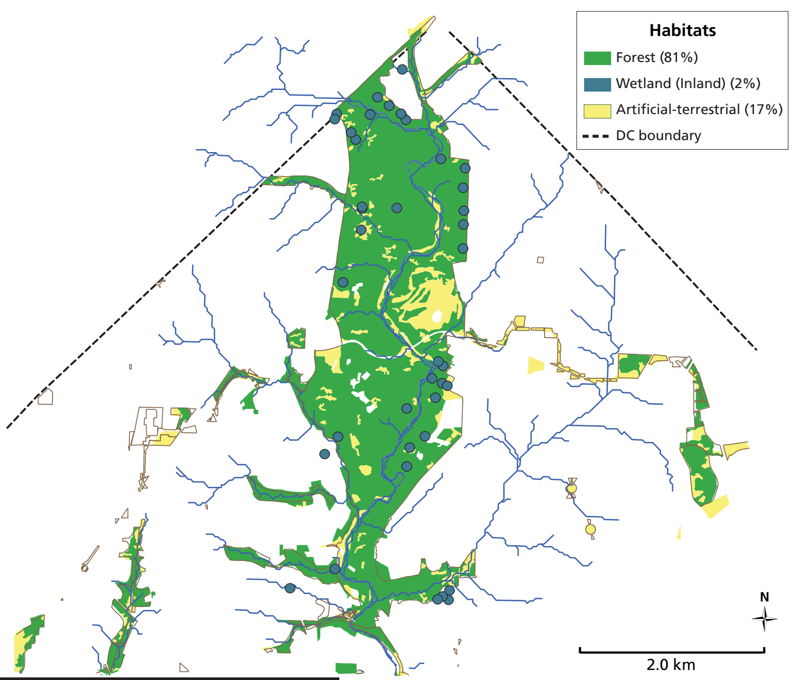
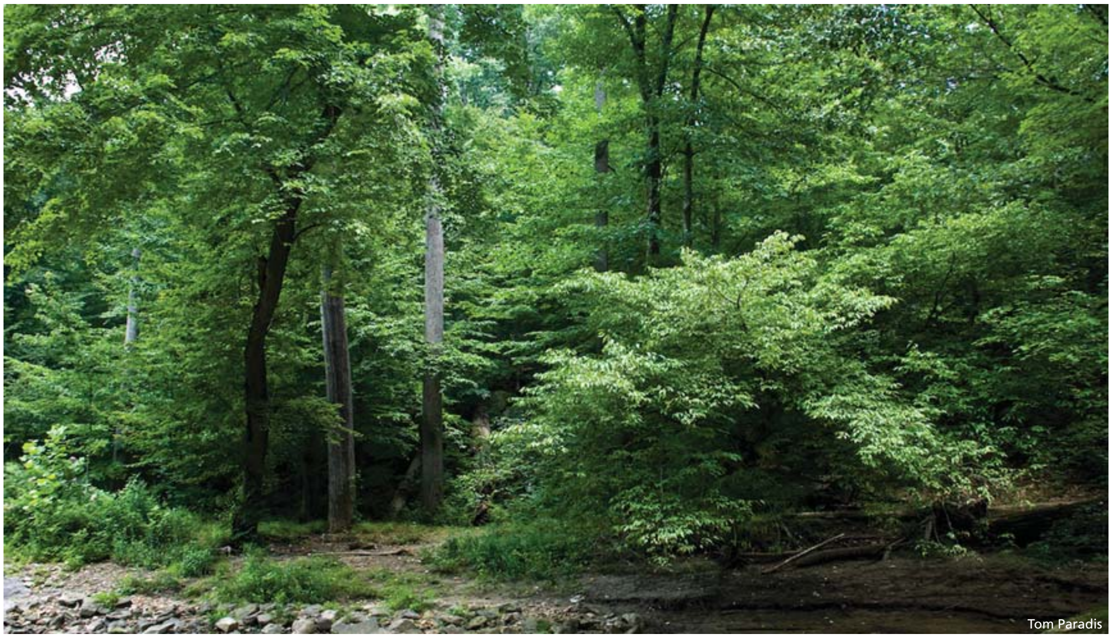


Figure 2.4. GIS data layer[7] of major habitat types in Rock Creek Park, Washington, D.C., as defined by aggregation of vegetation in Figure 2.6.

[6] *http://www.iucnredlist.org/static/major_habitats;* Appendix Table B.1.
[7] NCRN I&M



Beech-white oak/ may apple forest association in Rock Creek Park.

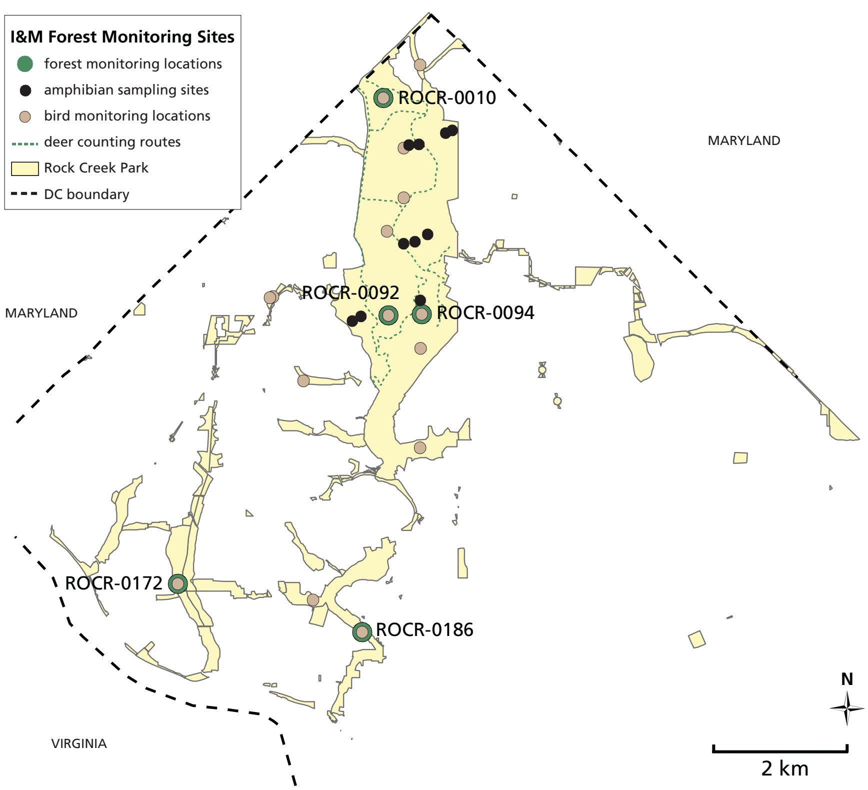


Figure 2.5. Sampling sites[8] for fauna and forest vegetation within Rock Creek Park.

[8] Norris et al. 2007

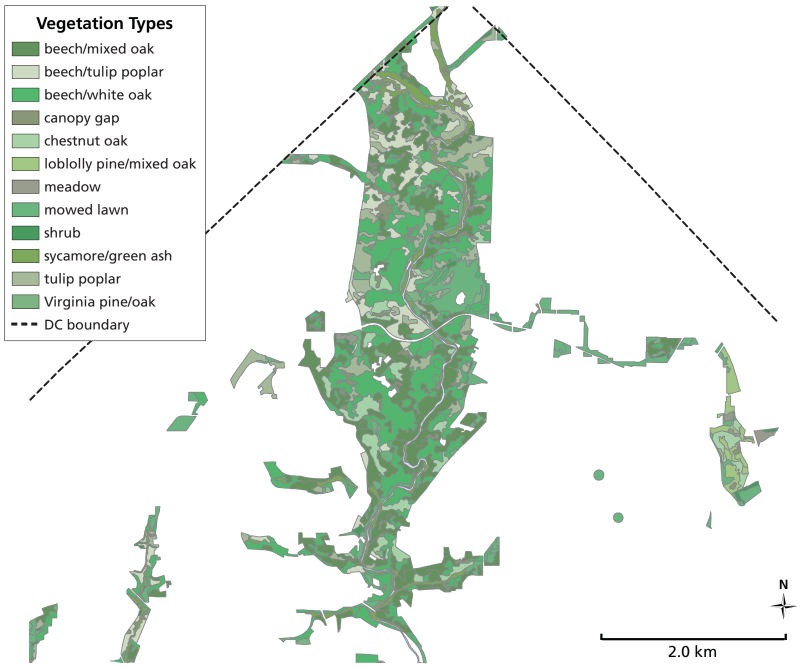


Figure 2.6. GIS data layer[9] of predominant vegetation types for Rock Creek Park, Washington, D.C.

park have been estimated to be more than 280 years old and may be remnants of virgin growth. Today's forests are primarily a mixture of deciduous species typical of the eastern deciduous forest in the later stages of succession.

The dominant forest type within this region historically was a "mixed oak forest" (Monk et al. 1990). The composition of dominant species within this forest type has undoubtedly shifted since the nation's capital was established. White oak (*Quercus alba*) has declined 12-49% in mid-Atlantic forests as a result of fire suppression, land conversion, selective logging (Abrams 2003), and to some extent as a result of forest pests like gypsy moth. In northern Virginia, white oak has declined 19% in forest composition since pre-settlement (Orwig and Abrams 1994). White oak has been replaced by red maple (*Acer rubrum*) and red oak (*Quercus rubra*), which benefitted from fire suppression, chestnut blight, and logging of other species (Abrams 2003). On a regional scale, fire suppression has led to a cascade of changes in composition and structure of eastern forests. Grasslands, woodlands, and savannas have been replaced by closed-canopy, shade-tolerant, fire-sensitive species (mesophytes) via a process called "mesophication" (Nowacki and Abrams 2008). The impacts of fire suppression and mesophication will likely play a significant role in shaping the long-term character of mesophytic forest communities of the mid-Atlantic region.

On a finer scale, the following five forest associations have been identified and mapped in Rock Creek Park using the National Vegetation Classification System developed by The Nature Conservancy (Grossman et al. 1998). The *beech-white oak/may apple forest association* occurs on moist to somewhat drier slopes. It is the most common of all associations found in the park. Two variants include the mixed oak/beech

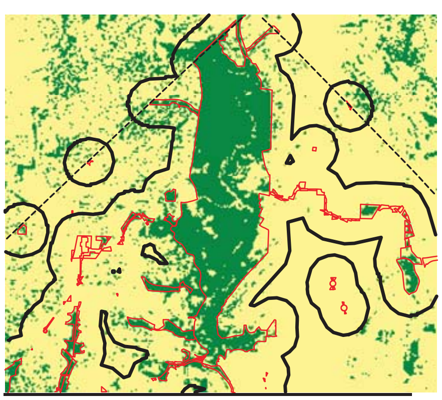
[9] NCRN I&M

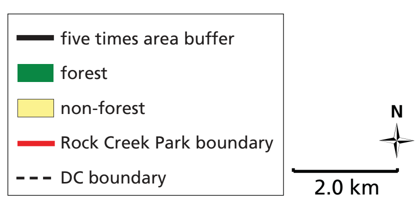
Uninterrupted forest cover provides the shade needed for a wetland habitat in Rock Creek Park.

variant and the beech-tulip poplar variant. The *tulip poplar forest association* is uncommon and occurs on moist, mid-slope to low-slope sites that were cleared in the past. These sites are dominated by tulip poplar (*Liriodendron tulipifera*). The *chestnut oak-black oak/huckleberry forest association* is uncommon and occurs on ridge tops, convex upper slopes, and south-facing slopes on rocky, well-drained soils. The *sycamore-green ash forest association* is uncommon and occurs along stream banks, floodplains, and other low-lying areas subject to temporary or irregular flooding. The *Virginia pine-oak forest association* is rare because it is an early to mid-successional forest that is being replaced by hardwood forests.

Remnants of this association occur on dry soils of hilltops in limited areas where forest succession has not yet replaced it.

Recent studies have been carried out to assess the habitat value of the forest within Rock Creek Park, as well as the surrounding area (Townsend et al. 2006). While there is high connectivity and low impervious surface within the park boundary, making this valuable habitat for flora and fauna, these features are more challenged when the park is placed in the context of the surrounding landscape (Figure 2.7).





Metric	Inside Park	Park + Buffer
Connectivity (m)	340	270
Impervious surface (%)	5	45
Dominant land cover (% forest)	71	24

Figure 2.7. Extent of forest and non-forest landcover[10] (Landsat 30 m) within and around Rock Creek Park, Washington, D.C. for 2000.

[10] Townsend et al. 2006

Wetland (Inland) Habitat

Wetland habitats, monitored at various stations (Figure 2.8) and which is primarily associated with the main Rock Creek and tributaries, makes up 2% of the 1,754 acres within the park (Figure 2.4). Rock Creek flows generally south for 33 miles from its headwaters near Laytonsville, Maryland, to its confluence with the Potomac River at Georgetown (Figure 2.9). Elevation at stream height falls from approximately 98 feet at the north end of the park to nearly sea level at the south end of the park (Figure 2.10).

The creek and tributaries support a diversity of fish species (at least 39 species; Table 2.1). The waters within the parks, as determined by long-term monitoring stations (Figure 2.8), are of neutral pH (Figure 2.12), well-mixed (Figure 2.13), well buffered (Figure 2.14), and exhibit acceptable seasonal fluctuations in temperature (Figure 2.15).

Another important component of wetland habitats are the approximately 40 seeps and springs throughout Rock Creek Park (Figure 2.11). Several of the seep habitats are classified as "hypotelminorheic," meaning they share a unique set of physical and chemical characteristics and often provide subterranean habitat to rare species (Culver et al. 2006). For example, one species of the amphipod genus *Stygobromus* (Holsinger 1978) is federally endangered (*S. hayi*) and has extremely limited distributions. Another amphipod, S*tygobromus kenki*, is a candidate for similar federal protection (*S. kenki* is known from only a few sites—all within or near Rock Creek Park).

Rock Creek in late spring flow.

NPS

NPS

NPS

RIGHT: Sampling for amphipods.

LEFT: *Kenk's amphipod (S. kenki)* is known to exist only within or near Rock Creek Park.

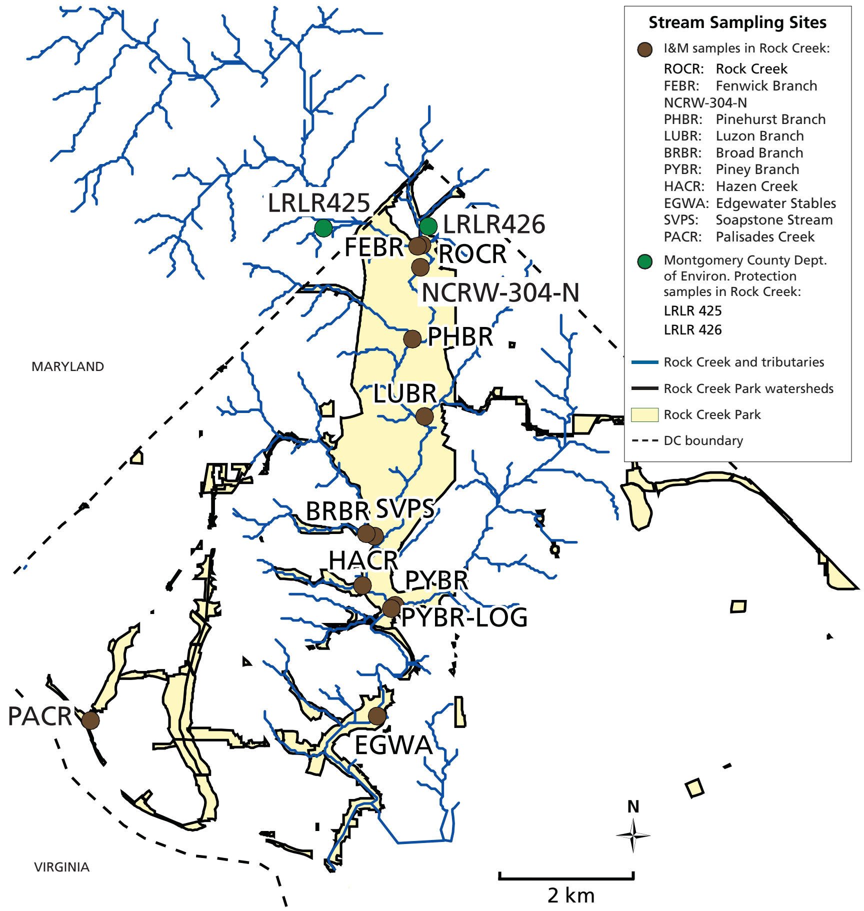


Figure 2.8. Stream sampling locations (n=10) used for long-term water quality monitoring[11] at Rock Creek Park, Washington, D.C.

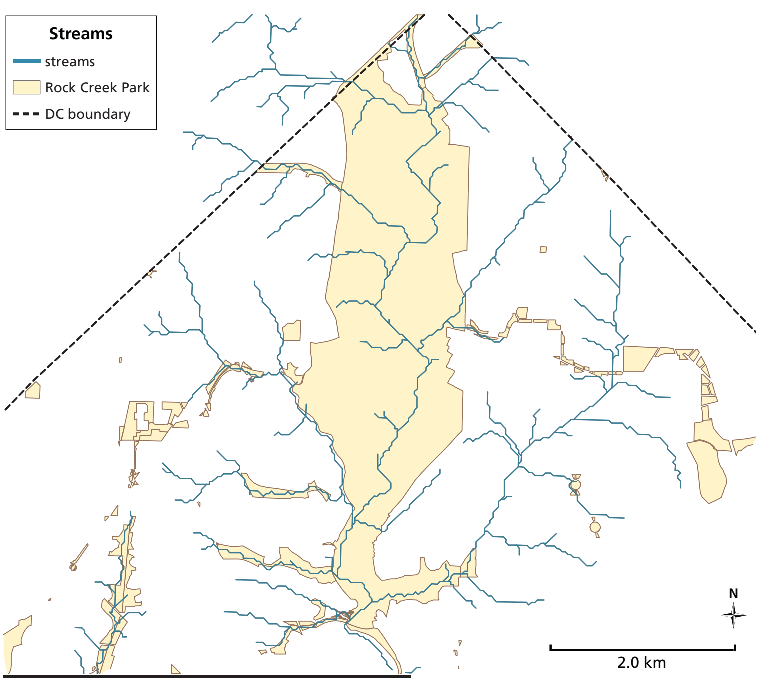


Figure 2.9. GIS data layer[12] depicting a portion of the stream network for Rock Creek Park, Washington, D.C. Upstream tributaries (Montgomery County, MD) are also shown.

NATURAL RESOURCES

[11, 12] NCRN I&M

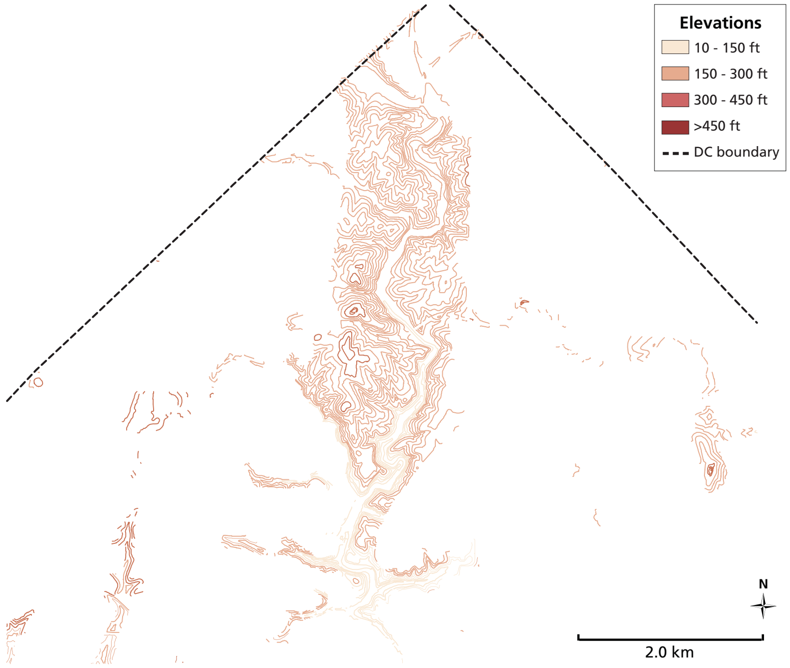


Figure 2.10. GIS data layer[13] of topographic elevation for Rock Creek Park, Washington, D.C.

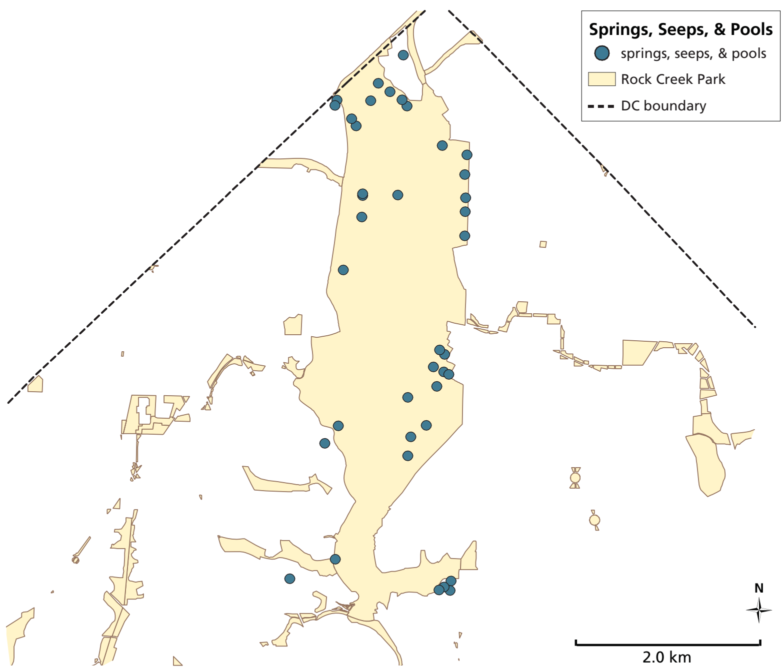


Figure 2.11. GIS data layer[14] depicting the location of springs, seeps, and pools (n=15) in Rock Creek Park, Washington, D.C.

[13, 14] NCRN I&M

Table 2.1. Fish species and number of individuals captured during annual park surveys (2002-2005).

Common Name	Species	2002	2003	2004	2005	Total
Alewife	*Alosa pseudoharengus*	379	472	361	287	1499
Longnose Dace	*Rhinichthys cataractae*	54	34	188	763	1039
Spottail Shiner	*Notropis hudsonius*	262	95	361	279	997
White Sucker	*Catostomus commersoni*	296	159	229	303	987
Bluegill	*Lepomis macrochirus*	162	134	101	153	550
Blacknose Dace	*Rhinichthys atratulus*	56	38	66	256	416
Tessellated Darter	*Etheostoma olmstedi*	83	54	111	168	416
Pumpkinseed	*Lepomis gibbosus*	202	23	54	125	404
Swallowtail Minnow	*Notropis procne*	38	92	120	107	357
Bluntnose Minnow	*Pimephales notatus*	53	53	55	150	311
American Eel	*Anguilla rostrata*	31	49	84	84	248
Spotfin Shiner	*Cyprinella spiloptera*	53	49	50	26	178
Yellow Bullhead	*Ameiurus natalis*	34	37	32	61	164
Largemouth Bass	*Micropterus salmoides*	26	90	20	11	147
Fallfish	*Semotilus corporalis*	51	17	30	19	117
Channel Catfish	*Ictalurus punctatus*	4	39	32	11	86
Redbreast Sunfish	*Lepomis auritus*	21	11	12	6	50
Carp	*Cyprinus carpio*	26	17	2	1	46
Cutlips Minnow	*Exoglossum maxillingua*	6	3	9	19	37
Golden Redhorse	*Moxostoma erythrurum*	2	1	17	9	29
Hickory Shad	*Alosa mediocris*			22		22
Smallmouth Bass	*Micropterus dolomieu*	5	1	2	11	19
Creek Chubsucker	*Semotilus atromaculatus*	8	3	4	1	16
Green Sunfish	*Lepomis cyanellus*	1	4	4	7	16
Brown Bullhead	*Ameiurus nebulosus*		3	2	7	12
Eastern Silvery Minnow	*Hybognathus regius*				12	12
Sea Lamprey	*Petromyzon marinus*	1	1	4	5	11
Goldfish	*Carassius auratus*	2	3		4	9
Greensided Darter	*Etheostoma blennioides*	2		1	6	9
Gizzard Shad	*Dorosoma cepedianum*			5		5
Central Stoneroller	*Campostoma anomalum*				4	4
Golden Shiner	*Moxostoma erythrurum*		2		2	4
Redear Sunfish	*Lepomis microlophus*		2			2
Black Crappie	*Anguilla rostrata*			1	1	2
Musky	*Esox masquinongy*			1		1
Quillback Carpsucker	*Carpiodes cyprinus*			1		1
Striped Bass	*Morone saxatilis*				1	1
White Perch	*Morone americana*				1	1
Yellow Perch	*Perca flavescens*			1		1
Total		**1858**	**1486**	**1982**	**2900**	**8226**

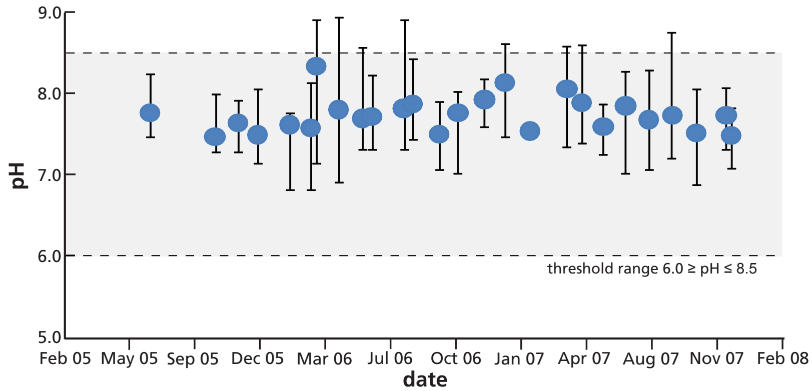


Figure 2.12. Median, minimum, and maximum monthly pH values[15] for 10 stream sampling locations (see Figure 2.8) from 2005-2007 for Rock Creek Park. Acceptable ranges (6.0 ≥ pH ≤ 8.5) are shown.

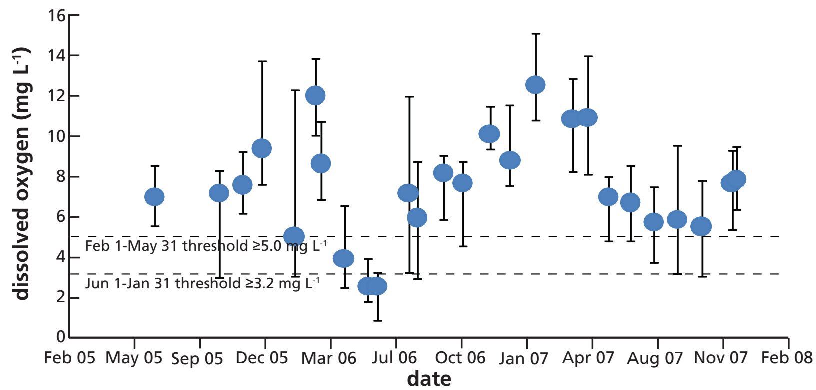


Figure 2.13. Median, minimum, and maximum monthly dissolved oxygen concentration (mg L^{-1}) for 10 stream sampling locations[16] (see Figure 2.8) from 2005-2007 for Rock Creek Park. Acceptable ranges (DO ≥ 3.2 mg L^{-1} from Jan-Jun, DO ≥ 5.0 mg·L-1 from Feb-May) are shown.

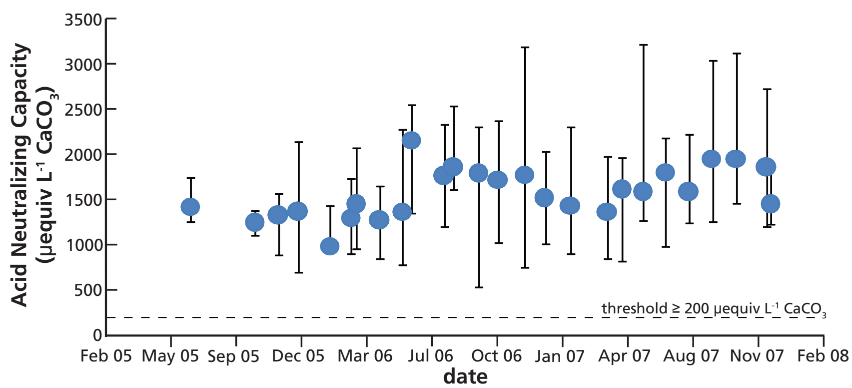


Figure 2.14. Median, minimum, and maximum monthly acid neutralizing capacity (ANC; mg $CaCO_3$ L^{-1}) for 10 stream sampling locations[17] (see Figure 2.8) from 2005-2007 for Rock Creek Park. Acceptable range (mg $CaCO_3$ L^{-1} ≥ 10 mg L^{-1}) is shown.

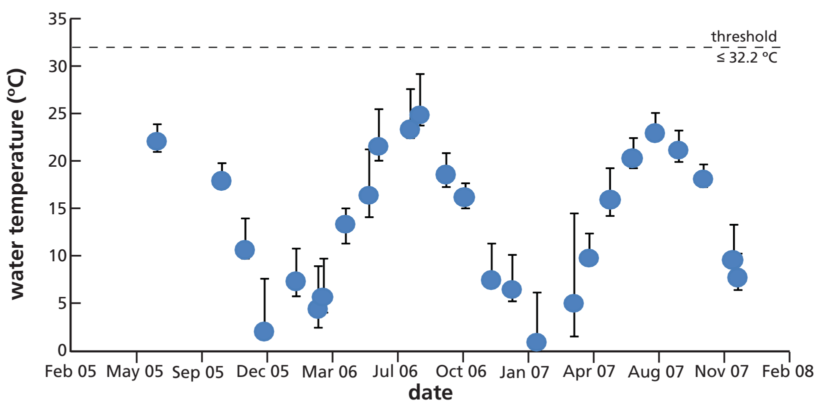


Figure 2.15. Median, minimum, and maximum monthly water temperature (°C) for 10 stream sampling locations[18] (see Figure 2.8) from 2005-2007 for Rock Creek Park. Acceptable range (temp. ≤ 32.2°C) is shown.

[15, 16, 17, 18] Norris et al. 2007

Artificial-terrestrial Habitat

The artificial-terrestrial habitats, which make up 17% of Rock Creek Park (Figure 2.4), include managed meadows, community gardens, and lawns. One of the largest habitat areas is the golf course in the central eastern section of the main body of the park along Rock Creek itself. These artificially created or maintained habitats are important resources for recreation while also providing dispersal and stopover habitat for animals and insects (Angold et al. 2006, Snep et al. 2006).


Lisa Florkowski

Rock Creek Park has many picnic areas and recreational lawns.


Chadwick Cipiti, DCNature.com

While the natural resources of Meridian Hill Park are not included in this particular condition assessment, the park is a component of Rock Creek Park and is a good example of an artificially created landscape with its many fountains, statues, and gardens.

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Invasive exotic English ivy (*Hedera helix*) overtakes tree.

Jane Thomas, IAN

Chapter 3: Current & Potential Stressors

A summary of key data available on the current and potential stressors of natural resources within Rock Creek Park.

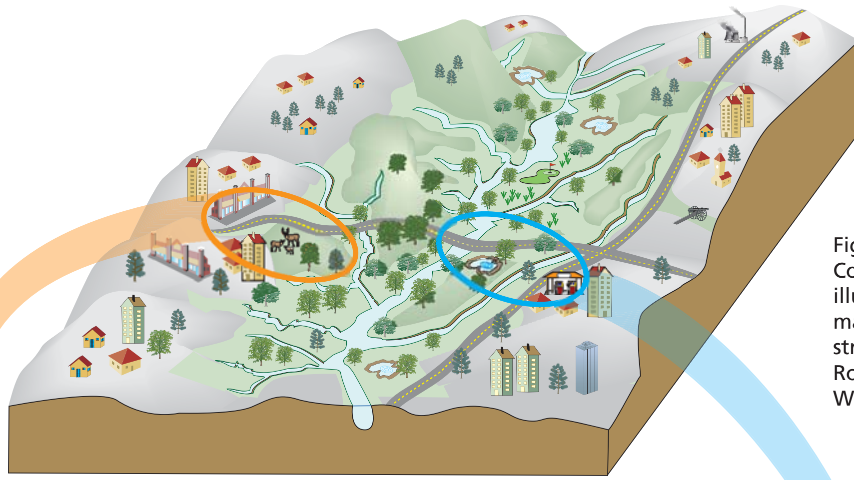
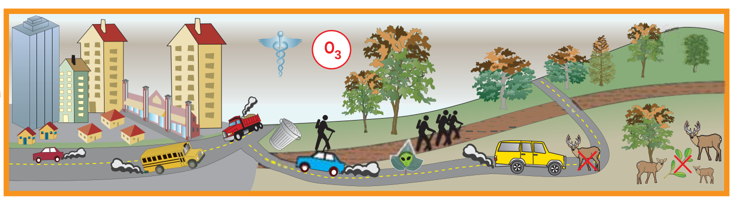


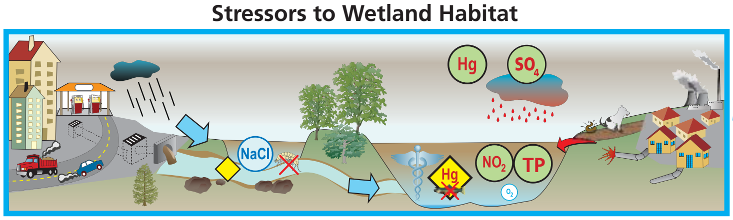
Figure 3.1. Conceptual diagram illustrating the major environmental stressors facing Rock Creek Park, Washington, D.C.

Stressors to Forest Habitat



Dense urban development surrounding Rock Creek Park brings intense visitor use of trails which can introduce invasive plant species, and trash dumping. High ozone levels O_3 during summer can cause potential human health issues and damage plants and trees. Deer overpopulation reduces seedling survival and is a hazard to vehicles on the roads within and outside the park.

Stressors to Wetland Habitat

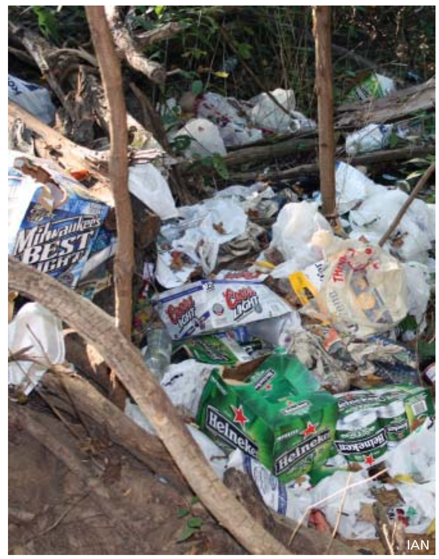


Urban impervious surfaces surrounding Rock Creek Park deliver road salt NaCl, nutrients NO_2 TP, and toxicants into park waterways, impacting water quality, and threatening fish and invertebrates. Storm events can deliver high water volumes to Rock Creek, disrupting stream flows and habitats. Atmospheric pollution can result in acid rain SO_4 and deposition into the park waterways, increasing mercury Hg in fish tissue and posing a potential human health risk. Leaking sewer lines crossing the park and pet feces raise nutrient levels in streams, and lead to eutrophication and a decline in fish health.

Introduction

Rock Creek Park is a green island in a sea of pavement. Dense urban development surrounds the park, bringing with it intense trail use, dumping, and continual introduction of invasive exotic species (Figure 3.1). Additionally, the park encompasses the bottom nine miles of the Rock Creek watershed, making the creek susceptible to degradations in water quality and increases in storm flows that are beyond management control. Of the 266,162 acre Rock Creek watershed, just 9,536 acres (3.6%) are managed by the National Park Service. Consequently, Rock Creek Park faces challenges in maintaining ecological integrity within a heavily urbanized landscape.

LEFT and RIGHT: Surrounded by houses, businesses, and roads, the dumping of trash and debris in Rock Creek Park is an on-going challenge.



BELOW: Stormwater originating in the park's watershed delivers sediment and toxicants that impact water quality downstream in Rock Creek Park.

Air quality

Stressors to air quality are additional external factors in an urbanized landscape. Data from surrounding ambient air quality stations (Figure 3.2) portray excessive ozone levels (Figure 3.3) and large amounts of wet deposition of nitrate (Figure 3.4), sulfate (Figure 3.5), and mercury (Figure 3.6). Regionally, atmospheric deposition of sulfate (Figure 3.7) and mercury (Figure 3.8) are persistent problems. As in the case of upstream pollution in park waters, these atmospheric stressors act to potentially degrade the resources in Rock Creek Park, yet stressor abatement outside the park poses significant challenges.

A coal-fired power plant (foreground) in Washington, D.C., emits particulate (soot) pollution to surrounding neighborhoods.

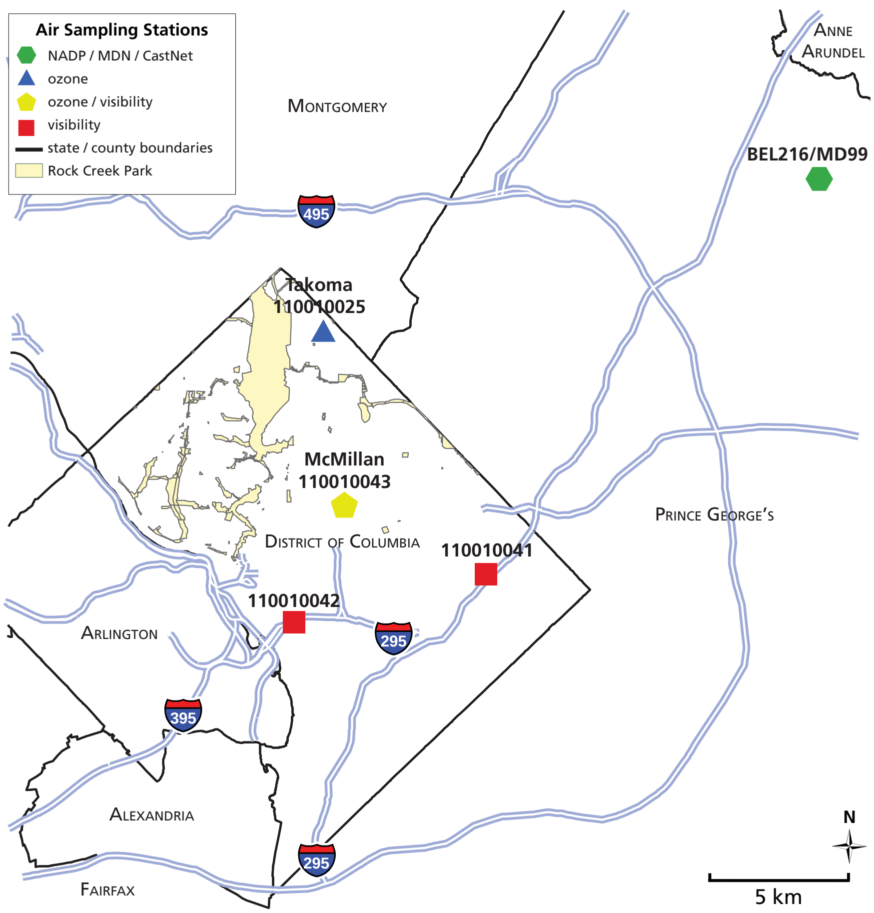


Figure 3.2. Map of sampling stations[19] used for measuring ambient air quality near Rock Creek Park, Washington, D.C.

[19] Data sources: National Atmospheric Deposition Program *http://nadp.sws.uiuc.edu/*; Mercury Deposition Network *http://nadp.sws.uiuc.edu/mdn/*.

Figure 3.3. Hourly atmospheric ozone concentration (8-hr mean ppm) from 1994-2003 at the southeast end of McMillan Reservoir[20] (see Figure 3.2), Washington, D.C. Acceptable range (8-hr mean ≤ 0.075 ppm) is shown.

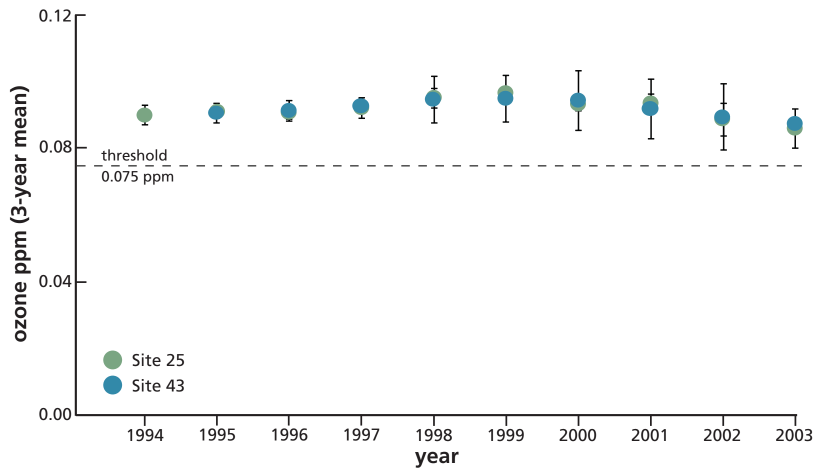
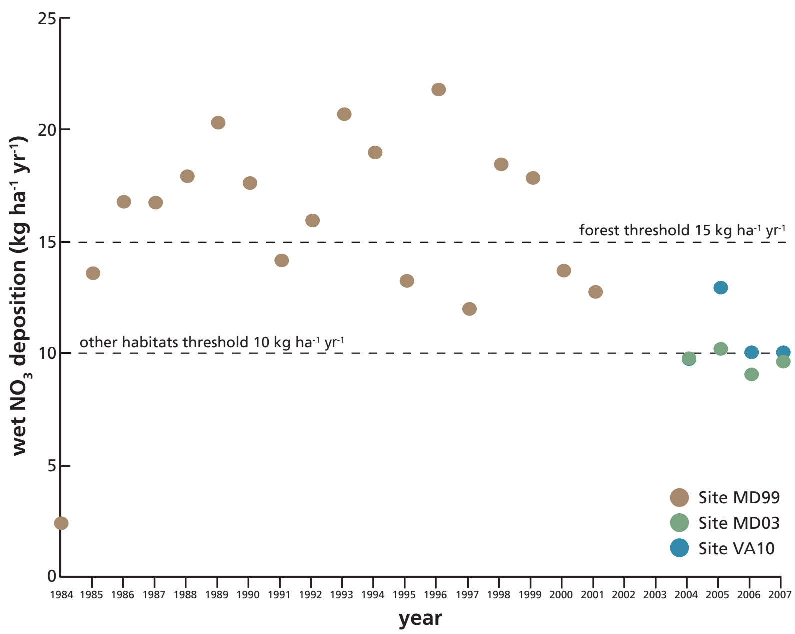


Figure 3.4. Annual wet nitrate deposition[21] (mg L^{-1}) from 1984-2007 for sites MD99, MD03, and VA10 (see Figure 3.2). Acceptable ranges for forest ($NO_3^- \leq 15$ kg ha^{-1} yr^{-1}) and cultivated ($NO_3^- \leq 15$ kg ha^{-1} yr^{-1}) habitats are shown.



[20] Environmental Protection Agency; NPS Air Resources Division; *http://www.epa.gov/castnet/*

[21] National Atmospheric Deposition Program; *http://nadp.sws.uiuc.edu/*

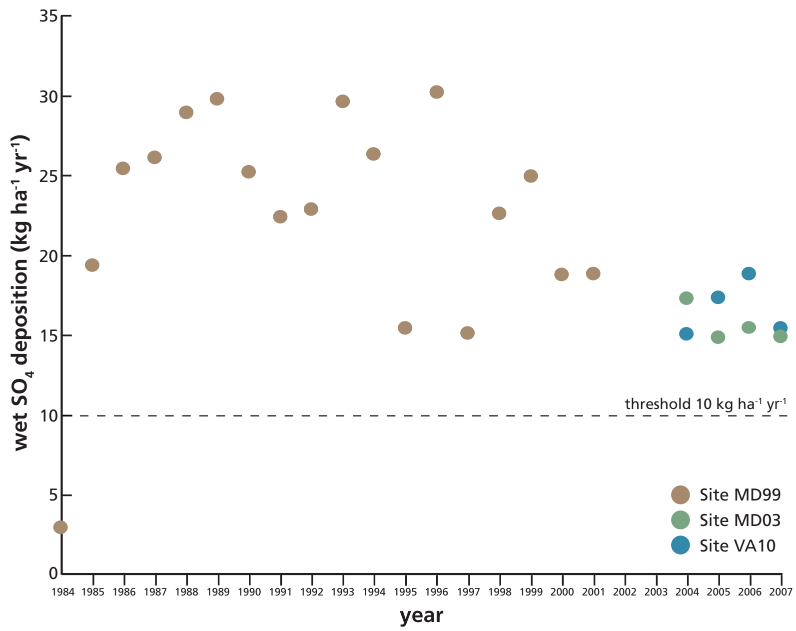


Figure 3.5. Mean annual wet sulfate deposition[22] (mg L^{-1}) from 1984-2007 for sites MD99, MD03, and VA10 (see Figure 3.2), Washington, D.C. Acceptable range ($SO_4^{-2} \leq 18$ kg ha^{-1} yr^{-1}) is shown.

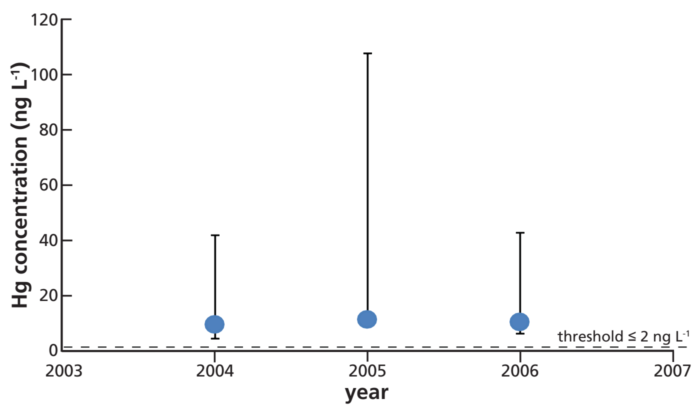


Figure 3.6. Mean monthly mercury (Hg) concentration (ng L^{-1}) at Beltsville Agricultural Research Center[23] (see Figure 3.2) in Beltsville, MD. Acceptable range (Hg ≤ 2 ng L^{-1}) is shown.

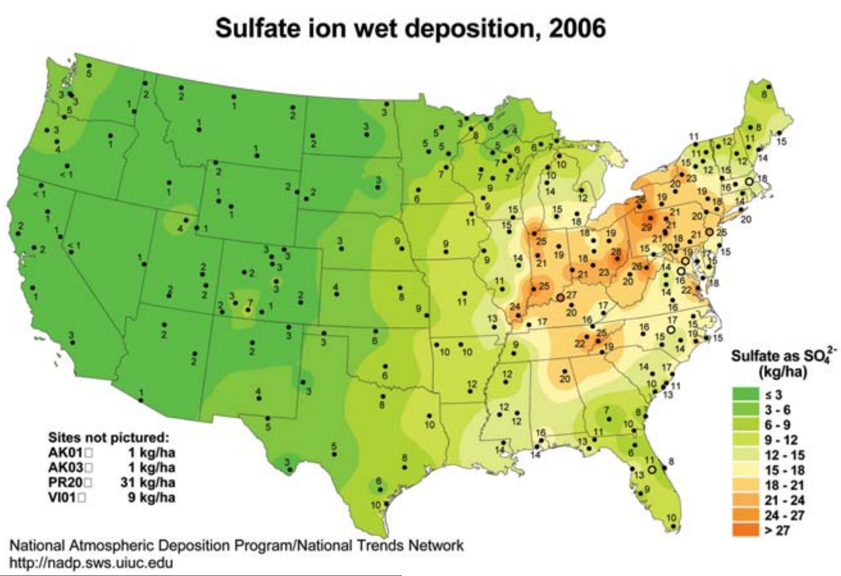
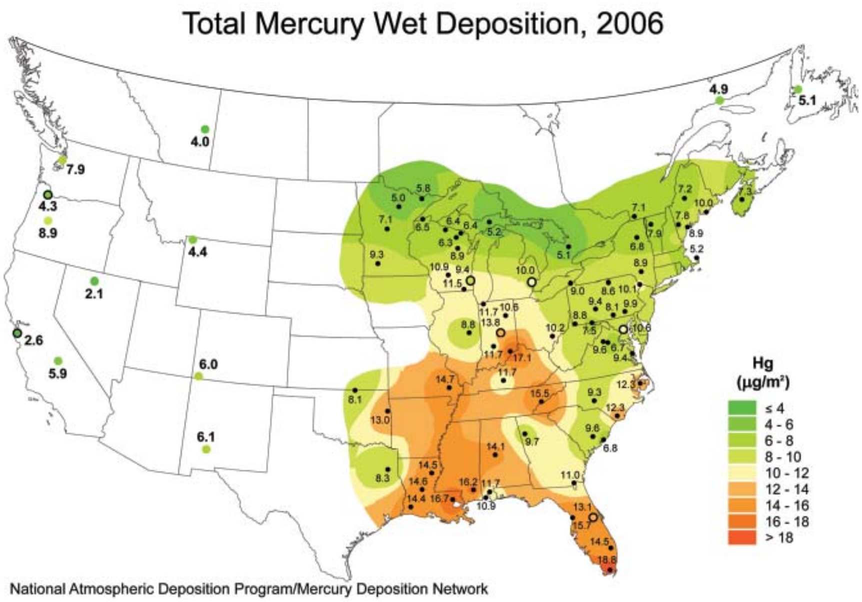


Figure 3.7. Total wet sulfate (SO_4^{-2}) deposition (kg ha^{-1}) for the continental United States in 2006.

STRESSORS

[22] National Atmospheric Deposition Program; *http://nadp.sws.uiuc.edu/*
[23] Mercury Deposition Network; *http://nadp.sws.uiuc.edu/mdn*

Figure 3.8. Total wet mercury (Hg) deposition (µg m^{-2}) for the continental United States in 2006.



Downtown Washington, D.C. area in: (TOP) October 2005 where the visual range was 55 miles, and, (BOTTOM) July 2006 where the visual range was 25 miles. Source: http://www.nature.nps.gov/air/WebCams/parks/nacccam/washcam.cfm.

The park is impacted heavily by the surrounding urban environment. It is positioned in the lower-most part of the watershed, making it vulnerable to upstream impacts. Air monitoring data (Figure 3.2) for visibility show a moderate amount of airborne particulate matter (soot; Figure 3.9). Surrounding land development has removed forest cover and isolated park habitats (Figure 2.7). Upstream development and increased imperviousness within the watershed appear also to be increasing the rise rate (i.e., "flashiness") of Rock Creek (Figure 3.10). A more detailed analysis of extra-park influences on natural resources is provided in Chapter 5.

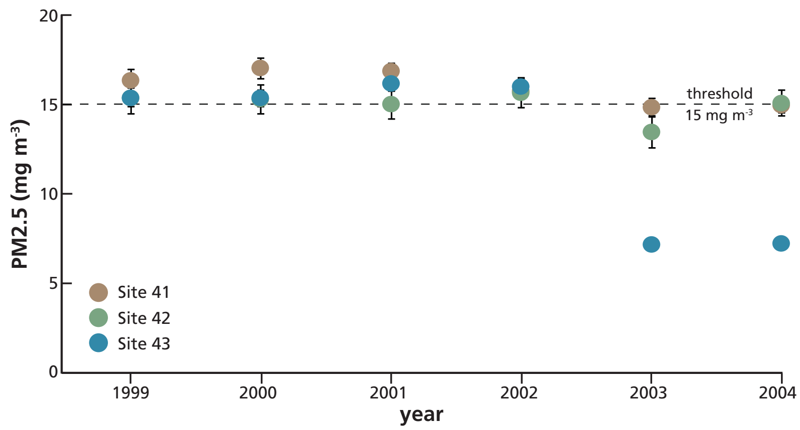


Figure 3.9. Mean monthly particulate matter (soot; PM2.5) concentration with standard deviation for sites 41, 42, and 43[24] from 1999-2004 (listed as 1100100xx Figure 3.2). Sampling intensity increased after 2003.

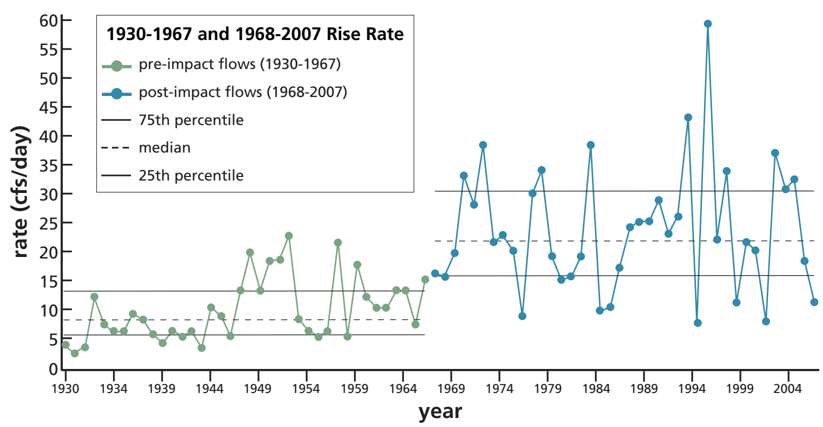


Figure 3.10. Comparisons in rise rate (cfs day^{-1}) between time period prior to (1930-1967) and after (1968-2007) Lake Needwood reservoir construction. Data from USGS level logger at Sherrill Drive[25] in Rock Creek Park, Washington D.C.

Lake Needwood is a 75-acre reservoir that is located on Rock Creek in Rock Creek Regional Park in Montgomery County near Rockville, Maryland. The man-made lake was created to provide flood control. It also protects the water quality of the creek by functioning as a retention basin to trap sediment from stormwater runoff.

[24] Interagency Monitoring of Protected Visual Environments *http://vista.cira.colostate.edu/improve/*
[25] NCRN I&M

Water quality

External stressors

Urban development has resulted in a dense grid of sewer lines, some of which run through the park (Figure 3.11). As a result, the park has over 217 combined sewer outfalls or stormwater drains that empty into Rock Creek (Figure 3.12). Hazardous materials also surround the park. Approximately 222 sites containing hazardous materials (e.g., fuel tanks) are located within 2 km of a park unit (Figure 3.13).

Figure 3.11. GIS data layer[26] of a portion of the Washington, D.C. sewer system.

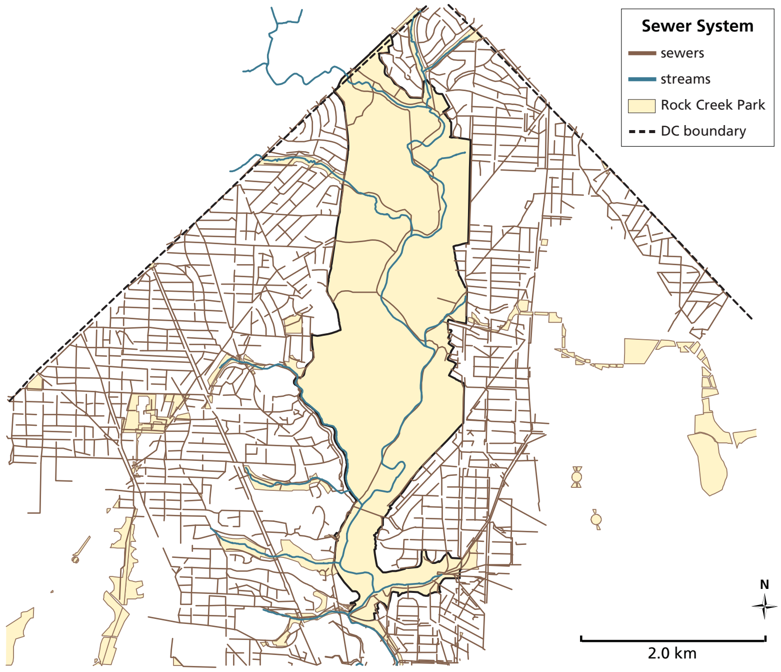
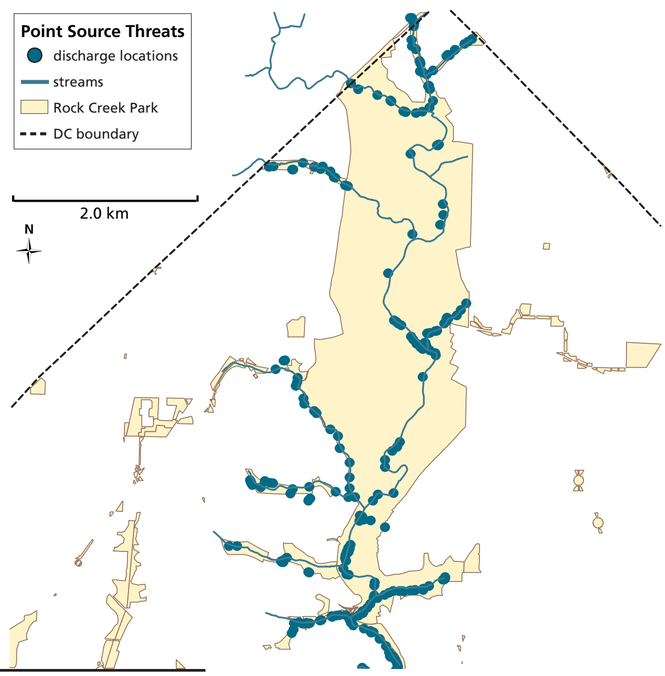


Figure 3.12. GIS data layer[27] of point source inputs (combined sewer outfalls and stormwater drains) to Rock Creek Park, Washington, D.C. Two hundred seventeen sources are shown in this geographic extent. A total of 342 are located in or adjoining the entire park unit.



[26, 27] NCRN I&M

TOP: This combined sewer outfall is slated to be modified to divert sewage to a treatment plant.

LEFT: Combined sewer outfalls can cause high bacteria levels in Rock Creek.

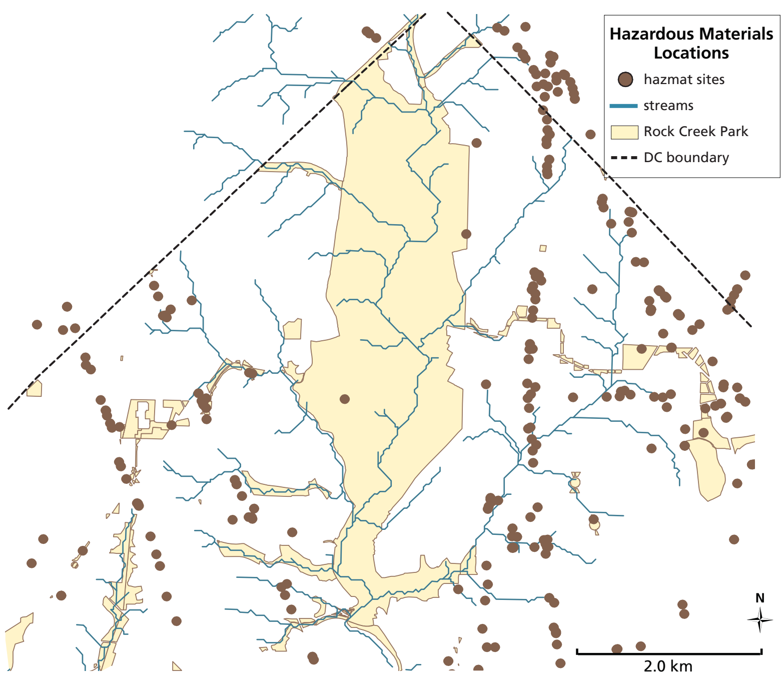


Figure 3.13. GIS data layer[28] showing 222 sites in and around Rock Creek Park, Washington, D.C. that contain hazardous materials.

STRESSORS

[28] NCRN I&M

Within park evidence

Data from ten stream monitoring sites in Rock Creek Park (Figure 2.8) characterize the type of stressors facing riparian fauna and flora. Stream salinity (Figure 3.14) was high when compared to acceptable concentrations. Nitrate concentrations fluctuate considerably according to park location (Figure 3.15). Total phosphorus was found at very high concentrations, orders of magnitude above acceptable levels (Figure 3.16).

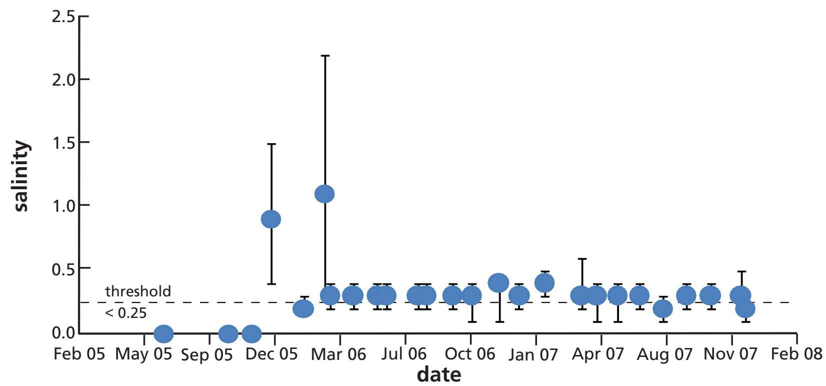


Figure 3.14. Median, maximum, and minimum monthly salinity concentration for 10 stream sampling locations[29] (see Figure 2.8) from 2005-2007 for Rock Creek Park, Washington, D.C. Acceptable range (salinity < 0.25) is shown.

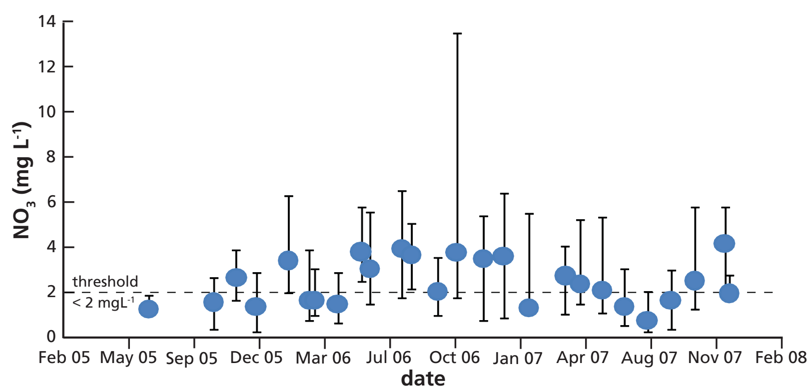


Figure 3.15. Median, maximum, and minimum monthly nitrate (NO_3^-) concentration (mg L^{-1}) for 10 stream sampling locations[30] (see Figure 2.8) from 2005-2007 for Rock Creek Park, Washington, D.C. Acceptable range ($NO_3^- \leq 2.0$ mg L^{-1}) is shown.

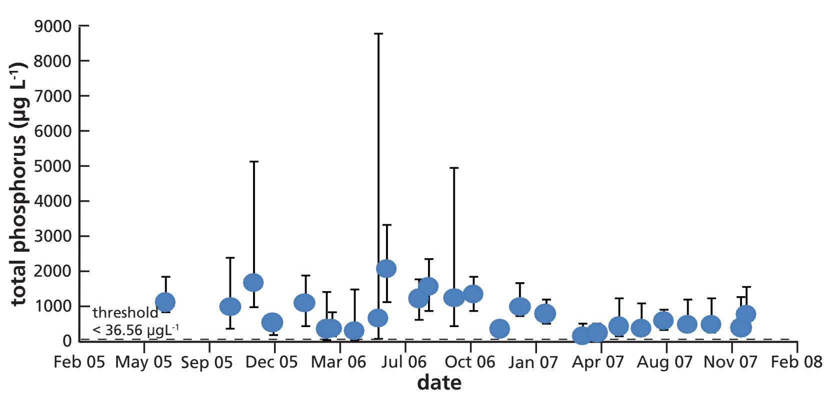


Figure 3.16. Median, maximum, and minimum monthly organic total phosphorus (TP) concentration (µg L^{-1}) for 10 stream sampling locations[31] (see Figure 2.8) from 2005-2007 for Rock Creek Park, Washington, D.C. Acceptable range (P ≤ 37 µg L^{-1}) is shown.

[29, 30, 31] Norris et al. 2007

Surrounding landscape

Scoping for GIS data was accomplished via a series of meetings with staff from Rock Creek Park, the Center for Urban Ecology (CUE), National Capital Region Network (NCRN), and the Maryland Biological Stream Survey. In addition, GIS data were obtained from federal, state, and local web portals, such as EPA STORET, USGS NWIS, USGS Seamless Server, and the USDA Geospatial Data Gateway. Three additional synthetic GIS layers (population, roads, and impervious surface) were generated.

Watershed

Although Rock Creek Park is 81% forested (accessible through multiple trails; Figure 3.17), the entire watershed contains just 24% forest and is one of the most rapidly growing urban areas within the United States.

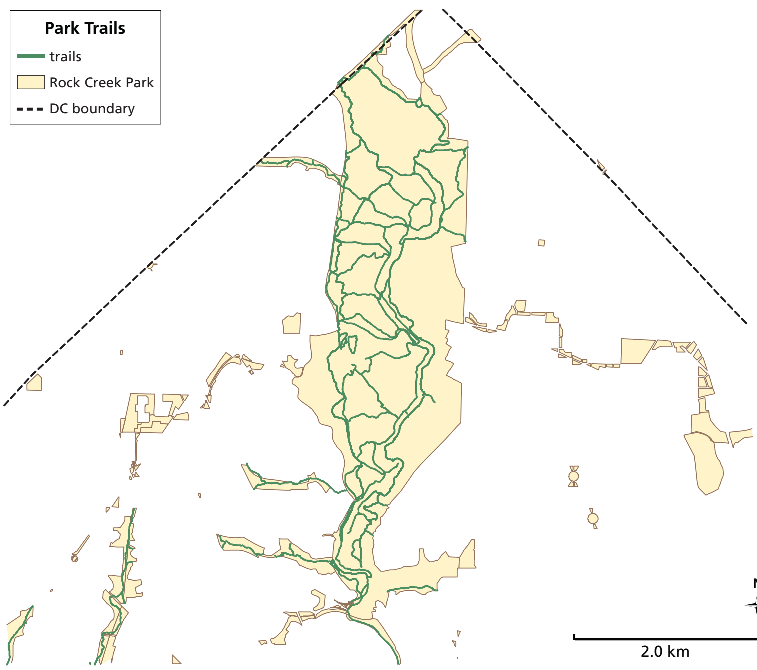
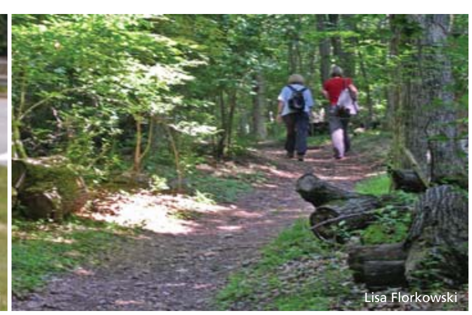


Figure 3.17. GIS data layer[32] showing the trail system of Rock Creek Park, Washington, D.C.



Visitors enjoy the many trails of Rock Creek Park.

STRESSORS

[32] NCRN I&M

Population

The population layer was derived using the Year 2000 Census block information. In ArcGIS 9.2, the base watershed layer was used to clip census blocks to the watershed boundaries. Using the ArcGIS field calculator, area was calculated for each of the census blocks and then for each of the clipped blocks. A ratio was calculated by taking the area of the clipped block compared to the area of the original block. The ratio and the population for the block were then multiplied to give a population for each clipped block. These clipped block populations were then summed within each sub-watershed to give a total population.

For this technique, the population was assumed to be evenly distributed throughout each census block. Census blocks are the smallest unit for which the Census Bureau maintains information. By using these units, the error associated with assuming evenly distributed population was minimized.

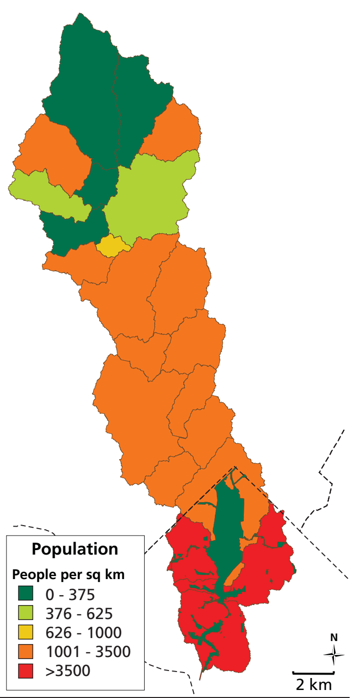


Figure 3.18. Population map derived from U.S. Census Bureau[33] block population estimates. Blocks were clipped to the subwatershed boundary and the total population was estimated for each subwatershed.

There was a large range of population values for each watershed. To facilitate comparison between watersheds, population was normalized to watershed area. Using the ArcGIS field calculator, the area was calculated for each watershed. The area of the park was removed from each watershed area to give an accurate population density. Since there are no people living in the park, population density was calculated using the area of each watershed outside the park rather than the total area of the watershed. These normalized population values are shown in the map (Figure 3.18). There is no population threshold and therefore the color breaks are based on quantities.

Roads

Roads have a significant effect on wildlife and habitat quality, and this effect contributes to ecosystem disruption and degradation (Bechtold et al. 1996). Roads affect wildlife directly through vehicle-animal collisions and noise pollution, and indirectly through increased runoff, erosion, sediment loading causing fish kills, decreased dissolved oxygen concentrations, increased temperature, and impaired habitat. Roads also lead to forest fragmentation, increased edge habitat and increased invasive exotic plants (Bechtold et al. 1996). Haynes et al. (1996) suggest road density classifications based on the spawning habitat of salmon. A road density of 0.02-0.1 miles per square mile (mi mi^{-2}) are considered very low; 0.1-0.7 mi mi^{-2} is considered low; 0.7-1.7 mi mi^{-2} is considered moderate; 1.7-4.7 mi mi^{-2} is considered high; and greater than 4.7 mi mi^{-2} is considered extremely high. Bechtold et al. (1996) similarly categorized road density into five classifications for an analysis of grizzly

[33] NCRN I&M

Wildlife are often casualties on the many busy roads that cross Rock Creek Park.

bear habitat. Their classifications were 0-0.5 mi mi^{-2}, 0.5-1.0 mi mi^{-2}, 1.0-2.0 mi mi^{-2}, 2.0-5.0 mi mi^{-2}, and > 5.0 mi mi^{-2}. Both classifications were similar, suggesting that these road densities are appropriate for a variety of species.

Multiple derived road layers were calculated from the same base map. The first was road density (Figure 3.19). This layer was calculated using the p. 32/104—TIGER/Line® Files (Census Bureau 2000). These line files were clipped to the watershed boundary layer and the park boundary layer. The length of the roads was then calculated using the ArcGIS spatial calculator. Using the watershed area previously calculated, road length was normalized to watershed area. The road densities found in Rock Creek watershed were much higher than the road densities found in Bechtold et al. (1996) and Haynes et al. (1996). There are only three watersheds that have a road density less than 5 mi mi^{-2}. In order to show some variation in the map, the classification scheme condenses the literature values into two colors and splits the remaining colors based on the range of road densities found in the watershed.

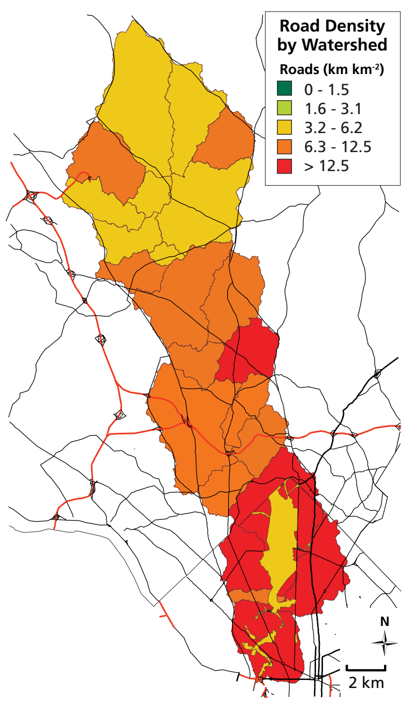


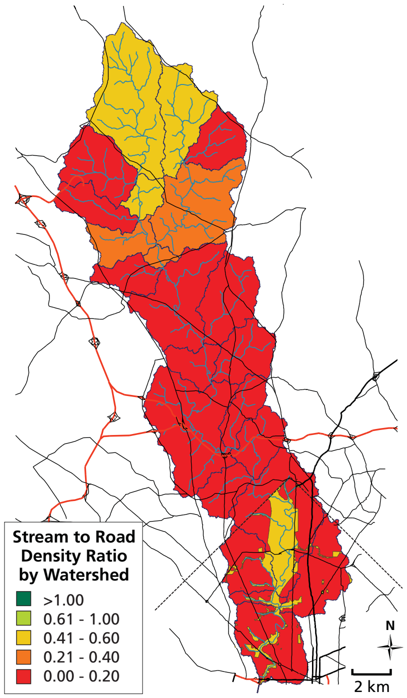
Figure 3.19. Road density[34] was calculated by measuring the length of the roads within the subwatershed boundary. The length was then divided by the subwatershed area to produce density.

[34] NCRN I&M

Milkhouse Ford, where a municipal road merges with Rock Creek.

The second road density map (Figure 3.20) is a comparison of road density and stream density. Stream density was calculated using the same method used for road density.

Figure 3.20. Stream density[35] was calculated using the same method used for road density. The ratio of road to stream density was then calculated.



The stream density was calculated from the high resolution National Hydrography Dataset stream layer. This stream layer was chosen over the layer created from the Digital Elevation Model (Figure 2.10) because the National Hydrography Dataset stream layer more accurately depicts the streams. It has been suggested that when road density approaches the same density as the stream network, the roads begin to become preferential flow paths for the runoff (Jones and Grant 1996). The map (Figure 3.20) shows the ratio of stream density to road density. If the ratio is 1, then the road density and the stream density are equal. When the ratio is less than 1 (yellow or red), the road density is greater than the stream density. There are no sub-watersheds that have a road density less than the stream density.

[35] NCRN I&M

Impervious surface

The impervious surface area (ISA) information is derived from a raster dataset (RESAC Impervious Surface Area Time Series, version 1.3) obtained from the Mid-Atlantic Regional Earth Science Applications Center (RESAC) and the Woods Hole Research Center. There are four georeferenced rasters containing the percent of impervious surface for each of the years 1986, 1990, 1996, and 2000. Dataset values indicate the fractional amount of impervious material present in a single 30 m x 30 m pixel and range from 0-100%. These datasets can be used to calculate the average percent ISA inside any GIS polygon, such as a watershed delineation or park boundary using the ArcMap Spatial Analyst/Zonal Statistics tool.

The calculated impervious surface values for each subwatershed were categorized and mapped (Figure 3.21). The 10% impervious surface threshold (Arnold and Gibbons 1996) was used to define the break between good and fair watershed condition. Impervious surface greater than 30% was defined as having severe stream degradation (Arnold and Gibbons 1996).

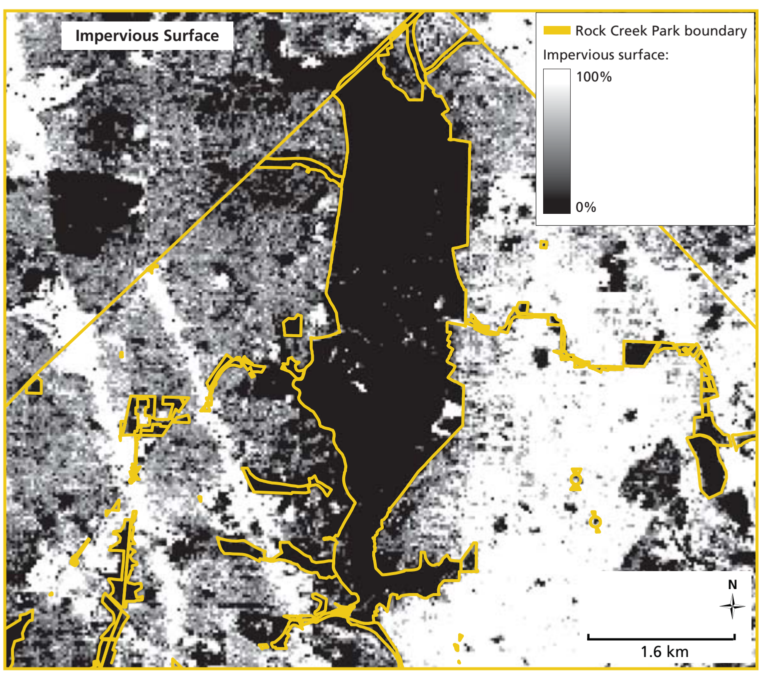


Figure 3.21. GIS data layer[36] showing percent impervious surface in and around Rock Creek Park, Washington, D.C., in 2000.

STRESSORS

[36] NCRN I&M

LEFT and RIGHT: As impervious surfaces increase, so can stormwater runoff volumes and pollutant levels in park streams.

The velocity of stormwater flows erode streambanks and scour streambeds.

Literature cited (Chapter 3)

Arnold Jr, C.L. and C.J. Gibbons. 1996. Impervious surface coverage. Journal of the American Planning Association 62(2): 243-269.

Bechtold, T., D. Havlick, and K. Stockmann. 1996. Analysis of Road Densities in Selected Grizzly Bear Management Units in the Northern Rockies. ESRI Proceedings of User Conference. *http://proceedings.esri.com/library/userconf/proc96/to450/pap413/p413.htm*.

Haynes, R.W., R.T. Graham, and T.M. Quigley (Eds.). 1996. A Framework for Ecosystem Management In the Interior Columbia Basin And Portions of the Klamath and Great Basins. U.S. Forest Service and U.S. Bureau of Land Management with assistance from the Pacific Northwest Forest Experiment Station. PNW-GTR-374. 75 p.

Jones, J.A. and G.E. Grant. 1996. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon. Water Resources Research 32(4): 959-974.

Norris, M., J.P. Schmit and J. Pieper. 2007. National Capital Region Network 2005-2006 Water Resources Monitoring Report. Natural Resource Program Center, Fort Collins, CO. NPS/NCRN/NRTR - 2007/066.

U.S. Census Bureau. 2000. *http://www.census.gov/geo/www/tiger/index.html*.

Cardinal Flower (*Lobelia cardinalis*), a native wildflower found in Rock Creek Park.

Tom Paradis

Chapter 4: Metrics & Thresholds

A referenced justification to the use of thresholds in assessment as well as establishing thresholds for the 29 metrics used in this natural resource condition assessment.

Introduction

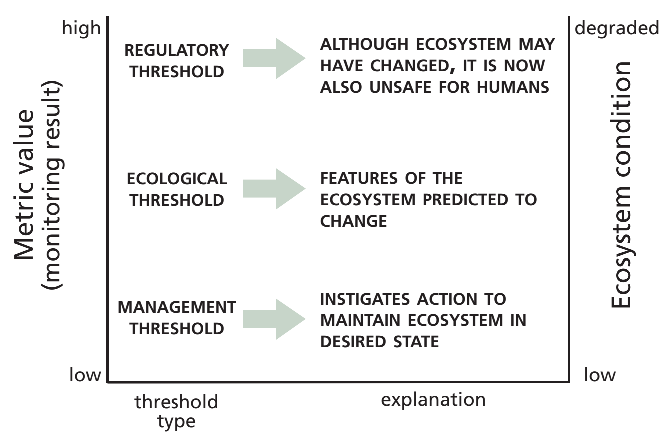
Utility of thresholds

A natural resource condition assessment requires the establishment of criteria for defining ecological condition and the current assessment was based upon explicitly defined threshold values. Even though increasing scientific research has been focused upon defining ecological thresholds, uncertainty in definition as well as spatial and temporal variability has often led to disagreement on specific values (Groffman et al. 2006, Huggett 2005). Even with the definition of agreed-upon thresholds, there is still the question of how best to use these threshold values in a management context (Groffman et al. 2006). Recognizing these challenges, thresholds can still be effectively used to track ecosystem change and define achievable management goals (Biggs 2004). As long as threshold values are clearly defined and justified, they can be updated in the light of new research or management goals and can therefore provide an important focus for the discussion and implementation of ecosystem management (Jensen et al. 2000, Pantus and Dennison 2005).

Definition and types of thresholds

A threshold indicates a tipping point or zone where current knowledge predicts an abrupt change in an aspect or some aspects of ecosystem condition. More generally, however, thresholds represent an agreed-upon value or range indicating that an ecosystem is moving away from a desired state and towards an undesirable ecosystem endpoint (Biggs 2004, Bennetts et al. 2007). Recognizing that many managed systems have multiple and broad-scale stressors, another perspective is to define a threshold as the level of impairment that an environment can sustain before resulting in significant (or perhaps irreversible) damage (Hendricks and Little 2003). Three types of thresholds are used for different aspects of natural resource management and all can provide useful information for the assessment of natural resource condition. These thresholds are management, ecological, or regulatory, and while in some cases they overlap (or are the same), these thresholds often provide different information as a result of being established for very different purposes (Figure 4.1; Bennetts et al. 2007).

Figure 4.1. Conceptual relationship between ecosystem condition and the different types of thresholds. In all cases, it is presumed that the metric is well-studied with a reliable measurement protocol and well-understood responses (e.g., available large spatio-temporal data sets).



METRICS & THRESHOLDS

Management thresholds are intended to instigate changes in management activity so as to maintain the natural resources of an ecosystem in a desired state. Therefore, these are likely to be the most conservative thresholds as it is necessary for management responses to occur before an ecological threshold is passed (Figure 4.1).

Ecological thresholds are based on best current scientific understanding and indicate a value where large changes in an ecosystem (and therefore natural resource values) are predicted (Figure 4.1). This definition includes the concept of 'critical loads,' as both ecological thresholds and critical loads estimate a metric value expected to be associated with change in the ecosystem. The difference is that an ecological threshold is based upon a response metric while a critical load relates to a known amount of some input to the system. Both ecological thresholds and critical loads are often determined by large modeling studies across multiple sites in varying ecosystem condition, e.g., the ecological threshold for benthic index of biologic integrity (Stribling et al. 1998) and critical loads for atmospheric nitrogen oxide and sulfur dioxide deposition (Dupont et al. 2005). If changes in an ecosystem begin without early warning to initiate a management response (e.g., no management threshold exists), and the change continues past the ecological threshold (so that the ecosystem changes and natural resource values become impacted) then regulatory thresholds become relevant.

Regulatory thresholds are likely to be the least conservative threshold as they are frequently based on an aspect of the ecosystem posing a threat to human health (e.g., mercury concentration in fish; Meili et al. 2003), in which case the ecosystem may well have already entered a degraded condition (Figure 4.1).

Process of threshold determination

Within this report, a range of management, ecological, and regulatory thresholds were ultimately used, although ecological thresholds were used preferentially. One very helpful resource was the report by Hendricks and Little (2003) to the U.S. Environmental Protection Agency (U.S. EPA) specifically working towards the establishment of environmental thresholds for multiple metrics. U.S. EPA documentation also provided a basis for **Air Quality** (National Ambient Air Quality Standards) and **Water Quality** (Freshwater Recreational Standards) thresholds, which were supplemented by scientific literature to clarify whether thresholds could be considered as ecologically relevant, rather than simply regulatory (Tables 4.1, 4.2). Thresholds for **Biodiversity** metrics were largely based on National Park Service (NPS) management thresholds, and so the scientific literature was further investigated for experimental or correlative justification of these thresholds (Table 4.3). Finally, the thresholds established for **Ecosystem Pattern and Processes** metrics were based on research studies, some of which are ongoing within the National Capital Region Network (Townsend et al. in prep.; Table 4.4).

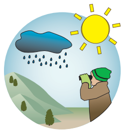


Table 4.1. Thresholds for Air Quality metrics.

Metric	Threshold	Justification	Threshold source
Ozone	0.075 ppm for the 3-yr mean of 4th-highest daily maximum 8-hr average	The ozone threshold was based on human health, but is also appropriate for plant health. Ozone was sampled on an hourly basis. An hourly value was calculated (mean of 4 hours before and after), recording the maximum 8-hr average value per day. For each year the 4th-highest daily value was recorded and then a 3-yr mean was calculated.	U.S. EPA 2004 NAAQS 2008 *http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=149923*
Total nitrate deposition	Forest: 15 kg ha^{-1} yr^{-1} Other: 10 kg ha^{-1} yr^{-1} (annual total per site)	The nitrate threshold was based on maintaining ecosystem structure and function. Annual total deposition was used—total NO_3^- deposition was calculated as 1.036 x wet deposition.	Greenfelt and Thornelof 1992 Dupont et al. 2005
Wet sulfate deposition	10 kg ha^{-1} yr^{-1} (annual total per site)	The sulfate threshold was based on limiting acidification of sensitive fresh waters.	Schindler 1988 Dupont et al. 2005
Particulate matter (soot; PM2.5)	15 µg m^{-3} (annual arithmetic mean) 35 µg m^{-3} (24-hr total)	The soot threshold was based upon human health and visibility. 24-hr threshold is 3-yr mean of annual 98th percentile (daily measurement). Annual threshold is 3-yr mean of annual means (based on daily measurement).	NAAQS 2008 U.S. EPA 2004a
Mercury deposition	2 ng L^{-1} (annual mean)	This modeled value corresponds to an inland fish tissue concentration of 0.5 mg methylmercury kg^{-1} wet weight.	Meili et al. 2003 Hammerschmidt and Fitzgerald 2006

Vehicle exhaust contributes to increased nitrate deposition and atmospheric soot concentrations.

Table 4.2. Thresholds for Water Quality metrics.

Metric	Threshold	Justification	Threshold source
pH	$6.0 \leq pH \leq 8.5$ (monthly instantaneous measurements)	Extreme pH values limit suitability of habitat for biota, e.g., salamander larvae abundance are reduced at extreme pH, directly, and indirectly by reducing available food.	DCMR 2005 U.S. EPA freshwater recreation standards 2005 Barr and Babbitt 2002
Dissolved oxygen	Instantaneous measures Jun 1- Jan 31 $\geq$ 3.2 mg L^{-1} Feb 1-May 31 $\geq$ 5.0 mg L^{-1} (monthly instantaneous measurements)	Low concentrations of dissolved oxygen cause limitation and ultimately death of fish, benthic invertebrates and aquatic plants.	DCMR 2005 U.S. EPA freshwater recreation standards 2005
Temperature	< 32.2°C (monthly instantaneous measurements)	Increased stream water temperature is unsuitable for many biota such as brook trout.	DCMR 2005 U.S. EPA freshwater recreation standards 2005 Wehrly et al. 2007
Acid neutralizing capacity (ANC)	> 200 μeq L^{-1} (monthly instantaneous measurements)	Threshold based on U.S. EPA "sensitive to acidification" standard of 200 μeq L^{-1} . Also justified by relationship to stream fish and benthic IBI.	Hendricks and Little 2003 Roth et al. 1999
Salinity	< 0.25 (monthly instantaneous measurements)	Threshold based on U.S. EPA human drinking water standards of maximum 250 mg L^{-1} chloride ions (equivalent to a salinity of 0.25).	U.S. EPA National Secondary Drinking Water Regulations 2009
Nitrate	< 2 mg L^{-1} (monthly instantaneous measurements)	Threshold based on relationship to benthic invertebrate index.	Roth et al. 1999
Total phosphorus	< 36.56 μg L^{-1} (monthly instantaneous measurements)	Threshold based on U.S. EPA nutrient ecoregional criteria, to maintain baseline conditions with minimal impact from anthropogenic eutrophication.	U.S. EPA 2000
Benthic index of biotic integrity (IBI)	Benthic IBI > 3 (once off sample per site)	Threshold based on statewide assessment of benthic communities; resulting in the scale: 1.0-1.9 (very poor), 2.0-2.9 (poor), 3.0-3.9 (fair), 4.0-5.0 (good).	Stribling et al. 1998 Hilderbrand et al. 2007
Physical habitat index (PHI)	PHI > 42 (once off sample per site)	Threshold based on 1994-1997 Maryland Biological Stream Survey data on the condition of MD streams: 1-11.9 (very poor), 12-41.9 (poor), 42-71.9 (fair), 72-100 (good).	Roth et al. 1999

Table 4.3. Thresholds for Biodiversity metrics.

Metric	Threshold	Justification	Threshold source
Percent cover of herbaceous species, woody vines, and target exotic trees and shrubs	< 5% cover. Measured as area of ground covered by herbs and vines, and percent of total basal area for shrubs and trees. (once off sample per site)	This threshold is more than a simple presence of these species, but an indication that they have the potential to increase in abundance, displacing native species.	This threshold is a guideline to commence active management of an area by removal of these species.
Presence of pest species	emerald ash borer: 0% gypsy moth: 600 egg masses ha^{-1} (once off sample per site)	The emerald ash borer threshold is based upon any observed presence of this pest species being unacceptable. The gypsy moth threshold is based on documented forest response.	Montgomery 1990 Liebhold et al. 1994
Native seedling regeneration	35,000 seedlings ha^{-1} (once off sample per site)	Based on natural densities of seedlings in a healthy and self sustaining forest. This threshold may vary depending on deer population.	McWilliams et al. 1995 Carter and Fredericksen 2007 Marquis et al. 1992
Fish index of biotic integrity (IBI)	Fish IBI > 3 (once off sample per site)	Based on 1994-1997 data from a total of 1,098 sites, sites were classified based on physical and chemical data and compared to a range of stream fish related metrics: 1.0-1.9 (very poor), 2.0-2.9 (poor), 3.0-3.9 (fair), 4.0-5.0 (good).	Roth et al. 1998 Roth et al. 2000
Proportion of area occupied (PAO) by adult amphibians	20% < PAO < 80% (once off annual sample)	The threshold is based on preserving a diverse and abundant population of amphibians. Calculated on a species-by-species basis; at < 20% PAO, a species risks becoming locally extinct and > 80% PAO indicates local disturbance favoring one species at the expense of others.	Although the technique is well established (Mackenzie et al. 2005), the threshold is a guideline currently used for management of these areas.
Presence of forest interior dwelling species (FIDS) of birds	> 1 highly sensitive and/or > 4 sensitive FIDS assessment (one assessment per year)	Threshold is based on bird sensitivity to forest fragmentation and disturbance both within and surrounding a forest patch, particularly during the breeding season. One highly sensitive species indicates high-quality FIDS habitat, > 6 highly sensitive species indicates exceptional quality habitat, and < 4 sensitive species indicates severe forest fragmentation and poor FIDS habitat.	Jones et al. 2000
White-tailed deer density	Forest: < 8 deer km^{-2} Grassland: < 20 deer km^{-2} (one assessment per year)	The forest threshold for deer abundance is based on a 10 year manipulative experiment. The grassland threshold is a guideline currently used for management of these areas.	Horsley et al. 2003

Table 4.4. Thresholds for Ecosystem Pattern and Processes metrics.

Metric	Threshold	Justification	Threshold source
Percent forest (within the park)	59% (once off assessment)	USGS digital land use data were used for forest cover in areas of North Carolina, West Virginia, and Alabama to determine the critical value of 59.28%. Forest was chosen as it is a dominant vegetation type within the region, providing major structure to faunal and floral communities.	Gardner et al. 1987 Gardner and O'Neill 1991 Hargis et al. 1998
Percent forest (within the park + 5 times buffer area) Figure 2.16.	59% (once off assessment)	as above	as above
Critical dispersal threshold index (within the park)	Dcrit < 360 m (once off assessment)	Based on the distance that many small mammals and tree seeds can disperse, Dcrit is a measure of the distance where 75% of forest patches are connected (allowing dispersal).	Townsend et al. in prep Bowman et al. 2002 He and Mladenoff 1999
Critical dispersal threshold index (within the park + 5 times buffer area) Figure 2.16.	Dcrit < 360 m (once off assessment)	as above	as above
Impervious surface (within the park)	10% (once off assessment)	Studies on many ecosystem components such as wetlands, floral and faunal communities, and streambank structure all show signs of impact above this impervious surface threshold. Recent studies on stream macro-invertebrates continue to show shifts to tolerant species and reductions in biodiversity near this threshold. Overall, < 10% is protected, 10-30% is impacted and > 30% is degraded.	Arnold and Gibbons 1996 Lussier et al. 2008
Impervious surface (within the park + 5 times buffer area) Figure 2.16.	10% (once off assessment)	as above	as above

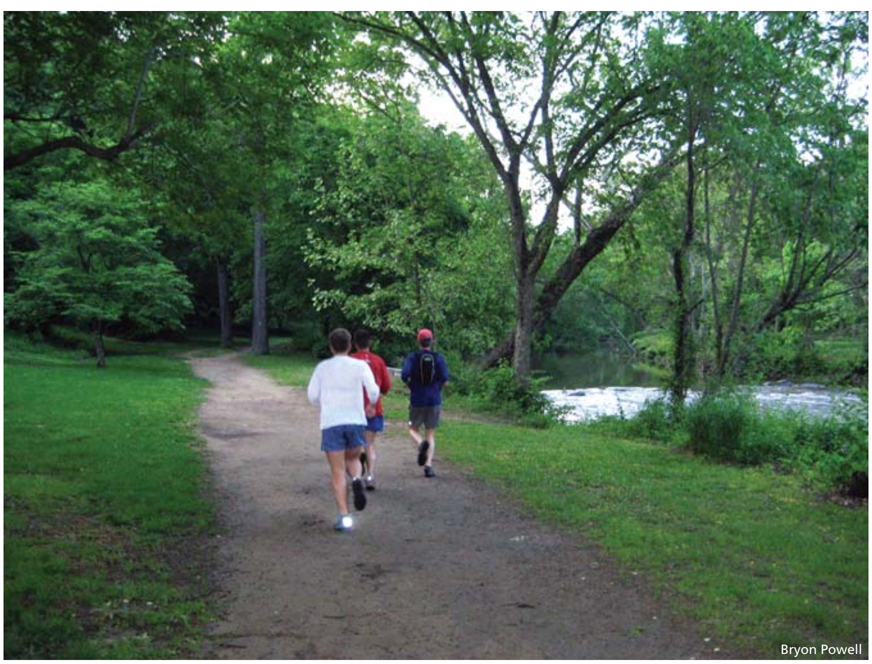
Air Quality

Ozone—*regulatory*

Ground-level ozone is regulated under the Clean Air Act, and the U.S. EPA is required to set standard concentrations for ozone (U.S. EPA 2004). In 1997, the ozone threshold was set by the National Ambient Air Quality Standards (NAAQS) as 0.08 ppm (U.S. EPA 2006), but has recently been revised and lowered to 0.075 ppm (NAAQS 2008), where the threshold concentration is the three-year average of the fourth-highest daily maximum eight-hour average ozone concentration measured at each monitoring station. In humans, ozone can cause a number of health-related issues, such as lung inflammation and reduced lung function, which can result in hospitalization. Concentrations of 0.12 ppm can be harmful with only short exposure during heavy exertion such as jogging, while similar symptoms can occur from prolonged exposure to concentrations of 0.08 ppm ozone (McKee et al. 1996). One study on 28 plant species, where plants were exposed for between three and six weeks, showed foliar impacts including premature defoliation in all species at ozone concentrations between 0.06 and 0.09 ppm (Kline et al. 2008). This suggests that a specifically plant-based ecological threshold would likely be lower than the regulatory 0.075 ppm (Kline et al. 2008).

Wet nitrate deposition—*ecological*

NPS Air Resources Division has estimated that natural background deposition of nitrogen in the eastern United States is 0.5 kg ha^{-1} y^{-1} (NPS 2005). For deciduous forest habitats, greater than 15-20 kg ha^{-1} y^{-1} nitrate can result in nutrient imbalances and changes to plant morphology such as increased shoot-root ratios (SAR 1995). Dupont et al. (2005) suggest a wet deposition target load for freshwater Canadian lakes of



Atmospheric ozone and soot concentrations can negatively affect the health of joggers on park trails.

10 kg ha^{-1} y^{-1} for nitrate deposition. This target load is intended to be the highest concentration of these chemicals that will not lead to long-term harmful effects on ecosystem structure and function (Dupont et al. 2005).

Wet sulfate deposition—*ecological*

NPS Air Resources Division has estimated that natural background deposition of sulfur in the eastern United States is 0.5 kg ha^{-1} y^{-1} (NPS 2005). Threshold amounts as low as 2.7-6.7 kg S ha^{-1} y^{-1} have been recommended for oligotrophic lakes and streams in Canada (Hendricks and Little 2003), and 10 kg S ha^{-1} y^{-1} for Canadian freshwater lakes in general has been suggested (Dupont et al. 2005). Studies within the U.S., assessing the correlation of lake pH values and sulfur deposition rates, have also concluded that loading above 10 kg S ha^{-1} y^{-1} can be expected to cause some degradation (due to acidification) of sensitive fresh waters (Schindler 1988).

Particulate matter (soot)—*regulatory*

Ground-level particulate matter (soot) is regulated under the Clean Air Act, and the U.S. EPA is required to set standard concentrations for airborne particulates (U.S. EPA 2004). The particulate matter threshold set by the National Ambient Air Quality Standard in 1997 was 65 μg m^{-3} (U.S. EPA 2004a), however this has recently been revised and lowered to 35 μg m^{-3} (NAAQS 2008), where the threshold concentration is the three-year average of the annual 98th percentile concentration, measured daily at each monitoring station. The equivalent concentration of this threshold as an annual arithmetic mean is 15 μg m^{-3}. Fine particles (PM2.5, particles < 2.5 μm diameter) are emitted as smoke from power

The red-backed salamander (*Plethodon cinereus*), found in Rock Creek Park, can be effected by extreme soil acidity.

Older coal-fired power plants, in particular, can be a major source of particulate and atmospheric mercury pollution.

plants, gasoline and diesel engines, wood combustion, smelters, steel mills, and forest fires or are the result of chemical reactions such as the release of sulfur dioxide or nitrogen dioxide. A large review conducted by the U.S. EPA as part of the revision of the regulatory threshold found that airborne soot can aggravate lung disease, and cause; non-fatal heart attacks, asthma attacks, acute bronchitis, increased respiratory infection, coughing, wheezing, shortness of breath, and changes in lung function (U.S. EPA, 2006a).

Mercury deposition—*regulatory*

The threshold value of 2 ng L^{-1} in rain is an indirect modeled estimate of rainfall mercury concentrations that result in a mercury concentration of 0.5 mg kg^{-1} wet weight within inland fish species (Meili et al. 2003). The authors do concede that this value is for low organic soils, as highly humic soils are known to potentially store large amounts of mercury which can slowly leach into inland waters, in some cases contributing much more to mercury concentrations than current atmospheric deposition (Meili et al. 2003). Currently, the U.S. EPA also has a lower recommended fish tissue regulatory maximum of 0.3 mg kg^{-1} wet weight, which would result in reducing the modeled atmospheric deposition threshold (U.S. EPA 2001). Human and mammalian regulatory thresholds are based on the effects of exposure. In utero exposure can cause mental retardation, cerebral palsy, deafness, blindness and dysarthria (speech disorder) and adult exposure can cause motor dysfunction and other neurological and mental impacts (U.S. EPA 2001). Avian species are particularly susceptible as mercury reduces reproductive potential. Measured atmospheric wet and dry mercury deposition trends from west to east across North America can also be measured in the common loon (*Gavia immer*), and throughout North America in mosquitoes (Evers et al. 1998, Hammerschmidt and Fitzgerald 2002). Mercury is also recognized to have a toxic effect on soil microflora, although no ecological depositional threshold is currently available (Meili et al. 2003).

Water Quality

pH, dissolved oxygen, temperature—*regulatory*

The District of Columbia Municipal Regulations (DCMR 2005) have classified streams on the basis of their current and future uses. These categories determine the water quality standards that are applied to Rock Creek and its tributaries. Rock Creek and its tributaries are designated for beneficial use as primary and secondary contact recreation (A, B), aesthetic enjoyment (B), protection and propagation of fish, shellfish, and wildlife (C), protection of human health related to consumption of fish and shellfish (D), and navigation (E) (DCMR 2005). In addition, Rock Creek and its tributaries have been designated as "Special Waters of the District of Columbia" which indicates that the "surface waters are of water quality better than needed for the current use or have scenic or aesthetic importance" (DCMR 2005). The thresholds for dissolved oxygen concentration, pH, and water temperature are determined from these designated beneficial uses. The regulated range for pH is 6.0-8.5 (DCMR 2005). Salamanders are susceptible to extreme pH values and can be limited by food availability even at less extreme acidification (Barr and Babbitt 2002). The dissolved oxygen concentration is required to be greater than 5 mg L^{-1} from Feb 1-May 31 and above 3.2 mg L^{-1} from Jun 1-Jan 31 (DCMR 2005). In all cases, water temperature is regulated to be less than 32.2°C (DCMR 2005), which is greater than the critical thermal maximum for Brook Trout, 28.3-29°C (Wehrly et al. 2007).

Acid neutralizing capacity—*ecological*

The acid neutralizing capacity (ANC) threshold was developed by the Maryland Biological Stream Survey

Spotfin shiners (*Cyprinella spiloptera)*, found in Rock Creek, require good water quality and intact streams.


Brian Gratwicke, DCNATURE.com

(MBSS) program after their first round of sampling (1995-1997). The MBSS data were used to detect stream degradation so as to identify streams in need of restoration and to identify 'impaired waters' candidates (Roth et al 1999). A total of 539 streams that received a fish or benthic index of biotic integrity (FIBI or BIBI) rating of poor (2) or very poor (1) were pooled and field observations and site-specific water chemistry data were used to determine stressors likely causing degradation. The MBSS then used threshold values to indicate stress. The ANC threshold for determining degraded streams is less than 200 µeq L^{-1} (Roth et al. 1999, Hilderbrand et al. 2007). A less conservative threshold of 50 µeq L^{-1} has also been suggested (Hendricks and Little 2003, Schindler 1988).

Salinity—*regulatory*

Salinity in drinking water is regulated by U.S. EPA under the National Secondary Drinking Water Standards (NSDWS) regulations. These regulations control contaminants in drinking water and are non-enforceable. The Secondary Maximum Contaminant Level (advisory only) for salinity is 250 mg L^{-1} (NSDWS 1997), which is equivalent to a salinity of 0.25. Therefore, the salinity threshold for this assessment is < 0.25.

Nitrate—*ecological*

The nitrate concentration threshold was developed by the MBSS program after their first round of sampling as described for the ANC threshold. The MBSS determined that a nitrate concentration of 2 mg L^{-1} indicated stream degradation (Roth et al. 1999, Hilderbrand et al. 2007).

Total phosphorus—*ecological*

The total phosphorus threshold is based on the U.S. EPA Ecoregional Nutrient Criteria. These criteria were developed to prevent eutrophication nationwide and are not regulatory (U.S. EPA 2000). The criteria were developed as baselines for specific geographic regions. Rock Creek Park is located in Ecoregion IX or the Southeastern Temperate Forested Plains and Hills region (U.S. EPA 2000). The ecoregional reference condition value, which is used as the threshold for phosphorus, is 36.56 µg L^{-1} (U.S. EPA 2000).

Benthic index of biotic integrity—*ecological*

The aquatic macroinvertebrates threshold is based on the MBSS interpretation of the benthic index of biotic integrity (IBI). The IBI scores range from 1 to 5 and are calculated by comparing the site's benthic assemblage to the assemblage found at minimally impacted sites (Hilderbrand et al. 2007). An IBI score of 3 means that a site is considered to be comparable (not significantly different) to reference sites. A score greater than 3 indicates that a site is in better condition than the reference sites. Any sites with IBIs less than 3 are in worse condition than reference sites (Roth et al. 1999, Hilderbrand et al. 2007), and the entire scale is 1.0-1.9 (very poor), 2.0-2.9 (poor), 3.0-3.9 (fair), 4.0-5.0 (good; Stribling et al. 1998). Therefore, the threshold for aquatic macroinvertebrates is an IBI greater than 3, indicating that a site is in, at least, reference condition (Roth et al. 1999).

Physical habitat index — *ecological*

For the physical habitat index (PHI), in-stream and near-stream habitat measures of first through third-order streams are recorded between June and September at the same time as the fish are being sampled (Hilderbrand et al. 2007). This sampling period was chosen because the low flow conditions are typically limiting to the abundance of lotic (living in moving water) fish. The PHI consists of measures of bank stability, epibenthic substrate, shading, remoteness, riparian width, riffle quality, instream wood, instream habitat quality, and embeddedness. Sites are given scores for each of the applicable categories and then those scores are adjusted to a percentile scale (Hilderbrand et al. 2007). The PHI threshold was developed by the MBSS program after their first round of sampling as described for the ANC threshold. The MBSS determined the scale for PHI values to be 1-11.9 (very poor), 12-41.9 (poor), 42-71.9 (fair), 72-100 (good; Roth et al. 1999, Hilderbrand et al. 2007).

Biodiversity

Percent cover of herbaceous species, woody vines, and target exotic trees and shrubs—*management*

Invasive exotic plants may compete with native plants and therefore lead to a reduction in biodiversity of the native flora (Mack et al. 2000). The current threshold is that abundance of these plants should not exceed 5% cover, measured as area of ground covered by herbs and vines, and percent of total basal area for shrubs and trees. The threshold is intended to indicate both the simple presence of these exotic species, and also that abundance of these species is sufficient to potentially establish and spread.

Presence of pest species—*management, ecological*

Emerald ash borer (*Agrilus planipennis*) was first observed in the U.S. in 2002, and since then has been responsible for the death of an estimated 15-20 million ash


IAN


Leslie J. Mehrhoff, U of Conn, bugwood.org

LEFT: A Rock Creek Park stream bed is scoured by flash flooding.

RIGHT: Lesser celandine (*Ranunculus ficaria*) is an invasive exotic plant that spreads rapidly across the forest floor to form a blanket of leaves which native species are unable to penetrate.

trees in southern Michigan alone (McCullough and Siegert 2007). A total of 16 ash species in North America are potentially affected by this invasive exotic species, which has now been observed in dozens of locations outside of southern Michigan (McCullough and Siegert 2007). The drastic effects and potential for forest damage result in the threshold being any observations of adults or larvae. The gypsy moth (*Lymantria dispar*) was accidentally introduced to North America in the late 1860s and has spread widely, resulting in an estimated 40 million acres of forest defoliation during the 1980s alone (Liebhold et al. 1994). A standard threshold of 600 egg masses per hectare (250 per acre) has been established as a management threshold (Montgomery 1990, Liebhold et al. 1994); however, forest response is known to be very variable between 240 and 2400 egg masses per hectare. As a result, ecological thresholds may be higher than 600 egg masses ha^{-1}. Observations suggest 1,240-1,850 egg masses per hectare are likely to lead to > 30% defoliation, 1,730-2,220 egg masses per hectare are likely to result in growth loss (i.e., > 40% defoliation), and 2,470-3,460 egg masses per hectare are likely to result in tree mortality (Liebhold et al. 1994).

Native seedling regeneration—*ecological*

The ecological seedling regeneration threshold of 35,000 seedlings ha^{-1} is based upon seedling numbers in a mature, non-industrial private forestland in south-central Virginia (Carter and Fredericksen 2007). However, some estimates of native regeneration for silviculture under different deer grazing scenarios are much higher—15 million seedlings per hectare (all desirable species), under very low, and as many as 21 million seedlings per hectare (all desirable species), under very high, deer grazing pressure (Marquis et al. 1992).

A gypsy moth shown here in three life stages: pupa, egg mass, and moth.

Fish index of biotic integrity—*ecological*

A threshold value of 3 was used as an ecological threshold indicating attainment of overall reference ecosystem condition. The fish index of biotic integrity (FIBI) was proposed as a way to provide a more informative measure of anthropogenic influence on fish communities and ecological integrity than measurements of physiochemical metrics alone (Karr 1981). The metric was then adapted and validated for streams of

The Denil fish ladder at Peirce Mill Dam was installed in 2006 to enable the upstream migration of migratory fish such as the alewife (*Alosa pseudoharengus*) and the blueback herring (*Alosa aestivalis*).

Maryland using a reference condition approach, finding that 29% of stream sites sampled in Maryland were in poor or very poor condition (Roth et al. 1998, Roth et al. 2000). The IBI scores range from 1-5 with a score greater than 3 indicating that a site is considered to be comparable to or better than reference sites (Roth et al. 2000).

Proportion of area occupied by adult amphibians—*management*

The threshold of between 20 and 80% area occupied (PAO) is currently used as a management threshold, intended to maintain abundant and diverse amphibian communities. The percent area occupied is calculated according to whether amphibians are: 1) present and detected, 2) present and not detected, or 3) not present, with a probabilistic function to determine differences between not present versus present but not detected (Bailey et al. 2007). The probabilistic function has been developed for diverse faunal species (Mackenzie et al. 2003).

Presence of forest interior dwelling species of birds—*ecological*

Presence of bird species can effectively provide a bio-indicator of subtle or unexpected changes in environmental condition (Koskimies 1989). Throughout Maryland, there was a documented 63% decline in individual birds of neotropical origin (including forest interior dwelling species [FIDS]) between 1980 and 1989 (Jones et al. 2000). This represented a continuation of documented declines at some sites between 1940 and 1980 (Terborgh 1992). The presence of sensitive FIDS is used as an indicator of high-quality forest interior habitat. The Guide to Conservation of FIDS lists 25 species that can potentially breed in critical areas in Maryland. Thirteen of the 25 species are considered 'highly area-sensitive' and presence of one highly area-sensitive species indicates high-quality forest interior habitat (Jones et al. 2000; Appendix Table A.14). Presence of six or more highly area-sensitive species indicates exceptional forest interior habitat. The other

LEFT: The shaded wetlands, seeps, streams, and wooded habitats of Rock Creek Park are home for several amphibian species, such as this northern two-lined salamander, *Eurycea bislineata*.

RIGHT: Bird watching in Rock Creek Park, Washington, D.C.

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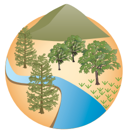
12 FIDS are less area-sensitive; but they still require large forest tracts for stable populations (Jones et al. 2000). Using this information, the ecological threshold was based on the presence of appropriate habitat for forest interior dwelling species of birds and defined as observation of at least four FIDS or one highly area-sensitive species. In both cases, these birds must be observed in probable or confirmed breeding status (Jones et al. 2000).

White-tailed deer density—*forest: management, ecological; grassland: management*

The forest threshold for white-tailed deer density (8.0 deer km^{-2}) is a well-established ecological threshold, and this threshold is also used as the management threshold. Species richness and abundance of herbs and shrubs, although showing change in some studies at densities as low as 3.7 deer km^{-2}, are consistently reduced as deer densities approach 8.0 km^{-2} (Decalesta 1997). One large manipulation study in central Massachusetts found that deer densities of 10-17 km^{-2} inhibited the regeneration of understory species, while densities of 3-6 km^{-2} supported a diverse and abundant forest understory (Healy 1997). There are multiple sensitive species of songbirds that cannot be found in areas where deer grazing has removed understory vegetation needed for nesting, foraging, and protection. Even though songbird species vary in how sensitive they are to increases in deer populations, these changes generally occur at deer densities greater than 7.9 km^{-2} (Decalesta 1997). In contrast, the grassland (or agricultural land) management threshold for deer abundance is less well-studied or justified but is currently 20 deer km^{-2}. Studies of national parks within the National Capital Region (Antietam, Monocacy, and Chesapeake and Ohio Canal) have shown that the current abundances of 45-54 deer km^{-2} cause significant damage to agricultural crops maintained as grassland habitat (Stewart et al. 2007).

Overgrazing by large numbers of white-tailed deer in Rock Creek Park can degrade forest conditions.



Ecosystem Pattern and Processes

Percent forest—*ecological*

Modeling studies have found that in ecological systems, there is a tipping point of forest cover below which a system becomes so fragmented that it no longer functions as a single system (Hargis et al. 1998). This 'percolation' theory was initially developed in metallurgy to assess coherence of material aggregates (Gardner et al. 1987). USGS digital land use data were used for forest cover in areas of North Carolina, West Virginia, and Alabama to determine the critical value of 59.28% (Gardner et al. 1987). Forest was chosen as it is a dominant vegetation type within the region, providing major structure to faunal and floral communities.

Critical dispersal threshold index—*ecological*

The critical dispersal threshold index (Dcrit; distance < 360 m) is based on the distance that many small mammals and tree seeds can disperse (He and Mladenoff 1999, Bowman et al. 2002). Dcrit is a measure of the distance where 75% of forest patches are connected, therefore allowing dispersal (Townsend et al. in prep.). From 13 tree species, an effective dispersal distance of 65 ± 15 m (mean ± standard error) has been calculated, indicating on average a 95% probability of effective dispersal over this distance. The maximum dispersal distance for these same species was 997 ± 442 m, indicating rare (< 1% probability) success of dispersal at this distance (He and Mladenoff 1999).

Impervious surface—*ecological*

A study carried out in coastal New Jersey demonstrated measurable effects of impervious surface on pH and specific conductance at impervious surface cover as low as 2%, and recommended a threshold for those systems between 2.4% and 5.1% (Conway 2007). Percent urban land is highly correlated to impervious surface and can provide a good approximation of watershed

Inside Rock Creek Park, the grounds are threaded with roads, bridges, and parking lots, all adding impervious surface and forest fragmentation.

Surburban neighborhoods that border Rock Creek Park, such as this one, add to the high percentage of surrounding impervious surface.

degradation due to increases of impervious surface. This correlation occurs because residential land use ranges from 12-65% impervious surface (Conway 2007).

The three Ecosystem Pattern and Processes metrics were calculated at two scales: 1) within the park boundary, and 2) within the park boundary plus an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary (Figure 2.7). The purpose of this analysis was to assess the influence on ecosystem processes of land use immediately surrounding the park.

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White-tailed deer (*Odocoileus virginianus*) of Rock Creek Park.

Ryan Valdez, DCNATURE.com

Chapter 5: Resource Condition Assessment

Using the data from Chapters 2 and 3 and the thresholds from Chapter 4, the vital signs and habitat framework to assess Rock Creek Park's natural resource condition are presented.

Introduction

It is increasingly recognized that monitoring data collected for specific purposes, such as assessing the implementation of environmental regulations, does not necessarily allow for regional assessments of ecosystem condition (U.S. EPA 2000, 2002). As a result, one of the key challenges of large-scale monitoring programs is to develop integrated and synthetic data products that can translate a multitude of diverse data into a format that can be readily communicated to decision-makers, policy developers, and the public (Fancy et al. 2008). These timely syntheses of ecosystem condition can provide feedback to managers and stakeholders, so that the effectiveness of management actions as well as future management goals can be determined at multiple scales (Dennison et al. 2007; Figure 5.1).

One approach to synthesizing data is the development of multiple-metric indices to summarize the status of many aspects of a community, such as fish, and then draw inferences on the status of the supporting ecosystem (Karr 1981). The development of combined metrics improved upon a traditional approach of acute toxicity testing on organisms as toxicity limits can show large regional differences depending on the local environment. Multi-metric indices also improved on the use of just one measure, such as fish biomass or abundance, which often show complex and variable responses to changes in environmental condition (Karr 1981). Metrics such as the fish index of biotic integrity (IBI) and the benthic IBI have been widely applied, both internationally and locally (in Maryland streams), and are seen as providing greater insight into ecosystem condition than physical measurements (e.g., water quality) alone, as biological communities provide an integrated summary of ecosystem condition over time (Roth et al. 1998, 2000, Harrison and Whitfield 2004). Although these synthetic indices and bioindicators can provide important information about overall status of an ecosystem, no data, of itself, can improve our practice of ecosystem management decision making (Carter et al. 2007). Therefore, to clearly identify major environmental issues and assist in directing effective management actions, some format of score card or report card of multiple metrics is necessary (U.S. EPA 2000, 2002).

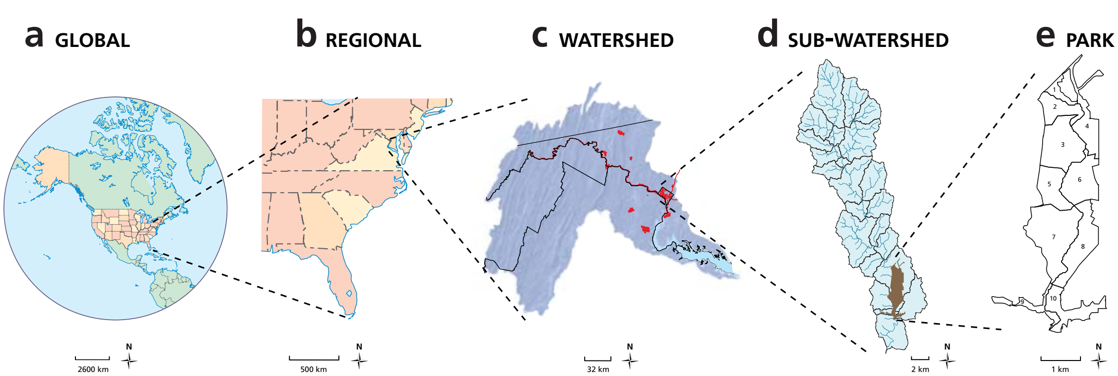


Figure 5.1 Multiple spatial scales relevant to assessing natural resource conditions.

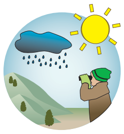
For broad application, a reporting framework needs to be flexible because, depending on the spatial and temporal scales being assessed (Figure 5.1), different metrics are most appropriate. While development of a ‘regional index of biological integrity,’ combining multiple synthetic indices (e.g., invertebrate, avian, and amphibian indices) has been used for mid-Atlantic forest riparian ecosystems (Brooks et al. 1998) and an assessment of the 422 km^2 Maryland Coastal Bays used an index of water quality metrics (Wazniak et al. 2007), remote sensing data of impervious surface, road density, and vegetation cover were used to compare sub-watersheds of the 86,752 km^2 Ordos Plateau in Inner Mongolia (Ding et al. 2008). Spatially explicit regional report cards, using biological and water quality metrics and targeted specifically at identifying and communicating key issues to managers and decision-makers as well as at tracking effectiveness of management actions over time, have been developed for estuaries in Moreton Bay, Australia (Pantus and Dennison 2005) and Chesapeake Bay in the U.S. (Williams et al. in press). Integrated assessments of multiple metrics using a threshold approach have also been applied to the comparison of estuaries at broad spatial scales (Ferreira 2000, Kiddon et al. 2003, Bricker et al. 2008). Elements of many of these assessment approaches are appropriate to include in the assessment of natural resource condition of Rock Creek Park, however, some unique challenges with respect to available data and also the diversity of habitats required the use of modified frameworks.

Rock Creek assessment approach

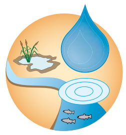
For the assessment of natural resource condition within Rock Creek Park, two synthetic frameworks were applied, both based on categories that addressed key structural and functional aspects of the ecosystem (U.S. EPA 2002). Recognizing the large amount of data included in this assessment from the NPS Inventory & Monitoring Program (I&M), the first framework utilized was the ecological monitoring framework or ‘vital signs’ categorization developed by NPS I&M (Fancy et al. 2008). Fancy et al. (2008) identified a key challenge of such large-scale monitoring programs to be the development of information products which integrate and translate large amounts of complex scientific data into highly aggregated metrics for communication to policy-makers and non-scientists. Aggregated indices were developed and presented within the current natural resource condition assessment for Rock Creek Park. More specific indices and even raw data (Appendix A) were also presented to facilitate communication of key conclusions to scientists and field practitioners and to ensure that all approaches and calculations were explicit. The second framework, using the same data set, calculated aggregated condition indices based upon the three main ecological habitats present within Rock Creek Park—**Forest**, **Wetland (Inland)**, and **Artificial-terrestrial Habitats** (predominantly managed meadows, community gardens, and mown lawns with trees and shrubs).

Methods

Ecological monitoring framework

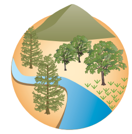


Air Quality



Water Quality

Biodiversity



Ecosystem Pattern and Processes

An ecological monitoring framework has been established by NPS I&M (Fancy et al. 2008), based on multiple efforts, such as the U.S. EPA scientific advisory board assessment on reporting ecological condition (U.S. EPA 2002). The NPS ecological monitoring framework has six high-level data categories; air and climate, geology and soils, water, biological integrity, human use, and landscapes (Fancy et al. 2008). In the assessment of natural resource condition of Rock Creek Park, data were available for four of these six data categories; air and climate (**Air Quality**), water (**Water Quality**), biological integrity (**Biodiversity**), and landscapes (**Ecosystem Pattern and Processes**).

Entrance to Rock Creek Park borders a busy roadway.

Lisa Florkowski

Habitat framework

Forest

Wetland (Inland)

Artificial-terrestrial

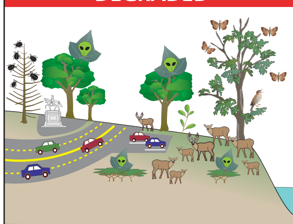
The habitat list defined by the International Union for the Conservation of Nature (IUCN) was chosen as the standard (IUCN 2007). The IUCN habitat classification includes 16 habitat types at the highest level, which are further divided into sub-habitats (Table 5.1, Appendix Table B.1). A total of three general habitat types were defined for Rock Creek Park (Figure 5.2). To determine the habitat types present within Rock Creek Park, a classified vegetation base map (Figure 2.6) was aggregated into general habitat types: beech/mixed oak, beech/tulip poplar, beech/white oak, chestnut oak, loblolly pine/mixed oak, tulip poplar, Virginia pine/oak, and sycamore/green ash were classified as **Forest Habitat**; streams (Figure 2.9), seeps, and springs (Figure 2.11) were classified as **Wetland (Inland) Habitat**; and canopy gap, managed meadows, community gardens, and mown lawns with trees and shrubs were classified as **Artificial-terrestrial Habitat** (Figure 2.4). To provide a basis for condition assessment for each habitat, the desired versus degraded extremes were conceptually described (Figure 5.2) based on a series of seven metrics which can be used to track the relative condition of the habitat between these two states. These metrics were chosen as being of a relevant spatial scale, responsive to change, and, where possible, with an established ecological threshold (Chapter 4, Metrics & Thresholds).

Table 5.1. Summary of IUCN major habitat classifications (for full listing, see Appendix Table B.1).

	IUCN general habitat description	# sub-habitats
1	**Forest**	9
2	Savanna	2
3	Shrubland	8
4	Grassland	7
5	**Wetland (Inland)**	18
6	Rocky areas (inland cliffs and mountain peaks)	0
7	Caves and non aquatic subterranean	2
8	Desert	3
9	Marine neritic (submerged nearshore, oceanic islands)	10
10	Marine oceanic	4
11	Marine deep benthic	6
12	Marine intertidal	7
13	Marine coastal/supratidal	5
14	**Artificial-terrestrial**	6
15	Artificial aquatic	13
16	Other	

FOREST HABITAT

DEGRADED

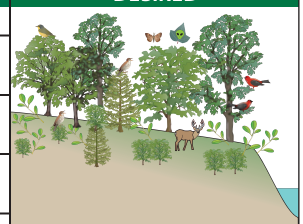


Degraded forest habitat has high numbers of exotic shrubs and trees, high % of impervious surface, and large deer populations. Native seedling regeneration and diversity of forest-dwelling bird species are low in patch forest with high occurance of insect pests.

Indicators

Degraded	Indicator	Desired
high	Density of Exotic Shrubs and Trees	low
high	Presence of Insect Pests	low
low	Presence of Forest Interior-dwelling Bird Species	high
high	Deer Population	low
low	Native Seedling Regeneration	high
low	Forest Connectivity	high
high	Percentage of Impervious Surface	low

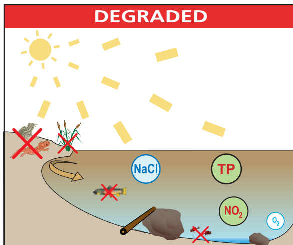
DESIRED



Desired forest habitat has low numbers of exotic shrubs and trees, low % of impervious surface, and small deer populations. Native seedling regeneration and diversity of forest-dwelling bird species are high in continuous forest with low occurance of insect pests.

WETLAND (INLAND) HABITAT

DEGRADED

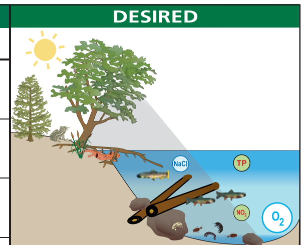


Degraded wetland habitat has eroded streambanks and no shade, high nutrients and salinity, resulting in turbid water, low oxygen levels, and low populations of fish, amphibians, and benthic invertebrates.

Indicators

Degraded	Indicator	Desired
high	Total Phosphorus	low
high	Salinity	low
high	Nitrate	low
low	Dissolved Oxygen	high
low	Benthic Invertebrates	high
unstable	Area Occupied by Adult Amphibians	stable
low	Physical Habitat Index	high

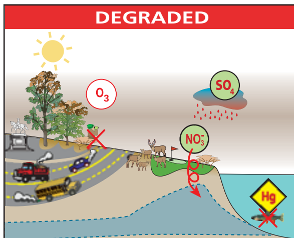
DESIRED



Desired wetlands habitat has intact streambanks with shade and sheltering roots and debris, low nutrients, and salinity, resulting in high oxygen, clear water, and high populations of fish, amphibians, and benthic invertebrates.

ARTIFICIAL-TERRESTRIAL HABITAT

DEGRADED

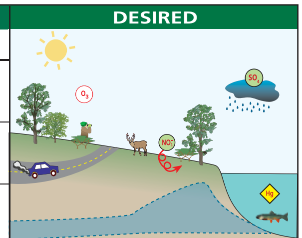


Degraded artificial terrestrial habitat has high particulate matter (low visibility), high % impervious surface, and large deer populations. High levels of ozone result in unhealthy plants, high sulfate deposition results in acid rain, high nitrate deposition reaches the water table, and fish may die due to high mercury deposition.

Indicators

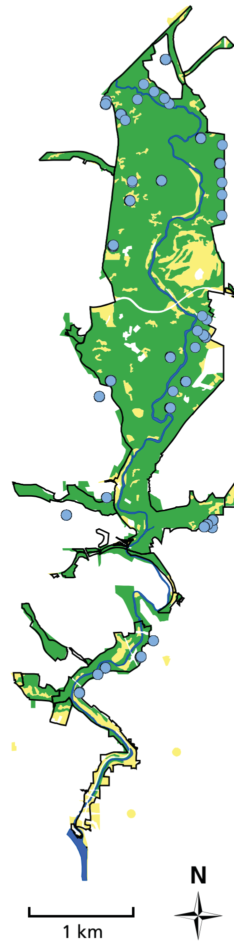
Degraded	Indicator	Desired
high	Deer Population	low
high	Percentage of Impervious Surface	low
high	Particulate Matter (soot)	low
high	Ozone	low
high	Sulfate Wet Deposition	low
high	Nitrate Wet Deposition	low
high	Mercury Deposition	low

DESIRED



Desired artificial terrestrial habitat has low particulate matter (good visibility), low % impervious surface, and small deer populations. Low ozone levels result in healthy plants, low sulfate deposition results in neutral rain, low nitrate deposition is used by plants locally, and low mercury deposition permits healthy fish.

ROCK CREEK PARK



Habitat type

- Forest (81%)
- Wetland (Inland) (2%)
- Artificial-terrestrial (17%)

Figure 5.2. Conceptual framework for desired and degraded condition of habitats present within Rock Creek Park, indicating metrics to track status of condition.

Data and thresholds

Ecological monitoring framework

A total of 29 metrics across the four ecological monitoring framework categories were included, each with an established threshold and based on a categorical scoring of threshold attainment (Table 5.2, 5.3; Chapter 4, Metrics & Thresholds). While some metrics were measured at the park scale and therefore only have one sampling site (e.g., deer density and **Ecosystem Pattern and Processes** metrics), there are 13 sampling sites for **Water Quality** within Rock Creek Park. Temporal intensity of measurement also varied between metrics, with only single assessments of **Ecosystem Pattern and Processes** metrics, while **Water Quality** metrics were measured monthly during the available data range (Table 5.2). All data used in the assessment were collected between 2000 and 2007 (Table 5.2). Data used in the assessment were obtained from multiple sources, with the **Air Quality** data largely coming from national air monitoring programs, **Water Quality** and **Biodiversity** data from the NPS I&M monitoring program, and **Ecosystem Pattern and Processes** data from a collaborative project between NPS and the University of Maryland Center for Environmental Science (Table 5.3).

Water sampling in the streams of the Rock Creek Park watershed.

Table 5.2. Summary of data used in Rock Creek Park natural resource condition assessment.

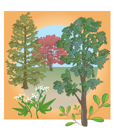
Metric (by vital sign category)	Threshold	Sites	Samples	Period
Air Quality				
Ozone	< 0.075 ppm	2	8	2000-2003
Total NO_3^- deposition (forest habitat)	< 15 kg ha^{-1} yr^{-1}	3	10	2000-2007
Total NO_3^- deposition (other)	< 10 kg ha^{-1} yr^{-1}	3	10	2000-2007
Wet SO_4 deposition	< 10 kg ha^{-1}1 yr^{-1}	3	10	2000-2007
Particulate matter (soot; PM2.5) concentration	< 15 mg m^{-3}	3	15	2000-2004
Hg deposition	< 2 ng L^{-1}	1	86	2004-2006
Water Quality				
pH	6.0 ≥ pH ≥ 8.5	13	234	2005-2007
Dissolved oxygen	June 1-Jan 31: ≥ 3.2 mg L^{-1} Feb 1-May 31: ≥ 5.0 mg L^{-1}	13	241	2005-2007
Water temperature	≤ 32.2°C	13	242	2005-2007
Acid neutralizing capacity (ANC)	≥ 200 µeq L^{-1}	13	241	2005-2007
Salinity	< 0.25	13	219	2005-2007
Aqueous nitrate	< 2 mg L^{-1}	13	234	2005-2007
Total phosphorus	< 36.56 µg L^{-1}	13	230	2005-2007
Benthic index biological integrity (BIBI)	> 3	6	6	2000-2004
Physical habitat index (PHI)	> 42	3	8	2000-2004
Biodiversity				
% cover of exotic herbaceous species	< 5% (of area)	5	5	2006-2007
Exotic tree/shrub density	< 5% (of total basal area)	3	4	2006-2007
Presence of forest pest species	< 1% of trees infested	3	3	2006-2007
Native seedling regeneration	> 31,875 seedlings ha^{-1}	5	5	2006-2007
Fish index biological integrity (FIBI)	> 3	3	6	2000-2004
Prop. of area occupied (PAO) by amphibians	20% < PAO < 80% each spp.	Park	9	2005-2007
Presence of forest interior dwelling species (FIDS) of birds	> 1 'highly sensitive' FIDS > 4 'sensitive' FIDS	Park	3	2003-2008
Deer density	Forest: < 8 deer km^{-2} Grassland: < 20 deer km^{-2}	Park	8	2000-2007
Ecosystem Pattern and Processes				
Proportion forest cover (within park)	0.59	Park	1	2001-2002
Prop. impervious surface (within park)	0.1	Park	1	2000
Critical connectivity (Dcrit; within park)	< 360 m	Park	1	2001-2002
Prop. forest cover (within park) + 5X buffer	0.6	Park	1	2001-2002
Prop. imperv. surface (within park) + 5X buffer	0.1	Park	1	2000
Critical connectivity (within park) + 5X buffer	< 360 m	Park	1	2001-2002

Table 5.3. Sources of data used in Rock Creek Park natural resource condition assessment.

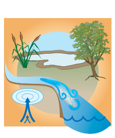
Metric (by vital sign category)	Agency	Reference/source
Air Quality		
Ozone	NPS ARD (U.S. EPA)	NPS CUE
Total NO_3^- deposition (forest habitat)	NADP	*http://nadp.sws.uiuc.edu/*
Total NO_3^- deposition (cultivated)	NADP	*http://nadp.sws.uiuc.edu/*
Wet SO_4 deposition	NADP	*http://nadp.sws.uiuc.edu/*
Particulate matter (soot; PM2.5) concentration	IMPROVE	*http://vista.cira.colostate.edu/improve/*
Hg deposition	MDN-NADP	*http://nadp.sws.uiuc.edu/mdn/*
Water Quality		
pH	NPS I&M	Norris et al. 2007
Dissolved oxygen	NPS I&M	Norris et al. 2007
Water temperature	NPS I&M	Norris et al. 2007
Acid neutralizing capacity (ANC)	NPS I&M	Norris et al. 2007
Salinity	NPS I&M	Norris et al. 2007
Aqueous nitrate	NPS I&M	Norris et al. 2007
Total phosphorus	NPS I&M	Norris et al. 2007
Benthic index biological integrity (BIBI)	NPS I&M, Montgomery County	Hilderbrand et al. 2007, Montgomery County DEP
Physical habitat index (PHI)	NPS I&M, Montgomery County	Hilderbrand et al. 2007, Montgomery County DEP
Biodiversity		
% cover of exotic herbaceous species	NPS I&M	Schmit and Campbell 2007, 2008
Exotic tree/shrub density	NPS I&M	Schmit and Campbell 2007, 2008
Presence of forest pest species	NPS I&M	Schmit and Campbell 2007, 2008
Native seedling regeneration	NPS I&M	Schmit and Campbell 2007, 2008
Fish index biological integrity (FIBI)	NPS I&M Montgomery County	Hilderbrand et al. 2007, Montgomery County DEP
Prop. of area occupied (PAO) by amphibians	NPS I&M	Mattfeldt et al. 2008
Presence of forest interior dwelling species (FIDS) of birds	D.C. Birdscape II, NPS I&M	Hadidian et al. 1997, Dawson and Efford 2006
Deer density	NPS I&M	Bates 2007
Ecosystem Pattern and Processes		
Proportion forest cover (within park)	UMCES; NPS	Townsend et al. 2006
Prop. impervious surface (within park)	UMCES; NPS	Townsend et al. 2006
Critical connectivity (Dcrit; within park)	UMCES; NPS	Townsend et al. 2006
Prop. forest cover (within park) + 5X buffer	UMCES; NPS	Townsend et al. 2006
Prop. imperv. surface (within park) + 5X buffer	UMCES; NPS	Townsend et al. 2006
Critical connectivity (within park) + 5X buffer	UMCES; NPS	Townsend et al. 2006

Habitat framework

To ensure assessments were broad-based, metrics from at least two categories from the ecological monitoring framework (**Air Quality**, **Water Quality**, **Biodiversity**, and **Ecosystem Pattern and Processes**) were included in the assessment of each habitat (Table 5.4). The data used range from 2000 to 2008, with data density ranging from one park assessment at one time (impervious surface, critical connectivity) through to 241 measurements monthly from 13 sites (dissolved oxygen) (Table 5.4). The data set was a subset of that used for the ecological monitoring framework, so the sources of all data are presented in Table 5.3 and the threshold justifications are presented in Chapter 4, Metrics & Thresholds. Justification for the inclusion of metrics as relevant to a particular habitat assessment is provided below.



Forest Habitat
The majority of indicators used to assess ecosystem condition of forest habitats were measures of Biodiversity (five), with two indicators of **Ecosystem Pattern and Processes** (Table 5.4). Of the seven indicators, three are relevant to the measurement of the quality of a resource within forest habitats (presence of forest interior dwelling birds, native seedling regeneration, critical connectivity), while the remaining four (exotic tree/shrub density, presence of pest species, deer density, impervious surface) measure the scale of stressors that are likely to directly impact forest habitats (Table 5.4).



Wetland (Inland) Habitat
Six of the seven indicators used to assess condition of wetland habitats were **Water Quality** indicators: three indicators of stressors (total phosphorus, salinity, aqueous nitrate) and three indicators of habitat quality for aquatic fauna (dissolved oxygen, benthic IBI, physical habitat index; Table 5.4). The remaining indicator (proportion of area occupied by adult amphibians) is a measure of **Biodiversity** and provides information regarding the ecosystem resource value of the habitat (Table 5.4).

Artificial-terrestrial Habitat
Assessment of artificial-terrestrial habitats condition was based on indicators in three categories: **Biodiversity** (deer density), **Ecosystem Pattern and Processes** (impervious surface), and **Air Quality** (soot, ozone, sulfate deposition, nitrate deposition, mercury deposition) (Table 5.4). Recognizing that **Air Quality** indicators could be used for any habitat, particularly any terrestrial habitat, they were considered especially appropriate for use in the predominantly mown grass characterizing artificial-terrestrial habitat within Rock Creek Park. These open vistas rely most heavily on the resource of high visibility. The impacts to plant health by high ozone are not well studied for artificial habitats, though exposure to atmospheric deposition is likely greater due to decreased foliar interception. Wet deposition of sulfate, nitrate, and mercury is more likely to have a negative impact in open areas where transport rate to groundwater and creeks will be greater than areas such as forest where more rainfall is intercepted by plant canopies and where there is greater plant biomass above and below ground to re-absorb nutrients from soils.

Table 5.4. Summary of data used in Rock Creek Park habitat-based natural resource condition assessment.

Metric (by habitat)	Threshold	Sites	Samples	Period
Forest				
Exotic tree/shrub density	< 5% (of total basal area)	3	4	2006-2007
Presence of forest pest species	< 1% of trees infested	3	3	2005-2007
Presence of forest interior dwelling species (FIDS) of birds	> 1 ‘highly sensitive’ FIDS > 4 ‘sensitive’ FIDS	park	3	2003-2008
Deer density	Forest: < 8 deer km^{-2}	park	8	2000-2007
Native seedling regeneration	> 31,875 seedlings ha^{-1}	5	5	2006-2007
Critical connectivity (Dcrit; within park)	< 360 m	park	1	2001-2002
Prop. impervious surface (within park)	< 0.1	park	1	2000
Wetland (Inland)				
Total phosphorus	< 36.56 μg L^{-1}	13	230	2005-2007
Salinity	< 0.25	13	219	2005-2007
Aqueous nitrate	< 2 mg L^{-1}	13	234	2005-2007
Dissolved oxygen	June 1-Jan 31: ≥ 3.2 mg L^{-1} Feb 1-May 31: ≥ 5.0 mg L^{-1}	13	241	2005-2007
Benthic Index Biological Integrity (BIBI)	> 3	6	6	2000-2004
Prop. of area occupied (PAO) by amphibians	20% < PAO < 80% each spp.	park	9	2005-2007
Physical habitat index (PHI)	> 42	3	8	2000-2004
Artificial-terrestrial				
Deer density	Grassland: < 20 deer km^{-2}	park	8	2000-2007
Prop. impervious surface (within park)	< 0.1	park	1	2000
Particulate matter (soot; PM2.5) concentration	< 15 mg m^3	3	15	2000-2004
Ozone	< 0.075 ppm	2	8	2000-2003
Wet SO_4 deposition	< 10 kg ha^{-1} yr^{-1}	3	10	2000-2007
Total NO_3^- deposition (other)	< 10 kg ha^{-1} yr^{-1}	3	10	2000-2007
Hg deposition	< 2 ng L^{-1}	1	86	2004-2006

Calculation of natural resource condition

Ecological monitoring categories

All data were collected between 2000 and 2008. However, due to the number of sampling sites (or spatial scale of measurement) and sampling frequency (monthly to annual), the amount of information used to characterize park resources (data density) varied from 1 (e.g., assessment of impervious surface within the park) to 242 (water temperature) during the eight-year period (Table 5.2). These data were compared to threshold values (Chapter 4, Metrics & Thresholds), as a percentage of measurements attaining the threshold value for each metric, where a value of 1.0 indicated that all sites and times met the threshold to maintain natural resources, and a value of 0.0 indicated that no sites at any sampling time met the threshold value. As there were two thresholds determined for total NO_3^- deposition—one for forest and one for cultivated lands—an area-weighted mean was used to calculate just one score for total NO_3^-. For determination of status of metrics and metric categories, percentage attainment scores were categorized on a scale from very good to very degraded (Table 5.5).

Habitats

For each individual metric, the percent attainment of the threshold value was calculated as described for ecological monitoring categories. For determination of status of metrics and habitats, percentage attainment scores were categorized on a scale from very good to very degraded (Table 5.6).

Use of habitat framework for calculating sub-park assessments

In consultation with NPS staff, Rock Creek Park was divided into sub-regions of potential interest to management. The 10 regions were based largely on physical divisions within the park caused by Rock Creek itself as well as major roads (Figure 5.3). Monitoring data were not available to provide a direct natural resource condition assessment between these park sub-regions; however, the habitat assessment framework was used to provide an indication of sub-region condition assessments within the park, based upon habitat occurrence within each sub-region (Table 5.8). The underlying assumption was that condition of each habitat was uniform across the park. After calculating the area of the three habitats within each sub-region, overall habitat attainment values (Table 5.7) were used to calculate a habitat area-weighted mean for each of the 10 sub-regions within the park (Table 5.8).

Base-flow sampling off the bridge at Rock Creek and Joyce Road.

Table 5.5. Categorical ranking of threshold attainment categories.

Measured attainment of thresholds	Natural resource condition
81-100%	Very good
61-80%	Good
41-60%	Fair
21-40%	Degraded
0-20%	Very degraded

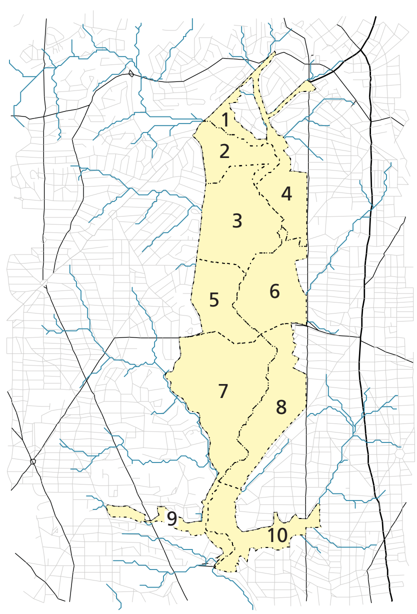
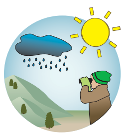


Figure 5.3. Defined management based sub-regions within Rock Creek Park.

Results

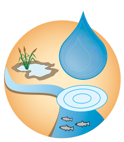
Ecological monitoring framework

Within the ecological monitoring framework, the metric scores ranged from 0 (very degraded) to 100% (very good) attainment of threshold values (Table 5.5). The overall condition of Rock Creek Park, based on attainment of ecological threshold for 29 metrics, was assessed as fair.



Air Quality

Air Quality for Rock Creek Park was generally in degraded condition (Table 5.6). Total NO_3^- deposition was in very good condition (89% attainment), particulate matter (soot; PM2.5) was in degraded condition (27% attainment), and ozone, wet SO_4 deposition, and mercury deposition were all in very degraded condition (all 0% attainment). While most metrics had a mean value similar to the threshold value, mean mercury deposition (13.5 ng L^{-1}) was an order of magnitude higher than the threshold value (2 ng L^{-1}) (Tables 5.2, 5.6).

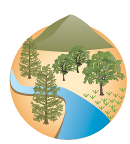


Water Quality

Water Quality for Rock Creek Park was very variable between metrics (Table 5.6). Of the nine metrics, five were in very good condition (pH 93%, dissolved oxygen 87%, water temperature 100%, acid neutralizing capacity 100%, physical habitat index 100%), aqueous nitrate was in fair condition (46%), salinity in degraded condition (30%), and two metrics were in very degraded condition (total phosphorus 0%; benthic IBI 0%; Table 5.6). Total phosphorus was notable, with a mean concentration (929 μg L^{-1}) that was an order of magnitude higher than the threshold value (36.56 μg L^{-1}; Tables 5.2, 5.6).

Biodiversity

Biodiversity for Rock Creek Park was assessed to be in a fair condition (Table 5.6). High numbers of observed forest interior dwelling bird species and lack of forest pest species resulted in very good conditions for these metrics (100% attainment). Proportion of area occupied by adult amphibians was assessed as good/very good condition (78% attainment) and the limited presence of exotic trees and shrubs resulted in a good assessment (70%). Higher abundance of exotic herbaceous species indicates degraded/fair condition (40%) and low fish IBI, high deer density, and low native seedling regeneration (17%, 2%, 0% attainment respectively) indicated very degraded condition for these metrics (Table 5.6). High mean percent cover of invasive exotic species but moderate to high attainment of the threshold suggests that when invasive exotic species are present, abundance is high (Table 5.6). The well-established forest threshold for deer density (8 deer km^{-2}) is well below the measured mean density for Rock Creek Park of 26 deer km^{-2} and the mean native seedling regeneration of 6,000 seedlings ha^{-1} was well below the threshold density for forest maintenance (35,000 seedlings ha^{-1}) (Tables 5.2, 5.6).



Ecosystem Pattern and Processes

Ecosystem Pattern and Processes within Rock Creek Park were overall in a good condition (Table 5.6). Two of the park plus five times buffer metrics had 0% attainment (forest cover, impervious surface) and one received 100% (critical connectivity). The three interior park metrics achieved 100% attainment (forest cover, critical connectivity, impervious surface).

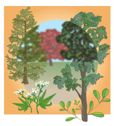
Table 5.6. Summary natural resource condition assessment for Rock Creek Park by metric categories.

Categories and Metrics	Mean (refer to Chapter 4)	Condition	
		% attainment	Assessment
Air Quality			
Ozone	0.09 ppm	0	Very degraded
Total NO_3^- deposition (forest habitat)	10.8 kg ha^{-1} yr^{-1}	90	Very good
Total NO_3^- deposition (cultivated)	10.8 kg ha^{-1} yr^{-1}		
Wet SO_4 deposition	18.2 kg ha^{-1} yr^{-1}	0	Very degraded
Particulate matter (soot; PM2.5) concentration	14.4 mg m^{-3}	27	Degraded
Hg deposition	13.5 ng L^{-1}	0	Very degraded
Water Quality			
pH	7.8	93	Very good
Dissolved oxygen	7.5 mg L^{-1}	87	Very good
Water temperature	13.5 °C	100	Very good
Acid neutralizing capacity (ANC)	1597 µeq L^{-1}	100	Very good
Salinity	0.4	30	Degraded
Aqueous nitrate	2.6 mg L^{-1}	46	Fair
Total phosphorus	929 µg L^{-1}	0	Very degraded
Benthic index biological integrity (BIBI)	1.5	0	Very degraded
Physical habitat index (PHI)	56.2	100	Very good
Biodiversity			
% cover of exotic herbaceous species	20.5%	40	Degraded/Fair
Exotic tree/shrub density	16.7%	70	Good
Presence of forest pest species	0%	100	Very good
Native seedling regeneration	6,000 seedlings ha^{-1}	0	Very degraded
Fish index biological integrity (FIBI)	2.5	17	Very degraded
Prop. of area occupied (PAO) by amphibians	53.4%	78	Good
Presence of forest interior dwelling species (FIDS) of birds	2.3 'highly sensitive' 7 'sensitive'	100	Very good
Deer density (forest 1421 acres) Deer density (grassland 298 acres)	26.4 deer km^{-2}	2	Very degraded
Ecosystem Pattern and Processes			
Proportion forest cover (within park)	0.71	100	Very good
Prop. impervious surface (within park)	0.05	100	Very good
Critical connectivity (Dcrit; within park)	340 m	100	Very good
Prop. forest cover (within park) + 5X buffer	0.24	0	Very degraded
Prop. imperv. surface (within park) + 5X buffer	0.45	0	Very degraded
Critical connectivity (within park) + 5X buffer	270 m	100	Very good

NB: Total NO_3^- deposition forest attainment 100%, cultivated attainment 40%, area-weighted park total 89.6% attainment; Deer density forest attainment 0%, grassland attainment 12.5%, area-weighted park attainment 2.2%.

Habitat Framework

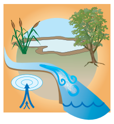
Within the habitat assessment framework, the metric scores ranged from 0 (very degraded) to 100% (very good) attainment of threshold values (Table 5.7). The overall condition of Rock Creek Park was assessed as fair (Table 5.7, Figure 5.4).



Forest Habitat
Forest Habitat within Rock Creek Park was assessed to be in good condition (Table 5.7, Figure 5.4). These habitats have high deer populations (0% attainment) and low native seedling regeneration (0% attainment). However, low percentage of impervious surface and high forest patch connectivity (100% attainment within the park), together with low forest pest species, low presence of exotic trees and shrubs (70% attainment), as well as diverse forest interior dwelling bird species (100% attainment) result in the good assessment (Table 5.7).

Table 5.7. Summary of Rock Creek Park habitat-based natural resource condition assessment.

Metric (by habitat)	Mean (refer to Chapter 4)	Condition	
		% attainment	Assessment
Forest: 1421 acres (81%)			
Exotic tree/shrub density	16.7%	70	Good
Presence of forest pest species	0%	100	Very good
Presence of forest interior dwelling species (FIDS) of birds	2.4 'highly sensitive' 7.8 'sensitive'	100	Very good
Deer density	26.4 deer km^{-2}	0	Very degraded
Native seedling regeneration	6,000 seedlings ha^{-1}	0	Very degraded
Critical connectivity (Dcrit; within park)	340 m	100	Very good
Prop. impervious surface (within park)	0.05	100	Very good
Wetland (Inland): 35 acres (2%)			
Total phosphorus	929 µg L^{-1}	0	Very degraded
Salinity	0.4	30	Degraded
Aqueous nitrate	2.6 mg L^{-1}	46	Fair
Dissolved oxygen	7.5 mg L^{-1}	87	Very good
Benthic index biological integrity (IBI)	1.5	0	Very degraded
Prop. of area occupied (PAO) by amphibians	53.4%	78	Good
Physical habitat index (PHI)	56.8	100	Very good
Artificial-terrestrial: 298 acres (17%)			
Deer density	26.4 deer km^{-2}	12	Very degraded
Prop. impervious surface (within park)	0.05	100	Very good
Particulate matter (soot; PM2.5) concentration	14.4 mg m^{-3}	27	Degraded
Ozone	0.09 ppm	0	Very degraded
Wet SO_4 deposition	18.2 kg ha^{-1} yr^{-1}	0	Very degraded
Total NO_3^- deposition (cultivated)	10.8 kg ha^{-1} yr^{-1}	40	Degraded/Fair
Hg deposition	13.5 ng L^{-1}	0	Very degraded



Wetland (Inland) Habitat

Wetland Habitat within Rock Creek Park was assessed to be in fair condition (Table 5.7, Figure 5.4). These habitats have high total phosphorus concentrations (0% attainment), low benthic index of biotic integrity (0% attainment), high salinity (30% attainment) and high nitrate concentration (46% attainment), but they also have high dissolved oxygen (87% attainment), physical habitat index (100% attainment), and attainment of the proportion of area occupied by adult amphibians (78%; Table 5.7, Figure 5.4).

Artificial-terrestrial Habitat

Artificial-terrestrial Habitat within Rock Creek Park was assessed to be in degraded condition (Table 5.7, Figure 5.4). Though these habitats have low percentage of impervious surface within the park (100% attainment), they are in degraded conditions for NO_3^- (40% attainment) and soot deposition (PM2.5; 27% attainment), and in highly degraded conditions for deer density (12.5% attainment), ozone concentration, wet SO4 deposition, and mercury deposition (all 0% attainment; Table 5.7, Figure 5.4).

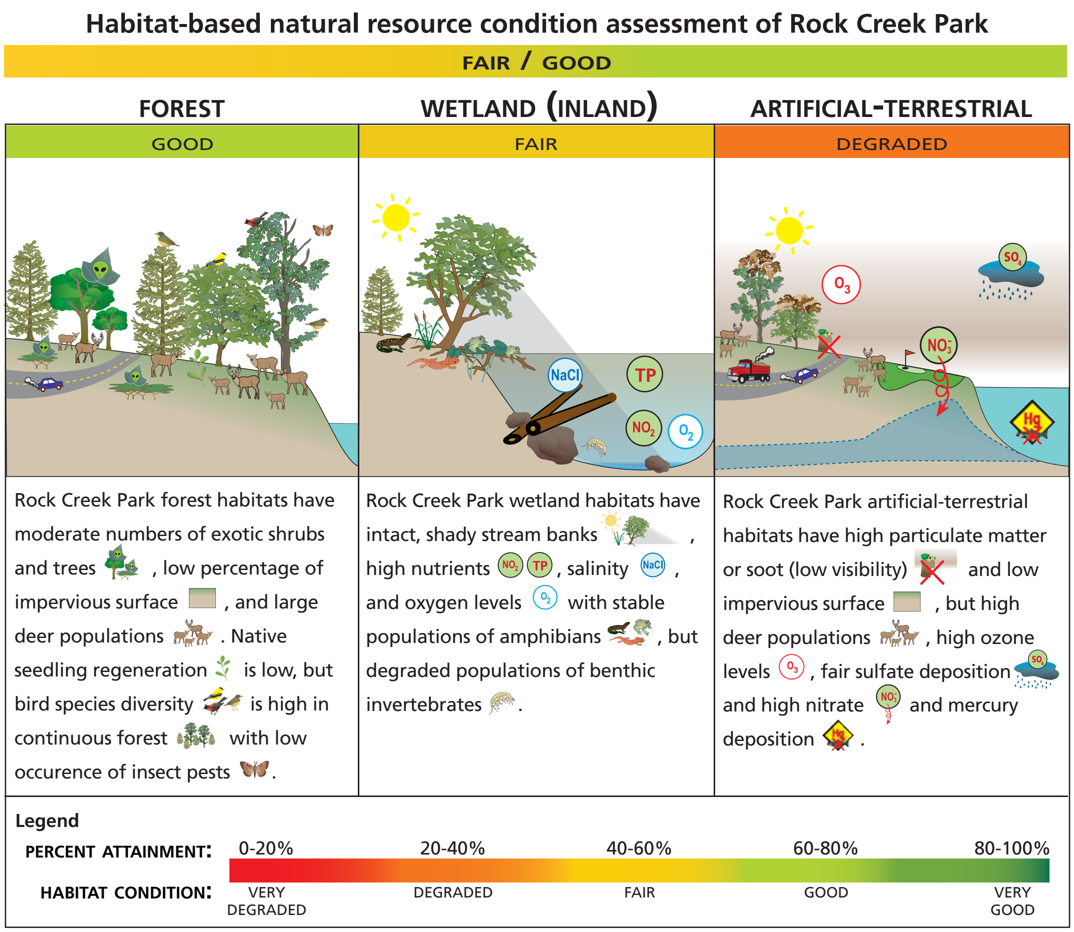


Figure 5.4. Summary results of habitat-based Rock Creek Park natural resource condition assessment.

Table 5.8. Habitat-based natural resource condition assessment within sub-regions of Rock Creek Park.

Habitat	Threshold attainment	Area of each park sub-region (Figure 5.3), divided by habitat type (acres)									
		1	2	3	4	5	6	7	8	9	10
Forest	67%	44.2	127.1	258.2	147.4	135.8	119.3	348.8	174.3	57.3	132.7
Wetland (Inland)	49%	0.3	4.6	0.7	5.4	0.5	7.6	2.6	12.0	2.4	3.9
Artificial-terrestrial	26%	0.8	4.5	18.2	12.6	13.9	80.7	31.5	16.6	9.2	14.7
Habitat area-weighted sub-region attainment (%)		66	65	64	63	63	50	64	63	61	63
Sub-region condition		Good	Good	Good	Good	Good	Fair	Good	Good	Good	Good

Assessment of park sub-regions
Using habitats within each park sub-region (Figure 5.3) to assess resource condition resulted in a range from 46.6% attainment in region six (east central) up to 60.0% attainment in region one (northern-most sub-region), which resulted in all sub-regions assessed as being in fair condition (Table 5.8). Forest habitat dominates all sub-regions, with the exception of region six, which also contains significant artificial-terrestrial habitat (39% of total area; Table 5.8).

Mark Thiessen, National Geographic Society

This green luna moth (*Actias luna*), resting in the hand of Smithsonian's National Museum of Natural History entomologist Gary Hevel, was one of the more than 665 species identified during a 24-hour BioBlitz held in Rock Creek Park in the spring of 2007.

Discussion

Using two different frameworks based upon ecological monitoring categories and dominant habitat types, natural resource condition within Rock Creek Park was assessed as being in fair to good condition (Figure 5.4, Tables 5.6 and 5.7). **Air Quality** and **Artificial-terrestrial Habitat** were assessed to be in degraded condition, however, **Water Quality**, **Ecosystem Pattern and Processes**, and **Forest Habitat** were assessed to be in good condition.

Ecological monitoring framework

Air Quality within Rock Creek Park was overall in a degraded condition reflecting regional and local trends. **Water Quality** was in good condition, however, it was compromised by high nutrient and salinity concentrations and very degraded benthic communities (Table 5.6). Species abundance in macroinvertebrate communities has been found to be negatively correlated with concentrations of both nitrogen and phosphorus (Wiegel and Robertson 2007). The same study found a distinct break point or threshold in benthic species between 64 μg L^{-1} and 150 μg L^{-1} total phosphorus, which is similar to the threshold used in this assessment

(36.56 μg L^{-1}) and is well below the mean of all samples reported for Rock Creek Park, 929 μg L^{-1} (Table 5.6). **Biodiversity** was in fair condition, partially resulting from the degraded condition of fish communities which have been found to be highly negatively correlated with nutrient concentration (Wiegel and Robertson 2007), and degraded stream condition in general (Roth et al. 2000). Many studies have shown that high deer densities can inhibit the development and regeneration of understory species (Healy 1997, Decalesta and Stout 1997, Horsley et al. 2003). Mean deer densities over 25 deer km^{-2} are therefore likely to be one of the causes of the degraded native seedling regeneration (Table 5.6). While forest dwelling bird species met the threshold condition, long term data sets collected within the park show that the park is consistent with a regional pattern of large reductions in total number as well as number of species of long distance migratory songbirds (Terborgh 1992). **Ecosystem Pattern and Processes** were in overall good condition, with a clear trend between very good conditions (high forest cover, good patch connectivity, and low impervious surface) within the park boundaries, however, rapid reduction of forest cover and an increase in impervious surface directly surrounds the park (Table 5.6).

Habitat framework

Forest Habitat was assessed as being in good condition with relatively diverse forest interior dwelling bird species, forest connectivity, low presence of pest species, and low percentage impervious surface within the park. High deer abundance, low native seedling regeneration, and presence of exotic tree and shrub species are compromising the resource condition of forest habitats. **Wetland (Inland) Habitat** is in fair condition, reflecting the high stream water nutrients and salinity, and degraded benthic invertebrate communities. **Artificial-terrestrial Habitat** is most impacted by poor air quality, but also by high deer density.

Comparison of approaches

Both frameworks resulted in very similar overall assessments of resource condition within Rock Creek Park. The benefit of the habitat framework is the strong linkage between habitat types, metrics, and the desired and degraded condition of each represented habitat, with a data-based assessment approach to track condition.

Data gaps

While it was possible to assess all habitat types within Rock Creek Park, it is recognized that limited data is available for seeps and springs within the park, and this is seen as a significant data gap. These important and regionally vulnerable resources could not be included in the current assessment, but would ideally be included within assessment of **Wetland (Inland) Habitat**.

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American redstart (*Setophaga ruticilla*), a highly sensitive bird species sometimes found in Rock Creek Park.

Simon Tan

Chapter 6: Implications

In light of the assessment in Chapter 5, the data gaps, management recommendations, and guidelines on applying the assessment to an adaptive management cycle are identified.

Use of natural resource condition assessment in an adaptive management cycle

The approach taken in this natural resource condition assessment was to survey and compile available data for resources and stressors within Rock Creek Park (ROCR) (Chapters 2 and 3), use available literature to develop thresholds for these metrics (Chapter 4) and then use an ecological monitoring framework (Inventory and Monitoring 'Vital Signs') as well as a newly developed habitat framework to assess the status of resources within Rock Creek Park (Chapter 5). The syntheses and assessment frameworks presented in this report have the potential to directly include monitoring data into a park adaptive management cycle of conceptualization, implementation, evaluation, and communication (Figure 6.1). The two assessment frameworks provide a conceptualization (Figure 5.4, Table 5.2) that can potentially assist in the planning and prioritization of management action implementation. The synthetic condition reporting (Figure 5.4, Table 5.7) provides an evaluation of current status assessment, based upon available data, and is presented as a snapshot for the park resource condition during the current 2000 decade (see Tables 5.2 and 5.4 for data used in assessment). Within Rock Creek Park, the developed conceptual framework can also be used to assess the effectiveness of the implementation of management strategies over the decadal time scale (Figure 6.1). Rock Creek Park is at the downstream end of a large urban watershed, such that engagement of community organizations (such as the Friends of

Figure 6.1. Example of how the natural resource condition assessment framework can be applied to the adaptive management cycle within Rock Creek Park and in association with community partners.

In April 2008, the Friends of Rock Creek's Environment (FORCE) cleanup crew at Kensington Parkway in Chevy Chase piled up about 40 bags of trash. (Several more volunteers participated than this photo represents.)

Rock Creek's Environment - FORCE) and communication of key ecological issues within the park to the public could be an important component of managing watershed stressors. The presented habitat frameworks (Figures 5.2 and 5.4, Table 5.7) summarize a diversity of complex data into a format conducive for communication to an audience of not only park resource managers, but also to the much broader audience of interested public.

Use of the assessment framework to direct monitoring and decision making

One of the challenges or data gaps that became apparent in the process of synthesizing available data was the disparity between the scales of available data and the scales of required management questions or needs. During this assessment process, discussions with park resource managers identified relevant sub-park geographic regions based upon physical structures (rivers and roads; Figure 5.3) and the habitat framework was used to provide initial overall ecosystem condition between these regions (Table 5.8). It is recognized, however, that this assessment could only be based upon the relative proportions of different habitat types within these regions and cannot be used to address the question of the resource condition of forest habitat between these ten park sub-regions. However, by identification of relevant ecosystem metrics that are sensitive and measurable and by the development of relevant threshold values, the presented habitat assessment framework can be directly used to collect monitoring data to answer such a question. A once-off assessment of the seven metrics for a habitat (Figure 5.2) could be carried out between two relevant park sub-regions to quickly assess relative condition to directly inform management decisions.

Implementation strategy for Rock Creek resource condition assessment

The habitat framework for assessment of resource condition within Rock Creek Park was used to summarize key findings (stressors as well as features), ecological implications of these findings and the recommended next steps to improve degraded features or maintain features currently in a desired condition (Table 6.1, Figure 5.2).

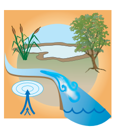
Forest Habitat

Within forest habitats, one of the largest challenges is overpopulation of deer, resulting in overgrazing of vegetation and limited regeneration of native seedlings as well as negative impacts upon diversity and abundance of forest interior

Table 6.1. Key findings, implications, and recommendations resulting from Rock Creek natural resource condition assessment.

Key findings by habitat	Management implications	Recommended next steps
FOREST		
Deer overpopulation reducing forest regeneration capacity	•Increased herbivory reducing desired plant and bird species	•Implement deer population control measures
Presence of exotic plants	•Displacement of native species, reducing biodiversity	•Early detection •Exotic control measures (spraying and mechanical) •Prioritize control strategies
Intact forest within Rock Creek Park	•Acts as a refuge for forest interior dwelling species of birds, amphibians	•Minimize stressors (fires, dumping) •Minimize fragmentation (roads, structures and trails)
WETLAND (INLAND)		
Rock Creek and tributary streams have degraded water quality (phosphorus, nitrogen, salinity)	•Affects stream flora and fauna •Reduces quality of visitor experience	•Reduce point source nutrients within the park and watershed (partnerships with agencies) •Road salt management
Stream benthic biota (IBI) regionally very poor, amphibian communities fair	•Reduced biodiversity •Reduces support of higher trophic levels	•Improve water quality
Stream physical habitats vary from good to poor (monitoring sites currently limited)	•Maintains riparian habitat and in stream fauna (fish) •protects park infrastructure (by limiting erosion)	•Identify priority tributaries and artificial drainage gullies for effective stormwater management
ARTIFICIAL-TERRESTRIAL		
This habitat is poorly characterized	•These habitats are highly visible and heavily used by visitors	•Identify priority monitoring needs (soil compaction, invasive exotic species) •Inventories (e.g. pollinator species)
Air quality severely compromised–least buffered in this habitat	•Human and ecosystem health impacted	•Regional partnerships and education to improve air quality

dwelling bird species (Table 6.1). Large deer populations have also led to an increase in road collisions and for all these reasons it is recommended to implement deer population control measures to reduce the current population of over 26 deer km^{-2} (Table 5.7) to the threshold value for maintenance of healthy forest habitat, 8 deer km^{-2} (Table 4.3). Another challenge to forest habitats is the presence of exotic plants (including shrubs and trees) currently over 16% by area (Table 5.7) in monitored plots, well above the threshold of 5% cover (Table 4.3). Exotic plants can displace native species as well as reduce biodiversity, so it is recommended to emphasize early detection of these species, continue controlling these species when detected and clearly prioritize control strategies based on characteristics such as relative invasion and expansion rates of different species. Even considering these challenges, the forest within Rock Creek Park provides an important regional resource and supports regionally high (though potentially threatened) communities of forest interior dwelling bird species and amphibians due to the relatively large patches of connected and intact forest (Table 5.7). To maintain the ecosystem value of this forest, stressors such as fires and dumping should be minimized where possible and maintenance of forest patches by minimizing further fragmentation due to roads, structures and trails should be encouraged.



Wetland (Inland) Habitat
This assessment was based on data collected from Rock Creek and its tributaries (Figure 2.8) and indicates that the largest challenges are elevated nutrient concentrations and salinity (Table 5.7), resulting in negative impacts on stream flora and fauna and potential reduction of visitor experience (Table 6.1). It is recommended that road salting should be managed to further reduce impacts to streams and that nutrient reduction strategies should be implemented. In recognition of the location of Rock Creek Park downstream of a large urban watershed, it is recommended that nutrient reduction will require partnerships with local and regional agencies and organizations as well as a strong communication and education effort. The overall poor water quality is implicated in the regionally poor stream benthic biota (mean IBI value within the park of 1.5, compared to an ideal value of 3 (Tables 4.2 and 5.7), which indicates a reduction in biodiversity within these communities and a reduced ability to support higher trophic levels such as fish communities. It is recommended that reducing nutrients and salt inputs would assist in improving benthic communities (Table 4.2). Although the number of sampling sites was limited, stream physical habitat condition was reported to be generally good (Tables 4.2 and 5.7), maintaining riparian habitat and providing potential habitat for fish species as well as assisting in protecting park infrastructure by limiting erosion. To maintain this important ecosystem feature, it is recommended to identify priority sites that may be susceptible to erosion and to implement stream bank stabilization where necessary. Finally, working with District of Columbia government agencies (DDOE–District Department Of Environment, DCWASA–D.C. Water And Sewer Authority, DDOT–District Department Of Transportation) is advised to address issues of stormwater quality and quantity, specifically stabilizing headwaters and addressing erosion and gully formation issues.

Artificial-terrestrial Habitat
The greatest challenge for this habitat is that the ecosystem status of this highly visible and highly utilized habitat is poorly characterized (Table 6.1). To improve future assessments as well as better identify management needs within this habitat, it is recommended to identify needs, implement monitoring such as soil compaction and invasive exotic species presence in these areas and develop

inventories of some key insect species. Due to the limited covering vegetation, this habitat is the most susceptible to poor air quality effects on the ecosystem (flora and fauna) as well as human health. To address issues of degraded air quality, it is recommended that regional partnerships are further developed. It is suggested that Rock Creek Park could play an important role in public education about regional issues of poor air quality and about solutions to these challenges.

Prioritizing identified research needs based upon management data gaps

The ecological monitoring framework (Inventory and Monitoring 'vital signs' framework) was used to characterize data gaps, provide an ecological justification and then suggest research needs to address the data gaps (Tables 5.2 and 6.2).

Air Quality (Tables 5.2 and 5.3)

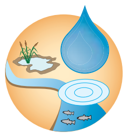
Although the direct effects of atmospheric pollutants upon flora and fauna are well established, one of the notable data gaps is a lack of data on the downstream impacts of sulfate and nitrate deposition upon artificial-terrestrial habitats within the park. Research on these deposition effects is recommended (Table 6.2). Metrics measuring air quality show broad scale (1000s of miles) patterns, but they also show daily variability at small spatial scales. This variability leads to challenges scaling down from regional measurements to the assessment of specific air quality and air quality impacts within Rock Creek Park. Collaborations using park data to calibrate and validate air transport and deposition models could help to alleviate this data gap, as would gathering data along park roads to assess the impact of park traffic on the air quality within Rock Creek Park.

A Rock Creek Park ranger demonstrates radio-tracking eastern box turtles for a group of young visitors.

Table 6.2. Data gaps and associated research needs resulting from Rock Creek natural resource condition assessment.

Data gaps	Justification	Research needs
AIR QUALITY		
Ecological thresholds (atmosphere to water and meadow particularly) deposition (sulfate and nitrate)	•Deposition and ecosystem impacts as well as human (acid rain and fertilization)	•Habitat specific effects •Deposition impacts, particularly meadow
Translating regional air data to park level	•Data regional but not downscaled to management unit	•Using transport and deposition models •Calibrating with roadside data within the park
WATER QUALITY		
Nutrient and salt sources are poorly defined both within and outside the park	•Need to know where to prioritize management actions	•Tracers, models and budgets needed (inside and outside the park) •Identify all inputs (breaks, sanitary sewers)
Importance of riparian buffer and in-stream processing in controlling water quality; effects of increased storm flow on stream bank erosion	•How in-park management practices can protect and benefit water resources	•In-stream processing capacity for nutrients •Impacts of park operations on water quality, quantity and erosion rates •Quantify bank erosion: Rock Creek and tribs
Groundwater inputs not well understood or quantified	•Buried stream network	•Seeps and spring characterization, groundwater monitoring and drainage delineation
What contaminants are in water and sediments and their ecological impacts	•Potential for bioaccumulation and legacy (long residence time)	•Contaminant inventory (personal care products etc.)
BIODIVERSITY		
Relative importance of forest pests and exotic pests	•Early detection important for effective control	•Increase monitoring (particularly spatial)
Understanding forest regeneration dynamics (with significant deer grazing)	•Intense herbivory prevents forest regeneration	•Intensive studies to examine rates of seedling regeneration (with and without grazing)
Biodiversity data lacking (invertebrate, amphibians in some habitats, mammals, fish, reptiles, FIDS, non-vascular and non-see vascular plants)	•Better understanding of what species are present and where	•Inventory and distribution maps •Inventory and distribution of arthropods
ECOSYSTEM PATTERN AND PROCESSES		
Local determination of ecological effects of forest connectivity	•Impacts population dynamics of plants and animals	•Ecologically relevant scales of dispersal (e.g. how large are faunal ranges, how far do seeds disperse)
Barriers to movement of invasion	•Impacts population dynamics of plants and animals	•Documentation of existing barriers (e.g. roads, fields, playgrounds, trails), and investigation of how 'hard' they are.
Accounting of inner-basin (watershed) transfers	•Maintenance of water quality and quantity (i.e. reducing flows)	•Coordination amongst stakeholders and regional agencies.

NB: FIDS – forest interior dwelling species of birds, and forest interior breeding species of birds

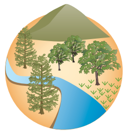


Water Quality (Tables 5.2 and 5.3)

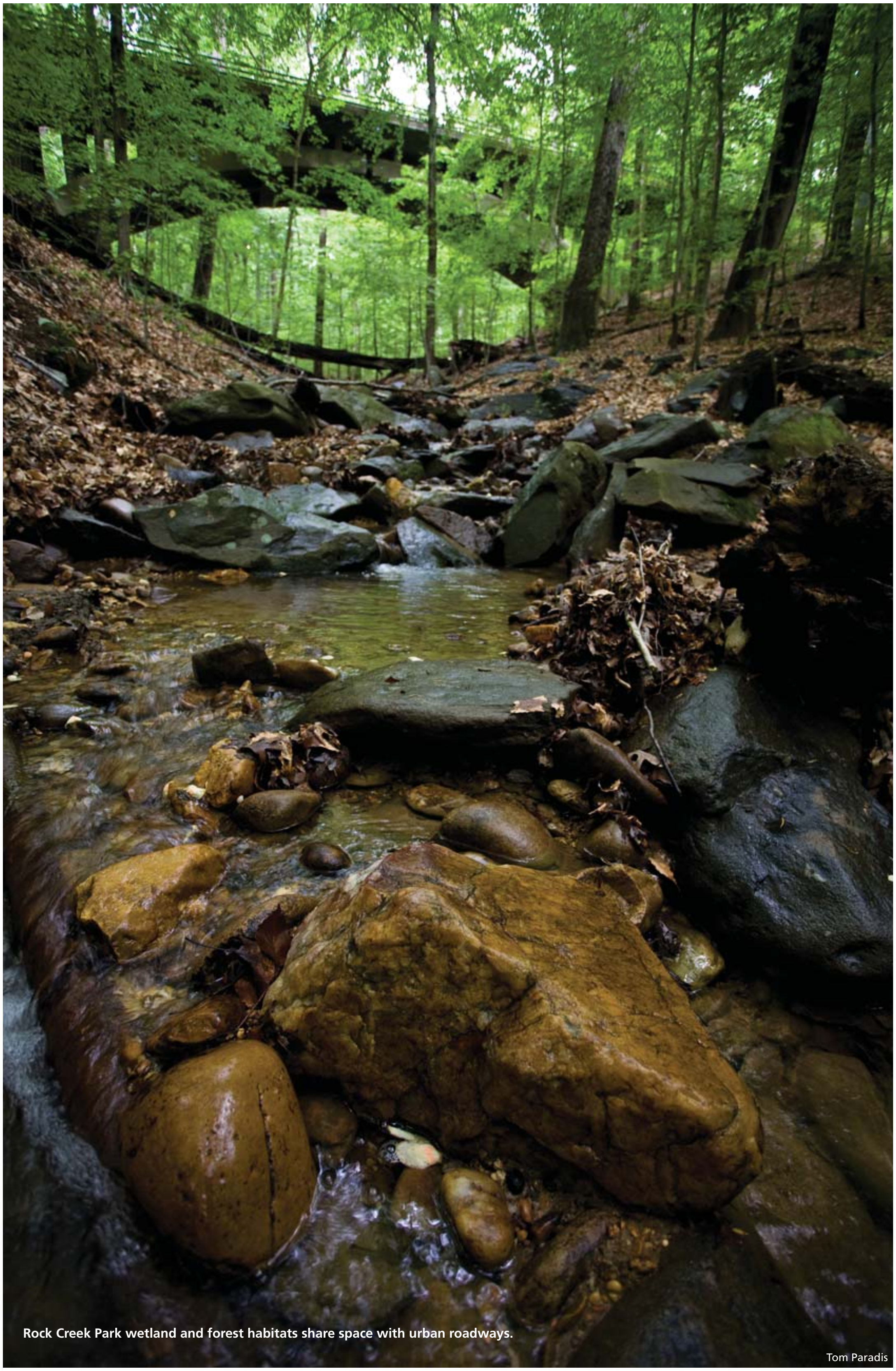
High nutrient and salt concentrations measured within the park have poorly defined sources, which is important for prioritizing management implementation (Table 6.2). Better characterization of point source inputs, tracers to identify both point and diffuse sources of nutrients within the park and throughout the watershed, and the development of nutrient budgets and models would help identify and manage these inputs as well as communicate the needs for these actions. The streamside vegetation currently provides a reasonably intact buffer, but full characterization of streamside vegetation—and therefore the potential for within park nutrient processing—would be beneficial, especially as the watershed becomes increasingly impervious, resulting in more rapid and greater volumes of runoff from surrounding urban areas. This challenge is exacerbated by the many buried streams surrounding the park and throughout the watershed. One major data gap is the quantification of groundwater inputs and better characterization of the water quality and biotic integrity of the many seeps and springs within the park. Monitoring of nutrients and bacteria within these wetlands as well as in the tributaries of Rock Creek is recommended. Many potential pollutants and contaminants, such as personal care products, are not currently being assessed although some of these have potential for bioaccumulation and a long residence time within the environment. An inventory of these pollutants within the watershed, developed through collaborations with regional agencies and organizations, would address this data gap.

Biodiversity (Tables 5.2 and 5.3)

Forest pest species as well as invasive exotic species are known to be a challenge in the region and early detection is the best approach to effective control, so it is recommended to increase the spatial density of monitoring sites for pest species (Table 6.2). Deer overabundance is a key challenge for Rock Creek Park. To assist in maintaining the parks valuable forest habitat in the best possible ecological condition, a better understanding of forest regeneration under the currently high deer populations would be of great benefit. Investigation of the potential benefits of deer exclusion areas may guide future management decisions as well as an understanding of the interaction of deer abundance, invasive exotic plants, and native seedling regeneration. For some key faunal communities such as invertebrates, amphibians in some habitats, and fish, there is a lack of biodiversity data (especially in forest areas and tributaries). Not only inventories, but distribution maps would assist in alleviating this data gap to better characterize and protect these communities. A more extensive characterization of forest interior dwelling species (FIDS) of birds would provide a clearer assessment of the sustainability of these populations.



Ecosystem Pattern and Processes (Tables 5.2, 5.3) Forest connectivity is important to maintain populations of both fauna and flora. There is currently limited local data available on the impacts of reduced forest connectivity, especially within an urban setting such as the forests of Rock Creek Park. Determination of dispersal distances for local species of plants and animals would greatly assist in putting a value on small patches of publicly-owned forest adjacent to Rock Creek Park (Table 6.2). Another significant aspect to the maintenance of these faunal and floral populations is the presence of barriers to movement as these can reduce dispersal distance. Documentation of current and proposed barriers such as roads, fields, playgrounds and trails, as well as how much of a barrier these provide to different plant and animal species (how 'hard' they are), could therefore inform management decisions as to the ecological acceptability of different structures and developments. Rock Creek Park has reasonably intact stream banks and the largest area of forest within the watershed, which is likely to have a positive influence on water quality exiting the park and ultimately reaching the Potomac River and Chesapeake Bay. These effects are currently not quantified, and synthetic assessments of water quality throughout the upper watershed are also not currently available. Coordination with stakeholders to provide watershed syntheses of water quality and some targeted data collection to assess water quality variation throughout the park would address this need.



Rock Creek Park wetland and forest habitats share space with urban roadways.

Tom Paradis

Boulder Bridge, Rock Creek Park.

Ryan Valdez, DCNATURE.com

Appendix A: Raw Data Used in Rock Creek Park Natural Resource Condition Assessment

Table A.1. Ozone (ppm). Values that fail the threshold (0.075) are in bold.

Site ID	Year	Days	4th highest daily max.	3-yr mean
MD25	1999	364	0.097	
MD25	2000	364	0.094	**0.093**
MD25	2001	352	0.089	**0.094**
MD25	2002	362	0.098	**0.089**
MD25	2003	361	0.080	**0.086**
MD25	2004	365	0.081	-
MD43	1999	365	0.10	
MD43	2000	366	0.08	**0.094**
MD43	2001	365	0.10	**0.096**
MD43	2002	365	0.11	**0.095**
MD43	2003	365	0.08	**0.090**
MD43	2004	366	0.08	.
			Mean	**0.090**
			SE	**0.002**

Table A.2. Total annual nitrate deposition (kg ha^{-1} yr^{-1}). Thresholds are 15 for forest and 10 for other habitats.

Site ID	Year	Total NO_3^-	Forest Habitat	Cultivated habitat
MD99	2004	9.76	pass	pass
MD99	2005	12.98	pass	**fail**
MD99	2006	10.06	pass	**fail**
MD99	2007	10.06	pass	**fail**
MD03	2000	13.75	pass	**fail**
MD03	2001	12.79	pass	**fail**
VA10	2004	9.81	pass	pass
VA10	2005	10.24	pass	**fail**
VA10	2006	9.08	pass	pass
VA10	2007	9.66	pass	pass
	Mean	**10.82**		
	SE	**0.53**		

Table A.3. Annual wet sulfate deposition (kg ha^{-1} yr^{-1}). Values that fail the threshold (10) are in bold.

Site ID	Year	Wet SO_4
MD99	2004	**15.10**
MD99	2005	**17.42**
MD99	2006	**18.92**
MD99	2007	**15.49**
MD03	2000	**18.90**
MD03	2001	**18.95**
VA10	2004	**17.38**
VA10	2005	**14.90**
VA10	2006	**15.52**
VA10	2007	**14.98**
	Mean	**16.76**
	SE	**0.55**

Table A.4. Particulate matter (soot; PM2.5 mg m^{-3}). Values that fail the threshold (15) are in bold.

Site ID	Year	Mean
41	2000	**17.02**
41	2001	**16.86**
41	2002	**15.79**
41	2003	14.89
41	2004	**15.01**
42	2000	**15.33**
42	2001	**15.05**
42	2002	**15.66**
42	2003	13.51
42	2004	**15.12**
43	2000	**15.39**
43	2001	**16.20**
43	2002	**16.05**
43	2003	7.32
43	2004	7.37
	Mean	**14.44**
	SE	**0.65**

Table A.5. Annual Mean Hg Deposition (ng L^{-1}). Values that fail threshold (2.0) are in bold.

Year	Count	Mean
2004	25	**14.07**
2005	40	**13.52**
2006	21	**12.91**
	Mean	**13.50**
	SE	**0.34**

Table A.6. Water quality data. Values that exceed threshold are in bold.

Station	DATE	pH	DO (mg L^{-1})	Temp (°C)	ANC (μeq L^{-1})	Sal	NO_3^- (mg L^{-1})	TP (μg L^{-1})
BRBR	6/27/2005	7.9	7.2	21.3	1752	-	1.60	1.85
BRBR	10/4/2005	7.8	8.3	18.2	1280	-	1.80	1.33
BRBR	11/3/2005	7.8	7.6	10.6	1560	-	**2.70**	5.16
BRBR	12/8/2005	7.9	8.6	1.9	708	**0.9**	1.10	0.75
BRBR	1/3/2006	7.7	5.3	7.9	940	0.2	**2.60**	1.14
BRBR	2/14/2006	8.0	13.5	4.4	1712	**1.2**	1.30	0.14
BRBR	3/8/2006	**8.9**	9.0	5.7	1856	**0.3**	1.50	0.85
BRBR	4/4/2006	**8.6**	6.6	13.1	1448	**0.3**	1.10	-
BRBR	5/4/2006	8.5	**2.6**	16.9	1176	**0.3**	**2.70**	2.01
BRBR	6/1/2006	7.8	**3.0**	21.7	2256	**0.3**	**3.00**	2.08
BRBR	7/20/2006	8.0	7.5	24.1	1216	**0.3**	**4.00**	1.09
BRBR	8/3/2006	8.0	6.0	25.9	2144	**0.4**	**4.30**	1.93
BRBR	9/12/2006	7.6	8.8	18.0	2240	**0.3**	**2.10**	1.18
BRBR	10/11/2006	7.9	7.7	16.4	1896	**0.3**	**3.80**	1.14
BRBR	11/21/2006	8.1	10.1	7.3	3200	**0.4**	**3.60**	0.53
BRBR	12/21/2006	**8.5**	10.0	6.4	2048	**0.4**	-	1.41
BRBR	1/30/2007	**0.0**	14.0	1.4	2064	**0.4**	1.05	0.53
BRBR	3/19/2007	8.3	12.2	4.4	1984	**0.4**	1.61	0.17
BRBR	4/18/2007	**8.6**	12.9	9.8	1864	**0.3**	**2.10**	0.30
BRBR	5/22/2007	7.9	7.2	16.0	1328	**0.4**	1.93	0.45
BRBR	6/25/2007	7.9	7.3	20.8	2192	**0.4**	1.60	0.81
BRBR	7/30/2007	7.7	5.6	24.2	1544	0.2	0.60	0.63
BRBR	9/4/2007	**8.6**	9.5	22.0	2344	**0.4**	1.70	0.86
BRBR	10/11/2007	7.7	4.8	17.4	2248	**0.3**	2.00	0.81
BRBR	11/5/2007	8.1	9.1	9.5	2472	**0.3**	**3.50**	0.79
BRBR	12/3/2007	7.7	8.3	8.1	1360	0.1	1.80	1.57
DUOA	10/3/2007	7.8	7.8	18.3	1872	**0.3**	**5.40**	0.35
DUOA	11/1/2007	7.8	8.3	13.0	1904	**0.3**	**4.40**	0.47
DUOA	11/26/2007	7.8	8.8	9.9	1856	**0.3**	**5.00**	0.31
EGWA	6/27/2005	8.2	8.6	24.0	1264	-	1.00	1.25
EGWA	10/4/2005	8.0	6.0	19.2	1120	-	0.90	1.16
EGWA	11/3/2005	7.9	8.2	10.8	980	-	1.80	2.08
EGWA	12/8/2005	7.5	11.5	2.0	1220	**1.0**	0.60	-
EGWA	1/3/2006	7.6	5.1	5.8	1020	0.2	**3.10**	-
EGWA	2/14/2006	7.6	12.2	3.2	928	**1.3**	0.90	-
EGWA	3/8/2006	**8.9**	6.9	6.1	1072	0.2	1.20	-
EGWA	4/4/2006	7.7	**3.9**	15.1	952	0.2	1.10	1.23
EGWA	5/4/2006	**8.6**	**2.9**	19.2	592	0.2	**2.60**	0.11
EGWA	6/1/2006	8.1	**2.5**	24.8	1360	0.2	1.80	1.17
EGWA	7/20/2006	8.2	7.3	27.0	1472	0.2	1.80	0.78

Table A.6. Water quality data. Values that exceed threshold are in bold (continued).

Station	DATE	pH	DO (mg L^{-1})	Temp (°C)	ANC (μeq L^{-1})	Sal	NO_3^- (mg L^{-1})	TP (μg L^{-1})
EGWA	8/3/2006	8.2	6.4	28.4	1616	0.2	**2.50**	1.22
EGWA	9/12/2006	7.9	9.1	19.3	1496	0.2	1.20	1.22
EGWA	10/11/2006	8.0	8.6	16.3	1176	0.1	**2.50**	0.94
EGWA	11/21/2006	7.9	10.8	8.6	880	0.1	1.90	0.36
EGWA	12/21/2006	**8.6**	9.9	5.9	1208	0.2	-	0.86
EGWA	3/19/2007	7.8	10.5	6.0	864	**0.3**	**4.06**	0.29
EGWA	4/18/2007	7.9	11.0	9.6	840	0.1	**5.23**	0.26
EGWA	5/22/2007	7.8	6.1	18.8	1432	0.2	1.79	0.21
EGWA	6/25/2007	8.3	7.5	22.6	992	0.2	0.70	0.20
EGWA	7/30/2007	7.9	6.0	25.2	1600	0.2	0.60	0.32
EGWA	9/4/2007	8.3	5.9	22.7	1960	**0.3**	0.90	0.49
FEBR	6/27/2005	7.6	6.9	21.2	1584	-	1.90	0.99
FEBR	10/4/2005	7.3	**3.0**	17.3	1144	-	0.50	0.38
FEBR	11/3/2005	7.7	8.5	12.1	1360	-	**2.90**	1.60
FEBR	12/8/2005	7.4	9.4	2.2	1380	**1.5**	1.60	0.23
FEBR	1/3/2006	7.1	5.4	7.4	940	0.2	2.00	1.90
FEBR	2/14/2006	7.6	12.8	3.0	1240	**2.2**	1.70	0.36
FEBR	3/8/2006	7.8	9.3	4.7	1384	**0.4**	**2.40**	0.48
FEBR	4/4/2006	7.3	**3.3**	11.6	1312	**0.3**	1.30	0.69
FEBR	5/4/2006	7.5	**1.7**	14.8	1856	**0.4**	**3.50**	0.51
FEBR	6/1/2006	7.3	**1.3**	20.1	2168	**0.4**	**3.10**	2.07
FEBR	7/20/2006	7.6	5.5	23.3	2256	**0.4**	**4.20**	1.25
FEBR	8/3/2006	7.6	3.6	25.0	2432	**0.4**	**3.70**	2.35
FEBR	9/11/2006	7.3	-	19.7	2040	**0.4**	2.00	1.26
FEBR	10/10/2006	7.5	4.6	15.1	1728	**0.3**	**3.60**	1.18
FEBR	11/21/2006	7.8	9.8	7.6	1800	**0.4**	**4.60**	0.21
FEBR	12/21/2006	7.7	7.7	7.8	1504	**0.4**	-	0.93
FEBR	1/30/2007	0.0	11.8	0.9	1440	-	1.37	0.57
FEBR	3/7/2007	7.6	10.0	2.3	1584	**0.6**	**3.15**	0.15
FEBR	4/19/2007	7.5	10.4	9.9	1704	**0.4**	**2.42**	0.13
FEBR	5/22/2007	7.3	**4.8**	15.1	3224	**0.4**	1.12	1.24
FEBR	6/25/2007	7.3	5.4	19.7	2112	**0.4**	1.40	0.38
FEBR	7/30/2007	7.4	4.6	22.7	1456	0.2	0.60	0.59
FEBR	9/4/2007	7.3	4.5	20.4	1440	**0.4**	1.20	0.31
FEBR	10/11/2007	6.9	**3.1**	18.2	1960	**0.3**	1.80	0.26
FEBR	11/5/2007	7.6	6.3	9.3	2168	**0.5**	**2.50**	0.30
FEBR	12/3/2007	7.1	7.6	7.6	1240	0.1	2.00	0.32
HACR	10/4/2005	7.7	8.0	17.9	1296	-	1.40	2.39
HACR	11/3/2005	7.9	8.9	10.4	1580	-	**2.70**	2.84
HACR	12/8/2005	7.8	12.2	2.4	1910	**0.9**	1.40	0.79

Table A.6. Water quality data. Values that exceed threshold are in bold (continued).

Station	DATE	pH	DO (mg L-1)	Temp (°C)	ANC (µeq L-1)	Sal	NO_3^- (mg L-1)	TP (µg L-1)
HACR	1/3/2006	7.7	4.8	7.5	1440	**0.3**	**3.30**	1.37
HACR	2/14/2006	7.5	11.3	4.9	1568	**0.9**	1.80	0.36
HACR	3/8/2006	8.5	8.3	5.8	1664	**0.3**	1.70	0.33
HACR	4/4/2006	7.9	**4.0**	13.1	1664	**0.4**	1.80	0.06
HACR	5/4/2006	7.6	**2.1**	16.1	1288	**0.4**	**4.20**	0.71
HACR	6/1/2006	7.7	**2.3**	21.4	2440	**0.4**	**3.90**	2.70
HACR	7/20/2006	7.8	7.1	23.3	2064	**0.4**	**3.80**	1.46
HACR	8/3/2006	7.9	5.8	24.9	2176	**0.4**	**3.60**	1.90
HACR	9/12/2006	7.5	8.8	17.4	2096	**0.4**	**2.30**	1.60
HACR	10/11/2006	7.8	8.0	15.9	1848	**0.4**	**13.50**	1.56
HACR	11/21/2006	8.0	10.7	7.5	2000	**0.4**	**3.50**	0.39
HACR	12/21/2006	8.2	8.7	7.5	2016	**0.4**	-	1.67
HACR	1/30/2007	-	12.9	2.5	1560	**0.4**	1.17	1.22
HACR	3/19/2007	8.1	11.3	5.6	1304	**0.3**	**2.66**	0.51
HACR	4/18/2007	7.9	10.2	10.6	1576	**0.3**	**2.59**	0.53
HACR	5/22/2007	7.8	7.3	16.2	1896	**0.3**	**2.54**	0.62
HACR	6/25/2007	7.9	6.7	20.3	1960	**0.3**	1.40	0.78
HACR	7/30/2007	7.9	6.6	22.5	2232	**0.3**	1.00	0.92
HACR	9/4/2007	7.7	5.8	20.5	1728	**0.4**	2.00	1.03
HACR	10/11/2007	-	-	-	-	-	-	-
HACR	11/5/2007	7.8	7.6	9.3	2232	**0.5**	**4.40**	0.69
HACR	12/3/2007	7.8	9.5	7.9	1896	**0.3**	2.00	0.69
LUBR	10/4/2005	7.5	7.2	20.0	1184	-	**2.70**	1.37
LUBR	11/3/2005	7.4	6.2	14.1	1160	-	**3.90**	3.22
LUBR	12/8/2005	7.6	7.6	7.7	1420	**0.5**	**2.90**	0.68
LUBR	1/3/2006	7.6	4.9	10.9	1300	**0.3**	**5.80**	1.09
LUBR	2/14/2006	7.5	13.8	2.4	1296	**1.7**	0.90	1.41
LUBR	3/8/2006	8.4	9.7	4.1	1520	0.2	1.00	0.53
LUBR	4/4/2006	7.7	**4.2**	13.6	1288	**0.3**	**2.90**	0.23
LUBR	5/4/2006	7.7	**3.1**	17.3	1456	**0.3**	**5.80**	1.47
LUBR	6/1/2006	7.5	**3.0**	20.7	1528	**0.3**	**5.60**	2.89
LUBR	7/20/2006	7.7	7.2	22.5	1656	**0.4**	**6.50**	1.28
LUBR	8/3/2006	7.7	6.7	23.9	1664	**0.3**	**5.10**	1.59
LUBR	9/12/2006	7.5	7.3	18.9	1800	**0.4**	**3.60**	4.96
LUBR	10/10/2006	7.6	6.6	17.8	1528	**0.3**	**5.50**	1.70
LUBR	11/21/2006	7.9	10.2	11.4	1540	**0.4**	-	0.46
LUBR	12/21/2006	7.9	7.5	10.1	1464	**0.3**	**6.40**	1.00
LUBR	1/30/2007	-	11.3	5.4	1344	**0.4**	1.72	0.80
LUBR	3/19/2007	7.8	8.2	7.5	1440	**0.5**	**3.06**	0.30
LUBR	4/19/2007	7.9	10.2	12.5	1624	**0.4**	**3.77**	0.36

Table A.6. Water quality data. Values that exceed threshold are in bold (continued).

Station	DATE	pH	DO (mg L^{-1})	Temp (°C)	ANC (μeq L^{-1})	Sal	NO_3^- (mg L^{-1})	TP (μg L^{-1})
LUBR	5/22/2007	7.5	6.9	16.0	1712	**0.4**	**5.35**	0.68
LUBR	6/25/2007	7.5	6.2	20.4	1872	**0.4**	**3.10**	0.26
LUBR	7/30/2007	7.5	5.8	22.9	1712	**0.3**	**2.10**	0.71
LUBR	9/4/2007	7.7	6.3	21.3	1904	**0.3**	**3.00**	1.19
LUBR	10/11/2007	7.3	4.4	18.1	-	**0.3**	**2.10**	1.26
LUBR	11/5/2007	7.7	7.6	12.2	2016	**0.4**	**4.20**	1.28
LUBR	12/3/2007	7.5	7.2	10.3	1624	0.2	**2.80**	0.86
NOST	10/3/2007	7.5	3.8	19.5	1680	**0.3**	**5.80**	0.79
NOST	11/1/2007	7.6	7.0	13.3	1304	**0.3**	**4.60**	0.58
NOST	11/26/2007	7.5	7.7	9.6	1216	**0.3**	**5.80**	0.26
PACR	11/8/2005	7.3	7.0	13.0	1080	-	**3.60**	0.99
PACR	1/26/2006	6.8	12.3	6.7	960	**0.3**	**6.30**	0.61
PACR	2/28/2006	7.8	10.0	5.5	920	**0.3**	**3.90**	-
PACR	4/12/2006	8.1	**3.1**	13.4	1024	**0.3**	**2.90**	1.50
PACR	5/18/2006	7.4	**2.5**	14.2	1168	**0.3**	**4.30**	8.82
PACR	1/12/2007	7.6	10.8	6.2	1048	**0.3**	**5.50**	1.11
PACR	2/23/2007	7.8	10.6	6.5	1088	**0.5**	**3.93**	0.74
PACR	3/27/2007	**8.6**	9.9	14.6	1024	**0.3**	**4.10**	0.41
PACR	5/14/2007	7.4	7.2	14.3	1288	**0.3**	**4.05**	0.17
PACR	10/3/2007	7.0	6.3	18.7	1472	**0.3**	**5.70**	0.46
PACR	11/1/2007	7.5	5.4	13.4	1448	**0.3**	**4.60**	0.42
PACR	11/26/2007	7.3	7.3	9.4	1568	**0.3**	**4.60**	0.33
PHBR	10/4/2005	7.4	7.8	17.3	1384	-	0.40	0.69
PHBR	11/3/2005	7.6	6.6	9.8	1420	-	1.70	1.79
PHBR	12/8/2005	7.5	9.0	1.7	1340	**1.1**	0.30	0.41
PHBR	1/3/2006	7.7	5.6	6.7	1280	0.2	**2.50**	0.44
PHBR	2/14/2006	7.7	11.9	9.0	1312	**0.7**	**3.00**	0.48
PHBR	3/8/2006	8.3	7.6	9.8	1272	**0.3**	**3.10**	0.15
PHBR	4/4/2006	8.0	6.0	11.4	1280	0.2	0.70	-
PHBR	5/4/2006	7.8	**3.9**	14.5	1664	0.2	**2.80**	0.61
PHBR	6/1/2006	7.5	**2.6**	20.2	2160	0.2	1.50	3.33
PHBR	7/20/2006	**8.9**	12.0	27.7	1792	**0.3**	**4.10**	0.68
PHBR	8/3/2006	7.5	3.7	24.9	1744	0.2	**2.30**	1.58
PHBR	9/12/2006	7.2	6.4	18.0	1768	0.2	1.00	1.03
PHBR	10/10/2006	7.4	7.9	15.1	1448	0.2	2.00	1.35
PHBR	11/21/2006	7.8	9.4	7.5	1780	0.2	**2.70**	0.25
PHBR	12/21/2006	8.0	8.8	5.3	1640	0.2	-	1.20
PHBR	1/30/2007	-	12.6	0.6	1560	**0.5**	1.07	1.10
PHBR	3/7/2007	8.1	11.3	1.6	1768	**0.3**	1.68	0.16
PHBR	4/19/2007	8.0	11.3	9.5	1784	0.2	1.52	0.11

Table A.6. Water quality data. Values that exceed threshold are in bold (continued).

Station	DATE	pH	DO (mg L-1)	Temp (°C)	ANC (µeq L-1)	Sal	NO_3^- (mg L-1)	TP (µg L-1)
PHBR	5/22/2007	7.3	5.5	14.4	1912	0.2	1.42	0.35
PHBR	6/25/2007	7.2	4.8	19.4	1656	0.2	0.60	0.31
PHBR	7/30/2007	7.1	4.1	22.3	1432	0.1	0.30	0.35
PHBR	9/4/2007	7.2	**3.2**	20.0	1272	0.2	0.40	0.46
PHBR	10/11/2007	-	-	-	-	-	-	-
PHBR	11/5/2007	-	-	-	-	-	-	-
PHBR	12/3/2007	7.4	7.1	6.9	1608	0.2	**2.10**	1.08
PYBR	10/4/2005	7.5	7.2	19.0	1232	-	1.80	0.64
PYBR	11/3/2005	7.9	9.2	10.4	1340	-	**2.70**	1.59
PYBR	12/8/2005	7.4	8.8	2.0	1400	**0.4**	**2.40**	0.20
PYBR	1/3/2006	7.6	4.5	7.3	970	0.2	**3.90**	0.64
PYBR	2/14/2006	7.5	11.6	4.5	1328	**0.6**	**2.20**	0.06
PYBR	3/8/2006	8.1	8.7	6.7	1464	**0.3**	**2.30**	-
PYBR	4/4/2006	7.6	3.8	15.0	1256	0.2	1.70	0.25
PYBR	5/4/2006	8.4	3.4	21.4	1488	**0.3**	**5.30**	0.49
PYBR	6/1/2006	8.2	3.0	25.6	1512	**0.3**	**4.40**	1.45
PYBR	7/20/2006	7.7	6.0	23.1	1776	0.2	**2.30**	1.23
PYBR	8/3/2006	8.4	8.7	29.4	1872	**0.3**	**3.70**	0.89
PYBR	9/12/2006	7.5	8.0	18.7	1776	**0.3**	**3.30**	1.57
PYBR	10/11/2006	8.0	7.0	16.6	1768	**0.3**	**3.90**	1.85
PYBR	11/21/2006	8.0	11.5	7.3	1600	**0.3**	**5.40**	0.16
PYBR	12/21/2006	**8.5**	11.5	6.5	1528	**0.3**	-	0.74
PYBR	1/30/2007	-	15.1	0.9	1312	**0.3**	1.70	0.57
PYBR	3/19/2007	8.1	12.9	6.2	1216	**0.3**	**2.89**	0.08
PYBR	4/18/2007	**8.6**	14.0	11.1	1208	**0.3**	**2.30**	0.19
PYBR	5/22/2007	7.7	8.0	19.4	1480	**0.3**	**4.09**	0.37
PYBR	6/25/2007	8.2	8.6	22.5	1768	**0.3**	1.50	0.32
PYBR	7/30/2007	8.3	7.5	24.6	1856	**0.3**	1.50	0.40
PYBR	9/4/2007	**8.8**	9.5	23.3	3048	**0.3**	2.00	0.32
PYBR	10/11/2007	7.6	6.7	17.5	2304	**0.3**	**3.10**	0.50
PYBR	11/5/2007	7.8	8.8	9.0	1928	**0.3**	**4.00**	0.33
PYBR	12/3/2007	7.4	6.4	7.2	1264	0.2	2.00	0.46
ROC3	10/3/2007	7.6	6.5	19.8	1864	0.2	**2.10**	0.36
ROC3	11/1/2007	7.7	8.3	11.7	1472	0.2	1.90	0.40
ROC3	11/26/2007	7.8	9.3	7.8	1872	0.2	**2.30**	0.30
ROCR	6/27/2005	7.5	5.6	23.2	1264	-	1.00	0.85
ROCR	10/4/2005	7.3	5.3	17.6	1320	-	1.80	0.84
ROCR	11/3/2005	7.3	6.7	9.9	900	-	1.70	1.01
ROCR	12/8/2005	7.2	9.4	1.5	960	**0.8**	0.70	-
ROCR	1/3/2006	7.2	**3.1**	5.8	940	0.2	3.90	-

Table A.6. Water quality data. Values that exceed threshold are in bold (continued).

Station	DATE	pH	DO (mg L^{-1})	Temp (°C)	ANC (μeq L^{-1})	Sal	NO_3^- (mg L^{-1})	TP (μg L^{-1})
ROCR	2/14/2006	6.8	10.3	2.7	952	**1.1**	0.80	-
ROCR	3/8/2006	7.2	7.6	4.6	968	0.2	1.50	0.16
ROCR	4/4/2006	6.9	**2.5**	13.9	864	0.2	0.90	-
ROCR	5/4/2006	7.3	**1.8**	16.2	792	0.2	**2.50**	0.08
ROCR	6/1/2006	7.4	**0.9**	22.8	1640	0.2	1.60	1.15
ROCR	7/20/2006	7.3	3.3	25.1	1456	0.2	**2.10**	0.62
ROCR	8/3/2006	7.5	**2.9**	27.0	1664	0.2	**2.20**	1.10
ROCR	9/11/2006	7.1	5.9	20.9	552	0.2	1.10	0.43
ROCR	10/10/2006	7.0	5.4	15.1	1032	0.1	1.80	0.88
ROCR	11/21/2006	7.6	9.4	8.6	760	0.1	0.80	0.29
ROCR	12/22/2006	7.5	8.0	6.1	1024	0.2	0.90	0.77
ROCR	1/30/2007	-	11.7	0.1	912	**0.3**	**2.70**	0.71
ROCR	3/7/2007	7.4	10.4	2.7	904	0.2	1.06	0.17
ROCR	4/19/2007	7.4	8.1	9.6	832	0.1	**2.60**	0.25
ROCR	5/22/2007	7.3	**4.8**	16.7	1288	0.2	1.69	0.43
ROCR	6/25/2007	7.0	6.1	21.4	1664	0.2	0.90	0.47
ROCR	7/30/2007	7.3	3.8	24.1	1248	0.1	0.80	0.53
ROCR	9/4/2007	7.3	4.8	21.5	2208	**0.3**	0.70	0.47
ROCR	10/11/2007	7.3	3.7	19.5	2400	**0.3**	1.30	0.48
ROCR	11/5/2007	7.6	6.8	9.0	1680	0.2	2.00	0.23
ROCR	12/3/2007	7.3	8.2	6.4	1304	0.1	**2.30**	0.48
SVPS	11/3/2005	7.4	7.6	11.2	1340	-	**3.10**	1.42
SVPS	12/8/2005	8.1	13.7	2.1	2150	**0.8**	1.70	0.55
SVPS	1/3/2006	7.8	5.0	8.1	1240	0.2	**3.60**	1.31
SVPS	2/14/2006	8.1	13.4	4.9	1744	**1.1**	1.70	0.62
SVPS	3/8/2006	**8.9**	10.7	5.5	2080	**0.4**	1.70	0.38
SVPS	4/4/2006	**8.9**	5.6	13.7	1584	**0.3**	2.00	0.31
SVPS	5/4/2006	8.2	**2.6**	16.7	2288	**0.3**	**4.60**	1.52
SVPS	6/1/2006	7.8	3.3	21.7	2552	**0.4**	**3.40**	2.66
SVPS	7/20/2006	8.0	7.2	23.5	2336	**0.4**	**4.70**	1.78
SVPS	8/3/2006	8.0	6.1	24.9	2544	**0.4**	**4.10**	1.62
SVPS	9/12/2006	7.6	8.4	18.0	2320	**0.3**	**2.40**	1.80
SVPS	10/11/2006	7.9	8.7	16.5	2376	**0.3**	**4.20**	1.84
SVPS	11/21/2006	8.2	11.1	7.5	1960	**0.4**	**4.30**	0.52
SVPS	12/21/2006	8.4	9.7	6.5	1544	**0.4**	-	1.35
SVPS	1/30/2007	-	13.6	0.9	2320	**0.5**	1.31	1.21
SVPS	3/19/2007	8.2	12.0	4.3	1952	**0.4**	1.96	0.11
SVPS	4/18/2007	**8.5**	13.9	9.6	1968	**0.4**	1.75	0.23
SVPS	5/22/2007	7.9	7.1	15.2	2408	0.1	**2.34**	0.99
SVPS	6/25/2007	7.9	7.4	20.3	1808	**0.4**	1.70	1.09

Table A.6. Water quality data. Values that exceed threshold are in bold (continued).

Station	DATE	pH	DO (mg L^{-1})	Temp (°C)	ANC (μeq L^{-1})	Sal	NO_3^- (mg L^{-1})	TP (μg L^{-1})
SVPS	7/30/2007	7.9	6.8	23.1	2168	**0.3**	1.10	0.63
SVPS	9/4/2007	8.1	6.7	20.7	2352	**0.4**	**2.40**	1.02
SVPS	10/11/2007	8.1	6.6	17.5	3128	**0.4**	**3.00**	0.99
SVPS	11/5/2007	8.1	9.1	9.7	2736	**0.4**	**3.70**	0.90
SVPS	12/3/2007	7.8	9.2	8.2	1560	0.2	1.90	0.88
	Mean	**7.8**	**7.5**	**13.5**	**1597**	**0.4**	**2.61**	**0.93**
	SE	**0.01**	**0.2**	**0.5**	**31**	**0.0**	**0.10**	**0.06**

Table A.7. Benthic index of biotic integrity (BIBI). Values that exceed threshold are in bold.

Site ID	BIBI
LRLR 425	**1.50**
LRLR 425	**1.00**
LRLR 426	**1.00**
LRLR 429	**2.25**
LRLR 434	**1.00**
NCRW 304-N-2004	**2.11**
Mean	1.48
SE	0.24

Table A.8. Physical habitat index (PHI). Values that exceed threshold (> 42) are in bold.

Site ID	PHI
NCRW-304-N-2004	**61.3**
LRLR 425	**55.5**
LRLR 425	**56.5**
LRLR 425	**49.5**
LRLR 425	**44.5**
LRLR 425	**63.5**
LRLR 426	**65.0**
LRLR 426	**58.5**
Mean	56.79
SE	2.47

Table A.9. Proportion (%) of cover of invasive exotic shrubs, trees, and herbaceous plants. Values that exceed threshold (> 5%) are in bold.

Site ID	Year	Species	Invasive basal area	Total shrub basal area	% invasive by basal area
SHRUBS					
ROCR-0094	2006	*Euonymus alatus*	45.36	78	**58.15**
ROCR-0010	2006		0		0.00
ROCR-0092	2006		0		0.00
ROCR-0172	2007	*Viburnum plicatum*	185.5	2217	**8.37**
ROCR-0186	2007	*Viburnum sieboldii*	405.18	406	**99.80**
TREES					
ROCR-0094	2006		0		0.00
ROCR-0010	2006		0		0.00
ROCR-0092	2006		0		0.00
ROCR-0172	2007		0		0.00
ROCR-0186	2007	*Acer platanoides*	289.53		
ROCR-0186	*2007*	*Malus sieboldii*	81.71	24917	0.33
Site ID	**Year**	**Species**	**Mean % cover**	**Error (std. dev.)**	**Total % cover**
HERBACEOUS					
ROCR-0092	2006	*Alliaria petioloata*	33	10	
		Ampelopsis brevipedunculata	2	1	
		Duchesnea indica	0.1	0.1	**35.1**
ROCR-0010	2006		0		0
ROCR-0094	2006		0		0
ROCR-0172	2007	*Alliaria petiolata*	0.1	0.1	
		Duchesnea indica	3	2	
		Hedera helix	16	3	
		Celastrus orbiculatus	6	2	
		Rosa multiflora	0.1	0.1	
		Euonymus fortunei	0.1	0.1	
		Lonicera japonica	0.1	0.1	**25.4**
ROCR-0186	2007	*Hedera helix*	40	13	
		Alliaria petioloata	2	1	**42**
				Mean	**20.5**
				SE	8.77

Table A.10.Presence of forest pest species. Values that exceed threshold (> 1%) are in bold.

Site ID	Year	Pest species observed
ROCR-0092	2006	0.00
ROCR-0010	2006	0.00
ROCR-0094	2006	0.00
ROCR-0172	2007	0.00
ROCR-0186	2007	0.00
	Mean	0.00

Table A.11. Native seedling regeneration (seedlings ha^{-1}). Values that do not meet the threshold (31,875 ha^{-1}) are in bold.

Site ID	Year	Tree seedlings	Shrub seedlings	Total
ROCR-0010	2006		0	**0**
ROCR-0092	2006		0	**0**
ROCR-0094	2006		12500	**12500**
ROCR-0172	2007	2500	12500	**15000**
ROCR-0186	2007	0	2500	**2500**
			Mean	6000
			SE	3221.02

Table A.12. Fish index of biotic integrity (FIBI). Values that exceed threshold (> 3) are in bold.

Stream ID	Year	FIBI
LRLR425	2000	1.9
LRLR425	2000	3
LRLR425	2003	2.3
LRLR426	2003	2.1
LRLR426	2000	2.8
NCRW 304-N	2004	2.78
	Mean	2.48
	SE	0.18

Table A.13. Proportion (%) of area occupied (PAO) by amphibians. Values that are outside the threshold range (20-80%) are in bold.

Species	2005 % area occ	2005 SE	2006 % area occ	2006 SE	2007 % area occ	2007 SE
Desmognathu fuscus	20.71	13.09	42.42	12.28	56.82	13.67
Eurycea bislineata	**92.3**	9.84	**83.77**	9.72	76.02	11.33
Pseudotriton ruber	30.43	14.7	36.2	14.52	41.49	15.87

APPENDIX A

Table A.14. Presence of forest interior dwelling species (FIDS) of birds. Values that do not meet the threshold (> 1 highly sensitive species; > 4 sensitive species) are in bold.

Species	2003	2007	2008	
HIGHLY SENSITIVE				
Mniotilta varia	**0**	1	**0**	
Setophaga ruticilla	**0**	**0**	5	
Seiurus motacilla	**0**	1	1	
Oporornis formosus	**0**	**0**	**0**	
Wilsonia citrina	**0**	**0**	**0**	
Buteo lineatus	**0**	1	**0**	
Dendroica virens	**0**	1	**0**	
Helmitheros vermivorus	**0**	1	**0**	
Number of species	**0**	5	2	
Mean				2.33
SE				1.45
SENSITIVE				
Picoides villosus	**0**	6	**3**	
Dryocopus pileatus	**0**	4	**0**	
Empidonax virescens	7	20	25	
Vireo olivaceus	5	25	22	
Catharus fucescens	**3**	7	**2**	
Hylocichla mustelina	5	55	14	
Parula americana	**0**	**1**	**0**	
Seiurus aurocapillus	**0**	15	**3**	
Piranga olivacea	**1**	9	4	
Number of species	5	9	7	
Mean				7.00
SE				1.15

Table A.15. Deer density (deer km^{-2}). Values that exceed the threshold (forest: 8 km^{-2}; grassland: 20 km^{-2}) are in bold.

Year	Deer density	95% CI
2007	**31.83**	24.86-40.75
2006	**22.09**	15.51-31.45
2005	20.00	14.66-27.99
2004	**28.91**	23.16-36.08
2003	**37.57**	24.39-57.86
2002	**22.92**	17.35-30.28
2001	**24.24**	14.89-39.47
2000	**23.60**	13.70-40.50
Mean	**26.40**	
SE	2.09	

Appendix B: Information Used in Rock Creek Park Natural Resource Condition Assessment

Table B.1. IUCN Habitats Classification Scheme (Version 3.0)—*www.iucnredlist.org/static/major_habitats.*

The habitat types listed below are standard terms used to describe the major habitat/s in which taxa occur. If recorded, these habitats are listed on the Fact Sheet page for each taxon. The three levels of the hierarchy are self-explanatory, as they use familiar habitat terms that take into account biogeography, latitudinal zonation, and depth in marine systems. The inland aquatic habitats are based primarily on the classification system of wetland types used by the Ramsar Convention (see *http://www.ramsar.org/ris/key_ris.htm#type*). It is acknowledged that the classification scheme used here is not satisfactory, hence a review of the scheme is underway.

1. FOREST
- 1.1 Boreal
- 1.2 Subarctic
- 1.3 Subantarctic
- 1.4 Temperate
- 1.5 Subtropical/Tropical Dry
- 1.6 Subtropical/Tropical Moist Lowland
- 1.7 Subtropical/Tropical Mangrove Vegetation Above High Tide Level
- 1.8 Subtropical/Tropical Swamp
- 1.9 Subtropical/Tropical Moist Montane

2. SAVANNA
- 2.1 Dry Savanna
- 2.2 Moist Savana

3. SHRUBLAND
- 3.1 Subarctic
- 3.2 Subantarctic
- 3.3 Boreal
- 3.4 Temperate
- 3.5 Subtropical/Tropical Dry
- 3.6 Subtropical/Tropical Moist
- 3.7 Subtropical/Tropical High Altitude
- 3.8 Mediterranean-type Shrubby Vegetation

4. GRASSLAND
- 4.1 Tundra
- 4.2 Subarctic
- 4.3 Subantarctic
- 4.4 Temperate
- 4.5 Subtropical/Tropical Dry Lowland
- 4.6 Subtropical/Tropical Seasonally Wet/Flooded Lowland
- 4.7 Subtropical/Tropical High Altitude

5. WETLAND (INLAND)
- 5.1 Permanent Rivers/Streams/Creeks [includes waterfalls]
- 5.2 Seasonal/Intermittent/Irregular Rivers/Streams/Creeks
- 5.3 Shrub Dominated Wetlands
- 5.4 Bogs, Marshes, Swamps, Fens, Peatlands
- 5.5 Permanent Freshwater Lakes [over 8 ha]
- 5.6 Seasonal/Intermittent Freshwater Lakes [over 8 ha]
- 5.7 Permanent Freshwater Marshes/Pools [under 8 ha]
- 5.8 Seasonal/Intermittent Freshwater Marshes/Pools [under 8 ha]
- 5.9 Freshwater Springs and Oases
- 5.10 Tundra Wetlands [includes pools and temporary waters from snowmelt]
- 5.11 Alpine Wetlands [includes temporary waters from snowmelt]
- 5.12 Geothermal Wetlands

Table B.1. IUCN Habitats Classification Scheme (Version 3.0)—*www.iucnredlist.org/static/major_habitats* (continued)

- 5.13 Permanent Inland Deltas
- 5.14 Permanent Saline, Brackish or Alkaline Lakes
- 5.15 Seasonal/Intermittent Saline, Brackish or Alkaline Lakes and Flats
- 5.16 Permanent Saline, Brackish or Alkaline Marshes/Pools
- 5.17 Seasonal/Intermittent Saline, Brackish or Alkaline Marshes/Pools
- 5.18 Karst and Other Subterranean Hydrological Systems [inland]

6. ROCKY AREAS [E.G. INLAND CLIFFS, MOUNTAIN PEAKS]

7. CAVES AND SUBTERRANEAN HABITATS (NON-AQUATIC)

- 7.1 Caves
- 7.2 Other Subterranean Habitats

8. DESERT

- 8.1 Hot
- 8.2 Temperate
- 8.3 Cold

9. MARINE NERITIC (SUBMERGENT NEARSHORE CONTINENTAL SHELF OR OCEANIC ISLAND)

- 9.1 Pelagic
- 9.2 Subtidal Rock and Rocky Reefs
- 9.3 Subtidal Loose Rock/Pebble/Gravel
- 9.4 Subtidal Sandy
- 9.5 Subtidal Sandy-Mud
- 9.6 Subtidal Muddy
- 9.7 Macroalgal/Kelp
- 9.8 Coral Reef
    - 9.8.1 Outer Reef Channel
    - 9.8.2 Back Slope
    - 9.8.3 Foreslope (Outer Reef Slope)
    - 9.8.4 Lagoon
    - 9.8.5 Inter-Reef Soft Substrate
    - 9.8.6 Inter-Reef Rubble Substrate
- 9.9 Seagrass (Submerged)
- 9.10 Estuaries

10. MARINE OCEANIC

- 10.1 Epipelagic (0-200 m)
- 10.2 Mesopelagic (200-1,000 m)
- 10.3 Bathypelagic (1,000-4,000 m)
- 10.4 Abyssopelagic (4,000-6,000 m)

11. MARINE DEEP BENTHIC

- 11.1 Continental Slope/Bathyl Zone (200-4,000 m)
    - 11.1.1 Hard Substrate
    - 11.1.2 Soft Substrate
- 11.2 Abyssal Plain (4,000-6,000 m)
- 11.3 Abyssal Mountain/Hills (4,000-6,000 m)
- 11.4 Hadal/Deep Sea Trench (> 6,000 m)
- 11.5 Seamount
- 11.6 Deep Sea Vents (Rifts/Seeps)

12. MARINE INTERTIDAL

- 12.1 Rocky Shoreline
- 12.2 Sandy Shoreline and/or Beaches, Sand Bars, Spits, Etc.
- 12.3 Shingle and/or Pebble Shoreline and/or Beaches
- 12.4 Mud Flats and Salt Flats
- 12.5 Salt Marshes (Emergent Grasses)
- 12.6 Tidepools
- 12.7 Mangrove Submerged Roots

Table B.1. IUCN Habitats Classification Scheme (Version 3.0)—*www.iucnredlist.org/static/major_habitats* (continued)

13. MARINE COASTAL/SUPRATIDAL
- 13.1 Sea Cliffs and Rocky Offshore Islands
- 13.2 Coastal Caves/Karst
- 13.3 Coastal Sand Dunes
- 13.4 Coastal Brackish/Saline Lagoons/Marine Lakes
- 13.5 Coastal Freshwater Lakes

14. ARTIFICIAL - TERRESTRIAL
- 14.1 Arable Land
- 14.2 Pastureland
- 14.3 Plantations
- 14.4 Rural Gardens
- 14.5 Urban Areas
- 14.6 Subtropical/Tropical Heavily Degraded Former Forest

15. ARTIFICIAL - AQUATIC
- 15.1 Water Storage Areas (over 8 ha)
- 15.2 Ponds (below 8 ha)
- 15.3 Aquaculture Ponds
- 15.4 Salt Exploitation Sites
- 15.5 Excavations (open)
- 15.6 Wastewater Treatment Areas
- 15.7 Irrigated Land [includes irrigation channels]
- 15.8 Seasonally Flooded Agricultural Land
- 15.9 Canals and Drainage Channels, Ditches
- 15.10 Karst and Other Subterranean Hydrological Systems [human-made]
- 15.11 Marine Anthropogenic Structures
- 15.12 Mariculture Cages
- 15.13 Mari/Brackish-culture Ponds

16. INTRODUCED VEGETATION

17. OTHER

18. UNKNOWN

Table B.2. Exotic herbaceous species found in Rock Creek Park.

TSN	Species	TSN	Species
18857	*Akebia quinata*	25898	*Lespedeza cuneata*
184481	*Alliaria petiolata*	35283	*Lonicera japonica*
28632	*Ampelopsis brevipedunculata*	35281	*Lonicera spp.*
18835	*Berberis thunbergii*	503829	*Microstegium vimineum*
506068	*Celastrus orbiculatus*	20889	*Polygonum cuspidatum*
501347	*Centaurea biebersteinii*	20914	*Polygonum perfoliatum*
36335	*Cirsium arvense*	504683	*Pueraria montana*
18712	*Clematis terniflora*	18603	*Ranunculus ficaria*
25163	*Duchesnea indica*	24833	*Rosa multiflora*
27950	*Euonymus fortunei*	25017	*Rubus phoenicolasius*
502801	*Glechoma hederacea*	505677	*Viburnum dilatatum*
29393	*Hedera helix*	30238	*Vinca minor*
42943	*Hemerocallis fulva*	27023	*Wisteria sinensis*

Table B.3. Reports for I&M data used in the natural resource condition assessment.

FOREST MONITORING REPORTS

Schmit, J.P. and J.P. Campbell. 2007. National Capital Region Network 2006 Forest Vegetation Monitoring Report. NPS. NPS/NCRN/NRTR-2007/046.

Schmit, J.P. and J.P. Campbell. 2008. National Capital Region Network 2007 Forest Vegetation Monitoring Report. NPS, Fort Collins, CO. NPS/NCRN/ NRTR—2008/125.

WATER MONITORING REPORTS

Norris, M., J. P. Schmit and J. Pieper. 2007. National Capital Region Network 2005 - 2006 Water Resources Monitoring Report. Natural Resource Program Center, Fort Collins, CO. NPS/NCRN/ NRTR - 2007/066.

AMPHIBIAN MONITORING REPORTS

Mattfeldt, S. D., E.H. Grant and L.L. Bailey. 2008. Amphibian Monitoring in the National Capital Region: A focus on lentic and lotic habitats. NPS, NCRN. NPS/NRTR/NCRN—2008/088.

Bates, S. 2007. National Capital Region Network 2006 Deer Monitoring Report. National Park Service, Fort Collins, CO. NPS/NCRN/ NRTR—2007/033.

PROTOCOLS

Schmit, J.P., D. Chojnacky, and M. Milton. 2006. National Capital Region Network Long-Term Forest Monitoring Protocol Ver. 1.0.

Bailey, L.L., E.H. Grant, and D. Mattfeldt. 2007. National Capital Region Network – Amphibian Monitoring Protocol.

Dawson, D.K. and M.G. Efford. 2006. National Capital Region Network – Protocol for Monitoring Forest-Nesting Birds in National Park Service Parks.

Bates, S. 2006. National Capital Region Network Inventory and Monitoring Protocol Version 1.1: Distance and Pellet-Group Surveys.

Hilderbrand, R.H., R. Raesly and D. Boward. 2007. National Capital Region Network Biological Stream Survey Protocols.

LANDSCAPE DYNAMICS

Townsend, P.A., R.H. Gardner, T.R. Lookingbill, and C.C. Kingdom. 2006. National Capital Region Network – Remote Sensing and Landscape Patter Protocol for Long-Term Monitoring of Parks.

SURFACE WATER DYNAMICS

Norris, M. and G. Fisher. 2006. National Capital Region Network Surface Water Dynamics Protocol. Water Chemistry (Note: no report number, still draft):

Norris, M., J. Pieper and A. Cattani. 2008. National Capital Region Network Inventory and Monitoring Program Water Chemistry Monitoring Protocols. Natural Resource Report. NPS/NCRN/ NRR—2008/XXX.

Table B.4. Participants at the data scoping workshop held at the Center for Urban Ecology on June 20th, 2006.

UNIVERSITY OF MARYLAND CENTER OF ENVIRONMENTAL SCIENCE

Integration and Application Network (IAN): Tim Carruthers, Bill Dennison, Jane Hawkey, Lisa Florkowski

Appalachian Lab: Todd Lookingbill

US GEOLOGICAL SURVEY

Water Resources for MD/DE/D.C.: Cherie Miller

Patuxent Wildlife Research Center: Larissa Bailey, Deanna Dawson, Evan Grant

NATIONAL PARK SERVICE

Rock Creek Park: Ken Ferebee, Joe Kish, Bill Yeaman

Center for Urban Ecology: Scott Bates, Doug Curtis, Dan Sealy, Jeff Runde, Diane Pavek, Bob Stroik

Inventory & Monitoring: Pat Campbell, Shawn Carter, Marian Norris, Geoffrey Sanders, John Paul Schmit

Exotic Plant Management: Sue Salmons

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown.

Aalto, Jaworski, and Schremp. 1969. A water quality study of the Rock Creek watershed—This report provides data on the existing water quality in Rock Creek, analyzes changes in the water quality since 1966, when corrective actions were taken, and publishes all water quality data collected since 1966.

Adams, Hadidian, Leedy, Manski, and Riley. 1991. Daytime resting site selection in an urban raccoon population—This article is part of the long-term raccoon ecology research at Rock Creek Park. The daytime resting habits and habitats of adult raccoons were determined using mark-recapture and radio telemetry techniques.

Anderson and McFaden. 1978. The vegetative community structure of the Glover-Archbold, Battery Kemble, and additional reservations of Rock Creek Park—This report presents information on the vegetation community structure, specifically dominant overstory trees and cover types, of Rock Creek Park. The information was gathered with on-site field checking as well as use of aerial photos.

Anderson, Doe, Jones, Kramer, and McFaden. 1977. Rock Creek Park and Rock Creek and Potomac Parkway: vegetation community structure and automated classification of vegetation communities—This report is the result of an effort to establish an information base on the vegetative communities of Rock Creek Park. Aerial photos were analyzed for vegetation information, field checks were made to confirm the data.

Aquatic Ecology Class. 1991. Analysis of the 27th street stream—Members of an aquatic ecology class at GW examined the biota and the abiotic characteristics of a stream in Rock Creek Park from January to April 1991. Results are presented here.

Aquiar. 1991. Ecological competition: ant interactions at bonanza food sources (Hymenoptera: Formicidae)—Interspecific competition among ant species in three habitats was studied in Glover-Archbold Park for a senior thesis at Georgetown University.

Baer, Hadidian, Jenkins, Johnston, Manski, and Savarie. 1989. Acceptance of simulated oral rabies vaccine baits

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

by urban raccoons—A study on the effectiveness of vaccinating raccoons for rabies using oral baited vaccines was conducted in Rock Creek Park. Bait cubes were distributed in the par containing a detectable substance. Raccoons were trapped and evaluated for the presence of rabies.

Bailey. 1923. Mammals of the District of Columbia—This article describes all the mammals reported to occur in the District of Columbia in 1923. Descriptions of natural history and some occurrences are given for each animal.

Baker. 1956. Hydraulics report for Rock Creek Park, Washington, D.C.—This report gives flow data for Rock Creek at 7 proposed bridge sites.

Baker. 1957. Hydraulics report supplement: Rock Creek Park, Washington, D.C.—This report gives flood flow data for Rock Creek at 7 proposed bridge sites in order to supplement a previous report.

Banta and Horowitz. 1992. Rapid bioassessment of macroinvertebrates in select lotic waters of the District of Columbia—As part of a follow-up study on macroinvertebrates in D.C. streams, this report presents water quality assessments of 5 streams: Carroll branch, East Creek, Klingle Creek, Pinehurst Branch, and Soapstone Creek. Data includes water quality measurements and

Banta, Fithian, and Horowitz. 1992. Final Report: National Park Service, National Capital Region, Urban Stream Survey Phase II—This study continues an investigation into the physical and biological conditions in urban streams and their changes over time. Phase II applies the background information in developing a classification system for streams.

Banta, Fithian, Horowitz, and Shellum. 1991. Final Report: National Park Service, National Capital Region, Urban Stream Survey Phase I—This study began an investigation into the physical and biological conditions in urban streams and their changes over time. Phase I entailed selection of 6 park streams and collection of water quality, quantity, and macroinvertebrate data.

Banta. 1993. Biological water quality of the surface tributary streams of the District of Columbia—This study examined water quality and habitat quality of 29 streams in the D.C. area, including 4 tributaries of Rock Creek. Animal species were identified, erosion was examined, and chemical analysis was performed to assess the presence of pollutants.

Bassler. 1943. Geology in the Capital Parks—This paper presents and describes a tour of the geology of some of the National Capital Parks, starting from Potomac Park, going by the zoo, and including the downtown monuments.

Batra and Rudolph. 1975. Fungi in Rock Creek Park—This is a list of the scientific and common names of fungi found in Rock Creek Park.

Bean and Smith. 1899. List of fishes known to inhabit the waters of the District of Columbia and vicinity—This is an annotated list of the fish species recognized in D.C. waters. Locations common to each fish are given.

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

Belew and Scott. 1987. Exotic plant survey of *Hedera helix, Pachysandra terminalis, Vinca minor, and Euonymus fortune*—Four areas within the park were surveyed for four species of exotic plants in the winter of 1986. The plants were mapped, as well as significant native plants, and methods for control are recommended.

Belew, Scott, and Sporko. 1986. Rock Creek Park 1986 gypsy moth integrated pest management—This is a description of gypsy moth management in the Rock Creek Park in 1986, including egg mass and defoliation survey results, treatment histories, and maps of treated areas.

Bergendahl, Richards, and Wlaschin. 1978. Riprap study for the Rock Creek basin, Washington, D.C.—This study determined a mean stone size required to prevent erosion in the Rock Creek channel throughout its length in D.C.

Besse and Watt. 1984. Identification and prioritization of the water resources problems and research needs in the District of Columbia—A survey was conducted to identify and prioritize the water resources problems and research needs in the District of Columbia. The survey was directed to individuals knowledgeable of the District's water resources.

Bigoni, Hadidian, Stanyon, and Wienberg. 1993. A standardized G-banded karyotype for the raccoon (*Procyon lotor*) compared with the domestic cat—This study of the chromosomes and genetic evolution of the raccoon used blood samples taken from 16 raccoons in Rock Creek Park.

Blackburn. 1989. Metropolitan Washington climate review—These climate reviews present data on the temperatures and precipitation for D.C. for each time period. A map of precipitation levels is included.

Blake and Robbins. 1931. Cladonia in the District of Columbia and vicinity—This report presents a list of lichen species of the genus Cladonia occurring in the D.C. region. Locations of specimens are given.

Blonder. 1988. Non-chemical treatments of the problem exotic plants *Ampelopsis brevipedunculata* and *Celastrus orbiculatus*—This report describes an experiment on the efficacy of four non-chemical control methods for exotic vine plants in Rock Creek Park from June to September 1988.

Boettcher. 1979. Survey and collection of wasps and associated insects in Rock Creek Park Meadows, Washington, D.C., March 15 through June 22, 1978—This is the report of a collection of wasp and associated species in eight meadows in Rock Creek Park in 1978. 71 specimens were collected. Flowering plants used were recorded and a list of the bee and wasp species is included.

Bowden and Yeaman. 1996. Macroinvertebrate sampling, 1996—These are field notes from sampling of stream macroinvertebrates in the winter of 1996 on Portal Branch, Fenwick Branch, Normanstone Run, Foundry Branch, and Hazen Run.

Bowman. 1967. *Asellus kendi*, a new isopod crustacean from springs in the eastern United States—A new species of crustacean was discovered in a spring in Rock Creek Park by Roman Kenk. The species is described here.

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

Briggs and Chriswell. 1979. Gradual silencing of Spring in Washington: selective reduction in species of birds found in three woodland areas over the past thirty years—This document describes a study of the reduction of bird species in three woodland areas, specifically Cabin John Island, Glover-Archbold Park, and Rock Creek Park, over the period of 1947-1977.

Briggs. 1959. The first Glover-Archbold Park census—This article contains species lists and results from a breeding bird census conducted in Glover-Archbold Park in 1959.

Briggs. 1960. Glover-Archbold Park—These articles contain species lists and results from annual breeding bird censuses conducted in Glover-Archbold Park.

Burchick. 1986. Annual auto wildlife road kill statistics from 1980 to 1985—This data table summarizes the numbers of each animal species recorded as road kill for each year from 1980 to 1986.

Bushong. 1990. Historic resource study: Rock Creek Park, District of Columbia—This study focuses primarily on a survey of historic and existing cultural resources of Rock Creek before and after its establishment as a park. Information on historic and present day land uses is provided, however.

Butcher. 1943. The Capitals little wilderness: Rock Creek Park—This is a descriptive article of some of the wildflowers occurring in Rock Creek Park in spring and summer and conservation problems facing the park.

Carroll and Flanagan. 1976. Mica schist, SDC-1, from Rock Creek Park, Washington, D.C.

Carroll and Flanagan. 1979. Mica Schist, SDC-1, from Rock Creek Park, Washington, D.C.—This describes a sample of mica shist excavated from a sewer tunnel in Rock Creek Park.

Center for Urban Ecology. 1980. Raw water quality field data—These are data charts from field and lab analysis of water quality of Rock Creek between 1980 and 1982.

Center for Urban Ecology. 1983. Field statistics for Rock Creek and Battery Kemble Tribs for water year 1983—These are summary statistics of water quality data collected in 1983 from Rock Creek and Battery Kemble tributaries.

Center For Urban Ecology. 1987. Rock Creek Park gypsy moth integrated pest management 1987 annual report—This is a description of gypsy moth management in the Rock Creek Park in 1987, including egg mass and defoliation survey results, treatment histories, and maps of treated areas.

Center for Urban Ecology. 1989. Rock Creek Park gypsy moth integrated pest management 1989 annual report—This is a description of gypsy moth management in the Rock Creek Park in 1989, including egg mass and defoliation survey results, treatment histories, and maps of treated areas.

Center for Urban Ecology. 1990. Dutch Elm Disease--1990: Rock Creek Park, Rock Creek Parkway, Glover-Archbold Park—This printout contains information about 7 elm trees in the Rock Creek Parks--the extent of dieback and any treatments made.

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

CH2m Hill. 1977. Rock Creek stormwater and water quality management study—This study was conducted to provide information for the master plan for management of the watershed. The environmental setting of the watershed is described, including land use, physiography, and wildlife; hydrology, flood, and water quality data are given.

CH2m Hill. 1979. Rock Creek ultimate land use—These maps are part of the Watershed Conservation Study and depict the 10, 25, 50 and 100-year flood profiles for the Rock Creek system in D.C.

CH2m Hill. 1979. Rock Creek watershed conservation study—The purpose of this study was to compile baseline information for planning evaluations and to develop a set of action-oriented recommendations in order to mitigate the effect of flooding, erosion, pollution, and sedimentation in Rock Creek.

CH2m Hill. 1984. Rock Creek spring inventory—This study compiled an inventory of spring locations and characteristics in Rock Creek Park in 1983. Seasonal flow measurements and water quality samples were taken at each spring. Geologic and water source descriptions are also provided.

Chang, O'Conner, Wade, and Watt. 1993. Ground water resource assessment study for the District of Columbia: Final Report—This report describes the groundwater resources in the District, and details data gained from a study of 6 sample wells installed to determine and monitor groundwater quality and the effect of pollutant runoff on it in D.C.

Clark. 1932. The occurrence of butterflies in the District of Columbia—This section of a book describes the butterfly species occurring in the D.C. area and the general habitat or locations of each.

Coffelt and Weissert. 1977. Survey of American chestnut trees existing in Rock Creek Park north of Military Road—A field study in the park on the location and sizes of American chestnut trees.

Cohn. 1989. Will palm trees replace pines on the Potomac?—This article describes the projected effects of global warming on the D.C. area by 2050. Park areas along the Potomac would be flooded by the rising sea levels. A diagram of the flooding is included.

Conlin. 1981. Rock Creek intensive survey—This report is the result of a study to describe the major trends in water quality in Rock Creek Park and compare the results to 1978-1979 sampling data.

Copley. 1978. Pathology record on deer killed in Rock Creek Park, 3/19/78—These forms present results of a necropsy on a white-tailed deer killed in Rock Creek Park in 1978.

Coues and Prentiss. 1883. Avifauna Columbiana: being a list of birds ascertained to inhabit the District of Columbia, with the times of arrival and departure of such as are non-residents, and brief notices of habits, etc.—This is a description of all the birds known to occur in D.C. in the 1800s, including some natural history information and common habitats.

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

Coues and Prentiss. 1883. Topography of the District: Rock Creek Region—This article describes the topography and physiology of the Rock Creek region in D.C. Included is a map of the region.

Crane. 1995. Action plan for an exotic species—This is an IPM plan for controlling the exotic plant porcelain berry (*Ampelopsis brevipedunculata*) which is invading the park.

Criswell. 1957. 1957 Winter bird population studies—This article summarizes results of annual winter bird counts in Rock Creek Park and Cabin John Park in Washington, D.C. Following are specific accounts for each area.

Criswell. 1968. 1968 Breeding bird population studies—This article summarizes results of annual breeding bird counts in Rock Creek Park, Glover-Archbold Park, Cabin John Park, and Woodend Park in Washington, D.C. Following are specific accounts for each area.

Criswell. 1969. 1969 Winter bird population studies—This article summarizes results of annual winter bird counts in Rock Creek Park, Glover-Archbold Park, Cabin John Park, and Woodend Park in Washington, D.C. Following are specific accounts for each area.

Criswell. 1972. Winter bird population studies, 1972—This article summarizes results of annual winter bird counts in Rock Creek Park, Glover-Archbold Park, Cabin John Park, and Woodend Park in Washington, D.C. Following are specific accounts for each area, but these are not included in this reprint.

Criswell. 1973. Breeding bird population studies, 1973—This article summarizes results of annual breeding bird counts in Rock Creek Park, Glover-Archbold Park, Cabin John Park, and Woodend Park in Washington, D.C. Following are specific accounts for each area.

Criswell. 1973. Winter bird population studies, 1973—This article summarizes results of annual winter bird counts in Rock Creek Park, Glover-Archbold Park, Cabin John Park, and Woodend Park in Washington, D.C. Following are specific accounts for each area, but these are not included in this reprint.

Criswell. 1978. Winter and breeding bird population studies: 1977 and 1978—This paper presents results of winter and breeding bird censuses in Rock Creek Park and Glover-Archbold Park in 1977 and 1978.

Czaplak. 1983. The first breeding record of brown creeper in the District of Columbia—This page documents the first report of a breeding brown creeper in Rock Creek Park in May 1983. This is the first record for the District of Columbia.

Czaplak. 1983. Unusual breeding birds in RCP—This page documents the unusual birds documented as breeding in Rock Creek Park in May 1983.Details of the reports are included.

Czaplak. 1989. Bird survey--field habitat in Rock Creek Park - October 1988—This is a list of species of birds observed in the field habitat of Rock Creek Park in October 1988. Survey areas and results are summarized in the cover letter.

Czaplak. 1990. Fledgling screech owl—This is a photo of a fledgling screech owl taken in Rock Creek Park behind

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

the Kennedy Warren building on 3/19/90. This is an early nesting date for this area.

Czaplak. 1992. Connecticut warbler—This is a photo of a Connecticut warbler taken in Battery Kemble Park on 9/14/92. This is a rarely seen migrant in this area.

Czaplak. 1992. Dickcissel—This is a photo of a dickcissel taken in Battery Kemble Park on 9/18/92. This is a rare migrant in this area.

Czaplak. 1993. Rock Creek migration census, 1989-1992—This packet contains the data lists from fall migration surveys of birds in Rock Creek Park from 1989 to 1992. An important plant for the birds is the giant ragweed.

Dames and Moore. 1982. Characterization of the resource variables of two spring habitats in Rock Creek Park—A study was conducted on 2 spring habitats in Rock Creek Park to assess impacts on environmental quality. Parameters examined were water quality, habitat, vegetation, topography, soils, geology, ground water recharge, and park usage.

Davis. 1949. Rock Creek Park—This article describes the natural features of Rock Creek Park and lists birds observed in each season of the year.

Department of The Army. 1992. Lyme disease risk assessment no 16-61-AL92-92, Walter Reed Army Medical Center, Washington, D.C. 26-29 May 1992—A collection of ticks from small mammals in Rock Creek Park was analyzed for Lyme disease and Rocky Mountain Spotted Fever and found to be without the disease vectors.

Didden, Droege, Hadidian, Handly, Huff, Sauer, Swarth, Williams, Blake, and Robbins. 1996. A city-wide breeding bird survey for Washington, D.C.—A breeding bird survey of the entire Washington D. C. area was conducted in 1993. Species richness and composition was analyzed by land use and distribution. Species lists are presented by land use, including parks, and maps are included.

Dietemann. 1975. A provisional inventory of the fishes of Rock Creek, Little Falls Branch, Cabin John Creek, and Rock Run, Montgomery County, Maryland—In 1974 surveys of fish populations and water quality throughout the Rock Creek system were conducted to supplement data obtained in previous studies. Land use changes have changed the composition of fish over time.

Disalvo and Whitlock. 1985. Integrated pest management 1985 gypsy moth program: Rock Creek Park and Great Falls, Virginia—This is a description of gypsy moth management in the Rock Creek Park in 1985, including egg mass, burlap, and male moth survey results.

Doria. 1984. Gold in the Washington area. The Beltway Naturalist.

Drake, Fleming, and McCartan. 1992. The Rock Creek shear zone: a major tectonic boundary in the central Appalachian Piedmont.

Dranitzke and Fleming. 1989. Pine survey—The results of a 1989 survey of the distribution of Virginia pine and other pine trees in the park are penciled onto the map. One map has details about the areas of diseased trees as well as other trees of special interest.

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

Dynamic Corporation. 1993. Rock Creek fisheries study, final report—The objectives of this 3-year study were to characterize the present and historic fish populations of Rock Creek, to identify habitat characteristics, and to make management recommendations.

Eac Helicopters. 1997. Rock Creek Park and Glover: infrared deer census—A survey of deer populations in Rock Creek and Glover parks was conducted using infrared imaging from a helicopter in 1997. The results are presented here.

Edmondson. 1988. 1987 Macro-invertebrate census of the District of Columbia—During the summer of 1987 the District of Columbia sampled macroinvertebrates from 10 separate water bodies in the city to gather baseline data and to assess the current ecological status of streams. Some sampling sites were on Rock Creek.

Fales. 1950. 1950 Winter bird population studies—This article summarizes results of annual winter bird counts in Rock Creek Park in Washington, D.C.

Fales. 1951. 1951 Winter bird population studies—This article summarizes results of annual winter bird counts in Rock Creek Park in Washington, D.C.

Fales. 1977. Butterfly counts in Rock Creek Park, Washington, D.C.—This report presents the results of a survey of the butterflies of Rock Creek in 1977. Species lists are included.

Fales. 1978. 1978 butterfly counts in Rock Creek Park, Washington, D.C.—This report presents the results of a survey of the butterflies of Rock Creek in 1978. Species lists are included.

Fales. 1978. A preliminary list of butterflies that may occur in Rock Creek Park—This report presents a species list of butterflies and skippers possibly occurring in Rock Creek Park.

Fales. 1978. Report of all-day butterfly count in Rock Creek Park—This table lists the species of butterflies observed on 1 day in 1978 and the number of butterflies recorded.

Fales. 1978. Skippers and butterflies known from Rock Creek Park and the District of Columbia—This report presents a species list of butterflies and skippers possibly occurring in Rock Creek Park, including the months they are known to occur in.

Fales. 1979. 1979 Spring butterfly counts in Rock Creek Park, Washington, D.C.—This table lists the species of butterflies observed on 3 days in 1979 and the location of each observation.

Fales. 1980. Spring butterfly counts at Boundary Bridge in Rock Creek Park, Washington, D.C.—This table lists the species of butterflies observed on 3 days in 1980 at Boundary Bridge.

Fales. 1987. The butterflies of Rock Creek Park, Washington, D.C.—This paper describes the species of butterflies known to occur at Rock Creek Park. Fifty-eight species are documented.

Fales. 1988. 1988 butterfly counts in Rock Creek Park, Washington, D.C.—This paper describes a survey of butterflies in Rock Creek Park in 1988. Species list of results are given as well as photos of the survey areas.

Fales. 1989. Skippers and butterflies known from Rock Creek Park and the District of Columbia—This chart lists

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

species of butterflies and skippers and notes whether they are known to occur in Rock Creek Park.

Fales. 1989. Some butterflies observed in Rock Creek Park, Washington, D.C., in 1989—This is a table of observations of butterflies along two survey routes in RCP in 1989.

Favre, Sherald, and Schneeberger. 1993. Gypsy moth management in Rock Creek Park, Washington, D.C.—This article describes the history of gypsy moth management in Rock Creek Park, including monitoring efforts, and control efforts.

Favre. 1993. 1992 Dutch elm disease suppression report—This memo describes the treatment of two elm trees in Rock Creek with cacodylic acid and includes the data printout of the program.

Favre. 1993. Rock Creek Park survey for hemlocks and HWA—This is the report of a survey of Rock Creek Park for hemlock trees and signs of the hemlock woolly adelgid. Little sign of adelgids were found.

Feller. 1995. An aquatic subterranean macroinvertebrate survey of Rock Creek and associated National Parks, Washington, D.C.—This progress report summarizes the findings of a literature search and fieldwork in 1994 documenting aquatic subterranean macroinvertebrates in Rock Creek Park, Glover-Archbold Park, and other park units in D.C. The study focused on groundwater springs.

Fellows. 1950. Notes on the geology of Rock Creek Park, District of Columbia—This paper presents and describes a geologic map of the park from 1949.

Ferguson. 1967. *Potamocypris bowmani*, a new freshwater ostracod from Washington, D.C.—A new species of ostracod was discovered in a spring in Rock Creek Park by Thomas Bowman. The species is described here.

Fleming and Kanal. 1992. Newly documented species of vascular plants in the District of Columbia—This paper presents a species list of the results of a survey of the vascular plants of ROCR, Columbia Island, Anacostia Kenilworth, and Oxon Run from 1986 through 1990. Voucher specimens from the study were placed in the US National Herbarium.

Fleming and Kanal. 1995. Annotated checklist of vascular plants of Rock Creek Park, National Park Service, Washington, D.C.—This paper presents a species list of the results of a survey of the vascular plants of ROCR from 1986 through 1994. Voucher specimens from the study were placed in the US National Herbarium in the District of Columbia and Vicinity collection.

Fleming and Kemball. 1990. *Ranunculus ficaria* mapping—The results of a 1990 survey of the distribution of the exotic plant *Ranunculus ficaria* (lesser celandine).

Fleming and Rosenberg. 1982. Grasses identified in Rock Creek Park meadows, Washington, D.C., 1977-1981—This report contains a list of grasses identified from 9 meadows in Rock Creek Park from 1977 to 1981. The name, location, blooming dates, and relative abundance are given for each species.

Fleming and Tasha. 1990. Dogwood mapping—The results of a 1990 survey of the distribution of dogwood trees

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

in the park are penciled onto the map. One map has details about the areas of diseased trees as well as other plants of special interest.

Fleming. 1977. Park Road meadow--what to do about it—This memo describes the current state of the Park Road meadow, listing problems, and makes management recommendations.

Fleming. 1978. The geology of the crystalline rocks of West-Central Washington, D.C.—This study investigated and mapped the crystalline rocks which underlie the Piedmont portion of Washington, D.C. Rock Creek Park was included in the upper half of the study area. The rock types are described in the text.

Fleming. 1979. Plant and animal diversification in an urban park through the development of meadows—This report details the history of the 3-year old meadow restoration program at Rock Creek, listing vegetation changes and bird use and covering the success and future of the program.

Fleming. 1980. Meadow plantings, 1980—These are lists of plants planted in the Rock Creek meadows in 1980.

Fleming. 1981. Soil samples of six meadows and adjacent woods and lawns in Rock Creek Park—Eighteen soil samples were taken from six managed meadows in Rock Creek Park in June 1981 and analyzed for coarse fragment, particle size, pH, soluble salts, organic matter, magnesium and other ions, and soil series.

Fleming. 1981. Soil samples of six meadows and adjacent woods and lawns in Rock Creek Park - raw data—Eighteen soil samples were taken from six managed meadows in Rock Creek Park in June 1981 and analyzed for coarse fragment, particle size, pH, soluble salts, organic matter, magnesium and other ions, and soil series.

Fleming. 1987. Small mammal survey data 1980-1987—These are original data sheets from a small mammal survey conducted in two meadows (Military Field and Sherrill Drive) in Rock Creek Park from 1980-1987. Trapping data includes species, weight, sex, and number of traps with animals in them.

Fleming. 1988. Problem exotic plants in Rock Creek Park—This lists the exotic plants found in Rock Creek Park , their habitat, and their habitat in the park.

Fleming. 1988. Significant native plants in Rock Creek Park—This is a list of “significant” plants observed in Rock Creek, including their reason for being on the list. Also included are a list of sig. plants not yet seen by the author but expected, and a list of problem exotic plants.

Fleming. 1993. Fascine planting in Rock Creek Park—This report describes attempts to revegetate and restore disturbed areas of Rock Creek Park using fascines and live stakes. Plantings were begun in 1988 and monitored for 5 years.

Folkerth. 1988. Bird observation records for Rock Creek Park—Bird observations from Natural history field observations (1976-1988), observation records (1973-1987), and Christmas bird count records (1973-1987) were searched and a list of species observed in ROCR was compiled in order to be used for a checklist of birds.

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

Ford. 1979. Release of spotted salamanders—This memo describes the release of 5 spotted salamanders along Pinehurst Branch from collection sites in Oxon Cove.

Ford. 1983. Breeding birds of Rock Creek Park, Washington, D.C.—This is a list of bird species nesting in the parks of Northwest Washington, D.C., as well as 13 questionable nesters (in need of confirmation).

Ford. 1991. Flowering dogwood seed collection—This note describes the collection of several thousand seeds of flowering dogwoods in Rock Creek Park in September 1991. The seeds were sent to CUE for processing for the National Seed Lab.

Forgey. 1991. One Hundred Years of Serenity (Rock Creek Park, Washington, D.C.)—This article summarizes the history of the establishment and management of Rock Creek Park, discusses current problems, and the values of the urban forests and the historical aspects of the park.

Foster. 1964. Slides of chestnut trees—These slides depict American chestnut trees in Rock Creek Park—diseased, fallen, reproducing, and Chinese chestnuts as well.

Fowler. 1945. The amphibians and reptiles of the National Capital Parks and the District of Columbia region—This report contains a checklist of amphibian and reptile species reported to occur in Rock Creek Park, C&O Canal, Kenilworth, or Mt. Vernon.

Frank. 1954. The Rock Creek watershed—This article describes the history of deterioration of Rock Creek, including data on soils, rainfall, and erosion.

Gabor. 1979. Fish spawning data, Rock Creek—These documents provide information on spawning survey results from 1979 surveys of Rock Creek, as well as lists of anadromous fish species.

Gallagher. 1991. Raccoon rabies in Washington, D.C.: (1988-1991): The geography of an urban epizootic—This study examined the geographic distribution of raccoons, rabies accounts, and land uses from 1988 to 1990. Data from Rock Creek Park is included.

Givens, Johnson, Kasim, Medlin, Schartzman, and Wright. 1982. Lead and cadmium biogeochemistry: a case study using lichens as monitors of airborne pollution.

Guerrero and Hadidian. 1986. Biological data for raccoons trapped in Rock Creek Park—These sheets contain biological data (size, weight, age, etc.) collected from raccoons trapped in Rock Creek Park in 1983 and 1984 under a cooperative study involving the UDC, NPS, CDC, National Zoo, and the D.C. Health Dept.

Guerrero. 1993. Inventory and status of wetlands in the District of Columbia.

H.. 1953. Oaks native to the Washington, D.C. region—This report lists and describes the species of oak trees found in D.C. Locations of each species common to the national parks are given.

Hadidian, Manski, and Riley . 1997. Population density and survival of raccoons (*Procyon lotor*) in an urban national park—This paper presents the results of a study on raccoon populations in Rock Creek Park over

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

an 8-year period. Raccoon densities and survival were monitored using mark-recapture techniques and radio tracking. Average density for the park was 1 raccoon per 0.8 ha.

Hadidian, Manski, and Riley. 1998. Population density, survival, and rabies in raccoons in an urban national park—This paper presents the results of a study on raccoon populations in Rock Creek Park over an 8-year period. Raccoon densities and survival were monitored using mark-recapture techniques and radio tracking.

Hadidian. 1983. Field notes from Hazen raccoon study—These are copies of the field notebooks from the raccoon study by CUE at Hazen from 1983 to 1984.

Hadidian. 1987. Field notes from Nature Center raccoon study—These are copies of the field notebooks from the raccoon study by CUE at the Rock Creek nature center from 1987 to 1991.

Hadidian. 1989. Field notes from Bingham raccoon study—These are copies of the field notebooks from the raccoon study by CUE at Bingham from 1989 to 1990.

Hadidian. 1991. Citizen coon—In 1982 a study of the behavior and ecology of urban raccoons *Procyon lotor* was started in the Rock Creek Park area of Washington D.C., but the study was soon expanded into a much more ambitious project when rabies reached Washington.

Haggerty, Onken, and Schneeberger. 1989. Summary of 1989 gypsy moth suppression activities—This is a description of gypsy moth management in the Capital Region in 1989, including maps of areas in the parks where *Bacillus thuringiensis* was sprayed. The Pinehurst area of Rock Creek was treated this year.

Harris. 1975. Distributional survey (Amphibia/Reptilia): Maryland and the District of Columbia—This survey lists the species of reptiles and amphibians occurring in MD and D.C. and provides a distributional map for each.

Hay. 1902. A list of the batrachians and reptiles of the District of Columbia and vicinity—This article describes species of reptiles and amphibians in D.C. and describes the location of the collection. Specific mention of Rock Creek is mentioned in reference to the black snake.

Hermann. 1941. A checklist of plants in the Washington-Baltimore area—This is a checklist of flora of the Washington-Baltimore area, updating the 1918 flora by Hitchcock and Stanley. Locations of plants are not given.

Hermann. 1946. A checklist of plants in the Washington-Baltimore area—This is a checklist of flora of the Washington-Baltimore area, updating the1918 flora by Hitchcock and Stanley. Locations of plants are not given.

Hitchcock and Standley. 1919. Flora of the District of Columbia and vicinity—This is a systematic key to flora of the Washington area. Locations of some important specimens are given.

Holm. 1896. Fourth list of additions to the flora of Washington, D.C.—This paper presents additions to Ward's Guide to the flora of Washington and Vicinity. Locations of specimens are given and some are from Rock Creek.

Horner and Sherman. 1935. Report on measures for elimination of pollution

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

of Rock Creek and its tributaries in Washington—This report is a comprehensive investigation of the amount and source of pollution throughout the Rock Creek watershed. It includes information on flow rates, flood histories, precipitation data, water quality, and historical pollution reports.

Inashima. 1985. Archeological survey report: an archeological investigation of thirty-one erosion control and bank stabilization sites along Rock Creek and its tributaries—In association with planning for erosion control and bank stabilization measures along Rock Creek, the sites proposed for construction were surveyed for archeological value and cultural resources.

International Science & Technology, Inc. 1989. Annual report: Rock Creek Park fisheries study—This is the report of the first year of a multi-year study of the fisheries resources of Rock Creek Park. Progress on the following 6 tasks is described: search the information base; develop information on the fish species in the park; analyze instream migration barriers; evaluate the physical habitat of the creek; survey recreational fishing; and develop management recommendation.

International Science & Technology, Inc. 1992. Final report: Rock Creek Park fisheries study: Year 2—This is the second annual report of a multi-year study of the fisheries resources of Rock Creek Park. Progress on the following 4 tasks is described: search the information base; develop information on the fish species in the park; evaluate the physical habitat of the creek; survey recreational fishing; and develop management recommendation.

International Science & Technology, Inc. 1989. Information data base deliverable: Rock Creek Park fisheries study—This is part of a multi-year study of the fisheries resources of Rock Creek Park. This part is the result of identifying, assembling, and evaluating present and historical information sources relevant to the aquatic resources of Rock Creek.

International Science & Technology, Inc. 1991. Annual report: Rock Creek Park fisheries study: Year 1 report—This is the first annual report of a multi-year study of the fisheries resources of Rock Creek Park. Progress on the following 6 tasks is described: search the information base; develop information on the fish species in the park; analyze instream migration barriers; evaluate the physical habitat of the creek; survey recreational fishing; and develop management recommendation.

International Science & Technology, Inc. 1991. Information data base deliverable: Rock Creek Park fisheries study—This document is the result of a study to assemble information on the aquatic resources, including water quality, habitat, and fish species of Rock Creek in Maryland and D.C. One section summarizes ongoing research and one lists fish species known to occur.

James, Simmons, and Strain. 1994. Water resources data, Maryland and Delaware, water year 1994: Volume 1 Surface-water data—This data contains one survey point within Rock Creek Park, called Rock Creek at Sherrill Drive. The 2 pages on this site contain discharge records by date and month as well as a chart of the flow over the year.

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

Johnson. 1989. 1988 rapid bioassessment of streams in the District of Columbia—During the summer of 1987 the District of Columbia sampled macroinvertebrates from 10 separate water bodies in the city to gather baseline data and to assess the current ecological status of streams. This study was intended to fill in the gaps.

Johnsson. 1962. A checklist of vascular plants of the National Capital Region—This checklist is the result of botanical collections made by the author in 1961 and 1962. Date and location of collection are given, including sites in Rock Creek Park, Pinehurst Branch, C&O Canal, and Catoctin Mountain Park.

Johnston. 1962. The geology of Washington, D.C., and vicinity—This article describes the geology of D.C., including geological maps.

Johnston. 1964. Geology and ground-water resources of Washington, D.C., and vicinity—This study established an updated geological map of D.C. and used it to study groundwater resources in the region as well. 1022 wells and springs were sampled and analyzed chemically and physically.

Jorling. 1969. An analysis of the vegetation of Rock Creek National Park, Washington, D.C.—This master's thesis study examined the plant communities of Rock Creek Park. Nineteen study plots were established for data collection on tree, shrub, and herbaceous layers. Soil samples were also examined for nutrient composition.

Kemball. 1990. *Ranunculus ficaria*: The northern floodplain: Rock Creek Park, and Glover-Archbold Park—These papers discuss the survey of these two parks for *Ranunculus ficaria* in the spring of 1990. Survey sites are described, and recommendations are made for managing this exotic plant.

Kerk. 1969. Observations on springs in the Washington, D.C. area—This lists by date a survey conducted on springs in the Rock Creek area looking for aquatic invertebrates.

Krakow. 1990. Historic resource study: Rock Creek and Potomac Parkway, George Washington Memorial Parkway, Suitland Parkway, Baltimore-Washington Parkway—This study focuses primarily on a survey of historic and existing cultural resources of these 4 areas before and after their establishment as a park. Information on historic and present day land uses is provided, however.

Lemov. 1985. Country walks. Travel Holiday.

Lewis. 1989. Rock Creek Park fish collection—These are fish specimens collected between 1989 and 1991 from Rock Creek.

Limno-Tech, Inc. 1994. Final Report: Urban Stream Study Phase III—This study continues an investigation into the physical and biological conditions in urban streams and their changes over time with the intent of developing a classification system for identifying protection needs.

Lipske. 1985. Night stalker (rabies study in Rock Creek Park, Washington, D.C.)—This brief article describes a study overseen by the Center for Urban Ecology of raccoons in Rock Creek Park. Raccoons were radio collared, tracked, and tested for rabies.

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

Loxley. 1991. Wildlife observations 1988-1991—This is a compiled list of all wildlife sightings in Rock Creek from 1988-1991.

Loxley. 1992. *Ranunculus ficaria* mapping—The results of a 1992 survey of the distribution of the exotic plant *Ranunculus ficaria* (lesser celandine) in Pinehurst Branch are diagrammed on a map.

Ludwig. 1985. Element occurrences in Maryland near D.C.'s Rock Creek Park—This is a printout from the MD Natural Heritage database of element occurrences of special plants and animals in the vicinity of Rock Creek Park.

Manski. 1984. Field notes from Piney Branch raccoon study—These are copies of the field notebooks from the raccoon study by CUE in Piney Branch from 1983 to 1984.

Maryland Department of Natural Resources. 1974. Maryland freshwater fisheries data--Rock Creek—This is data from an electrofishing survey of Rock Creek in September 1974. Each page is for a different segment of stream and describes the stream and sampling conditions and the fish found.

Maryland-National Capital Park and Planning Commission. 1979. Draft functional master plan for conservation and management in the Rock Creek Basin, Montgomery County, Maryland—This plan is the result of a study of the Rock Creek watershed in Maryland, giving policy recommendations based on stormwater and water quality data, floodplain analysis, and environmental inventories.

Maryland-National Capital Park And Planning Commission. 1985. A comprehensive amendment to the Upper Rock Creek Master Plan—This plan is the result of a study of the Rock Creek watershed in Maryland, giving policy recommendations based on stormwater and water quality data, floodplain analysis, and environmental inventories.

McAllister. 1985. An annotated checklist of the specimens from the Rock Creek Park jurisdiction deposited in the District of Columbia and vicinity collection of the US National Herbarium—This list is an annotated list of all the specimens of plants in the US National Herbarium which were collected from lands within the Rock Creek Park jurisdiction. The list is organized in multiple ways: by species, by location, and by collector.

McAtee. 1918. A sketch of the natural history of the District of Columbia together with an indexed edition of the US Geological Surveys 1917 map of Washington and vicinity—This is a comprehensive description of the natural history of the capital region, with specific sections on botany, insects, invertebrates, fish, reptiles and amphibians, birds, mammals, and biotic communities such as magnolia bogs.

McAtee. 1930. Seventh supplement to the flora of the District of Columbia and Vicinity—This paper presents additions to Ward's Guide to the flora of Washington and Vicinity. Locations of specimens are given and some are from Rock Creek.

McFarlane. 1975. Population investigations of the wood ducks (*Aix sponsa*) of Rock Creek Park—This senior thesis study was conducted

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

to investigate wood duck habitats and populations in Rock Creek Park and identify methods to increase the populations within the park. Twenty-six ducks were found during the study.

Medford. 1950. A distributional survey of the fishes of Rock Creek—This master's thesis presents results of a survey of the Rock Creek fish populations from 1947 to 1950. Fish were collected from the creek, water quality was measured, and habitat was analyzed.

National Capital Parks. 1944. A report treating of flood damage in the Rock Creek Valley, District of Columbia—This report describes an analysis of erosion and flood-caused damage to the Rock Creek valley conducted in the 1940s. The maps accompanying the report show the extent of high water in a 1933 flood; changes in development extent; location of flood damage.

National Park Service, Denver Service Center. 1989. Map A: Park system of the nation's capital and environs—Map shows National Park Service holdings in D.C. in green.

National Park Service, Denver Service Center. 1992. Draft environmental impact statement: Tennis stadium, Rock Creek Park, Washington, D.C.—Issues and concerns involved with activities at the Rock Creek Park Tennis Center are discussed within 7 alternatives for action. Impact to the effected natural environment is discussed, including vegetation, soils, wildlife, air quality, and water resources.

National Park Service, Water Resources Division. 1994. Baseline water quality data inventory and analysis: Rock Creek Park—This report was designed to inventory existing water quality data for the park and establish a water quality database for Rock Creek. Already existing data sources were inventoried and compiled, descriptive statistics were calculated on these data.

Newberry. 1974. Crystalline rocks in Rock Creek Park—These maps show the rock type distributions in Rock Creek Park, the "structural planes and axes," and the "joint orientations."

Nichols. 1960. Wintering bats in Glover-Archbold Park—This article describes bats observed in Glover-Archbold park in the winter of 1960.

Norden. 1994. Rare species survey of four springs in Rock Creek Park, Washington, D.C.—This study looked at four springs in Rock Creek Park, sampling the fauna of the spring habitats and measuring water quality and quantity.

Northeast Team, Denver Service Center. 1985. Adjacent land use study: Rock Creek Park, Washington, D.C.—This study was conducted in 1985 of land uses around Rock Creek park for the General Management Plan. One of the maps is of canopy vegetation in and around the park.

O'Brien and Gere. 1983. Appendix B: Macroinvertebrate survey of Rock Creek, Anacostia, and Potomac Rivers—This appendix to a sewer study details results of a survey of macroinvertebrates in Rock Creek and Anacostia and Potomac rivers. Species compositions are given by area.

O'Brien and Gere. 1986. Rock Creek Park outfall survey—This study was an investigation of all outfall sources falling into Rock Creek, Foundry Branch, and Battery Kemble Run during

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

dry-weather. Outfalls which were found flowing were further evaluated for chemical composition and water quality.

O'Connor. 1980. The city and its creek: implications for the 1980s from a half century of hydro-data.

O'Connor. 1982. Geological excursion through the Rock Creek Valley, NW Washington—This guidebook takes the reader on a trip around Rock Creek park area, describing the geology at each stop. Maps of D.C. geology are included.

O'Connor. 1986. Landforms and soil erosion in the Nation's Capital. UDC Geoscience Guidebook: 5th annual Erosion and Sediment Control Program administrators conference.

O'Connor. 1986. Urban geology: satellite parkland for the NPS Rock Creek Division—This guidebook takes the reader on a trip around Rock Creek park area, describing the geology at each stop. Maps of D.C. geology are included.

O'Connor. 1989. Exploration of Rock Creek Park—North—This guidebook takes the reader on a trip around Rock Creek park area, describing the geology at each stop. Maps of D.C. geology are included.

O'Connor. 1989. Geological exploration of the southern Rock Creek Valley in D.C.—This guidebook takes the reader on a trip around the southern Rock Creek park area, describing the geology at each stop. Maps of D.C. geology are included.

Office of Resource Management, Rock Creek Park. 1983. Rock Creek Park natural history field observation reports and breeding bird census for 1982—This document is a list of all wildlife sightings made in the park in 1982. The list is separated by mammals, reptiles and amphibians, plants, birds, and other (fish, butterflies, mammal sign).

Olmstead Brothers. 1918. Rock Creek Park: a report—This report describes the value of Rock Creek Park, describing some of the natural features and landscapes, the areas of the park, and some of the future construction plans.

Onken. 1988. 1988 Gypsy moth suppression project report—This is a gypsy moth management report for Washington, D.C. in 1988, describing spray action location and monitoring.

O'Shaughnessy. 1969. Rock Creek Park--trees and shrubs—This map is the result of a park ranger's survey of the tree, shrub, and vine species of the park. Locations of each species are marked, and unusual occurrences are shown in red. Spring locations are also marked.

Partridge. 1991. Ecological competition: ant interactions—Interspecific competition among ant species in three habitats was studied in Glover-Archbold Park for a senior thesis at Georgetown University.

Pease. 1982. Mammals of Rock Creek Park—These notes are the result of a search of the literature and the Rock Creek wildlife observation cards to compile a list of possible, and confirmed mammals occurring in the park.

Pendleton. 1994. Factors controlling local temperature variation in an urban heat island—This master's thesis examined

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

the question of whether local air temperatures in an urban setting were related to tree density. Study sites included Rock Creek Park and Glover-Archbold Park. Maximum temperatures were reduced by forest cover.

Petrides. 1943. Mammals of the National Capital Parks and the District of Columbia Region—This article describes all the mammals reported to occur in parks in the National Capital region. Descriptions of natural history and some occurrences are given for each animal in a table.

Pittman. 1990. Report of lichen species determined at Rock Creek Park—This memo identifies specimens of lichens and bryophytes collected from Rock Creek in 1989.

Putz. 1995. Relay ascension of big trees by vines in Rock Creek Park, District of Columbia—This is a biological note describing observations of vines found on trees in Rock Creek Park, the different species, and their methods of climbing.

Quinn. 1987. Herp study-summer 1987—This map shows the results of a herp survey done in the summer of 1987. Locations of herps observed are marked on the map.

Reed, Donnald, Widatalla, and Wilson. 1953. The ferns and fern-allies of Maryland and Delaware including District of Columbia—This key to identification of ferns also describes the history of plant studies in the D.C. area and the general distribution of ferns in the three areas. The key includes a description and range map of each species.

Reid. 1987. *Attheyella* (Mrazekiella) *spinipes*, a new harpacticoid copepod (Crustacea) from Rock Creek Regional Park, Maryland—A new species of crustacean was discovered in a spring in Rock Creek Park by William Yeaman and Stephen Syphax. The species is described here.

Reid. 1996. Checklist of the copepoda (Crustacea) of the District of Columbia—This list includes a list of copepod species identified from collections of detritus from National Capital Parks and Rock Creek Park. Each species is listed by family and species and collection site, date, and collector.

Reiff. 1980. Water quality of streams in Montgomery County, Maryland: January-December 1989—This report presents water quality data on the streams of Montgomery County collected in the year 1989. Some sampling points are located on Rock Creek and are on the border of D.C. Data includes water chemistry, turbidity, pollution levels, and temperature.

Richards. 1934. A list of the mollusks of the District of Columbia and vicinity—This article contains a list of mollusk species occurring in D.C. in 1934.

Richards. 1934. A list of the mollusks of the District of Columbia and vicinity—This article contains a list of mollusk species known to occur in the waters of D.C. Specific locations are not given.

Robbins. 1979. Effect of forest fragmentation on bird populations—This paper presents the results and trends of breeding bird censuses conducted in New Jersey, Maryland, and the District of Columbia, including Rock Creek Park and Glover-

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

Archbold Park. The data is examined to document the effect of forest fragmentation.

Roberts, Sherald, and Stidham. 1994. Evaluation of eight species of Cornus for resistance to dogwood anthracnose—A study on the survival of different species of dogwoods was conducted in Rock Creek Park. Trees were placed under a naturally infected canopy. The survival of the different species has been monitored. Only the *Cornus florida* was affected by the fungus.

Robertson. 1977. First annual Rock Creek Park herp hunt - April 23, 1977—This is a brief report listing the results of a 3 hour search for amphibians and reptiles along Pinehurst Branch.

Rock Creek Park Staff. 1983. Gypsy moth pre-1988 data—These files contain various counts of gypsy moth infestations in D.C. Methods included male moth trapping, burlap wrap trapping, and egg mass counts.

Rock Creek Park Staff. 1988. Gypsy moth egg mass survey data—Data from annual surveys of the extent of gypsy moth egg masses in the Rock Creek Park.

Rock Creek Park Staff. 1988. Gypsy moth survey data figures—Data from annual surveys of the extent of gypsy moth egg masses and male moths have been plotted on various graphs.

Rock Creek Park Staff. 1989. Gypsy moth 1989, 1990 data—These files contain various counts of gypsy moth infestations in D.C. Methods included male moth trapping, burlap wrap trapping, and egg mass counts.

Rock Creek Park Staff. 1991. Gypsy moth egg mass survey data—Data from annual surveys of the extent of gypsy moth egg masses in the Rock Creek Park.

Rock Creek Park. 1975. Resource Management—The section in the annual report entitled Resource Management describes the activities of the resource management staff each year.

Rock Creek Park. 1991. Wildfire management plan for Rock Creek Park, Washington, D.C.—This is the wildfire management plan for the park. All wildfires are to be suppressed and prevented.

Schlee. 1957. Fluvial gravel fabric. Journal of Sedimentary Petrology.

Schneeberger and Scott. 1988. Summary of 1988 gypsy moth suppression activities—This is a description of gypsy moth management in the Capital Region in 1988, including maps of areas in the parks where *Bacillus thuringiensis* was sprayed. Rock Creek Park was treated this year.

Schneeberger. 1987. Summary of 1987 gypsy moth suppression activities and project review—This is a description of gypsy moth management in the Capital Region in 1987, including maps of areas in the parks where *Bacillus thuringiensis* was sprayed. The Pinehurst area of Rock Creek was treated this year.

Schneeberger. 1988. 1988 Gypsy moth suppression project report—This is a gypsy moth management report for Washington D.C. in 1988, describing spray action location and monitoring.

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

Seiger. 1993. The ecology and control of *Reynoutria japonica* (*Polygonum cuspidatum*)—This PhD dissertation study examined the status of Japanese knotweed in Rock Creek Park, predicted the potential for further invasion, and tested methods in a greenhouse for controlling the existing populations.

Shaw. 1977. Periods of flowering of common flowers, trees, and shrubs of Rock Creek Park—This is a list of common flowers, trees, and shrubs of Rock Creek Park and the approximate dates that they flower.

Sherald. 1989. Dogwood anthracnose—This memo describes a July 1989 survey for dogwood anthracnose in Rock Creek Park. Five areas were found with the disease, the first occurrence in the District.

Shetler and Wiser. 1985. An annotated checklist of the specimens from the Rock Creek Park jurisdiction deposited in the District of Columbia and vicinity collection of the US National Herbarium—This list is an annotated list of all the specimens of plants in the US National Herbarium which were collected from lands within the Rock Creek Park jurisdiction. The list is organized in multiple ways: by species, by location, and by collector.

Shetler and Wiser. 1987. First flowering dates for spring-blooming plants of the Washington, D.C. area for the years 1970 to 1983—A chart of the first flowering dates is presented for blooming plants in the D.C. area from observations in the Northwest D.C. area. Heavy observations were recorded in the C&O Canal and Rock Creek areas.

Shosteck. 1975. Fungi in Rock Creek Park—This is a list of the scientific and common names of fungi found in Rock Creek Park.

Shosteck. 1976. Field guide to Rock Creek Park—This report details information about all aspects of Rock Creek: geology, mammals, birds, fish, amphibians, insects, trees, flowers, ferns, fungi, lichens, and maps of the park.

Shosteck. 1976. Periods of flowering of common flowers, trees, and shrubs of Rock Creek Park, Washington, D.C.—This is a guide for visitors of common flowers, trees, and shrubs of Rock Creek Park and the approximate dates that they flower.

Shosteck. 1977. Rock Creek watershed habitat survey and inventory of fauna and flora, Montgomery County, Maryland—This report describes the ecology and natural history of the Rock Creek watershed in Maryland. Included are inventories of flora and fauna complete with species lists.

Sidwell Friends School, Environmental Science Class. 1996. Rock Creek stream study: a water quality assessment—Students at Sidwell Friends School, under direction of the teacher Paula Wang, have monitored water quality in Rock Creek since January 1995. This report summarizes the first year's data and presents data charts and tables of monthly samples of chemical analysis and macroinvertebrate sampling.

Sidwell Friends School, Environmental Science Class. 1997. Rock Creek stream study: a water quality assessment—Students at Sidwell Friends School, under direction of the teacher Paula Wang, have monitored water quality

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

in Rock Creek since January 1995. This packet contains the data from January 1996 through January 1997and presents data charts.

Smith. 1976. Soil survey of District of Columbia—This is the report of the soil survey for D.C., describing the soil types which are then mapped on the map sheets at the back. Maps corresponding to park areas can be selected using the index to map sheets.

Spangler. 1976. Additions to 1975 Rock Creek fish survey—This list details fish species caught in Rock Creek Park in 1976 on a rod.

Stanton. 1972. Bacteriological and chemical study of the Rock Creek watershed—This study was conducted by the University of Maryland and Montgomery College to conduct an intense bacteriological investigation of the Rock Creek watershed. Chemical and bacteria analysis was examined throughout the watershed.

Stidham. 1993. Dogwood anthracnose research in Rock Creek Park: Interim report 1—This is a progress report for a long-term monitoring study of dogwood anthracnose in Rock Creek Park. Trees were placed under a naturally infected canopy. Half of the trees were treated with a fungicide, and the survival of the groups has been monitored.

Stose. 1919. Travertine from Rock Creek Park, District of Columbia—This biological note describes the location of a travertine deposit at the mouth of a spring in Rock Creek Park. It may have originated from a reservoir feeding the spring.

Sullivan. 1957. Rock Creek Park observation—This preliminary report on the Rock Creek Ecological study lists plant and animal observations made as a part of an ecological survey of the park.

Syphax. 1986. Evaluation of manual grubbing, heat, and herbicide treatments as methods of managing *ampelopsis*.

Terborgh. 1992. Why American songbirds are vanishing—This article discusses the trend of decreasing songbirds in America. Breeding bird census data from Rock Creek Park is cited and included in a chart by species and year.

Thatcher. 1948. Breeding-bird population studies—This article reports the results of a breeding bird survey conducted in Rock Creek Park in 1947. The area is compared to Cabin John Island.

Thatcher. 1948. The Wood Thrush—This article reports the results of a winter bird survey conducted in Rock Creek Park in 1948. The area is compared to Cabin John Island.

The American University. 1977. Forest association maps—These overlays go with the park base map (aerial photos) and are a product of the American University vegetation cover type study. Twelve different forest associations were mapped, including a disturbance category.

The American University. 1977. Rock Creek Park photo base map—These are the park base map (aerial photos) and are accompanied by various Mylar overlays which depict water and forest resources.

The Rock Creek Study Project. 1972. Bacteriological and chemical study of the Rock Creek watershed—This study

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

was conducted by the University of Maryland and Montgomery College to conduct an intense bacteriological investigation of the Rock Creek watershed. Chemical and bacteria analysis was examined throughout the watershed.

Thomas. 1969. Survey of areas for significant natural values—This survey was designed to develop methods for identifying significant natural features and presents preliminary results of its application in describing singular natural features of National Capital Parks. Features of all the capital parks are listed.

Thomas. 1972. Determination of new species of trees in Rock Creek Park—This note describes the occurrence of three tree species unusual to the park.

Thomas. 1997. Changes in dominance on the Rock Creek Park flood plain, District of Columbia—This document is a scientific note describing observations on the Rock Creek floodplain vegetation and suggesting a change in the dominance structure of the trees over time.

Thompson. 1976. Flood-plain delineation for Rock Creek basin, Washington, D.C.—This study determined 10, 25, 50, and 100-year flood profiles for the Rock Creek system in D.C. Hydraulic data from the USGS was used and is included in an appendix.

Thompson. 1995. Audubon Naturalist Society water quality monitoring program—These are data sheets from a water quality monitoring program by the Audubon Naturalist Society on Pinehurst Branch since 1995 and on Rock Creek since 1997. Habitat and water quality are assessed, and macroinvertebrates are sampled in 3 sampling periods.

Tufty et al. 1994. Rock Creek watershed: a compendium of articles—Articles from park resource personnel, local scientists, and activists address topics such as plants, fish, butterflies, birds, geology, pollution control, and preservation issues.

US Army Corps of Engineers. 1989. Anadromous fish passage study, Rock Creek, District of Columbia—This report examines passage problems for migratory fish in Rock Creek and proposes solutions for getting the fish over the barriers. Fish migrating in the creek include alewife, blueback herring, and white perch.

USGS. 1983. Topographic maps of Rock Creek—These are various topographical quadrangle maps of the area of Rock Creek Park.

Van Huizen. 1978. Fishing survey of Rock Creek Park—This study was to determine human fishing pressures and types of fishing in the park. Fishermen were interviewed in the spring of 1978 and were asked about their reasons for fishing, type and size of fish caught, and equipment used.

Van Huizen. 1978. Second annual Rock Creek Park herp hunt - April 29, 1978—This is a brief report listing the results of a 3 hour search for amphibians and reptiles along Pinehurst Branch.

Venables. 1990. Preliminary assessment of the susceptibilities of non-target Lepidopteron species to *Bacillus thuringiensis* (Bt) and dimilin used for gypsy moth suppression—This study was designed to estimate the impact of gypsy moth suppression programs

Table B.5. Listing of known literature pertaining to Rock Creek Park, Washington D.C., based on a query of NPS NatureBib made on November 26, 2008. Brief abstract information is provided. Citations not having a date or author are not shown. (continued)

on non-target Lepidopterons using species observed in Catoctin Mountain Park, National Capital Parks-East, Prince William Forest Park, and Rock Creek Park.

Water Resources Management Division, District of Columbia. 1992. The District of Columbia water quality assessment—This report provides a water quality assessment of the District's water resources, based on water quality monitoring data which is also summarized here. The appendices have data broken down by water body, including streams administered by Rock Creek Park.

Wheelock. 1993. Cultural landscape report: Pierce-Klingle Mansion, Rock Creek Park—The purpose of this report was to trace the physical history of the site of the Pierce-Klingle mansion, document and compile significant landscape characteristics, and recommend preservation of the landscapes.

Wilsnack. 1991. Ecological competition: ant interactions (Hymenoptera: Formicidae)—Interspecific competition among ant species in three habitats was studied in Glover-Archbold Park for a senior thesis at Georgetown University.

Yeaman. 1986. Sewer line crossings notes—These notes describe observations of sewer line crossings on Rock Creek and its tributaries and mention threats of pollution, leaks, or erosion.

Zug. 1975. Possible extirpated species—This is a list compiled from Smithsonian records of possible extirpated species of reptiles and amphibians and the last known record of their presence, some of which were in Rock Creek Park.

Table B.6. List of acronyms.

Acronym	Description
AL	Appalachian Laboratory (UMCES)
ANC	Acid Neutralizing Capacity
ANTI	Antietam National Battlefield (NPS-NCRN)
AWQC	Ambient Water Quality Criterion
BIBI	Benthic Index of Biotic Integrity
BSS	Biological Stream Survey
CASTnet	Clean Air Status and Trends Network
CATO	Catoctin Mountain Park (NPS-NCRN)
CHOH	Chesapeake & Ohio Canal National Historical Park (NPS-NCRN)
CUE	Center for Urban Ecology (NPS-NCRN)
D.C.	District of Columbia
DC DOE	District of Columbia Department of the Environment
DCMR	District of Columbia Municipal Regulations
DO	Dissolved Oxygen
FIBI	Fish Index of Biotic Integrity
FIDS	Forest Interior Dwelling Species of birds
FRS	Freshwater Recreational Standards
GWMP	George Washington Memorial Parkway
HAFE	Harpers Ferry National Historical Park (NPS-NCRN)
I&M	Inventory & Monitoring Program (NPS)
IAN	Integration & Application Network (UMCES)
IBI	Index of Biotic Integrity
ISA	Impervious Surface Area
IUCN	International Union for Conservation of Nature
MANA	Manassas National Battlefield Park (NPS-NCRN)
MBSS	Maryland Biological Stream Survey
MD DNR	Maryland Department of Natural Resources
MDN	Mercury Deposition Network
MONO	Monocacy National Battlefield (NPS-NCRN)
NAAQS	National Ambient Air Quality Standards
NACE	National Capital Parks-East (NPS-NCRN)
NADP	National Atmospheric Deposition Program
NPS	National Park Service
NPS ARD	NPS Air Resources Division
NCRN	National Capital Region Network
NSDWS	National Secondary Drinking Water Standards
PAO	Proportion (%) of Area Occupied
PHI	Physical Habitat Index

Table B.6. List of acronyms. (continued)

Acronym	Description
PRWI	Prince William Forest Park (NPS-NCRN)
RESAC	Regional Earth Science Applications Center
ROCR	Rock Creek Park (NPS-NCRN)
RTE	Rare, Threatened, and Endangered
SMCL	Secondary Maximum Contaminant Level
TP	Total Phosphorus
UMCES	University of Maryland Center for Environmental Science
U.S. EPA	U.S. Environmental Protection Agency
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WOTR	Wolf Trap National Park for the Performing Arts (NPS-NCRN)

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National Park Service
U.S. Department of the Interior

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