Abstract

Title of Thesis: DEVELOPMENT OF A RECOMMENDED ANALYTICAL FRAMEWORK FOR ENVIRONMENTAL REPORT CARDS: AN EXAMPLE FROM ROCK CREEK PARK, WASHINGTON DC AND ITS WATERSHED

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Integrated environmental report cards help to focus management efforts and track the effectiveness of management initiatives over time. This study used NPS I&M Program data to compare alternative methods for the assessment of ecological status and trends for Rock Creek Park. The recommended analytical framework is a potential model for assessing other NPS units or protected areas.

The condition of Rock Creek Park is highly dependent upon the surrounding land. Synoptic nutrient sampling – nitrate, phosphate, dissolved oxygen, and salinity – was conducted throughout the Rock Creek watershed. The results were combined to create a water quality index. It was determined that the Urban Stream Syndrome, or the interaction of many anthropogenic forces, was causing decreased water quality throughout the watershed. The results of this study suggest that managers work across political boundaries within the watershed and work to decrease the connectedness of urban surfaces and Rock Creek.

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by

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Chapter 1: Introduction

It was like lying in a great solemn cathedral,
far vaster and more beautiful
than any built by the hand of man.
- Theodore Roosevelt describing Yosemite National Park

National Park Service History

American historian Wallace Stegner described the National Parks as "the best idea we ever had. Absolutely American, absolutely democratic, they reflect us at our best."

The National Park Service was created by the 1916 National Park Service Organic Act. It is the lead federal organization for the preservation of the United States cultural heritage (NPS 2006b). The purpose of the National Park Service, as laid out in the Organic Act, 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." This mission was best paraphrased by President Theodore Roosevelt when speaking of the flagship western parks: "our people should see to it that they are preserved for their children and their children's children forever, with their majestic beauty all unmarred."

In addition to creating the National Park Service, the Organic Act directed the Secretary of the Interior to "investigate, study, and continually monitor the welfare of areas whose resources exhibit qualities of national significance." In the National Parks Omnibus Management Act of 1998, Congress directed the NPS to "undertake a program of inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources." As a result of these directives, the Inventory and Monitoring (I&M) Program was developed to track overall condition of park resources (Fancy et al. 2009). These monitoring data are available for park managers and scientists to improve resource management decisions.

As part of the national I&M Program, the 270 national park units deemed to have significant natural resources were divided into 32 ecoregional networks. This thesis focuses on the National Capital Region Network (NCRN) of the I&M Program. The majority of the 11 NCRN parks are found in the Potomac River watershed in Maryland, Virginia, West Virginia, and Washington DC. When designing the monitoring program for the Region, the NCRN developed conceptual ecological models which provide a simplified view of the ecosystem structure and function (Lookingbill et al. 2007). These conceptual models provide an overview of the scientific understanding and can be communicated to multiple audiences. From these conceptual models, specific Network monitoring protocols were developed to outline the sampling design and data collection steps required for each metric (e.g. Bailey et al. 2007; Bates 2006; Hilderbrand et al. 2007; Schmidt et al. 2006).

Rock Creek Park History

Rock Creek Park was established in 1890 as one of the first federal parks. At that time, it was located on the edge of the growing Washington DC and was created to preserve and maintain a natural forest and stream ecosystem. The park also contains many historic features including Peirce Mill, the only remaining 19th century mill on the banks of the creek. The park managers therefore must protect both the natural and cultural resources of the park from the ravages of the urban and suburban development surrounding the park (Mackintosh 1985). Small urban parks, such as Rock Creek Park, are important biological refugia, migration stops, and dispersal corridors. Managing these important resources requires broad understanding of numerous stressors (Lookingbill et al. 2007).

NCRN and IAN Partnership

To communicate the results of the I&M Program, the NCRN partnered with the Integration and Application Network (IAN). The partnership began in 2005 with a workshop between I&M staff and park resource managers, which was facilitated by IAN. The products of this workshop included a newsletter (IAN 2005), a booklet (NPS 2006a), and a poster series (NPS 2006b-d, f-n). These communication products were designed to help the I&M Program build consensus with the resource managers as well as interface with the public. Additional communication products have been designed to interface with the scientific community including a scientific paper (Dennison et al. 2007) and associated poster (Dennison et al. 2006). A second scientific paper is in preparation to expand upon the habitat framework for integrated assessment (Carruthers et al. In prep).

Thesis Purpose

Report cards have become a part of the adaptive management process (Boesch 2000). There is no universally accepted method to calculate a report card, but there are numerous examples of report cards. Some report cards use mathematical relationships to calculate threshold attainment (Oregon Water Quality Index, Cude 2001), others use a relative ranking of regions (Maryland Coastal Bays, Wazniak et al. 2004), and still others use scientifically available information to develop thresholds (Chesapeake Bay Habitat Health Index, Williams et al. 2009). Some report cards have hundreds of metrics (State of the Parks, NPCA 2003; Chesapeake Bay Report Card, CBP 2008), whereas others only use a few (Moreton Bay Ecosystem Health Monitoring Program, Pantus & Dennison 2005). Some report cards are only calculated once (State of the Parks, Maryland Coastal Bays) while others report on an annual basis (Chesapeake Bay Habitat Health Index, Moreton Bay Ecosystem Health Monitoring

Program). Additionally, some are calculated on a 5- or 10-year cycle (Heinz Center State of the Nation's Ecosystems, Heinz Center 2002; National Estuarine Eutrophication Assessment, Bricker et al. 2003). All of these report cards create an interface between the scientific and management communities (Dauvin et al. 2008).

This thesis describes an analytical framework for integrated environmental report cards. Environmental report cards can assist in focusing management efforts as well as tracking the effectiveness of management initiatives over time. This study used the I&M Program data to determine a recommended method for assessing ecological status and trends for Rock Creek Park. The recommended analytical framework is a potential model for an integrated assessment of the entire NCRN as well as other NPS units and other protected areas.

A Natural Resources Condition Assessment was conducted in concert with this thesis. The Natural Resources Condition Assessment will help the NPS better understand and evaluate the existing data that are available concerning the state of knowledge and condition of natural resources within park units. This information can be used to guide Department of the Interior land heath goal reporting as prescribed by the Government Performance and Results Act of 1993. Both the Natural Resources Condition Assessment and this thesis used similar data and threshold information. However, the Condition Assessment can be described as an inventory of available data and some minor condition information. The work developed through this thesis was a process-based approach that expanded upon the scope of the Condition Assessment in both conceptual and geographic information.

Thesis Summary

The overall purpose of this thesis was to determine how an analytical framework could be used to calculate report cards at a park and watershed scale.

The second chapter of this thesis describes the monitoring data collected by the I&M Program and determines a recommended report card for Rock Creek Park. The questions asked during the analysis include:

- How many metrics should be included in the report card?
- How should metrics be combined to calculate the report card?
- How should metrics be grouped?
- How should threshold attainment be calculated?

The results of the analysis were used to calculate a recommended report card for Rock Creek Park.

The third chapter of this thesis brings context to the report card developed in the second chapter. The main body of Rock Creek Park is located in the lower portion of the Rock Creek watershed. Therefore, the condition of the Park is dependent upon the condition of the surrounding watershed. Further data scoping was necessary to discover additional monitoring data within the entire watershed. The results of this chapter are intended to be synoptic and should not be considered a final report card for the Rock Creek watershed.

Chapter 2: Developing the recommended analytical framework for an assessment of Rock Creek Park

Abstract

Integrated environmental report cards can assist in focusing management efforts as well as tracking the effectiveness of management initiatives over time. This study used the National Park Service Inventory & Monitoring Program data for the National Capital Region Network to determine the recommended method for assessing ecological status and trends for Rock Creek Park. Assessment methods tested include the required number of metrics, the report card calculation method, the inherent report card weighting due to metric groupings, and the type of thresholding. The full suite of monitoring data was used to determine a recommended analytical framework for future assessments. The recommended analytical framework is a potential model for an integrated assessment of the entire National Capital Region Network as well as other National Park Service units and other protected areas.

Introduction

Report cards have become a part of the adaptive management process (Boesch 2000). There is no universally adopted method to calculate a report card, but there are numerous examples of report cards. Some report cards use mathematical relationships to calculate threshold attainment (Oregon Water Quality Index, Cude 2001), others use a relative ranking of regions (Maryland Coastal Bays, Wazniak et al. 2004), and still others use scientifically available information to develop thresholds (Chesapeake Bay Habitat Health Index, Williams et al. 2009). Some report cards have hundreds of metrics (State of the Parks, NPCA 2003; Chesapeake Bay Report Card, CBP 2008), whereas others only use a few (Moreton Bay Ecosystem Health Monitoring Program, Pantus & Dennison 2005). Some report cards are only calculated once (State of the Parks, Maryland Coastal Bays) while others report on an annual basis (Chesapeake Bay Habitat Health Index, Moreton Bay Ecosystem Health Monitoring Program). Additionally, some are calculated on a 5- or 10-year cycle (Heinz Center State of the Nation's Ecosystems, Heinz Center 2002; National Estuarine Eutrophication Assessment, Bricker et al. 2003). All of these report cards create an interface between the scientific and management communities (Dauvin et al. 2008).

I&M Program vital sign framework

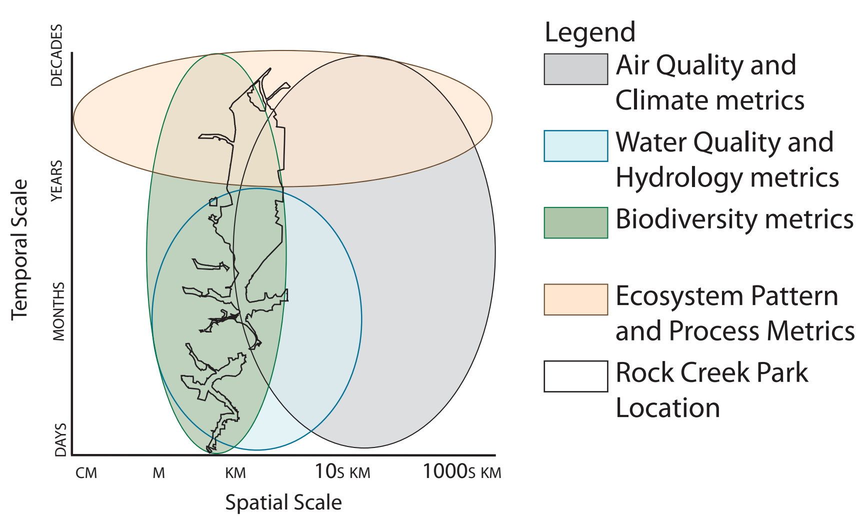
The framework chosen for this assessment was developed by the NPS I&M Program (Fancy et al. 2009). It is based on work by numerous scientists and has been adopted as a part of the Natural Resource Monitoring Partnership (NRMP 2007). The framework is a tiered structure with six broad Level I categories. These categories are further broken down into Level II categories. Level III categories are more specific and are the level at which vital signs are selected.

Vital signs are selected through a process that ensures that the monitoring information meets important data needs and provide scientifically credible data (Fancy et al. 2009). The I&M networks began by defining clear monitoring objectives and goals. These goals provided important focus for the subsequent steps of the process (Fancy et al. 2009). The networks then summarized existing information and built conceptual models. These models provided important linkages between the chosen metrics and the resources they represent (Lookingbill et al. 2007, Noss 1990). Metrics were then selected to represent the condition of park resources, the park stressors or effects of stressors, and the resources that have important human value (Fancy et al. 2009, Noss 1990). The NCRN selected a total of 21 vital signs to be measured throughout the network (NPS 2005a).

Spatial and temporal scales of monitoring data

The data collected by the NCRN as part of the I&M Program are measured at different spatial and temporal scales (Figure 2.1). The Air Quality and Climate metrics are measured on very short (minutes) to long (years to decades) time scales and over great spatial scales (regionally). The Water Quality and Hydrology metrics are measured

Figure 2.1. Varying spatial and temporal scales of metrics measured at Rock Creek Park.



monthly or annually over moderate spatial scales (park-wide). The Biodiversity metrics are measured over moderate (annually) to long (years to decades) time scales. The Ecosystem Pattern and Process metrics are measured over moderate to large spatial scales and over long time scales. Rock Creek Park is the scale of measurement for many of the metrics. The main section of the Park is 7 km^2 and is protected in perpetuity. Therefore, these disparate metrics measured over varying spatial and temporal scales can all be summarized at the scale of the park.

The aim of this chapter was to determine a method for assessing the physical and biological resources of a National Park. This method was developed by testing the number of metrics needed, the report card framework, the integration calculation and the way to calculate threshold attainment.

Using thresholds in environmental assessments

Each of the vital signs selected by the NCRN is associated with one or more management objectives. These objectives are laid out in the monitoring protocols for the network. To use the I&M data to determine whether management objectives are met (Mehaffey et al. 2005), it was necessary to evaluate the data relative to pre-determined threshold values or assessment points (Carter & Bennetts 2007). These threshold values were important to the vital signs monitoring program as they provided a means for measuring ecological condition in relation to management performance goals (Huggett 2005). The ecological conditions that can be evaluated using thresholds range from managed artificial systems to a pristine ecosystem (Harwell 1997, Harwell 1998).

Thresholds can be considered environmental or management goals, research hypotheses, or indicators of trends (Huggett 2005, Radford et al. 2005, Biggs 2004). They can indicate dramatic nonlinear change, critical loads (amount of pollution with a system can safely absorb before function changes), or extrinsic factor thresholds (change in variable at large scale alters drivers and responses at a small scale) (Groffman 2006). Few of the thresholds described in this paper indicated nonlinear change. Most are critical loads or extrinsic factors. It is important to note that threshold values do not have to be permanent. If management goals change or new research is published, the threshold can be modified accordingly (Jensen et al. 2000; Pantus & Dennison 2005). These flexible environmental thresholds are a key part of the adaptive management cycle. Adaptive management requires approaching management as an experiment that relies on a monitoring program to inform future management decisions (Boesch 2000).

The goal for threshold development was to use ecologically relevant thresholds that could be found in the scientific literature. Ecological thresholds suggested a location at which a feedback switch occurs, which could lead to a degraded ecosystem (Briske et al. 2006). However, when threshold values are not found in scientific journals, values from legislation or expert opinion are often considered (Bertollo 1998; Shear et al. 2003; Pantus & Dennison 2005). Thus, thresholds are developed in accordance with science as well as social and management goals (Gentile & Harwell 2001).

Optimizing the report card

This paper describes the monitoring data collected by the I&M Program and determines a recommended report card for Rock Creek Park. The questions asked during the analysis include:

- How many metrics should be included in the report card?
- How should metrics be combined to calculate the report card?
- How should metrics be grouped?
- How should threshold attainment be calculated?

The hypotheses for this chapter were:

- When creating a report card, fewer metrics can provide comparable information as many metrics.
- A summation method is the appropriate calculation method for a report card.
- Metrics in unbalanced groupings have a larger effect on the final score of the report card than metrics in balanced groupings.
- Linear threshold attainment calculations provide managers with more information regarding park condition than binary thresholds.

The results of the analysis were used to calculate a report card for Rock Creek Park.

Methods

Study Area: Rock Creek Park

The Rock Creek Park Fed Fee boundary was chosen as the unit for this assessment. The Fed Fee boundary refers to the parks legislative boundary, which includes all land that the park owns. National Park Service (NPS) jurisdiction limitations generally prohibit the park from managing resources outside of park boundaries. Therefore, knowing the status of the resources within the park boundary is important for park management.

Long-term monitoring of Rock Creek Park by the I&M Program began in 2005 (Fancy et al. 2009). The I&M Program is a part of the NPS and therefore is constrained by the same jurisdictional issues as the park. All monitoring is conducted within the Fed Fee boundary of Rock Creek Park (pers comm. G. Sanders). The park resource management staff is considered the primary audience and users of the monitoring results (Fancy et al. 2009).

Metrics and Thresholds

The framework for the I&M Program monitoring data begins with four broad vital sign categories (Level II categories) (Table 2.1). These categories were broken down into multiple vital signs (2-7 vital signs per category). The vital signs were further broken

Table 2.1. The framework developed by NPS I&M and used for this assessment. Shading indicates vital signs.

Level I Category	Level II Category	Level III Category	
	Category	Vital Sign	Metric
Air and Climate	Air Quality and Climate	Ozone	Ozone Concentration
		Wet Deposition	Annual Wet Nitrate Deposition
			Annual Wet Sulfate Deposition
		Visibility and Particulate Matter	Annual Fine Particulate Matter Concentration
		Mercury Deposition	Mercury Deposition
Water	Water Quality and Hydrology	Water Chemistry	Water pH
			Dissolved Oxygen Concentration
			Specific Conductance
			Water Temperature
			Acid Neutralizing Capacity
			Salinity
		Nutrient Dynamics	Nitrate Concentration
			Ammonium Concentration
			Total Phosphorus Concentration
		Aquatic Macroinvertebrates	Benthic Index of Biotic Integrity
		Physical Habitat Index	Physical Habitat Index
Biological Integrity	Biodiversity	Invasive/Exotic Plants	Percent Cover of Herbaceous Species and Woody Vines
			Density of Target Exotic Shrubs and Trees
		Forest Insect Pests	Presence of Pest Species
		Forest Vegetation	Seedling Regeneration
		Fishes	Fish Index of Biotic Integrity
		Amphibians	Proportion of Area Occupied by Adult Amphibians
		Landbirds	Bird Species Composition
		White-Tailed Deer	White-Tailed Deer Density
Landscapes	Ecosystem Pattern and Process	Land Cover/Land Use	Interior Percent Area of Dominant Land Cover (Forest)
			Exterior Percent Area of Dominant Land Cover (Forest)
			Interior Critical Dispersal Threshold Distance (D_{crit}) "Connectivity"
			Exterior Critical Dispersal Threshold Distance (D_{crit}) "Connectivity"
		Landscape Condition	Interior Percent Cover in Impervious Surface
			Exterior Percent Cover in Impervious Surface

down into specific vital sign metrics (1-6 metrics per vital sign). Metrics were the items for which data were available and thresholds were developed.

This framework includes only 17 of the 21 vital signs that were selected for the network. The 'Shoreline Features,' 'Weather,' 'Surface Water Dynamics' and 'Rare, Threatened, and Endangered Species and Communities' vital signs were not included. These vital signs were either not applicable to the park ('Shoreline Features'), used as explanatory variables ('Weather' 'Surface Water Dynamics') or not yet developed ('Rare, Threatened, and Endangered Species and Communities').

Collecting assessment data

With one exception, the data for this assessment was collected by the NPS through the I&M Program. Specific data collection methods are available through the NCRN website (NPS 2008). Data for the 'Landbirds' vital sign was collected as a part of DC Birdscape II, a program sponsored by the Audubon Naturalist Society, the NPS, and the Patuxent Wildlife Research Center (Hadidian et al. 1997). All data used in this assessment is available from the NCRN. A summary table of the data (Table 2.2) and monitoring locations (Figure 2.2) used in this paper are presented below. Additional data figures are available in Appendix A.

Determining thresholds

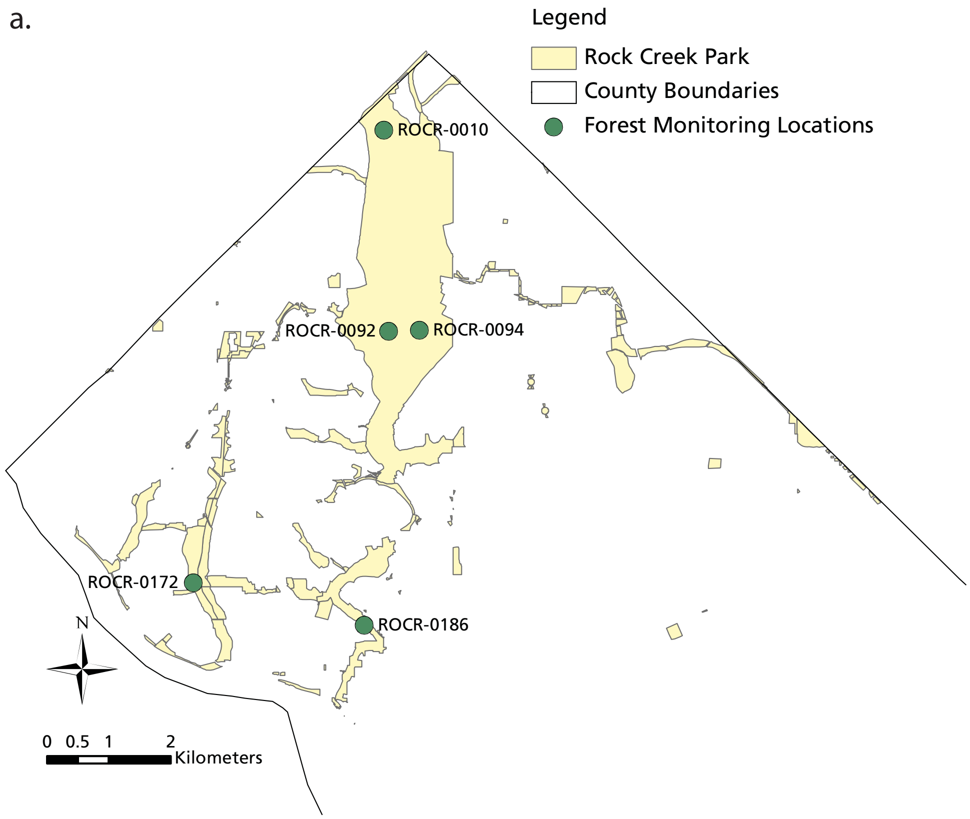
Thresholds were developed for the 30 metrics from scientific literature, NCRN monitoring protocols, and gray literature (Table 2.3). The thresholds were categorized as either ecologically relevant (E), legislative (L), or best professional judgment (P). Ecologically relevant thresholds were the preferred type of thresholds; however, they were not always available for each metric. If no ecologically relevant threshold was available, a legislative value was used. If neither an ecologically relevant nor a

Table 2.2. Summary table of the data for each metric used in the assessment. Maps of forest and water quality monitoring locations can be found in Figure 2.2.

Metric	Units	Sample Size	Data Year	Mean Value ± Standard Deviation
Ozone Concentration	ppm $(8h)^{-1}$	9000	2004	0.17 ± 0.13
Wet Nitrate Deposition	kg ha^{-1} y^{-1}	1	2002	2.23
Wet Sulfate Deposition	kg ha^{-1} y^{-2}	1	2002	1.49
Fine Particulate Matter Concentration	µg m^{-3}	9000	2004	11.73 ± 9.31
Mercury Deposition	ng L^{-1} y^{-1}	52	2005-2006	12.97 ± 9.65
Water pH	unitless	108	2005-2006	7.77 ± 0.45
Dissolved Oxygen Concentration	mg L^{-1}	108	2005-2006	7.16 ± 3.17
Specific Conductance	µS cm^{-1}	108	2005-2006	888.72 ± 702.76
Water Temperature	ºC	108	2005-2006	10.57 ± 6.27
Acid Neutralizing Capacity	mg L^{-1}	108	2005-2006	67.13 ± 15.97
Salinity	unitless	108	2005-2006	0.53 ± 0.45
Nitrate Concentration	mg L^{-1}	108	2005-2006	2.15 ± 1.21
Ammonium Concentration	mg L^{-1}	108	2005-2006	0.12 ± 0.14
Total Phosphorus Concentration	mg L^{-1}	108	2005-2006	0.97 ± 0.87
Benthic Index of Biotic Integrity	unitless	1	2005	2.11
Physical Habitat Index	unitless	1	2005	61.32
Percent Cover of Herbaceous Species and Woody Vines	% of area	5	2006-2007	8.54 ± 13.89
Density of Target Exotic Shrubs and Trees	% of area	5	2006-2007	16.78 ± 34.31
Presence of Pest Species	% of area	5	2006-2007	0
Seedling Regeneration	seedlings ha^{-1}	5	2006-2007	1500 ± 1490.61
Fish Index of Biotic Integrity	unitless	1	2005	2.78
Proportion of Area Occupied by Adult Amphibians	% of area	9	2005-2007	53 ± 25.28
Forest Interior Dwelling Bird Species Composition	number of species	20	2003	5 sensitive species
White-tailed Deer Density	number km^{-2}	1	2005	20
Interior Percent Area of Dominant Land Cover (Forest)	% of area	1	2001-2002	71
Exterior Percent Area of Dominant Land Cover (Forest)	% of area	1	2001-2002	24
Interior Critical Dispersal Threshold Distance (Dcrit)	% of area	1	2001-2002	340
Exerior Critical Dispersal Threshold Distance (Dcrit)	% of area	1	2001-2002	270
Interior Percent Cover of Impervious Surface	% of area	1	2000	4.6
Exterior Percent Cover of Impervious Surface	% of area	1	2000	44.9

Figure 2.2. I&M Program forest (a) and water quality (b) monitoring locations.

a.



b.

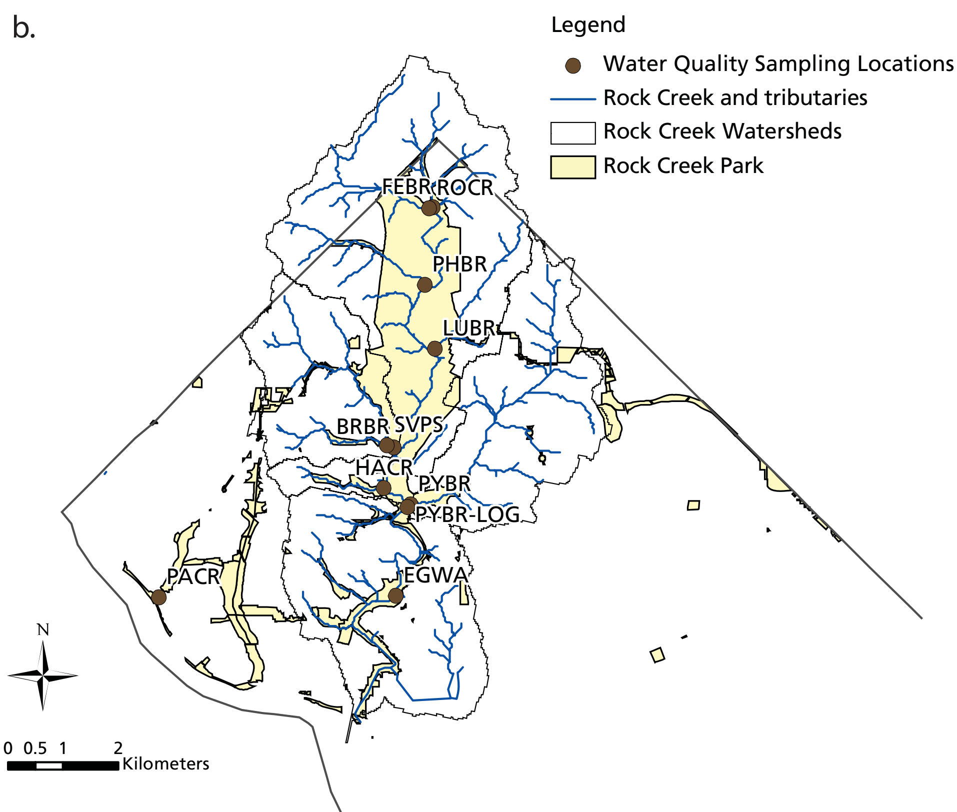


Table 2.3. Thresholds developed for the assessment of Rock Creek Park. Type refers to Ecological (E), Legislative (L), or Professional Judgment (P). Additional information can be found in Appendix B.

Metric	Threshold	Justification	Type	Reference
Ozone Concentration	< 0.08 ppm $(8hr)^{-1}$	NAAQS Primary and Secondary Standard	L	EPA 1997
Wet Nitrate Deposition	< 10 kg ha^{-1} y^{-1}	Highest load that will not lead to long-term harmful effects on ecosystem structure and function	E	Dupont et al. 2005
Wet Sulfate Deposition	< 10 kg ha^{-1} y^{-1}	Highest load that will not lead to long-term harmful effects on ecosystem structure and function	E	Dupont et al. 2005
Fine Particulate Matter Concentration	<15 µg m^{-3}	NAAQS Primary and Secondary Standard	L	EPA 1997
Mercury Deposition	< 1.2 ng L^{-1} y^{-1}	AWQC fish tissue concentration to protect human health	L	EPA 2001; Meili et al. 2002
Water pH	$6.0 \le X \le 8.5$	Regulatory value for the protection and propogation of fish and wildlife	E/L	DCMR 2005
Dissolved Oxygen Concentration	Mar-Jun $\ge$ 5mg L^{-1} Jul-Feb $\ge$ 4mg L^{-1}	Regulatory value for the protection and propogation of fish and wildlife	E/L	DCMR 2005
Specific Conductance	< 250 µS cm^{-1}	Value is protective of freshwater fish health	E	pers. comm. Ray Morgan
Water Temperature	< 32.2°C	Regulatory value for the protection and propogation of fish and wildlife	E/L	DCMR 2005
Acid Neutralizing Capacity	> 10 mg L^{-1}	Value indicates an impaired ecosystem in need of restoration	E	Roth et al. 1999; Hilderbrand et al. 2007
Salinity	< 0.25	SMCL non-enforceable standard for drinking water	L	EPA 2002
Nitrate Concentration	< 2 mg L^{-1}	Value indicates an impaired ecosystem in need of restoration	E	Roth et al. 1999; Hilderbrand et al. 2007

Table 2.3 (continued). Thresholds developed for the assessment of Rock Creek Park. Type refers to Ecological (E), Legislative (L), or Professional Judgment (P). Additional information can be found in Appendix B.

Metric	Threshold	Justification	Type	Reference
Ammonium Concentration	< 0.442 mg L^{-1}	Regulatory value for the protection and propogation of fish and wildlife	E/L	DCMR 2005
Phosphrus Concentration	< 36.56 µg L^{-1}	Nonregulatory value for preventing eutrophication of receiving waters	E	EPA 2000
Benthic Index of Biotic Integrity	Benthic IBI > 3	Sites with IBI greater than 3 are comparable to reference sites	E	Roth et al. 1999; Hilderbrand et al. 2007
Physical Habitat Index	PHI > 42	Value indicates an impaired ecosystem in need of restoration	E	Roth et al. 1999; Hilderbrand et al. 2007
Percent Cover of Herbaceous Species and Woody Vines	< 5% cover	Best professional judgment	P	NCRN I&M
Density of Target Exotic Shrubs and Trees	< 5% cover	Best professional judgment	P	NCRN I&M
Presence of Pest Species	< 1% of area	Best professional judgment	P	NCRN I&M
Seedling regeneration	> 31,875 seedlings ha^{-1}	Density of tree seedlings under low deer herbivory	E	McWilliams et al. 1995;
Fish Index of Biotic Integrity	Fish IBI >3	Sites with IBI greater than 3 are comparable to reference sites	E	Roth et al. 1999; Hilderbrand et al. 2007
Proportion of Area Occupied by Adult Amphibians	20% < X < 80%	Based on current population structure, no net loss	P	pers. comm. L. Bailey and E. Grant
Bird Species Composition	Presence of sensitive species	The presence of sensitive forest interior dwelling species (FIDS) indicates high quality forest habitat	E	Jones et al. 2000

Table 2.3 (continued). Thresholds developed for the assessment of Rock Creek Park. Type refers to Ecological (E), Legislative (L), or Professional Judgment (P). Additional information can be found in Appendix B.

Metric	Threshold	Justification	Type	Reference
White-Tailed Deer Density	$< 8\ km^{-2}$	High deer densities have negative effects on tree species composition, forest regeneration, small mammals and birds	E	Tilghman 1989, Horsley et al. 2003
Interior Percent Area of Dominant Land Cover	> 60%	Neutral models suggest that at this critical value, habitat clusters will be continuous. This a measure of habitat loss	E	Gardner et al. 1987
Exterior Percent Area of Dominant Land Cover	> 60%	Neutral models suggest that at this critical value, habitat clusters will be continuous. This a measure of habitat loss	E	Gardner et al. 1987
Interior Critical Dispersal Threshold Distance (D_{crit})	< 360 m	The distance at which 75% of patches within the area are connected allowing for small mammal and tree dispersal	E	Corry & Nassauer 2005; He & Mladenoff 1999
Exterior Critical Dispersal Threshold Distance (D_{crit})	< 360 m	The distance at which 75% of patches within the area are connected allowing for small mammal and tree dispersal	E	Corry & Nassauer 2005; He & Mladenoff 1999
Internal Percent Cover of Impervious Surfaces	< 10%	Watersheds with impervious surfaces above this value are impacted by non-point source runoff and stream habitat changes	E	Arnold & Gibbons 1996
External Percent Cover of Impervious Surfaces	< 10%	Watersheds with impervious surfaces above this value are impacted by non-point source runoff and stream habitat changes	E	Arnold & Gibbons 1996

legislative threshold value was available, then a management or best professional judgment threshold was developed by the NCRN staff or subject matter experts. Detailed threshold justifications can be found in Appendix B.

Two additional thresholds were developed for each metric for the threshold attainment assessment: 'Desired Condition', and 'Undesired Condition' (Table 2.4; Carter & Bennetts 2007). Bestelmeyer (2006) suggests that differentiating between restoration (desired condition) and preventative (undesired condition) thresholds is important as it helps resource managers locate areas that can benefit from restoration versus those that are in a highly degraded state.

The additional thresholds were based upon the single thresholds developed above (Threshold Condition) and the range of possible values of the metric. If a second ecological threshold was available, it was used as one of the thresholds (items numbered 5 in Table 2.4). Multiple ecological thresholds may identify the points where many species are lost (Undesired Condition) or where most species can maintain viable populations (Desired Condition) (Lindenmayer & Luck 2005). In most cases used in this assessment, the ability of the resource to meet a 'Desired Condition' threshold was considered when defining that threshold.

Calculating threshold attainment

The monitoring data (Appendix A) was compared to the established single thresholds (Table 2.3). Each data point was assigned either a one (1) or zero (0) score depending upon whether it met or did not meet the threshold, respectively. The percentage of time each metric was in attainment was calculated using the mean of the one and zero scores for all sampling point (Figure 2.3a). For example, the Nutrient Dynamics metrics were measured monthly for 1 year at 9 locations in Rock Creek Park. Therefore, the mean attainment for those 108 samples was used to determine the metric attainment

Table 2.4. Multiple thresholds developed for all metrics.

Metric	Units	Desired Condition	Threshold Condition	Undesired Condition
Ozone Concentration	ppm $(8h)^{-1}$	0.04[1]	0.08[2]	0.40[3]
Annual Wet Nitrate Deposition	kg ha^{-1} y^{-1}	5[4]	10[5]	20[6]
Annual Wet Sulfate Deposition	kg ha^{-1} y^{-1}	5[4]	10[5]	20[6]
Annual Fine Particulate Matter Concentration	µg m^{-3}	10[7]	15[2]	20[8]
Mercury Deposition	ng L^{-1} y^{-1}	0.6[1]	1.2[2]	12[3]
Water pH	unitless	$6.0 \leq X \leq 6.8$[9]	$6.0 \leq X \leq 8.5$[5]	$6.0 > X$; $8.5 < X$[10]
Dissolved Oxygen Concentration	mg L^{-1}	7.5[11]	5[5]	2[5]
Specific Conductance	µS cm^{-1}	125[4]	250[5]	500[6]
Water Temperature	ºC	24[12]	32[5]	40[13]
Acid Neutralizing Capacity	mg L^{-1}	15[11]	10[5]	5[4]
Salinity	unitless	0.12[4]	0.25[5]	0.5[6]
Nitrate Concentration	mg L^{-1}	0.69[5]	2[5]	3.31[14]
Ammonium Concentration	mg L^{-1}	0.221[4]	0.442[5]	4.42[15]
Total Phosphorus Concentration	mg L^{-1}	0.015[5]	0.036[5]	0.2[16]
Benthic Index of Biotic Integrity	unitless	5[5]	3[5]	1[5]
Physical Habitat Index	unitless	63[11]	42[5]	21[4]
Percent Cover of Herbaceous Specied and Woody Vines	% area	1[17]	5[16]	25[18]
Density of Target Exotic Shrubs and Trees	% area	1[17]	5[16]	25[18]
Presence of Pest Species	% area	0[19]	1[16]	5[18]
Seedling Regeneration	seedlings ha^{-1}	5.5×10^{4}[5]	3.0×10^{4}[5]	5.0×10^{3}[16]
Fish Index of Biotic Integrity	unitless	5[5]	3[5]	1[5]
Proportion of Area Occupied by Adult Amphibians	% area	80[16]	20[16]	0[19]
Bird Species Composition	# of species	1 highly sensitive[5]	4 sensitive[5]	1 sensitive[19]
White-Tailed Deer Density	deer km^{-2}	4[4]	8[5]	16[6]
Interior Percent Area of Dominant Land Cover (Forest)	% area	30[5]	60[5]	90[11]
Exterior Percent Area of Dominant Land Cover (Forest)	% area	30[5]	60[5]	90[11]
Interior Critical Dispersal Threshold Distance (D_{crit})	m	240[20]	360[5]	480[21]
Exterior Critical Dispersal Threshold Distance (D_{crit})	m	240[20]	360[5]	480[21]
Interior Percent Cover in Impervious Surface	% area	5[4]	10[5]	30[5]
Exterior Percent Cover in Impervious Surface	% area	5[4]	10[5]	30[5]

[1] 0.5 times the legislative threshold
[2] Legislative threshold
[3] 10 times legislative threshold
[4] 0.5 times ecological threshold
[5] Ecological threshold
[6] 2 times ecological threshold
[7] Minus 0.33 times legislative threshold
[8] Plus 0.33 times the legislative threshold
[9] Minus 0.2 times ecological threshold
[10] Outside the ecological threshold range
[11] Plus 0.5 times ecological threshold
[12] Minus 0.25 times ecological threshold
[13] Plus 0.25 times ecological threshold
[14] Equivalent distance between two ecological thresholds
[15] 10 times ecological threshold
[16] Best professional judgment threshold
[17] 0.2 times best professional judgment threshold
[18] 5 times best professional judgment threshold
[19] Minimum value of the metric
[20] Minus 0.33 times ecological threshold
[21] Plus 0.33 times ecological threshold

Figure 2.3. Equations used to calculate and test the report card methodology. (a) The equation used to calculate metric attainment using linear thresholds. (b) The equation used to calculate metric attainment using binary thresholds. (c) The equations used to test summation (Σ) versus product (Π) methods.

a. Calculating metric attainment using binary thresholds

$$\textit{metric attainment} = \frac{\Sigma \textit{ data attainment scores}}{\textit{number of samples}}$$

b. Calculating metric attainment using binary thresholds

if metric condition is worse than threshold condition:

$$\textit{metric attainment} = \frac{|\textit{Undesired Condition - metric value}|}{2\,|\textit{Undesired Condition - Threshold Condition}|}$$

if metric condition is better than threshold condition:

$$\textit{metric attainment} = \frac{|\textit{Threshold Condition - metric value}|}{2\,|\textit{Desired Condition - Threshold Condition}|} + 0.5$$

c. Calculating the vital sign, category, and park attainment scores.

	Vital Sign Attainment	Category Attainment	Park Attainment
Summation Method 1 (S1)	$\frac{\Sigma \textit{ metric attainment}}{\textit{number of metrics}}$	$\frac{\Sigma \textit{ vital sign attainment}}{\textit{number of vital signs}}$	$\frac{\Sigma \textit{ category attainment}}{\textit{number of categories}}$
Summation Method 2 (S2)	$\frac{\Sigma \textit{ metric attainmnent}}{\textit{number of metrics}}$	$\frac{\Sigma \textit{ vital sign attainment}}{\textit{number of vital signs}}$	$\frac{\Sigma \textit{ vital sign attainment}}{\textit{number of vital signs}}$
Summation Method 3 (S3)	$\frac{\Sigma \textit{ metric attainment}}{\textit{number of metrics}}$	$\frac{\Sigma \textit{ metric attainment}}{\textit{number of metrics}}$	$\frac{\Sigma \textit{ metric attainment}}{\textit{number of metrics}}$
Product Methods 1 and 2 (P1, P2)	$\frac{\Pi \textit{ metric attainment}}{\textit{number of metrics}}$	$\frac{\Pi \textit{ vital sign attainment}}{\textit{number of vital signs}}$	$\frac{\Pi \textit{ category attainment}}{\textit{number of categories}}$

scores. (See Table 2.2 for a list of the number of samples used in the assessment for each metric.) Thirty metric attainment scores were calculated for this assessment. These scores were used for all but the threshold attainment analysis.

Integration Approaches

Optimizing the number of metrics

To test multiple report card approaches, all metrics were used. Using all metrics helped provide a robust data set. However, this approach may not be the most accurate approach when designing a report card program. Therefore, an analysis of sample size was conducted to determine the number of metrics that result in a report card with the lowest variability.

The optimization technique used helps determine the number of metrics that would result in adequate resolving power without over-sampling (Bros and Cowell 1987). The standard error of the mean of a set of metrics and the number of metrics are related by an inverse asymptotic function. Using the minimum number of metrics or a greater number will not result in a significantly different resolving power (Bros and Cowell 1987).

This analysis was conducted on the 22 metrics with ecologically relevant thresholds (see Table 2.3). Monte Carlo techniques were used to draw samples of 2 to 21 (n-1) metrics from the available metrics. Ten random samples were drawn from the population for each number of metrics, for a total of 200 samples (Grinham et al. 2007). The standard error was calculated for each random sample. The minimum, maximum, and mean standard errors were then graphed versus the number of metrics to determine the standard error function.

An issue arises with this method due to drawing repeated samples from a fixed population size. For sample sizes greater than n/2 (11 metrics in this case), the variation in standard error will decrease as a result of the decreased number of available combinations. Therefore, this technique could not be used to provide an estimate greater than n/2 (Bros and Cowell 1987).

Summation versus Product Methods

A common challenge associated with the use of report cards is determining how to combine the subscore into a report card value (Lindenmayer et al. 2008). Five possible assessment methods were developed; three summation methods and two product methods (Figure 2.3c). The hypothesis was that using a summation method, which uses the mean of metric scores between zero and one, would result in a unit score close to 0.5. A product method, on the other hand, may solve some of the issues associated with the summation process. The product method should tend to result in a score approaching one, if all metrics are in good condition; whereas, a park where metrics are in poor condition should result in a score near zero.

Under the summation method (S1), the mean of the metric attainment scores was calculated to create vital sign attainment scores. Each vital sign attainment score was created from 1-6 metrics. Seventeen vital sign scores were calculated. Vital sign category scores were calculated from the mean of the two to seven vital sign scores. There were four vital sign category scores calculated as part of this assessment. The final score calculated as part of this assessment was the park score. This score was the mean of the vital sign category scores. The final score gave an indication of the overall park condition.

Under the product method, two sets of scores were calculated using the same framework as the summation method (S1). The first product method (P1) used the same scores as the summation method. The second product method (P2) included a data transformation step to remove all zeroes from the report card. This transformation consisted of adding 0.001 to all scores and using the same equations from the P1.

An analysis of multiple frameworks was conducted to determine how the calculation method affected the result of the report card. The summation method was used for this analysis. The summation method, S1, used the mean of scores from a previous tier to determine the next tier of scores. There were three rolling means calculated. To test how these rolling means affect the score, two additional report cards were calculated. For the first (S2), the park score was the mean of the vital sign scores rather than the category scores. The S2 method used two rolling means rather than the three used in the S1 method. For the second calculation (S3), both the category score and the park score were calculated using the metric attainment scores, resulting in no rolling means. A standard deviation was calculated for each of the category and park scores. The deviation was based on the scores of items that were used to calculate the score (i.e. for a category score the deviation was based on the vital sign scores). This analysis was conducted using the entire vital signs data set.

Metric Weights and Grouping Data

An analysis was conducted to determine the effect of specific metrics on the final score of the S1. This analysis was conducted by changing one metric, vital sign or category score from zero to one while holding the remaining scores constant. This was performed separately for each metric, vital sign and category. In addition, a variability estimate was calculated for the overall park score.

The I&M framework contains an unbalanced number of metrics in each category. To test the effect of a unbalanced system, a random number generator was used to determine the placement of metric scores within categories. For example, if the random number was less than 0.25 then the metric was placed in Category 1; between 0.25 and 0.5 the metric was placed in Category 2; between 0.5 and 0.75 the number was placed in Category 3; and, between 0.75 and 1.00 the metric was placed in Category 4. Multiple grouping rules were used to provide additional unbalanced groupings. A total of 1000 groupings were created.

Category and park scores were calculated from the unbalanced groupings using the S1 method. Category scores were the mean of the scores of each metric group. A park score was the mean of the four category scores.

An estimate of the amount of unbalancing was determined for each park score. The unbalanced estimate was calculated by taking the absolute value of the distance of the number of metrics per group from the mean number of metrics. There were 30 metrics used in this analysis, therefore, the mean group size was 7.5 metrics. The absolute values were then summed to give the unbalanced estimate. The unbalanced estimate ranged from 2 to 39. An unbalanced estimate of 2 indicates that metrics are evenly distributed in categories with all categories contain either 7 or 8 metrics. An unblanaced estimate of 39 indicates that the categories are highly unbalanced with three categories containing 1 metric each and one category containing 27 metrics.

Alternative Threshold Attainment Method

Following the work of Carter and Bennetts (2007), multiple thresholds were developed to test a second method of metric attainment. This method determined metric attainment on a linear scale rather than a binary scale. To calculate metric attainment using multiple thresholds, a set of equations was used (Figure 2.3b). Two equations were required for this example because the 'Undesired Condition' and 'Desired Condition' were not equally spaced from the 'Threshold Condition'. This allowed for different linear scaling between the Undesired and Threshold Conditions than between the Threshold and Desired Conditions. If the Undesired and Desired Conditions were equally spaced from the Threshold Condition, then only a single equation would have been needed to scale between the Undesired and Desired Conditions.

Metric attainment was calculated based on the mean monitoring data (Table 2.2) and a report card was calculated using S1. A report card using the same data set and the single threshold also was calculated to allow for comparison between the linear and binary methods.

Recommended report card framework

A recommended report card method was developed based on the results of the integration approach testing.

Results

Integration Approaches

Optimizing the number of metrics

The results of the number of metrics analysis show the optimal range of metrics to use in a report card (Figure 2.4). The minimum acceptable number of metrics was located beyond the maximum rate of change of the standard error function (6 metrics). The maximum number of metrics that could be suggested by this technique is 11. Therefore, the recommended number of metrics suggested by this technique was between 6 and 11 (Figure 2.4). This estimation of the number of metrics is supported by the difference in the maximum and minimun standard error (Figure 2.5). A standard error difference of 0.10 results in a recommendation of 6 metrics. A standard error of 0.01 results in 20 metrics; however, the maximum number of metrics that can be recommended by this technique is 11.

Summation versus Product Methods

The results of the summation method 1 (S1) analysis showed that Rock Creek Park was in fair condition (Table 2.5). The comparison between the qualitative descriptions and

Figure 2.4. Results of Monte Carlo sample size optimization. The figure suggested that between 6 and 11 metrics should be used in a report card.

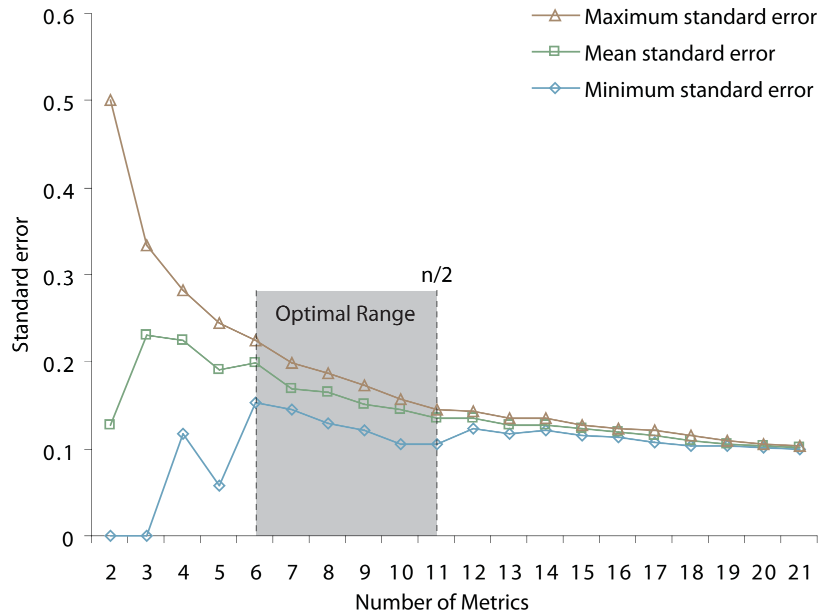
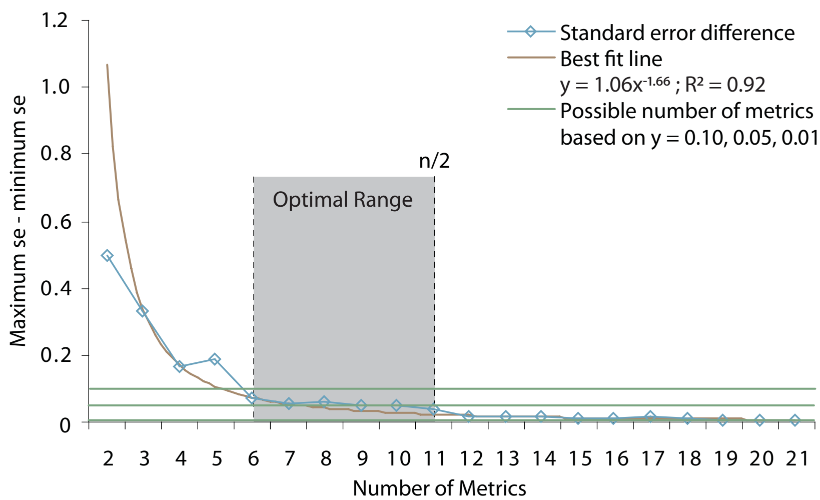


Figure 2.5. Difference between maximum and minimum standard error with best fit line. Green lines indicate the number of metrics based on various standard error differences.



quantitative scores used in this section is shown in Table 2.6a (Wazniak et al. 2004). The 'Ecosystem Pattern and Process' category was in good condition. This was driven by the high forest cover and connectivity. The 'Water Quality and Hydrology' and 'Biodiversity' categories were in fair condition. The 'Water Quality' score was driven by the degraded nutrient conditions. The 'Biodiversity' score was driven by the invasive

Table 2.5. Assessment results using S1. Shading indicates vital signs.

Metric	Score	Vital Sign	Score	Category	Score	Park Score
Ozone Concentration	0.28	Ozone	0.28			
Annual Wet Nitrate Deposition	0.00	Wet Deposition	0.50	Air Quality		
Annual Wet Sulfate Deposition	1.00			and Climate	0.28	
Annual Fine Particulate Matter Concentration	0.33	Visibility and Particulate Matter	0.33			
Mercury Deposition	0.00	Mercury Deposition	0.00			
Water pH	0.93					
Dissolved Oxygen Concentration	0.69					
Specific Conductance	0.00					
Water Temperature	1.00	Water Chemistry	0.65			
Acid Neutralizing Capacity	1.00					
Salinity	0.30			Water Quality	0.54	
Nitrate Concentration	0.52			and Hydrology		
Ammonium Concentration	0.95	Nutrient Dynamics	0.49			
Total Phosphorus Concentration	0.00					
Benthic Index of Biotic Integrity	0.00	Aquatic Macroinvertebrates	0.00			0.48
Physical Habitat Index	1.00	Physical Habitat Index	1.00			
Percent Cover of Herbaceous Species and Woody Vines	0.00	Invasive/Exotic Plants	0.00			
Density of Target Exotic Shrubs and Trees	0.00					
Presence of Pest Species	1.00	Forest Insect Pests	1.00			
Seedling Regeneration	0.00	Forest Vegetation	0.00			
Fish Index of Biotic Integrity	1.00	Fishes	1.00	Biodiversity	0.48	
Proportion of Area Occupied by Adult Amphibians	1.00	Amphibians	1.00			
Bird Species Composition	0.33	Landbirds	0.33			
White-Tailed Deer Density	0.00	White-tailed Deer	0.00			
Interior Percent Area of Dominant Land Cover (Forest)	1.00					
Exterior Percent Area of Dominant Land Cover (Forest)	0.00	Land Cover/Land Use	0.75			
Interior Critical Dispersal Threshold Distance (D_{Crit})	1.00			Ecosystem Pattern		
Exterior Critical Dispersal Threshold Distance (D_{Crit})	1.00			and Process	0.63	
Interior Percent Cover of Impervious Surface	1.00	Landscape Condition	0.50			
Exterior Percent Cover of Impervious Surface	0.00					

Table 2.6. Comparison for assessment scores and qualitative descriptions using the (a) binary and (b) linear threshold attainment methods. The excellent score in the binary method was equivalent to the acceptable score in the linear method.

a.

Description	Score
Excellent	0.81 - 1.00
Good	0.61 - 0.80
Fair	0.41 - 0.60
Degraded	0.21 - 0.40
Very Degraded	0.00 - 0.20

b.

Description	Score
Desired	0.81 - 1.00
Good	0.61 - 0.80
Acceptable	0.41 - 0.60
Degraded	0.21 - 0.40
Undesired	0.00 - 0.20

Table 2.7. Results of summation method S1 versus product methods P1 and P2.

	Summation 1	Product 1	Product 2
Category Score: Air Quality & Climate	0.28 ± 0.21	0.00	0.00
Category Score: Water Quality & Hydrology	0.54 ± 0.42	0.00	0.00
Category Score: Biodiversity	0.48 ± 0.50	0.00	0.00
Category Score: Ecosystem Pattern & Process	0.63 ± 0.18	0.00	0.00
Park Score	0.48 ± 0.15	0.00	0.00

plant cover, high deer density, and low seedling regeneration. The 'Air Quality and Climate' category was in degraded condition as a result of the poor condition of all of the metrics.

Both product methods resulted in zero scores for all categories and the park (Table 2.7). Using the transformed data (P2) was an attempt to remove the mathematical issues associated with multiplying by zero; however, including the transformation in the calculations did not result in a non-zero park score after adjusting for significant digits.

In comparing the three summation methods, all scores were within the standard deviation of S1 (Table 2.8). The scores for the separate methods were generally within 0.06 of one another. However, the largest difference in score was between the Ecosystem Pattern and Process scores for S1 (0.48) and S3 (0.80). This difference was still within the standard deviation of the S1. The park scores for all three methods were within 0.03 units of S1.

Table 2.8. Results of 3 summation assessment methods.

	Summation 1	Summation 2	Summation 3
Category Score: Air Quality & Climate	0.28 ± 0.21	0.28 ± 0.21	0.32 ± 0.41
Category Score: Water Quality & Hydrology	0.54 ± 0.42	0.54 ± 0.42	0.59 ± 0.42
Category Score: Biodiversity	0.48 ± 0.50	0.48 ± 0.50	0.42 ± 0.50
Category Score: Ecosystem Pattern & Process	0.63 ± 0.18	0.63 ± 0.18	0.80 ± 0.52
Park Score	0.48 ± 0.15	0.46 ± 0.39	0.51 ± 0.45

Metric Weights and Grouping Data

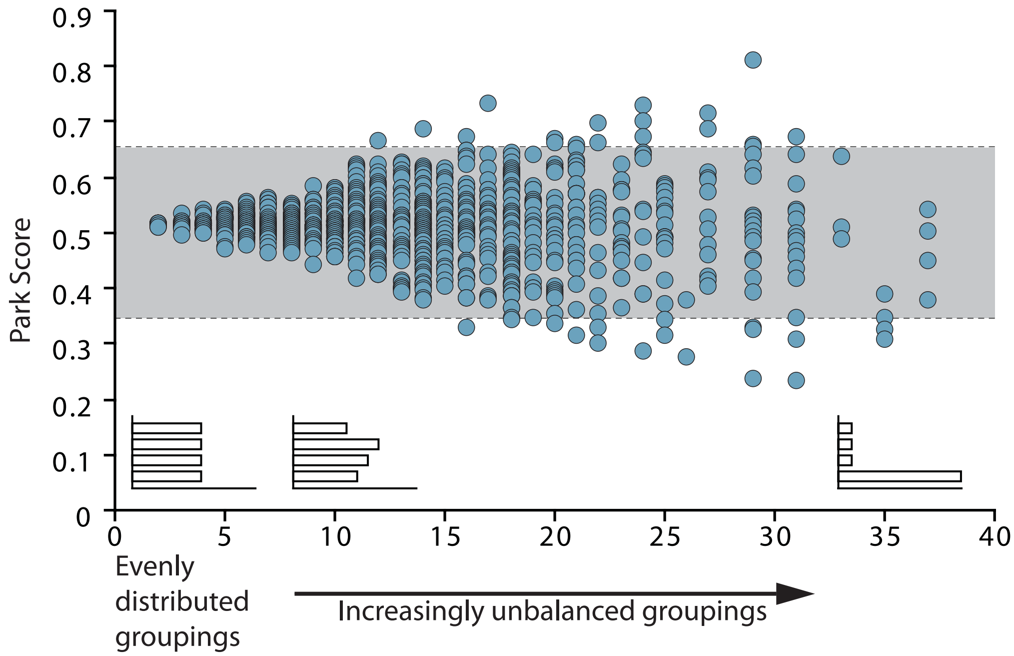
The results of the analysis of metric weights using S1 showed the weight of each metric, vital sign, and category in the park score (Table 2.9). Each of the categories was evenly weighted and therefore each contributed a quarter of the park score. Similarly for the vital signs, each contributed between four and 13 percent of the final score. The different numbers of vital signs within each category lead to the varying amount contributed. Each metric score contributed between one and six percent of the park score. Similar to the vital sign scores, this was due to the varying number of metrics contributing to each vital sign.

The results of the balance modeling showed that, as groups become more unabalanced, the variability in the report card result increased (Figure 2.6). Evenly distributed groups would result in a consistent report card result no matter which group of metrics were chosen. The results suggested that in order to have a robust report card framework using 30 metrics, groups should have an unbalanced estimate of less than 11. This meant that while evenly distributed groupings would provide the most precise estimate, slightly unbalanced groupings did not strongly affect the variability in the report card. The I&M framework has an unbalanced estimate of 8, and is, therefore, within the acceptable range. To use this type of analysis more broadly, the variability introduced through the framework should be less than the scorecard variability. The scorecard variability for this report card is ± 0.15 of the final score (see Table 2.8, Summation 1 method).

Table 2.9. Results of the unintentional weighting of each metric on the park score using S1. Shading indicates vital signs.

Metric	% Change	Vital Sign	% Change	Category	% Change	Park Score
Ozone Concentration	6.25	Ozone	6.25			
Annual Wet Nitrate Deposition	3.13	Wet Deposition	6.25	Air Quality and Climate	25	
Annual Wet Sulfate Deposition	3.13					
Annual Fine Particulate Matter Concentration	6.25	Visibility and Particulate Matter	6.25			
Mercury Deposition	6.25	Mercury Deposition	6.25			
pH	1.04					
Dissolved Oxygen Concentration	1.04					
Specific Conductance	1.04					
Water Temperature	1.04	Water Chemistry	6.25			
Acid Neutralizing Capacity	1.04					
Salinity	1.04			Water Quality and Hydrology	25	
Nitrate Concentration	2.08					
Ammonium Concentration	2.08	Nutrient Dynamics	6.25			
Total Phosphorus Concentration	2.08					
Benthic Index of Biotic Integrity	6.25	Aquatic Macroinvertebrates	6.25			100
Physical Habitat Index	6.25	Physical Habitat Index	6.25			
Percent Cover of Herbaceous Species and Woody Vines	1.79	Invasive/Exotic Plants	3.57			
Density of Target Exotic Shrubs and Trees	1.79					
Presence of Pest Species	3.57	Forest Insect Pests	3.57			
Seedling Regeneration	3.57	Forest Vegetation	3.57			
Fish Index of Biotic Integrity	3.57	Fishes	3.57	Biodiversity	25	
Proportion of Area Occupied by Adult Amphibians	3.57	Amphibians	3.57			
Bird Species Composition	3.57	Landbirds	3.57			
White-Tailed Deer Density	3.57	White-tailed Deer	3.57			
Interior Percent Area of Dominant Land Cover (Forest)	3.13					
Exterior Percent Area of Dominant Land Cover (Forest)	3.13	Land Cover/Land Use	12.50			
Interior Connectivity (D_{Crit})	3.13			Ecosystem Pattern and Process	25	
Exterior Connectivity (D_{Crit})	3.13					
Interior Percent Cover in Impervious Surface	6.25	Landscape Condition	12.50			
Exterior Percent Cover in Impervious Surface	6.25					

Figure 2.6. Results of unbalanced groupings analysis. Example groupings are shown in the lower bar graphs. The acceptable amount of variability introduced through unbalanced groupings should be less than the variability of the park score. In this case, this variability should be less than ± 0.15 of the mean park score (0.51 over all test runs).



Alternative Threshold Attainment Method

The linear threshold analysis showed that Rock Creek Park was in acceptable condition (Table 2.10). These results were not directly comparable to the previous report card analysis (Table 2.5) because they used mean metric values rather than percent spatial and temporal attainment. Therefore, a report card was calculated using the mean values and the binary threshold method (Table 2.11). Both threshold methods were analyzed using the S1 method.

Because these results used the same metric data, they could be compared. However, because of differences in the methods, the numbers were not directly comparable. The linear threshold method placed metrics that meet the 'Threshold Condition' at a score of 0.5 or greater, whereas the binary threshold method placed those same metrics at a score of 1.0. Therefore, a score of 0.5 in the linear method was equivalent to a score of 1.0 in the binary method (see Table 2.6).

Table 2.10. Threshold analysis results, linear method. Shading indicates vital signs.

Metric	Score	Vital Sign	Score	Category	Score	Park Score
Ozone Concentration	0.36	Ozone	0.36			
Annual Wet Nitrate Deposition	1.00	Wet Deposition	1.00	Air Quality		
Annual Wet Sulfate Deposition	1.00			and Climate	0.55	
Annual Fine Particulate Matter Concentration	0.83	Visibility and Particulate Matter	0.83			
Mercury Deposition	0.00	Mercury Deposition	0.00			
Water pH	0.50					
Dissolved Oxygen Concentration	0.93					
Specific Conductance	0.00					
Water Temperature	1.00	Water Chemistry	0.57			
Acid Neutralizing Capacity	1.00					
Salinity	0.00			Water Quality	0.56	
Nitrate Concentration	0.44			and Hydrology		
Ammonium Concentration	1.00	Nutrient Dynamics	0.49			
Total Phosphorus Concentration	0.02					
Benthic Index of Biotic Integrity	0.28	Aquatic Macroinvertebrates	0.28			0.50
Physical Habitat Index	0.90	Physical Habitat Index	0.90			
Percent Cover of Herbaceous Species and Woody Vines	0.41	Invasive/Exotic Plants	0.41			
Density of Target Exotic Shrubs and Trees						
Presence of Pest Species	1.00	Forest Insect Pests	1.00			
Seedling Regeneration	0.00	Forest Vegetation	0.00			
Fish Index of Biotic Integrity	0.45	Fishes	0.45	Biodiversity	0.39	
Proportion of Area Occupied by Adult Amphibians		Amphibians				
Bird Species Composition	0.50	Landbirds	0.50			
White-Tailed Deer Density	0.00	White-tailed Deer	0.00			
Interior Percent Area of Dominant Land Cover (Forest)	0.68					
Exterior Percent Area of Dominant Land Cover (Forest)	0.00	Land Cover/Land Use	0.54			
Interior Critical Dispersal Threshold Distance (D_{Crit})	0.58			Ecosystem Pattern		
Exterior Critical Dispersal Threshold Distance (D_{Crit})	0.88			and Process	0.52	
Interior Percent Cover of Impervious Surface	1.00	Landscape Condition	0.50			
Exterior Percent Cover of Impervious Surface	0.00					

Table 2.11. Threshold analysis results, binary method. Shading indicates vital signs.

Metric	Score	Vital Sign	Score	Category	Score	Park Score
Ozone Concentration	0.00	Ozone	0.00			
Annual Wet Nitrate Deposition	1.00	Wet Deposition	1.00	Air Quality		
Annual Wet Sulfate Deposition	1.00			and Climate	0.50	
Annual Fine Particulate Matter Concentration	1.00	Visibility and Particulate Matter	1.00			
Mercury Deposition	0.00	Mercury Deposition	0.00			
Water pH	1.00					
Dissolved Oxygen Concentration	1.00					
Specific Conductance	0.00					
Water Temperature	1.00	Water Chemistry	0.67			
Acid Neutralizing Capacity	1.00					
Salinity	0.00			Water Quality	0.50	
Nitrate Concentration	0.00			and Hydrology		
Ammonium Concentration	1.00	Nutrient Dynamics	0.33			
Total Phosphorus Concentration	0.00					
Benthic Index of Biotic Integrity	0.00	Aquatic Macroinvertebrates	0.00			0.51
Physical Habitat Index	1.00	Physical Habitat Index	1.00			
Percent Cover of Herbaceous Species and Woody Vines	0.00	Invasive/Exotic Plants	0.00			
Density of Target Exotic Shrubs and Trees	0.00					
Presence of Pest Species	1.00	Forest Insect Pests	1.00			
Seedling Regeneration	0.00	Forest Vegetation	0.00			
Fish Index of Biotic Integrity	0.00	Fishes	0.00	Biodiversity	0.43	
Proportion of Area Occupied by Adult Amphibians	1.00	Amphibians	1.00			
Bird Species Composition	1.00	Landbirds	1.00			
White-Tailed Deer Density	0.00	White-tailed Deer	0.00			
Interior Percent Area of Dominant Land Cover (Forest)	1.00					
Exterior Percent Area of Dominant Land Cover (Forest)	0.00	Land Cover/Land Use	0.75			
Interior Critical Dispersal Threshold Distance (D_{Crit})	1.00			Ecosystem Pattern		
Exterior Critical Dispersal Threshold Distance (D_{Crit})	1.00			and Process	0.63	
Interior Percent Cover of Impervious Surface	1.00	Landscape Condition	0.50			
Exterior Percent Cover of Impervious Surface	0.00					

The results of the threshold attainment analysis showed that the park was at threshold condition (Table 2.10), while the binary method suggested that the park was halfway to threshold condition (Table 2.11). The category scores were in a similar condition as the park score.

Recommended report card framework

The recommendations resulting from the integration analysis were a report card that contains between 6 and 11 metrics, multiple thresholds, balanced groupings, and a summation calculation method. The following section describes the recommended report card approach.

Selecting Metrics

Under the I&M framework, there are 30 possible metrics in four categories. The recommendation from the results of the Monte Carlo metric optimization was to include between 6 and 11 metrics. This particular framework was designed to provide a park-wide report card rather than focusing on each category grouping. If a balanced design was used, then two metrics per category would result in a report card using eight metrics. Eight metrics were chosen from the original 30 (Table 2.12). Independent and information-rich metrics were chosen in an attempt to create the most accurate report card.

For the 'Air Quality and Climate' category, 'Ozone Concentration' and 'Annual Fine Particulate Matter Concentration' were chosen as the metrics. These two air quality metrics have an effect on the visitor experience at the park. Low ozone concentrations allow recreational users to hike or bike the park trails without endangering their health. Low fine particulate matter concentrations result in clear vistas.

Table 2.12. Recommended report card framework.

Category	Metric
Air Quality and Climate	Ozone Concentration Annual Fine Particulate Matter Concentration
Water Quality and Hydrology	Nitrate Concentration Benthic Index of Biotic Integrity
Biodiversity	Seedling Regeneration Bird Species Composition
Ecosystem Pattern and Process	Interior Percent Area of Dominant Land Cover (Forest) Interior Critical Dispersal Threshold Index (D_{Crit}) "Connectivity"

For the 'Water Quality and Hydrology' category, 'Nitrate Concentration' and 'Benthic Index of Biotic Integrity' were chosen as the metrics. Nutrients have been shown to be a problem in Rock Creek Park. Nitrogen and phosphorus concentrations are generally highly correlated, therefore only one of the nutrients was selected. Because high phosphrus also may be an indicator of leaking sewer pipes (EPA 2006b), nitrogen was chosen as a measure of nutrient concentration. The resident fauna within a stream may provide an indication of stressors that a monthly monitoring program may not capture (Hilderbrand et al. 2007). Benthic organisms have been shown to be sensitive metrics of stream health (Hilderbrand et al. 2007). Therefore, the Benthic IBI was chosen as the second water quality metric.

For the 'Biodiversity' category, 'Seedling Regeneration' and 'Bird Species Composition' were chosen as the metrics. Seedling regeneration is an information-rich metric in that it captures both the growth potential of the forest, shading by invasive species, soil compaction, and deer browsing (Lookingbill et al. In Review). Bird species are sensitive to the quality of the forest habitat (Jones et al. 2000). They have a relatively large habitat range, which also can provide habitat for numerous other species. A healthy bird population also can provide an important visitor experience.

For the 'Ecosystem Pattern and Process' category, 'Interior Percent Dominant Land Cover' and 'Interior Connectivity' were chosen as the metrics. While exterior landscape metrics can have an important effect on the park, this report card was based on the park; therefore, only interior metrics were chosen. The chosen metrics provided a method to determine the availability of migration corridors as well as some indication of metapopulation dynamics.

Calculating the Report card

To calculate the report card, metric attainment was calculated using the mean value of the eight chosen metrics. The linear thresholds method was used for the calculation because it provided more information about the status of the metrics. The linear threhsold method provides a scale for resource managers from immediate triage needed (0), to acceptable condition (0.5), to desired condition in need of protection (1).

The method used for combining metrics was a summation method. The particular method did not greatly affect the report card outcome. Additionally, a summation method is intuitive with simple calculations that provide high level overview (Locantore et al. 2004). In this case, because evenly-distributed groups were used, there was no difference between methods S1 and S3. A category score was the mean of the two metric attainment scores. The park score was the mean of the four category scores. The recommended report card result is shown in Table 2.13.

Table 2.13. Recommended report card for Rock Creek Park.

Metric	Score	Category	Score	Park Score
Ozone Concentration	0.36	Air Quality and Climate	0.59	0.46
Annual Fine Particulate Matter Concentration	0.83			
Nitrate Concentration	0.44	Water Quality and Hydrology	0.36	
Benthic Index of Biotic Integrity	0.28			
Seedling Regeneration	0.00	Biodiversity	0.25	
Bird Species Composition	0.50			
Interior Percent Area of Dominant Land Cover (Forest)	0.68	Ecosystem Pattern and Process	0.63	
Interior Critical Dispersal Threshold Distance (D_{Crit})	0.58			

The recommended report card (Table 2.13) showed that Rock Creek Park was in acceptable condition (see Table 2.6b). However, the park did not meet the threshold condition (0.46). 'Air Quality and Climate' and 'Ecosystem Pattern and Process' both exceeded threshold condition and were in good condition (0.59 and 0.63 respectively). Air Quality was high because the particulate matter concentration was in desired condition (0.83) while the ozone concentration was in degraded condition (0.36). Ecosystem Pattern, on the other hand, was in good condition because both metrics were in acceptable (0.58) and good condition (0.68). 'Water Quality and Hydrology' was in degraded condition (0.36) because one metric was in degraded condition (0.28) and the other was in acceptable condition (0.44). 'Biodiversity' was in degraded condition (0.25) as the seedling regeneration was in undesired condition (0.00) while the bird species were in acceptable condition (0.50).

Discussion

The purpose of this chapter was to determine a method for assessing the physical and biological resources of a National Park. This method was developed by testing the number of metrics needed, the report card framework, the integration calculation and the way to calculate threshold attainment.

Integration Approaches

Optimizing the number of metrics

The results of the sample size optimization suggested using between 6 and 11 metrics (Figure 2.3). To have an accurate score, the item of interest must be based on at least 6 metrics. Fewer metrics would result in a report card with higher variability, while more metrics would result in the same variability for more effort.

A small number of metrics would therefore result in an acceptable report card. Additional metrics would not increase the reliability of the report card. Many report cards, such as the Chesapeake Bay Program (2008) and the National Parks Conservation Association (2003), contain more than 100 metrics. The report cards with a smaller number of metrics, such as the Chesapeake Bay Habitat Health Index (Williams et al., 2009) and the Moreton Bay Report Card (Pantus & Dennison 2005), both include the number of metrics suggested by this analysis. The Chesapeake Bay Habitat Health Index uses six metrics (Williams et al. 2009). The results of this analysis showed that the report cards that used fewer metrics provided the same results as the report cards that used many more metrics.

Summation versus Product Methods

The results of the integration method analysis suggested that a summation method was the preferred method. Rock Creek Park, like all of the NCRN parks, is surrounded by intense urban pressures (Lookingbill et al. 2007), which causes many metrics to not meet the defined threshold. The report card results from both product methods are zero. While ecologically this score may be valid, it was not a useful score if one was attempting to compare different areas under similar urban pressures. When working in an urban area it was possible to assume that at least one metric would not be within the specified threshold. This would result in all NCRN parks receiving a score of zero under a product method. For management and communication purposes, having zero scores in all categories and for the all of the park score would not provide any comparison among parks (Locantore et al. 2004). The chosen summation method allows park managers and the public to determine which aspects of the park to protect and which aspects might need restoration.

A more useful way to use a product method was in regards to extreme events. These extreme events could be items that a monthly monitoring program might not catch (Kirchner et al. 2004, Wazniak et al. 2004). For example, if a harmful algal bloom were found in an estuary (Anderson et al. 2002), then the summation score would be multiplied by zero, resulting in a zero score (Whitall et al. 2007, Bricker et al. 2003). Other examples of extreme events include: fish kills (Burkholder et al. 2001, Bozek & Young 1994, White 1981); oil spills (Wiens et al. 1996, Jackson et al. 1989, Teal & Howarth 1984); or, sewer line breaks (Chen et al. 2004, Shear et al. 1996). If one of these extreme events were recorded in a park unit, then the park score would be multiplied by zero, resulting in a zero score for the park.

The comparison of the three different summation methods (S1, S2 and S3) for determining a park score resulted in similar numbers for all three methods (Table 2.8). All of the results were within the standard deviation of S1. This suggested that the final score was not dependent upon the summation method chosen.

Choosing a particular summation method to use over the others depended on the importance of various levels within the framework. Using a method that is always based on the mean of the metric data (S3) suggests that the metrics were the most important and accurate numbers derived in the report card. However, in some cases, like the 'Water Chemistry' and 'Nutrient Dynamics' metrics, monitoring data may be readily available and highly correlated (Dennison et al. 1993). Wrapping those possibly information poor metrics into a single vital sign number provided a way to remove the prevalence of easy to collect, correlated data (Wazniak et al. 2004). Additionally, by using only the mean of the metric data, one equated the importance of water temperature with bird species presence.

Using vital signs to calculate the park score (S2) removed some of the correlation and weighting issues associated with the metric method; however, it may not allow for comparison across networks and between parks. Vital signs are not standardized across networks (Fancy et al. 2009). However, all networks chose their vital signs using the standardized Level I and Level II category descriptions (NPS 2005a). By creating a score for the categories using the vital signs (S1) comparison across broad geographic regions may be possible. Using report cards from multiple parks and regions one might be able to determine something about the status of water quality throughout the eastern seaboard of the United States (Whitall et al. 2007). This only would be possible on a small scale using the vital signs. Therefore, the S1 method was preferred because it allowed for the most comparative power among the three tested summation methods.

Metric Weights and Grouping Data

Under the first summation method, all metrics in the I&M Program framwork provided one to six percent of the final park score. While metrics were not evenly weighted, the differences in percent contributed to the final score were within five percent of all other metrics. Improvement or deterioration in one metric did not affect the park score more than any other metric. Importantly for Rock Creek Park, this meant that the metrics that are outside of park control, such as the 'Air Quality and Climate' metrics, and many of the 'Ecosystem Pattern and Process' metrics, did not affect the park score significantly more than the metrics that were within park control.

The balancing analysis showed that while evenly distributed groupings result in the least variability in final score, having some unevenness in the groupings did not result in high variability. If there were some metrics that were important for park management or the public (NPS 2005a), then they could be included in the report card without strongly affecting the structure of the report card. The weighting that results from unevenly distributed groups must be acknowledged as part of the description of the report card.

It should be noted that the groupings should not become too unbalanced, or the resulting report card may not be an accurate measure of park condition. As the unbalanced estimate increased, the precision of the report cards decreased. The more unbalanced groupings had increasing variability in park condition due solely to the chosen report card framework. The results of this analysis recommended that the variability introduced by the framework should be less than the total calculated variability in park score.

Alternative Threshold Attainment Method

The results of threshold attainment modeling showed that both methods provide different information to resource managers; however, the linear threshold attainment method provided more information than the binary method. Using the binary method with a single threshold that indicated a severe problem may result in poor resource management because when the metric has crossed the threshold it may be too late to restore the system. Using multiple thresholds provided managers with warning signs that the system was headed in the wrong direction (Bestelmeyer 2006; Briske et al. 2006, Lookingbill et al. In Review).

The linear threshold attainment method was more complex than the binary method; however, the increase in information provided by the final report card justified the increased complexity. While the linear method requires three thresholds, it allowed a resource manager to look at the state of their resources and determine which metrics were almost in an acceptable condition versus those that needed immediate restoration (Briske et al. 2006, Luck 2005). It also provided a way for resource managers to look at which metrics were in or close to desired condition and needed protection (Bestelmeyer 2006). By setting thresholds that take into account management needs, the linear threshold method can provide the information that resource managers need (Hugget 2005, Lindenmayer & Luck 2005).

Both methods provided for changing thresholds, either through changing management goals or new scientific information. However, the linear method allowed for multiple thresholds where the binary method did not. Some of the thresholds set as part of the linear method could be thought of as points where no management action was needed, but further research was suggested (Carter & Bennetts 2007). Others could be thought of as conditions that required immediate management intervention to prevent imminent loss (Carter & Bennetts 2007). Some metrics could have many more thresholds than others, depending upon the scientific understanding or management needs for a particular metric (Bestelmeyer 2006, Briske et al. 2006). The linear method required at least two thresholds; however, the total number was up to the scientific and management community to determine.

Recommended report card framework

The recommended report card was created using the results of the integration approach testing. It used a small number of independent and information-rich metrics, a linear threshold attainment method, a framework that was evenly distributed, and a summation calculation. This framework created a report card that was transparent and informative for scientists, managers, and the public (Dennison et al. 2007, Boesch 2006, Dennison et al. 2004). Additionally, the recommended analytical framework was flexible, dynamic, iterative, and adaptable (Gentile & Harwell 2001).

The scores for the 'Air Quality and Climate' category showed that high ozone concentration was an issue for the park (Nolte et al. 2008, Sickles & Shadwick 2007).

The air quality metrics were measured at a regional scale and there was little that the park could do within its jurisdictional boundaries to help resolve these problems. However, the park may be able to work with other organizations to bring these issues to light and create solutions. Because the ozone concentration threshold was a legislative threshold (EPA 1990), there are already governmental organizations working to decrease the ground-level ozone concentration (MWCOG 2007).

The 'Water Quality and Hydrology' metrics showed that nutrients were a problem throughout the park. Elevated nutrient concentrations have been an issue in Rock Creek Park for more than 30 years (CH2M Hill 1979). Nitrate concentration was above the threshold condition. High nitrate concentrations can cause eutrophication within Rock Creek, as well as downstream in receiving water bodies (Kemp et al. 2005). Rock Creek had poor benthic diversity that may be due to lack of habitat. Benthic IBI described the diversity of benthic macroinvertebrates found in the stream. The same was found in the 1979 study (CH2M Hill 1979). Sediment depositing on the stream bed may be smothering these animals and preventing them from finding suitable habitat (Wood & Armitage 1997). It also may be possible that the macroinvertebrates were succumbing to nutrient pollution or moderate dissolved oxygen concentrations (Kolar & Rahel 1993). One issue with the assessment of Benthic IBI was that there was only one monitoring location within Rock Creek. Additional monitoring locations may provide a better picture of the invertebrate diversity and health than the single monitoring point available today.

The 'Biodiversity' metrics were in poor condition. The poor condition of seedling regeneration suggests that there was minimal growth potential for the forest (Ruhren & Handel 2003). This may be due to shading by invasive species, soil compaction, or heavy deer browsing (Lookingbill et al. In Review). There were 5 sensitive bird species found within the Rock Creek Park forest. The park should maintain its current bird population and attempt to provide higher quality habitat for more highly sensitive species. These highly sensitive species require large blocks of undisturbed habitat (Robbins et al. 1989). One method to protect these bird species might be to continue to prevent the creation of social trails and enforce leash and other laws that prevent disturbances (Jones et al. 2000). This may provide the birds with the larger habitat required for successful survival and reproduction within the park.

The 'Ecosystem Pattern and Process' metrics within the park were in excellent condition. The park should continue to maintain its passive recreational status to maintain its high forest cover and high connectivity (Fischer & Lindenmayer 2007, Fahrig 2003). This analysis did not include the encroachment pressure that the park experienced as it was focused on the interior of the park.

Conclusion

The results of this chapter provide a recommended report card framework for resource managers. This framework used between 6 and 11 metrics, linear threshold analysis, a summation calculation method, and balanced groupings. These recommendations resulted in an information rich report card that provided resource managers with the status of important ecological resources. Multiple years of monitoring data can provide trend information that will allow resource managers to determine the trajectory of their resources. The report card result also can be used to communicate the condition of park resources with stakeholders and the general public as a way to help protect those resources.

Report cards are an important part of the resource management process. They provide geographic, overall, and temporal views which provide managers with important information. The geographic view allows resource managers to target restoration or protection to a location with poor health. The overall view allows resource managers to determine which metrics need the most management attention. And the temporal view provides resource managers with a consistent method to track metrics over time and determine trajectories of those metrics.

Additionally, report cards have the potential to improve the monitoring process through feedback. Reporting on monitoring data in a regular schedule may improve the timeliness of the monitoring data. A report card based on monitoring data from the previous year is of more interest to the public than a report card based on monitoring data from 3 years previous. A report card is an unofficial deadline for the quality assurance and quality control process. This deadline may improve the speed and accuracy of that process. Additionally, monitoring staff will see the usefulness of their data collection efforts and may improve the quality of their efforts. These improvements will improve the validity of data used in the report card and possibly improve resource health.

Report cards provide resource managers with scientifically valid information that can help the managers when communicating with business leaders and politicians in the target area. If resource managers knows where and when a problem is occurring, they can try to prevent its occurrence in the future. These report cards provide resource managers with targets for improving their resource. They also provide resource managers with targeted research questions to improve thresholds or understand why a resource is in a particular condition.

Chapter 3: A synoptic watershed context for Rock Creek Park.

Abstract

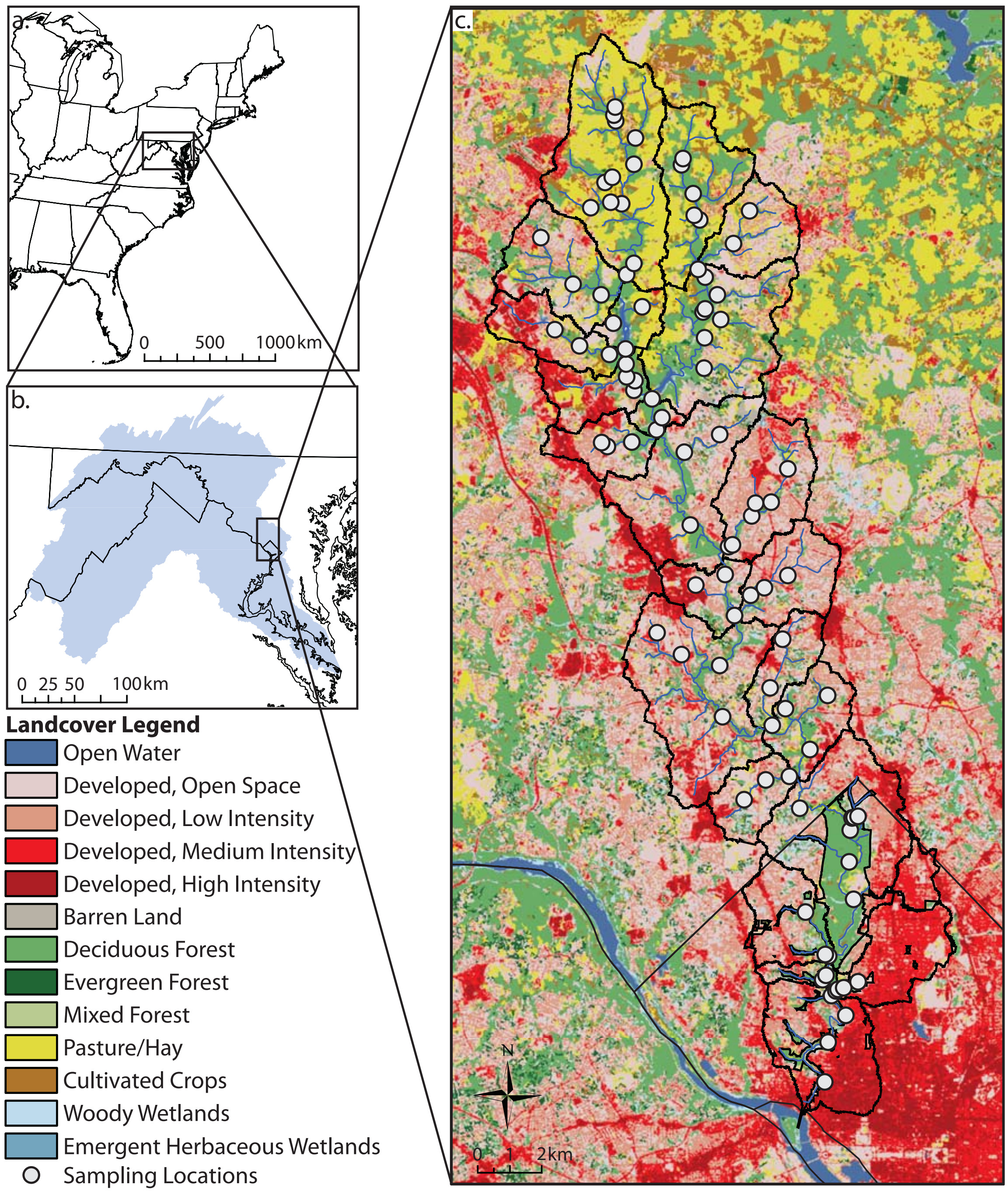
The condition of Rock Creek Park is highly dependent upon the condition of the surrounding land use. Nutrient sampling – nitrate, phosphate, dissolved oxygen, and salinity – was conducted during September 2007 throughout the Rock Creek watershed in Montgomery County, Maryland and Washington DC. The results were combined to create a water quality index which was highly correlated to the fish and benthic indices of biotic integrity. This index was highest in the upper portion of the watershed and decreased downstream. However, the riparian buffer of Rock Creek Park, both the Montgomery County and National parks, provided locations for nutrient cycling which improved the water quality index over the expected results. This index also was compared to landcover and other GIS-derived variables. No single variable was able to adequately describe the water quality index, and it was determined that the Urban Stream Syndrome, or the interaction of many anthropogenic forces, was causing decreased water quality. The results of this paper suggest that managers work across political boundaries within the watershed, work to decrease the connectedness of urban surfaces and Rock Creek, and prepare for possible wide sweeping change in water quality due to long-term climate change.

Introduction

Human land use pressures from outside a park boundary can adversely affect the protected resources within a park (Defries et al. 2007). These pressures include hydrologic alteration and pollution via dams, water impoundment, diversion, regulated flows, stream channelization, wetlands drainage, and groundwater extraction (Pringle 2000). As well as loss of ecosystem defining processes such as fire or flooding, and changing biodiversity due to the introduction of exotic species and loss of native species (Hansen & Defries 2007). Proper ecosystem management for a protected area requires managing across administrative boundaries to prevent the effects of these exterior pressures (Defries et al. 2007). The effort required to maintain a protected area increases as a result of contrasting land use inside and outside the boundary, as well as contrasting management goals between land users and managers (Schonewald-Cox 1988).

Small urban parks, such as Rock Creek Park, are important biological refugia, migration stops, and dispersal corridors. Managing these important resources requires broad understanding of numerous stressors (Lookingbill et al. 2007), including those located outside the park boundary. The ecological boundary of a protected area, as characterized by attributes such as the range of herbivores (Defries et al. 2007), may not be well defined (Schonewald-Cox 1988); however, the hydrological boundaries generally are well defined (Williamson et al. 2008). Because water quality was a focus of this study, the watershed boundary for Rock Creek, the focal stream of the park, was chosen as an appropriate ecological boundary. The main body of Rock Creek Park is located in the lower portion of the Rock Creek watershed (Figure 3.1). Therefore, the condition of the Park is dependent upon the condition of the surrounding watershed.

Figure 3.1. Rock Creek is located on the east coast of the United States (a) within the Potomac River watershed (b). The Rock Creek watershed (c) begins in Montgomery County, Maryland and drains through Rock Creek Park in Washington DC, before emptying into the Potomac River. The background image (c) is the National Land Cover Data from 2001 (EPA 2001).



The aim of this chapter is to determine the specific effects of the Rock Creek watershed on Rock Creek Park. In particular, to test the following hypotheses:

- In an urban system, the water quality will decrease as the water flows downstream.
- Rock Creek Park is a large riparian buffer and is acting as a filter for incoming nutrients.
- To determine if the water quality index was related to traditional measures of stream health.

Methods

Existing monitoring data were collected from the Washington DC Department of the Environment (DOE), the Maryland Department of Natural Resources (DNR), and Montgomery County. The data from DNR and Montgomery County was only fish and benthic index of biotic integrity (IBI) data. The DOE collects only nutrient data.

The existing monitoring data were collected at different times and did not have any spatial coverage for the lower watershed. Therefore, a synoptic nutrient sampling program was conducted over the entire watershed to give an indication of overall condition.

Sampling design and conditions

Samples were collected at 95 locations throughout the watershed between September 7, 2007 and October 1, 2007. These locations included all existing monitoring locations as well as some additional locations. The existing monitoring locations included the one NCRN IBI pilot sampling location, eight DNR Maryland Biological Stream Survey (MBSS) locations (Roth et al. 1999) and 52 Montgomery County Countywide Stream Protection Strategy (CSPS) sites (Montgomery County 2003). These locations were selected by these programs to evaluate stream condition within the State (MBSS) and the County (CSPS). The nutrient sampling locations were overlain on these sites to allow for comparison between the IBI data and the nutrient data.

Additional locations were chosen solely for the nutrient sampling to provide adequate replication within each subwatershed. These samples were chosen randomly throughout the subwatersheds. Stream order was not used as a factor in choosing the stream sampling locations. The original intent had been to collect data for at least 3 sampling points within each subwatershed. In one of the 23 subwatersheds it was only possible to collect 2 nutrient samples due to low flow conditions; however, the remaining subwatersheds contained at least 3 nutrient sampling locations (Figure 3.1c).

Weather and conditions.

Weather data were collected by the National Weather Service's Cooperative Observer Program (COOP) at the Ronald Reagan Washington National Airport (DCA). These data are available through the internet and consists of maximum and minimum temperatures and total precipitation. Reagan National Airport is approximately eight miles south of Rock Creek Park.

The maximum temperature recorded during the sampling period was 32 ^{o}C while the average daily maximum temperature was 27 ^{o}C. The minimum temperature recorded was 10 ^{o}C, while the average daily minimum temperature was 17 ^{o}C. Total precipitation was 15 millimeters (mm), all of which fell September 10 through September 14 with the majority of the precipitation falling on September 10 (10 mm) (NWS 2007).

Sample collection and laboratory analysis

The metrics sampled at each nutrient sampling location included dissolved oxygen, nitrate concentration, phosphate concentration and salinity. Dissolved oxygen concentration and salinity were measured using a WTW Multi 197i water quality probe. Salinity was chosen for this analysis rather than conductivity because of the direct linkage between road salt additions. Conductivity measurements can be influenced by karst geology, which is found at other NCRN parks. Water samples (20 mL) for the nutrient analysis were collected in the field and kept on ice until freezing (-20 °C) at the laboratory prior to analysis. Grab samples were analyzed at the Horn Point Laboratory, Cambridge, Maryland using standard methods (D'Elia et al. 1977; Kerouel and Aminot 1987).

Derived Stressor Layers

Landcover

Land use within and surrounding a park affects habitat and water quality. Urban land use, the matrix in which Rock Creek Park is embedded, can severely degrade both habitat and water quality (Wang et al. 2001). Changing land cover within and adjacent to the park can affect numerous biological, physical, and chemical resources within the park (Townsend et al. 2006). Remotely sensed landcover information can be used to determine fragmentation, buffers and land cover change and how these factors affect the abundance of rare, threatened and endangered (RTE) species, biodiversity, exotic plant invasions, terrestrial habitat, water quality, and stream habitat (Townsend et al. 2006).

The 2001 NLCD (Figure 3.1, EPA 2001) was used to determine the landcover of each subwatershed and geographic area. The NLCD image was clipped to each individual subwatershed boundary using the Raster Calculator in ArcGIS 9.1 (ESRI 2005). The landcover percentages for each watershed were calculated using Fragstats 3.3 (McGarigal et al. 2002). The data were analyzed at the Level II NLCD landcover classes; however, the classes were generalized to the Level I NLCD landcover classes when used in the analysis (EPA 2001).

Road Density

The road density layer was calculated using the Year 2000 TIGER/Line® Files (Census Bureau 2000). These line files were clipped to the subwatershed boundary layer and the park boundary layer. The length of the roads was then calculated using the ArcGIS field calculator and all road segments within each subwatershed were summed. Using the subwatershed area previously calculated, the road length was normalized to watershed area. There was a large range of road density values for each subwatershed. To facilitate comparison between subwatersheds, road density was divided by subwatershed area, resulting in a population density. The area for each subwatershed was calculated using the ArcGIS field calculator.

Roads have a significant effect on wildlife and habitat quality which 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 exotic plants (Bechtold et al. 1996). Haynes et al. (1996) suggest road density classifications based on the spawning habitat of salmon. Road densities of 0.01 – 0.06 kilometers per square kilometer (km km^{-2}) are considered very low; 0.06 – 0.4 km km^{-2} are considered low; 0.4 – 1.1 km km^{-2} are considered moderate; 1.1 – 2.9 km km^{-2} are considered high; and greater than 2.9 km km^{-2} are considered extremely high. Bechtold et al. (1996) similarly categorized road density into five classifications for an analysis of grizzly bear habitat. Their classifications were 0 – 0.3 km km^{-2}, 0.3 – 0.6 km km^{-2}, 0.6 – 1.2 km km^{-2}, 1.2 km km-2 – 3.1 km km^{-2}, > 3.1 km km^{-2}. Both classifications were similar, suggesting that these road densities are appropriate for a variety of species.

Impervious Surface

The Impervious Surface Area (ISA) information was 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 30m x 30m pixel and range from 0-100%. The year 2000 dataset was used to calculate the average percent ISA inside the subwatersheds using the ArcMap Spatial Analyst/Zonal Statistics tool.

The 10 percent impervious surface threshold (Arnold & Gibbons 1996) used in the previous chapter was used to define the break between green and yellow. The break between dark and light green is an arbitrary break and was half the threshold (5%). Arnold & Gibbons (1996) suggest that impervious surface greater than 30% creates severe stream degradation. Therefore, 30% was used as the break between dark and light red. The break between yellow and light red was again half of the difference between the thresholds (20%).

Population Density

The population density for each subwatershed was derived using the Year 2000 Census block information (Census Bureau 2000). In ArcGIS 9.1, the base watershed layer was used to clip census blocks to the subwatershed 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 subwatershed to give a total population per subwatershed.

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 the smallest possible.

There was a large range of population values for each subwatershed. To facilitate comparison between subwatersheds, population was divided by subwatershed area, resulting in a population density. The area for each subwatershed was calculated using the ArcGIS field calculator.

The population density color breaks were based upon stream health ratings. The break between light and dark green was 375 people per square kilometer (people km^{-2}). At this density, streams showed fair fish IBI (Couch et al. 1997). Population densities in the yellow category (between 625 and 1000 people km^{-2}) resulted in streams that are rated poorly (Couch et al. 1997). The color break between orange and red split the difference of the remaining data.

Statistical Analysis

Water Quality Index

Site condition scores were calculated for the nutrient sampling using the recommended analytical framework developed in Chapter 2. The water quality index was calculated by averaging the site score for phosphate, dissolved oxygen, nitrate, and salinity. The index was calculated for each sampling location. Subwatershed water quality index values were calculated by averaging the index for all sites within the subwatershed.

The IBI data were used as an indicator of site condition without any additional manipulation. Subwatershed IBI values were calculated by averaging the IBI for all sites within the subwatershed.

Correlation Analysis

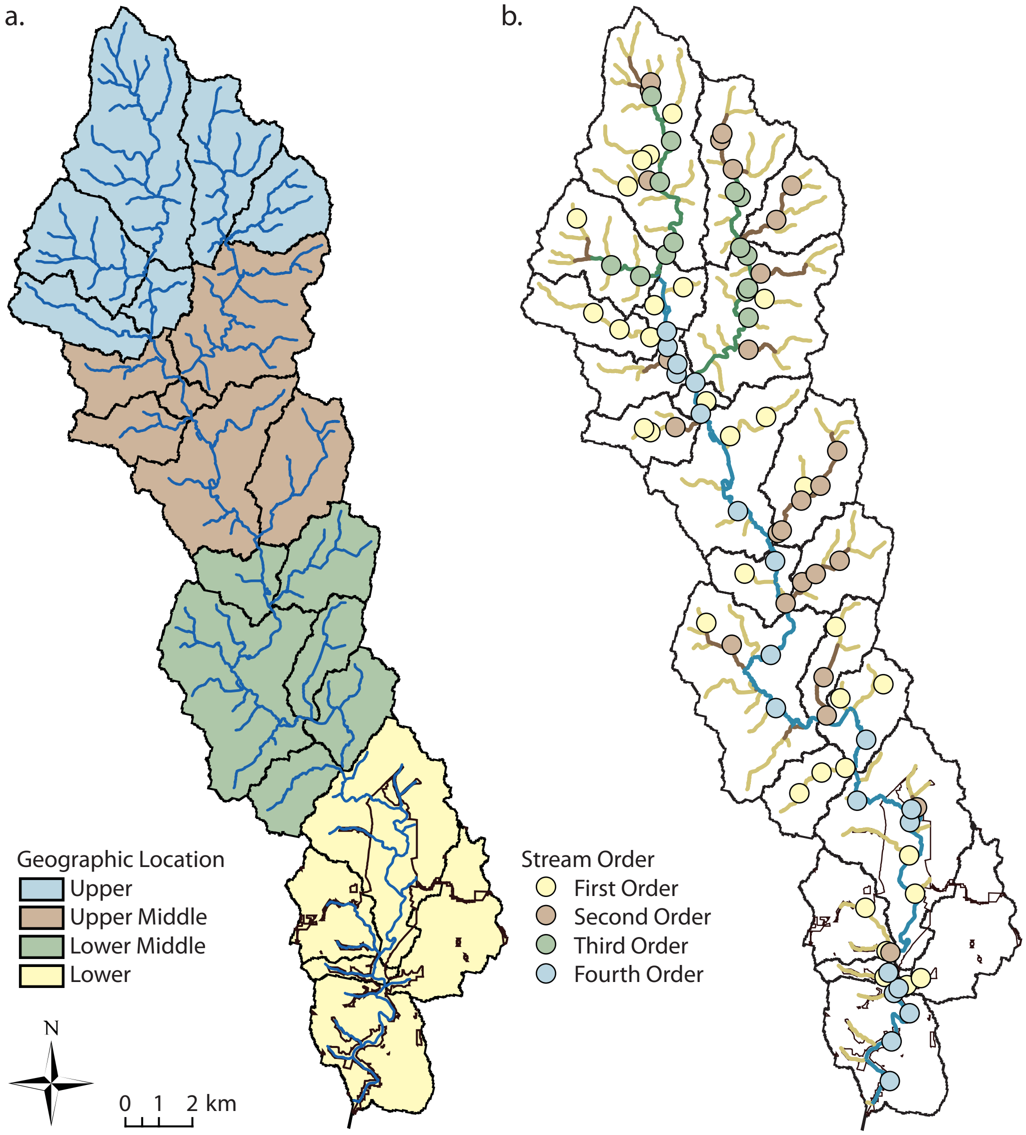
A correlation analysis between the water quality index, fish IBI, and benthic IBI was conducted using the CORR procedure of SAS 9.1 (SAS Institute 2003). These correlations were calculated at the site scale as well as at the subwatershed scale. There were a total of 61 sites that had water quality, fish IBI, and benthic IBI scores. There were 19 subwatersheds that had data for the correlation analysis.

A second correlation analysis between landcover variables was performed using the CORR procedure of SAS 9.1 (SAS Institute 2003). The variables used in the analysis were the derived layers – population density, road density, and impervious surface – and the NLCD Level I landcover classes – water, developed, barren, forest, planted, and wetland. This analysis was done at the subwatershed level and could not be performed at the site level as data was only available for a specified area.

Analysis of Variance

One-way analysis of variance (ANOVA) was conducted on the water quality index, benthic IBI, and fish IBI data using the MIXED procedure of SAS 9.1. There were many possible methods for categorizing the data, including watershed area denomination and the DS level from the NHD Plus dataset. The categorization methods used for this analysis were geographic area and stream order (Figure 3.2). The geographical categories were determined using subwatershed boundaries and breaking the large watershed into sections with approximately equal area. The stream order was determined using a shapefile extracted from the National Hydrography Dataset

Figure 3.2. Geographic location (a) and stream order (b) classifications used for ANOVA.



geodatabase for the Potomac River (USGS 1999). This dataset was preferable to one calculated from the digital elevation model because it more closely agreed with the stream locations in the field.

Multiple means comparison tests were conducted on both sets of categories. The Fisher's Least Significant Difference test was used to determine significant differences between means. A significance level of 0.05 was used to determine difference.

Results

Sampling Results

The synoptic sampling results show that the upper portion of the watershed was generally in better condition than the lower portion of the watershed (Figure 3.3). The thresholds developed in Chapter 2 were used as color break points (Table 3.1). Dark green indicated sampling points that met the desired condition value; light green indicated samples that met the threshold condition; yellow and orange indicated

Figure 3.3. Results of synoptic water quality sampling conducted in September 2007. Data for (a) salinity, (b) dissolved oxygen concentration, (c) nitrate concentration, and (d) phosphate concentration are shown.

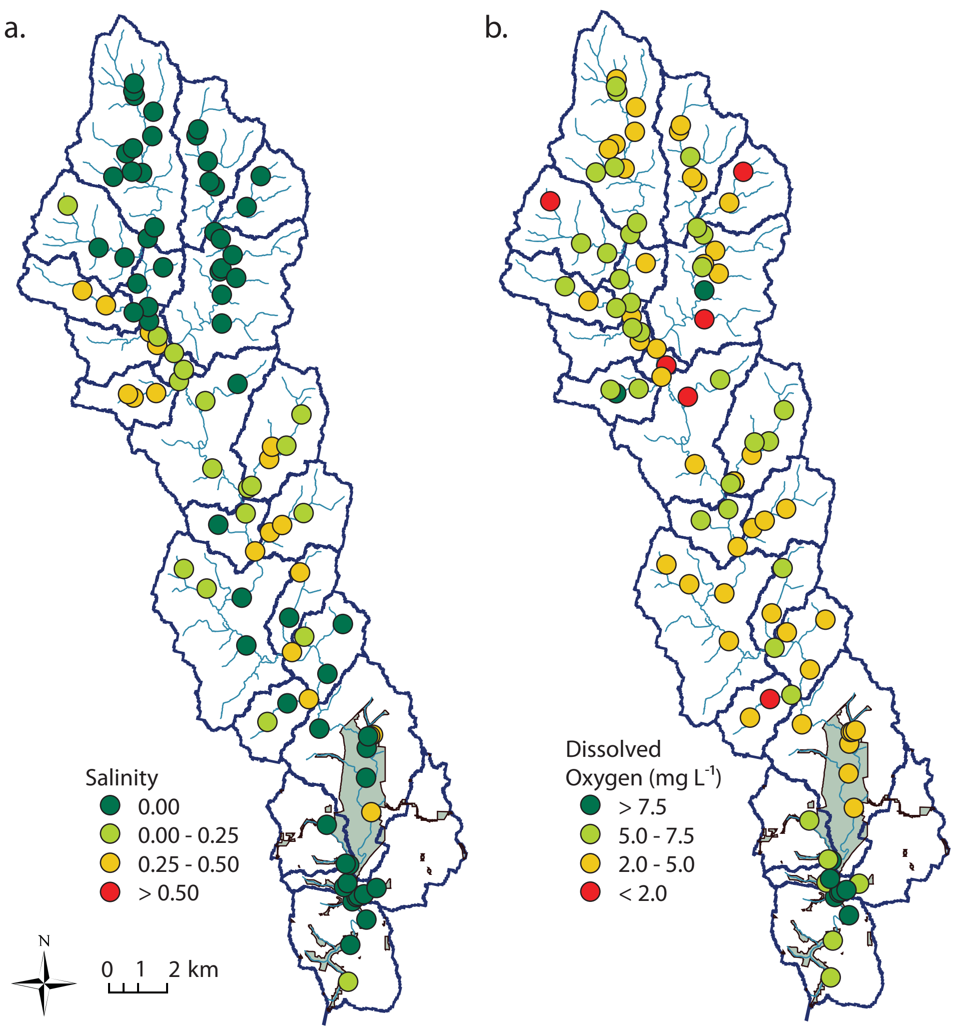


Figure 3.3 (continued). Results of synoptic water quality sampling conducted in September 2007. Data for (a) salinity, (b) dissolved oxygen concentration, (c) nitrate concentration, and (d) phosphate concentration are shown.

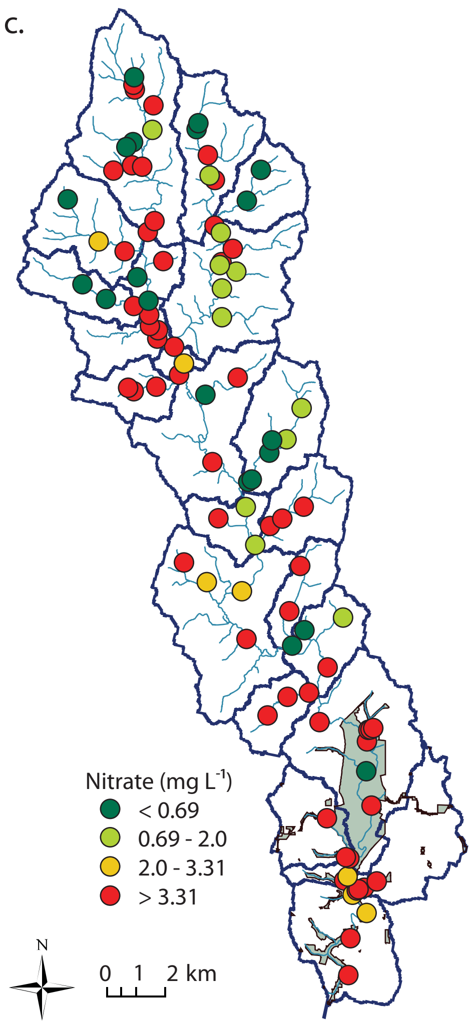


Table 3.1. Comparison between condition, color, and parameter value.

Condition		Phosphate (mg L^{-1})	Nitrate (mg L^{-1})	Salinity	Dissolved Oxygen (mg L^{-1})
Better than Desired	(dark green)	< 0.015	< 0.69	< 0.10	> 7.5
Between Desired and Threshold	(light green)	0.015 - 0.036	0.69 - 2.00	0.10 - 0.25	5.0 - 7.5
Between Threshold and Undesired	(yellow)	0.036 - 0.200	2.00 - 3.31	0.25 - 0.50	2.0 - 5.0
Worse than Undesired	(red)	> 0.200	> 3.31	> 0.50	< 2.0

samples that did not meet the threshold condition, but were better than the undesired condition; and, red indicated sampling points that did not meet the undesired condition.

The salinity (Figure 3.3a) at each sampling point was better than undesired condition throughout the Rock Creek watershed. 18 sampling locations were worse than threshold condition. 18 sampling locations were better than threshold condition but worse than desired condition. And 59 sampling locations were better than desired condition.

The dissolved oxygen concentration (Figure 3.3b) was in poor condition throughout the Rock Creek watershed. Only nine locations met the desired condition threshold, and were generally located in the lower portion of Rock Creek Park. 36 sampling locations were greater than the threshold condition, but less than the desired condition. 43 sampling locations were between undesired condition and threshold condition. And 6 sampling sites were in undesired condition.

The nitrate concentration (Figure 3.3c) generally exceeded the undesired condition in the lower watershed with some exceedences in the upper watershed. 55 sampling locations had nitrate concentrations greater than the undesired condition. 7 sampling locations throughout the watershed were between threshold and undesired condition. 12 sampling locations in the upper and middle watershed were between threshold and desired condition. And 20 samples in the upper and middle watershed met desired condition.

The phosphate concentration (Figure 3.3d) was generally below the threshold condition throughout the upper watershed. 20 sampling locations, all within the upper watershed, met the desired condition. 25 sampling locations, mostly in the upper watershed with a few scattered locations in the middle and lower watershed, were between threshold and desired condition. 36 sampling locations throughout the watershed were between threshold and undesired condition. And 13 sampling locations mainly in the middle and lower watershed were greater than the undesired condition.

Derived Stressor Layers

Land use varied throughout most of the Rock Creek watershed (Figure 3.1c). In the upper watershed there were a few subwatersheds that showed high agricultural land use, but most subwatersheds showed a mix of urban land uses. Many of the subwatersheds within Washington DC showed high intensity urban development.

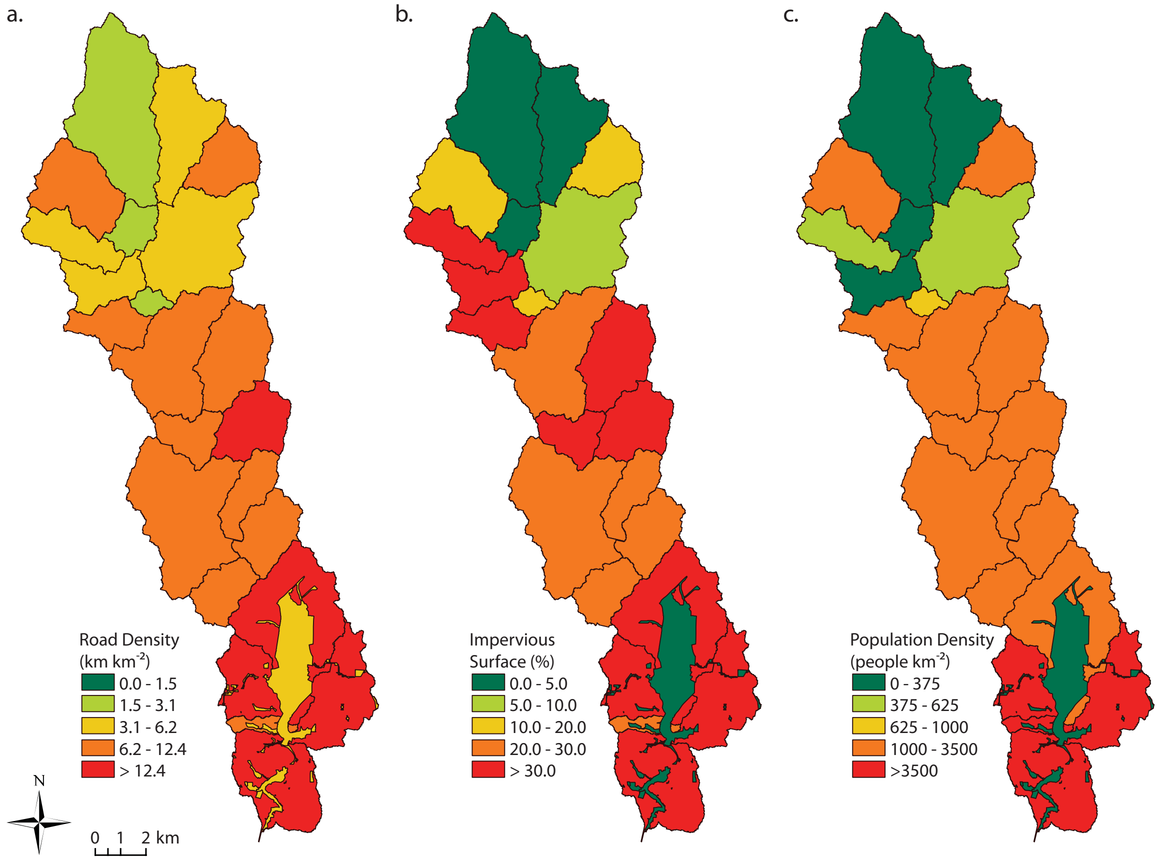
Road Density

The road densities found in the Rock Creek watershed (Figure 3.4a) were much higher than the road densities found in Bechtold et al. (1996) and Haynes et al. (1996). There were only three subwatersheds that had a road density less than 3.1 km km^{-2}. In order to show some variation in the map, the classification scheme condensed the literature values into two colors and the remaining colors were split based on the range of road densities found in the watershed. The road density in the Rock Creek watershed was lower in the upper watersheds and increased to very high densities around Rock Creek Park. Four subwatersheds and the park were in the yellow category, 11 subwatersheds were in the orange category, and 5 subwatersheds, mainly in the lower watershed, were in the red category.

Impervious Surface

The calculated impervious surface values for each subwatershed were categorized and mapped (Figure 3.4b). The impervious surface area was lowest in the 3 subwatersheds highest in the upper watershed and the park. One additional subwatershed, also in

Figure 3.4. Derived stressor layers, road density by subwatershed (a), impervious surface area by subwatershed (b), and population density by subwatershed (c). Color breaks are described in the text.



the upper watershed, had lower than threshold condition impervious surface. Three subwatersheds had impervious surface in the yellow category. Six subwatersheds had impervious surface in the orange category. And 10 subwatersheds had impervious surface greater than undesired condition.

Population Density

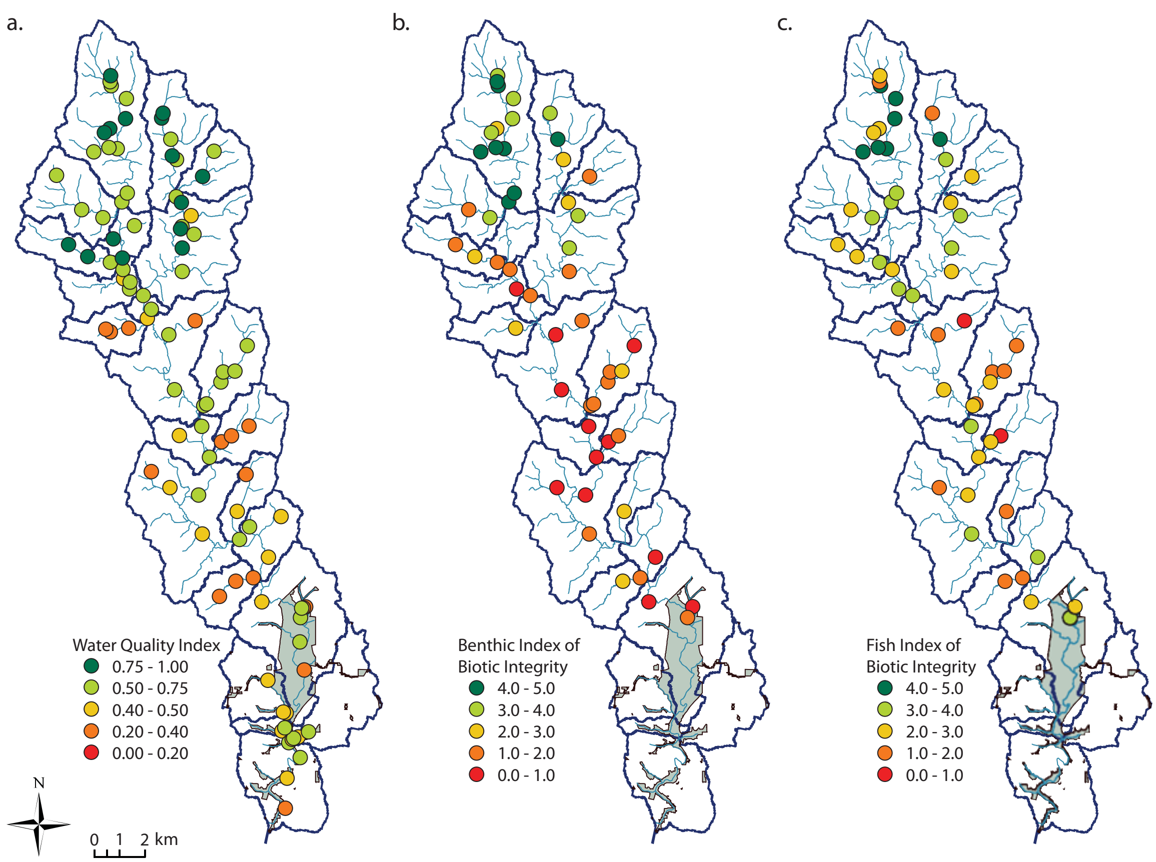
The population density for the Rock Creek watershed generally increased moving downstream (Figure 3.4c). The highest density of people was found in the four subwatersheds surrounging Rock Creek Park in the lower portion of the watershed. 12 additional subwatersheds had high population densities in the orange category. One subwatershed had moderate population density in the yellow category. Six subwatersheds and Rock Creek Park had low population densities in the light green (2) and green (4) categories.

Statistical Analysis

Water Quality Index

The water quality index was calculated using the nutrient data collected during the synoptic sampling (Figure 3.5a). The results showed generally good to excellent water quality in the upper portion of the watershed, and good to degraded condition in the middle and lower portions of the watershed. This was in contrast to the benthic IBI data (Figure 3.5b) which showed excellent to degraded condition in the upper

Figure 3.5. Values for each sampling point of the (a) water quality index, (b) benthic index of biotic integrity (Benthic IBI), and (c) fish index of biotic integrity (Fish IBI). Note there were fewer IBI sampling points than there were water quality sampling points.



watershed and fair to very degraded condition in the middle portion of the watershed. The fish IBI (Figure 3.5c) showed excellent condition only in the upper portion of the watershed and fair to degraded condition throughout. There was minimal IBI information available for the lowest portion of the Rock Creek watershed as IBI sampling was generally not conducted outside of the state of Maryland.

Correlation Analysis

The results of the correlation analysis (Table 3.2) showed stronger correlation between the water quality index, fish IBI, and benthic IBI at the site level (a) than at the subwatershed level (b). At the site level, all three measures of site condition were strongly correlated. At the subwatershed level, the water quality index was correlated with the fish and benthic IBI; however, the fish and benthic IBI were not correlated with each other. These correlations account for approximately 16% of the variability in the

Table 3.2. Results of the correlation analysis between the water quality index, fish index of biotic integrity, and benthic index of biotic integrity. Pearson correlation coefficients for all sites (a) and each subwatershed (b) are shown. Correlations were considered significant if $p \leq 0.05$.

a. n = 61	Water Quality Index	Fish Index of Biotic Integrity	Benthic Index of Biotic Integrity
Water Quality Index	1.00		
Fish Index of Biotic Integrity	0.35 $p < 0.01$	1.00	
Benthic Index of Biotic Integrity	0.41 $p < 0.01$	0.39 $p < 0.01$	1.00

b. n = 19	Water Quality Index	Fish Index of Biotic Integrity	Benthic Index of Biotic Integrity
Water Quality Index	1.00		
Fish Index of Biotic Integrity	0.52 $p = 0.02$	1.00	
Benthic Index of Biotic Integrity	0.47 $p = 0.04$	0.16 $p = 0.51$	1.00

IBIs. This suggests that there may be other factiors influencing the IBI measurements, including seasonality of measurements.

The correlation analysis indicated that there was high variability within subwatersheds. This was shown in the decreased significance of the correlations at the subwatershed scale compared to the site scale. In the data figures (Figure 3.4), the data groupings by color showed a range of 3 groups for the benthic IBI and the water quality index and a range of 4 groups per subwatershed for the fish IBI. This suggested that the subwatersheds were not the appropriate scale at which to aggregate data. This might have been an indication of high habitat variability within a subwatershed or high variability within the types of streams in each subwatershed. This high variability led to the larger geographic groupings used for the ANOVA.

The results of the landcover correlation analysis showed that many of the landcover variables were strongly correlated (Table 3.3). This was especially true of the derived layers. These layers were all dependent upon one another ($p < 0.01$ for all), as population density increases, so did road density and impervious surface. It would be interesting to study any locations that did not follow this general pattern.

Additionally, developed areas were strongly correlated with the derived layers. This was to be expected as the developed landcover type measures the same types of information as the impervious surface ($p < 0.01$) and road density ($p < 0.01$) layers. It was interesting to note that there is a negative correlation between development and open water ($r = -0.44$, $p = 0.036$). This might have been an indication of stream burial due to urbanization.

The forest and planted cover types were negatively correlated with the derived layers ($p < 0.01$ for most) and development ($p < 0.01$ for both). This was to be expected as

Table 3.3. Results of the correlation analysis between the water landcover variables. Derived layer variables are highlighted with a blue box. Correlations with significance of $p \leq 0.05$ are highlighted in yellow.

	Population	Road Density	Impervious Surface	Water	Developed	Barren	Forest	Planted	Wetland
Population	1.00	0.82 p < 0.01	0.73 p < 0.01	-0.26 p = 0.23	0.64 p < 0.01	-0.26 p = 0.23	-0.41 p = 0.05	-0.60 p < 0.01	0.24 p = 0.26
Road Density		1.00	0.72 p < 0.01	-0.39 p = 0.06	0.87 p < 0.01	-0.13 p = 0.54	-0.64 p = 0.001	-0.77 p < 0.01	0.28 p = 0.19
Impervious Surface			1.00	-0.36 p = 0.09	0.86 p < 0.01	-0.19 p = 0.39	-0.66 p < 0.01	-0.72 p < 0.01	0.06 p = 0.77
Water				1.00	-0.44 p = 0.03	-0.07 p = 0.75	0.17 p = 0.44	0.39 p = 0.06	0.23 p = 0.28
Developed					1.00	-0.07 p = 0.76	-0.73 p < 0.01	-0.87 p < 0.01	0.14 p = 0.52
Barren						1.00	0.07 p = 0.74	-0.00 p = 0.99	0.07 p = 0.74
Forest							1.00	0.32 p = 0.13	0.04 p = 0.87
Planted								1.00	-0.33 p = 0.13
Wetland									1.00

development generally occured on what were once forested or planted areas. Greater development would tend to lead to lower amounts of those cover types.

Analysis of Variance

There was a trend of decreasing water quality as water moved downstream, as measured by both the water quality index and the benthic IBI (Table 3.4a). The results of the multiple mean comparison tests showed that the upper watersheds were in the best condition for the water quality index (mean = 0.72[a]). The water quality index indicated that the upper middle watersheds were in the next best condition (mean = 0.58[b]) and that the lower middle (mean = 0.44[c]) and lower (mean = 0.48[c]) watersheds were in the worst condition. The benthic IBI showed that the upper watersheds (mean = 3.48[a]) were in the best condition. All the remaining watersheds were in worse

Table 3.4. Results of one-way analysis of variance for geography and stream order. Columns represent separate ANOVA runs. Numbers in columns followed by the same letters are not significantly different ($p < 0.05$). Numbers in parenthesis indicate the standard error of the mean.

a. One-Way Analysis of Variance for Geography

	Mean WQI	Mean BIBI	Mean FIBI
ANOVA Significance	$p < 0.0001$ $n = 95$	$p < 0.0001$ $n = 61$	$p = 0.0198$ $n = 61$
Upper Watersheds	0.72[a] (0.024)	3.48[a] (0.19)	3.23[a] (0.21)
Upper Middle Watersheds	0.58[b] (0.025)	2.01[b] (0.19)	2.67[ab] (0.21)
Lower Middle Watersheds	0.44[c] (0.029)	1.46[b] (0.26)	2.09[b] (0.29)
Lower Watersheds	0.48[c] (0.028)	1.22[b] (0.51)	2.92[ab] (0.58)

b. One-Way Analysis of Variance for Stream Order

	Mean WQI	Mean BIBI	Mean FIBI
ANOVA Significance	$p = 0.0002$ $n = 95$	$p = 0.0003$ $n = 61$	$p < 0.0001$ $n = 61$
First Order	0.53[b] (0.026)	2.25[b] (0.29)	2.32[b] (0.24)
Second Order	0.56[b] (0.029)	2.49[b] (0.23)	2.26[b] (0.29)
Third Order	0.76[a] (0.041)	3.33[a] (0.29)	3.70[a] (0.24)
Fourth Order	0.55[b] (0.034)	1.32[c] (0.32)	3.23[a] (0.27)

condition than the upper wateresheds (means = 2.01^b, 1.46^b, and 1.22^b). The fish IBI did not show a geographic pattern. The only significant pattern in the fish IBI data showed that the upper watersheds (mean = 3.23^a) were in better condition than the lower middle watershed (mean = 2.09^b).

The stream order analysis for water quality showed that third order streams were in the best condition (mean = 0.76^a) (Table 3.4b). The water quality index analysis showed that the remaining orders were in the same condition (means = 0.53^b, 0.56^b, and 0.55^b). The benthic IBI analysis showed that the third order streams were in the best condition (mean = 3.33^a). The first (mean = 2.25^b) and second (mean = 2.49^b) order streams were in the next best condition. The fourth order streams (mean = 1.32^c) were in the worst condition of all the stream orders. Finally, the fish IBI showed that third (mean = 3.70^a) and fourth (mean = 3.23^a) order streams were in the best condition while first (mean = 2.32^b) and second (mean = 2.26^b) order streams were in the worst condition.

It was possible that the high water quality observed in the third order streams was an artifact of the geographic location of those streams. All of the third order streams were located within the upper watersheds. These watersheds were generally in the best condition. There may be an additional artifact of water volume that could not be tested using this dataset. Not enough flow information was available to determine if there was a difference between first order streams in the upper watershed and first order streams in the lower watersheds. This flow difference may be due to differing stream densities between watersheds. A more appropriate grouping may be to determine flow volume and to separate the streams according to volume rather than order.

The high fish IBI scores in third and fourth order streams may be an indication of high habitat quality in those streams. The third and fourth order streams were protected by a forested riparian buffer throughout the majority of their length. This buffer consists of Montgomery County's Rock Creek Park as well as the National Park Service's Rock Creek Park. These parklands provided woody debris and stream shading that may be critical for fish habitat. However, some of the variability in the stream order results may be due to the species-area effect on fish IBI, where wider streams result in higher fish IBI regardless of habitat quality.

The data for the geographic location analysis were graphed using box and whisker plots versus the population density (Figure 3.6). The condition of the watershed generally decreased downstream. Interestingly, the average condition of the lower subwatersheds was in better condition than expected from the other areas. This was evident in the water quality index (Figure 3.6a). The median condition of the lower watersheds was better than the lower middle watersheds. The benthic IBI graph (Figure 3.6b) did not show this relationship as the metric did not have values below

Figure 3.6. Site condition measures (water quality index [a], benthic IBI [b], and fish IBI [c]) versus population density by geographic area. The box plots represent sites within the geographic areas.

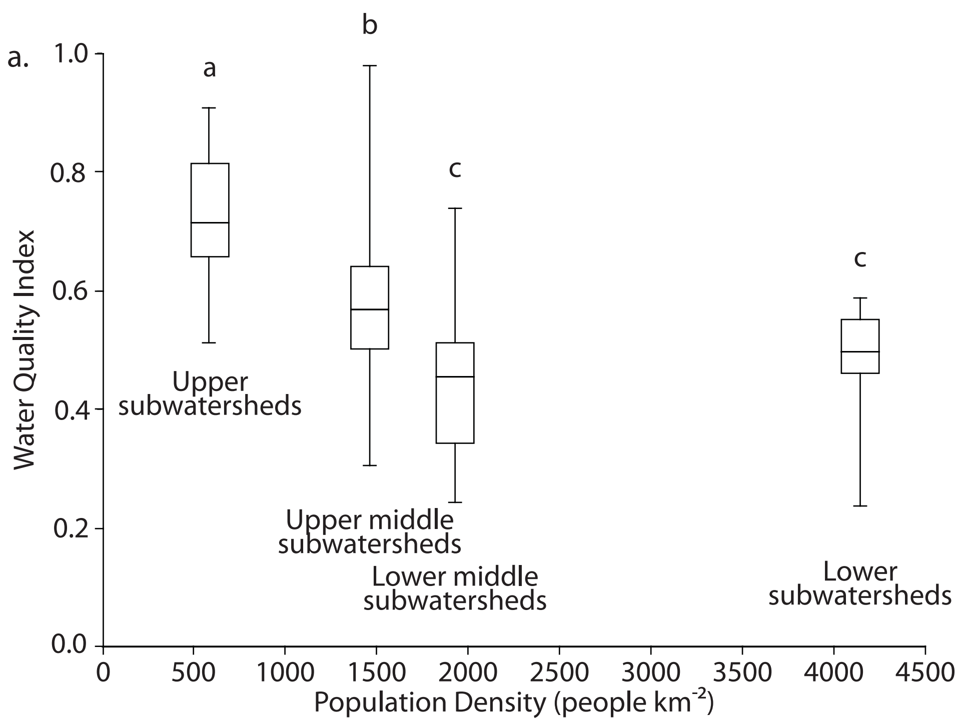
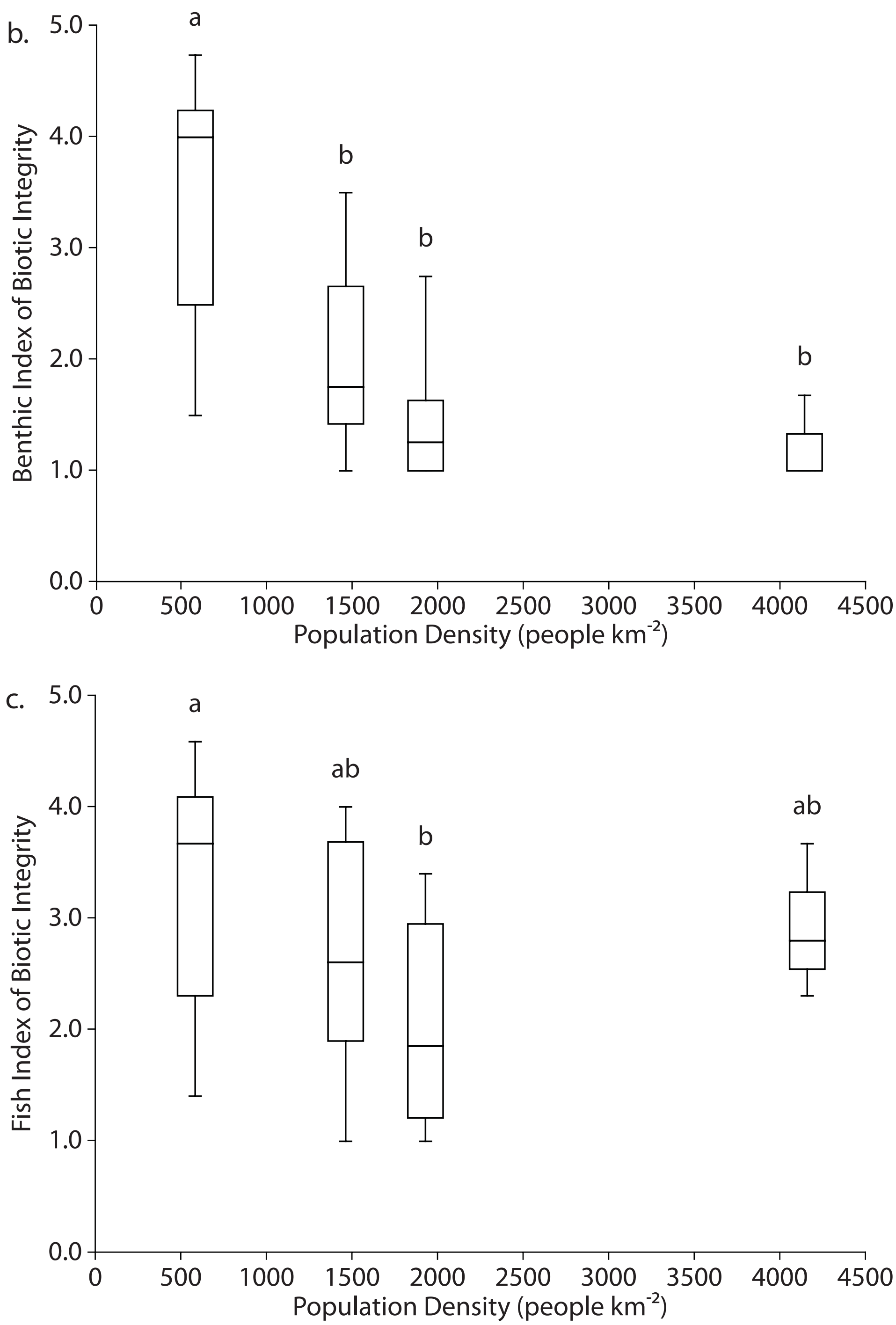


Figure 3.6 (continued). Site condition measures (water quality index [a], benthic IBI [b], and fish IBI [c]) versus population density by geographic area. The box plots represent sites within the geographic areas.



one. This relationship was most strongly evident in the fish IBI graph (Figure 3.6c). In this case, the lower watersheds were actually in better condition than the upper middle and lower middle watersheds.

Discussion

In general, the results of the watershed assessment showed that the water quality parameters tended to be in better condition in the upper Rock Creek watershed and degraded downstream. Rock Creek Park was in the same or better condition than the immediately surrounding subwatersheds.

Water Quality Index can provide a broad spatial picture of stream health

The correlation analysis showed that the water quality index and the benthic index of biotic integrity were highly correlated. The benthic IBI has been shown to be an indicator of stream condition (Engle & Summers 1999; Cao et al. 1997). The benthic IBI integrates community structure and function and can be used as an indicator of pollution as well as natural fluctuation in site condition (Engle et al. 1994). Because the water quality index was highly correlated to the benthic IBI, it can be assumed that the water quality index would give similar results for stream condition. The benthic IBI required many hours of sampling and cataloguing to determine site condition (Roth et al. 2005). The water quality index on the other hand only required a quick grab sample and probe reading at each site with minimal laboratory analysis. Therefore, the water quality index could be used as a reasonable rapid assessment procedure that would give similar results for stream condition using fewer resources than the benthic IBI.

Small stream burial in urban areas reduces nutrient cycling and habitat

Buried streams occur when small headwater streams, which are thought to have high nutrient cycling, are paved over to create commercial and residential developments.

The loss of these headwater streams may therefore decrease the amount of nutrient cycling within an urbanized watershed. Additionally, stream conversion decreases fish, benthic, and riparian habitat (Elmore & Kaushal 2008). This disrupts dispersal and colonization of species that depend on those habitats.

Stream burial can also increase contamination of current streams due to decreased contaminant processing. Rather than infiltrating or interacting with the landscape, rain water and contaminants immediately enter the stream system. The increased contamination can change food webs and ecosystems. Additionally, the water temperature regime of the stream can change because while ground water is a relatively consistent temperature, water streaming directly from pavement can be much hotter or cooler than expected (Elmore & Kaushal 2008, Cadenasso et al. 2008).

Stream hydrographs are also affected by stream burial. The hydrograph becomes flashier, which means stream flow increases and decreases more sharply than an undeveloped stream hydrograph. This flashiness can increase erosion because more water enters the system than is expected. This increased erosion can reduce important habitats by removing woody debris and decreasing pool locations. Increased sedimentation as a result of bank erosion can change benthic habitat from hard gravel to soft sediment; thereby changing the type of organisms that can live in the stream (Elmore & Kaushal 2008, Cadenasso et al. 2008).

Elmore & Kaushal (2008) have calculated a probability of stream burial in Baltimore County, Maryland. In Baltimore, there is a very high probability that streams will be buried in the city center, with radial lines of high burial probability extending along major highway arteries. Moving farther from the city, the probability of buried streams decreases, but for the linear road features. One can assume that the buried streams in Baltimore are correlated to the extent of buried streams in the Washington DC metropolitan area due to similar urbanization history. Developed landcover, one of the main inputs for determining stream burial, follows a similar pattern in the Washington DC metro area (Figure 3.1c) as the buried stream map in Baltimore County.

Particularly for the Rock Creek watershed, in the upper watershed the small headwater streams were still aboveground and were sampled as part of this effort. Traveling down the watershed, the small streams were increasingly buried. Bill Yeamen, long-time resource manager for Rock Creek Park, speaks of the increasing impervious surfaces around the park. He points out that what were previously open lots are now multi-family dwellings and that large tracts of land are being converted to homes throughout the watershed (pers comm. B. Yeamen) Within Washington DC, the only streams that were aboveground were located within the bounds of Rock Creek Park. This was consistent with the observations of Elmore and Kaushal (2008) in that open streams in urban areas are either too large to bury or are protected as a result of other land protection such as parks.

Members of the Friends of Rock Creek's Environment (FoRCE), a nonprofit group working to promote conservation, restoration and education in the Rock Creek watershed, are working with the DC DOE to possibly daylight a portion of Broad Branch, a Rock Creek tributary in Washington DC. Daylighting is the process of unburying a stream which reconnects the stream with its floodplain, slowing the delivery of water, reducing erosion, providing habitat and allowing for biological processing (Cadenasso et al. 2008). A public meeting was held in January 2008 regarding the possibility of daylighting this portion of the tributary.

Riparian buffers decrease nutrients and increase the interception of sediments and pollutants

Riparian buffers intersect the landscape adjacent to streams and help to remove pollutants through filtration and infiltration (Zhen et al. 2006, Peterjohn & Correll 1984). Stream restoration classically includes planting riparian buffers to reduce sedimentation, improve water quality, increase biodiversity, and create habitat for wildlife and recreational activities (Hassett et al. 2005, Walsh et al. 2005b). Within Maryland, increasing riparian buffer width correlates to increased numbers of amphibian and reptile species and increased benthic and fish IBI (Roth et al. 1996, Roth et al. 1999). Additionally, riparian land use nearest the stream is closely related to in-stream nutrient concentration (Osborne & Wiley 1988). Therefore, riparian forests result in lower stream nutrient concentrations.

Within Maryland and specifically the Potomac Washington Metro watershed, which includes Rock Creek, approximately 25% of streams have no riparian buffer. However, 40% of streams in the state have a buffer of 50m or greater (Roth et al. 1999). Therefore, buffers are fragmented throughout the local area. It has been suggested that a riparian buffer of less than 15 meters in width is an indicator of stress (Roth et al. 1999). However, some researchers suggest a riparian buffer of 60 to 120 meters to protect stream health (Mehaffey et al. 2005).

In Rock Creek, all third and fourth order streams are surrounded by parkland, which was generally forested. The width of the parkland varied along the length of the stream from 100 to 1500 meters. These parks were acting as riparian buffers for the highly urbanized watershed. The riparian buffers provided complex stream habitat for fish, which included shading, leaf litter, and woody debris that help in the formation of pool and riffle habitat (Roth et al. 1996, Volstad et al. 2003). However, while these parklands provided a high quality local stream habitat, upstream inputs may overwhelm the protective ability of the park buffers (Roth et al. 1996). The results of this study showed that Rock Creek Park was acting to maintain the incoming level of water quality and habitat, but could not improve the water quality due to the intense upstream pressures.

Urban infrastructure may be allowing water to bypass the riparian buffers

In some cases, the urban infrastructure of stormwater and wastewater management may be bypassing the riparian buffer zones because water is piped directly into streams (Pickett et al. 2008, Cadenasso et al. 2008, Hasset et al. 2005). Additionally, incised streams lower groundwater tables and can disassociate the stream from its riparian buffer. The incised channels prevent overbank flow, further decreasing the streams interaction with its floodplain and reducing the nutrient processing potential of the buffer (Pickett et al. 2008, Cadenasso et al. 2008). These problems, in addition to the further listed, have come to be known as the "urban stream syndrome" (Meyer et al. 2005, Walsh et al. 2005b) Symptoms of the urban stream syndrome include a flashy hydrograph, high concentrations of nutrients and contaminants, reduced channel complexity due to channel straightening and armoring, increased erosion, and reduced biodiversity (Paul & Meyer 2001, Meyer et al. 2005, Walsh et al. 2005b).

A single indicator may not be indicative of the urban stream syndrome as the cause of the syndrome is highly complex. Urban stressors can both interact and covary due to having the same overlying cause, which is anthropogenic (Walsh et al. 2005b). For example, urban land use and deforestation are correlated because as urban land is built it generally takes the place of riparian forest habitat or agricultural land (Walsh et al. 2005b). In the Rock Creek watershed, this may not be true as the large riparian forest was protected through the Park Service and Montgomery County.

One management practice that may help to prevent the symptoms of the urban stream syndrome is to increase residence time of stream water, thereby decreasing nutrients by allowing time for processing as well as providing complex habitat for fish and other species (Roth et al. 1996). Increasing stream sinuosity may help to prevent increasing erosion of streams by providing locations where sediment can settle into pools (Roth et al. 1996, Cadenasso et al. 2008). Additionally, increased stream sinuosity can provide help create local areas of anaerobic high organic matter sediments where denitrification can occur (Cadenasso et al. 2008). This sinuosity may already be available in Rock Creek Park as the stream travels 9.7 miles through 6.1 miles of parkland (CH2M Hill 1979).

While Rock Creek Park managers cannot prevent high amounts of impervious surface in the watershed outside the park, they can help promote ideas of decreasing stream connectedness. The traditional urban stormwater management treats streams as pipelines for removal of urban rainfall. These direct connections flush water and nutrients into the stream for small rainfall events that otherwise would have infiltrated and not created streamflow (Walsh et al. 2005a). In addition to traditional stream restoration techniques of riparian buffers, using stormwater management devices such as retention ponds, rain gardens and green roofs throughout the watershed may treat the symptoms of the urban stream syndrome by slowing water delivery, increasing nutrient processing and decreasing erosion (Cadenasso et al. 2008, Walsh et al. 2005b).

Land use models may over-predict water quality, especially in small watersheds

Land use models have been used to predict the water quality of receiving water bodies such as the Chesapeake Bay (Cerco et al. 2002; Li et al. 2007; Goetz & Fiske 2008; Bilkovic et al. 2006; Snyder et al. 2005; King et al. 2005; Weller et al. 2003; Lung

& Bai 2003). These models take into account remotely sensed information, but do not incorporate information such as increased connectivity of urban land to streams or stream incision, which may lead to incorrect model results. By not including these important parameters, the models may be predicting better water quality than is observed.

The results of this study did not suggest a correlation between land cover and water quality in small streams such as Rock Creek. This lack of correlation suggested that land use models were inconsistent at the scale of a small watershed. This had important management implications for small watersheds because tools must be developed to assist with predicting the results of management actions. If resource managers were unable to accurately predict the results of their actions, then limited restoration funds may be spent on projects that may not provide improved water quality in the target area.

Fish IBI responds differently in Rock Creek than in other urban watersheds

Fish index of biotic integrity may be responding to different factors than the other measures. Morgan & Cushman (2005) found that fish abundance decreased in Piedmont Maryland Biological Stream Survey sites as stream order increased. They also found that the fish index of biotic integrity was inversely correlated with urbanization. This was opposite the results of our study as we found that fish index of biotic integrity was higher in third and fourth order streams and in areas with higher urbanization. This may be due to factors such as stream shading and high habitat quality provided by the riparian buffer that is Rock Creek Park and the Montgomery County Rock Creek Park.

Spatially intense sampling is important for long-term monitoring programs

In this study there were 95 sampling locations throughout the Rock Creek watershed. This large amount of data collected in one month was similar to the amount of data that the NCRN will collect within Rock Creek Park in one year (Norris & Fisher 2006). For some long term monitoring programs, such as the MBSS program, this amount of data would take upwards of many decades. Therefore, a long-term monitoring program may require many years to accumulate enough data to return the same statistical significance as a single spatially intense synoptic sampling program.

However, single snapshot sampling, like the one done in this study, makes a tradeoff between spatial density and temporal density. The single snapshot sampling provided a high spatial density in that there were multiple sampling locations within each subwatershed. This provided a large amount of information about the water quality at that specific time. A long-term monitoring program allows for the development of temporal information. This would allow for discovery of trend information, how water quality changes through time. Both spatially and temporally intensive sampling designs provide important information for environmental management.

While a monitoring design that provides both intense spatial and temporal information would be the best solution, many monitoring programs do not have the funding to follow such a plan. An organization with limited funding could have sentinel sites at which they monitor water quality on a monthly basis. They then could develop a longer term (annual, biennial, or quinquennial) spatially intense water quality sampling throughout a watershed. This would provide the monitoring organization with trend data at the sentinel sites and snapshot sampling throughout their monitoring region.

In addition to these current management concerns, climate change may modify the current water quality regime. Increased precipitation in the greater Washington region (Boesch 2008) is likely to increase flow rates within Rock Creek. These increased flow rates may increase bank erosion and therefore increase channel incision. Increased channel incision may decrease the buffering capacity of Rock Creek Park if the incision brings the channel bottom below the forest root zone. These climate induced changes could be further exacerbated through the increasing urbanization of the Rock Creek watershed. It has been suggested that droughts in the Washington region (Boesch 2008) may reduce summer flow in Rock Creek. The sampling for this study was conducted during such a drought and most of the upper watershed had no flowing water in the stream channel. Increasing droughts would decrease the number and types of species able to survive, grow, and reproduce within the Rock Creek watershed. It has been suggested that the maple-beech-birch forests, which currently dominate Rock Creek Park, may be replaced by pine trees due to increased temperatures, drought stress, and storms (Boesch 2008). This change in forest type may change the effectiveness of the buffering provided by the park.

Resource managers must respond to pressures outside park boundaries

This study showed a direct linkage between population pressure (as measured by impervious surface, population density, and road density) and ecological integrity (as measured by water quality). This linkage had been termed the urban stream syndrome in the scientific literature (Cadenasso et al. 2008, Walsh et al. 2005b). The innovative restoration and stormwater management techniques, such as forcing flow through the root zone of the park, retention ponds, rain gardens, and green roofs, may help to decouple the population pressure from the stream water quality by slowing water delivery directly to the stream. The NPS has already begun some of this work by providing a green roof on the Center for Urban Ecology (Curtis 2005) which was within the Rock Creek Park boundaries, but not the Rock Creek watershed.

Effective management of Rock Creek Park requires resource managers to reach beyond the park boundaries and work with other agencies to improve the entire watershed. The National Park, along with the Montgomery County Rock Creek Park, provides a riparian buffer and protects an extensive open stream network within this heavily urbanized watershed. These protected forested buffers are maintaining a level of water quality, but are not able to improve upon that quality. If park managers could work with other agencies to improve the incoming water quality then the Park, acting as a riparian buffer, may be able to improve the overall water quality exiting the park.

Chapter 4: Summary and Recommendations

Summary of Previous Chapters

In Chapter 2 the recommended analytical framework for environmental report cards was created using monitoring data from the National Park Service Inventory & Monitoring Program. The recommended analytical framework contained between 6 and 11 metrics, had a balanced design, was calculated using a summation method, and relied on a linear thresholding method.

In Chapter 3, a watershed assessment was conducted to provide context for the Rock Creek Park assessment conducted in Chapter 2. This watershed assessment was a month long spatially intense sampling. The results showed that the park was heavily influenced by exterior urban pressures. The park was able to maintain the level of water quality incoming, but ecological processes were not able to improve upon that water quality.

Thesis Implications

The recommended analytical framework was a simple report card method that provides a high level overview of park condition (Locantore et al. 2004). The report card used eight metrics, two from each broad category, to provide a numeric indication of park health. This high level overview facilitated the communication of monitoring results and other scientific information to resource managers or the public. The simplicity of the recommended analytical framework can help non-technical audiences understand the connections between the monitoring data and the overall report card.

Previous report cards for the National Parks were in sharp contrast to the recommended analytical framework. In particular, the National Parks Conservation

Association promoted a report card that contains more than 100 metrics. These metrics ranged from 'Soil Flora and Fauna', to 'Air Quality' to 'Number of National Historical Places' and the 'Number of park staff' (NPCA 2005, NPCA 2003). This large number of metrics could be overwhelming for managers and the public, especially when the variety of metric types was so broad. Fewer metrics could provide similar information regarding the park without the need to collect such disparate data.

The monitoring framework developed by the I&M Program was highly useful for the collection of monitoring data as well as reporting at the vital sign category level (Fancy et al. 2009). To report at the park level, a different reporting framework should be developed. The recommended analytical framework provided this more targeted reporting framework. It also allowed park resource managers to select important metrics from within the greater I&M framework to determine park health solely within their legislative boundary.

The condition of Rock Creek Park was heavily influenced by the intense surrounding urban pressures (Lookingbill et al. 2007). The urban land use decreased the water quality in what was known as the urban stream syndrome (Meyer et al. 2005, Walsh et al. 2005b). The Park was acting as a riparian buffer and was able to maintain incoming water quality. However, the riparian buffer was not able to improve water quality due to the high nutrient concentrations and high water speed, both symptoms of the syndrome.

Because the intense urban pressures were affecting the park so significantly, it was important that resource managers work together with neighbors and other federal, state, and local groups to protect Rock Creek Park. The park resource managers are confined to manage within their legislative boundary; therefore, they need to work with others to improve the condition of exterior lands. Some specific organizations that the park resource managers should consider working with include the Washington DC Department of the Environment, the Montgomery County Department of the Environment, and the Friends of Rock Creek's Environment.

At the site level, the benthic and fish indices of biotic integrity were highly correlated with each other and the water quality index (Chapter 3, Table 2: $p < 0.01$ for all). However, as the spatial scale increases, the correlations became less significant. The water quality index remained significantly correlated with both the fish and benthic indices ($p = 0.02$ and $p = 0.04$ respectively); whereas the fish and benthic indices were no longer correlated ($p = 0.51$). The decrease in significance may be due to high variability between sites within the subwatersheds. This increased variability suggests that the immediate site surroundings are most important for determining stream quality. The MBSS takes into account the 75 meters around a stream location when calculating the IBI scores (Roth et al. 1999). These findings suggested that while upstream water quality may provide some indication of downstream quality, the immediate surroundings were the most important factor in determining local water quality.

Well-established indicators of poor water quality were found throughout the Rock Creek watershed. Incised stream channels and high nutrient concentrations were examples of these well-established indicators. Additional more novel indicators were found throughout the watershed, including increased salinity and decreased dissolved oxygen concentration. The techniques needed to manage these established and emerging problems were a combination of traditional and innovative technologies. Maintaining riparian buffer habitat along the stream banks had only provided enough protection to prevent declining water quality throughout the park. Additional techniques to decrease the connectedness of the urban habitat surrounding the park, such as rain gardens or increased stream sinuosity, are emerging as new techniques to improve water quality (Cadenasso et al. 2008). Rock Creek Park resource managers should look to these emerging techniques to protect and improve their park in the future.

The quick assessment described in Chapter 3 provided dense spatial water quality information that provided a similar indicator of stream health as the more time consuming indices of biotic integrity. While the two types of indicators provided similar information, both provided important information. The indices used bioindicators to determine important information about the water quality as it related to the biotic environment. Sampling for bioindicators is time consuming and costly; therefore, it can only be done at a limited number of sampling sites in a given amount of time. The water quality measurements conducted as part of Chapter 3 can provide a granular indication of the water quality of the stream and were quick to conduct relatively inexpensively. These properties suggested that spatially intense quick sampling spaced 3 to 5 years apart should be included as part of a long-term monitoring program. Sentinel sites, where information on bioindicators and more regular water quality sampling is conducted, should be a part of the monitoring program as well.

Applications

The recommended analytical framework developed in Chapter 2 can help future resource managers with streamlining the data needs for assessments of National Parks. Depending upon the assessment needs of the resource managers, they can choose a limited number of information rich metrics to sample for their park. Then, using a simple framework (Locantore et al. 2004), an assessment could be conducted for that area. The recommended analytical framework for a park assessment required a subset of the data that was being collected by the I&M Program. Therefore, park resource managers could determine which metrics were most important for their resources and determine a score for each resource. This type of framework has been included in the Natural Resources Condition Assessment for Rock Creek Park (Carter et al. 2009). These different types of assessments allow resource managers to quickly and accurately determine specific management needs for their park.

Another important aspect of the recommended analytical framework was its applicability to all protected areas including Federal, state, local, and non-governmental organization (NGO) protected areas. The recommended analytical framework provides a framework over which a resource manager can determine the condition of her particular protected area. If monitoring data were not available for a protected area, then resource managers could select a small number of metrics and thresholds to begin a monitoring program in their locale. As shown in Chapter 2, these metrics do not have to have a set spatial or temporal sampling schedule to provide a consistent assessment. If enough resource managers adopt this sort of framework, then regional and national comparisons of protected areas would be possible. These assessments could provide important insights into management methods between agencies, states, or eco-regions. Additionally, the recommended analytical framework could be used to compare parks in different locations throughout a watershed. Rock Creek Park is in the lower portion of the watereshed, whereas many other protected areas are in the upper portions of the watershed. These comparisons could provide insight into the effect of park location on park condition.

The recommended analytical framework provided a straightforward communication protocol for the data analysis conducted in a park assessment. By using a simple and clear framework, a non-scientific audience, such as the general public, could easily understand the results of the assessment. If a politician was solely interested in the score of their protected area versus the score of a nearby protected area, then that information was available. If a bird watcher was interested in the quality of forest habitat for birds, that information was easily accessible. If that same bird watcher wanted to continue further into the available monitoring data and determine if he has seen all of the bird species found in the forest, then that information also could be found by analyzing the monitoring data. The recommended analytical framework provided a framework to allow for access of these varying levels of information for all audiences.

The results of the recommended analytical framework allowed resource managers to determine management priorities for the park as well as the four broad resource categories. Resource managers could determine which metrics were most in need of restoration or protection based on the score in the assessment. The metrics with a score close to one were in excellent condition and should be protected for being in near desired condition. The metrics with a score close to zero were in very degraded condition and should be restored. Managers should prioritize the restoration and protection of these resources.

Resource managers need to implement innovative management practices to protect their resources from the emerging issues. In particular, these innovative practices will help to protect urban parks from the results of the urban stream syndrome (Meyer et al. 2005, Walsh et al. 2005b). Typical symptoms of the urban stream syndrome include a flashy hydrograph, high concentrations of nutrients and contaminants, reduced channel complexity due to channel straightening and armoring, increased erosion, and reduced biodiversity (Paul & Meyer 2001, Meyer et al. 2005, Walsh et al. 2005b). The innovative management practices that can help to address these symptoms help to decrease the connectedness of urban areas to the stream. The direct connections between impervious urban areas and the stream channel can bypass the protections of traditional management practices such as riparian buffers (Pickett et al. 2008). Innovative management practices include the use of rain gardens to increase infiltration and baseflow and increasing stream sinuosity to allow for increased sedimentation and nutrient cycling (Cadenasso et al. 2008, Walsh et al. 2005a). These innovative management practices may assist with the protection and restoration of urban parkland through the reduction of nutrients and increased biodiversity.

Future Research

In the future, it would be interesting to track the results of a management action through consecutive assessments. If, as a result of this assessment, a resource manager decides to increase nutrient cycling and fish habitat in the stream channel by adding woody debris, subsequent assessments should show the scores for nutrients and fish improving. It would be important to track the speed of resource improvement due to management action so that future managers would know what to expect when conducting the same action. Changing assessment results as a function of management action would be an important test of the recommended analytical framework.

Future researchers should attempt to determine particular causal agents for the urban stream syndrome. Certain aspects of urbanization may result in different effects on stream health. By looking at various locations throughout an urbanized locale, it may be possible to tease out information regarding the effects of habitat configuration or urban density. Habitat configuration could be tested by looking at watersheds that have forested riparian buffer habitat versus watersheds that contain the same amount of non-riparian forest habitat. It would be expected that those watersheds with a forested riparian buffer would have better water quality than those watersheds without a buffer. Differing urban density could be tested by looking at different types of urban development. For example, high density urban skyscrapers could be compared to an area where the building density is similar but the height of the buildings is less. These areas should have similar impervious surface, but differing vehicle or human inputs; therefore, one would expect that the stream with higher urban density would have more roadway contaminants or human inputs than the less densely populated watershed. By removing some of the correlated anthropogenic factors leading to the urban stream syndrome, it may be possible to show varying stream chemistry to help resource managers protect their land from urbanized surroundings.

Developing ecologically valid thresholds is one of the most difficult tasks of this assessment. Further research is needed into the specific ecological importance of those thresholds that currently are based on regulatory or professional opinion. Some of the thresholds used in this assessment were not based on local information, so studying those topics within or near the protected area of interest would result in more accurate thresholds. If resource managers are acting solely on historic or subjective information, then they may not be using the best information to make management decisions. By researching threshold values scientists can help managers make more informed decisions regarding protected areas.

If large amounts of monitoring data are available for a particular park, it is important to choose the best information when conducting an assessment, depending upon the objectives of the report card. Future researchers could determine which types of metrics are most informative for assessments. These metrics could be important to the local ecology or specific to a particular park. The metrics chosen under the recommended analytical framework were uncorrelated and measured information within the park boundary. These caveats were included in the description of the assessment so as not to bias the assessment. It is important to choose metrics based on their importance to the protected area, and not just based on whether those metrics will result in a low or high score. Some scientists would like to include only metrics that are in need of improvement (Lookingbill et al. In Review), while some managers would like to include only metrics that show their resources in good condition. It is important to be clear regarding the objectives of the report card when choosing metrics so that the audience understands the resulting condition score.

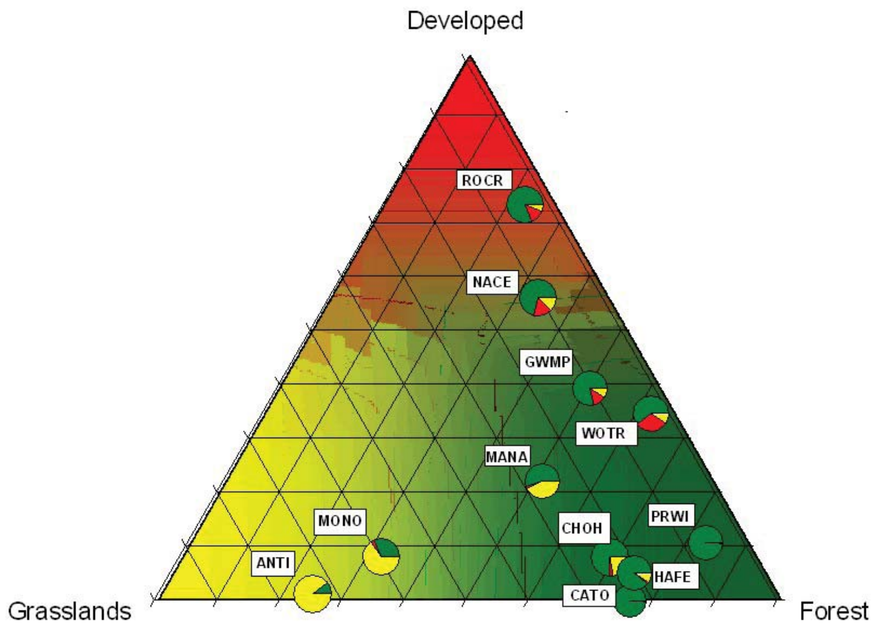
Future research based on the results of Chapter 3 should focus on testing and developing a protocol for rapid, spatially intense sampling plan. The results of Chapter 3 suggest that rapid, spatially intense sampling should be conducted on a regular time interval as part of a monitoring program. Developing a protocol for including this type of sampling along with sentinel, temporally intense sampling stations would provide a way for long-term monitoring programs to include all types of information. Having a protocol available may allow the park resource managers to work with other groups to allow park management to take into account information gathered outside the park.

Further research is needed into the different responses of the fish and benthic indices of biotic integrity at different spatial scales. The high correlation at the site scale, but low correlation at the subwatershed or greater scales is a very interesting set of relationships. Mesocosm studies which use variables such as water volume, water speed, stream shading, or water temperature may bring out causal relationships that were not possible to determine in this study. These mesocosms may need to be large scale and long-term in order to determine the differences between what may be subtle variables. Controlled experiments will help managers to interpret the results of this study and provide hard evidence for a future management response (Petersen et al. 2009).

Beyond the site scale, it is important to link monitoring or in situ information with land use models. These models are used to predict nutrient inputs to receiving water bodies such as the Chesapeake Bay (Cerco et al. 2002; Li et al. 2007; Goetz & Fiske 2008; Bilkovic et al. 2006; Snyder et al. 2005; King et al. 2005; Weller et al. 2003; Lung & Bai 2003). The models allow scientists to manipulate temporal and spatial scales beyond the bounds of natural experimental ecosystems (Petersen et al. 2009). Models could use the results of a mesocosm study on reducing impervious surface connectivity to streams and then determine the effect of increasing the use of that management decision (i.e. rain gardens or retention ponds) on the Chesapeake Bay ecosystem. By observing in this study that riparian buffers may be bypassed through wastewater management, future land use models may provide improved information to politicians and resource managers.

Rock Creek Park and its watershed is one endpoint in an urban to rural gradient. It would be interesting to test the recommended analytical framework in a variety of protected areas throughout the Potomac watershed to see how this endpoint compares to other locations in the watershed. The Potomac watershed has many different land use elements throughout and by choosing one watershed, climatic factors would be minimized. The National Capital Region Network parks would provide 11 locations in which to test the recommended analytical framework (Figure 4.1). It is recommended that additional locations be included as well, to provide further information on those locations along the urban to grassland or agricultural gradient. The results of this study would test the behavior of the recommended analytical framework and may bring out regional trends not visible in the study of the Rock Creek watershed.

Figure 4.1. This diagram shows the percentage of forest, developed, and grassland land use of the 11 NCRN parks (pie charts) within the matrix of exterior land use. Courtesy J. Schmidt, National Park Service.



Appendix A: Data used to determine attainment.

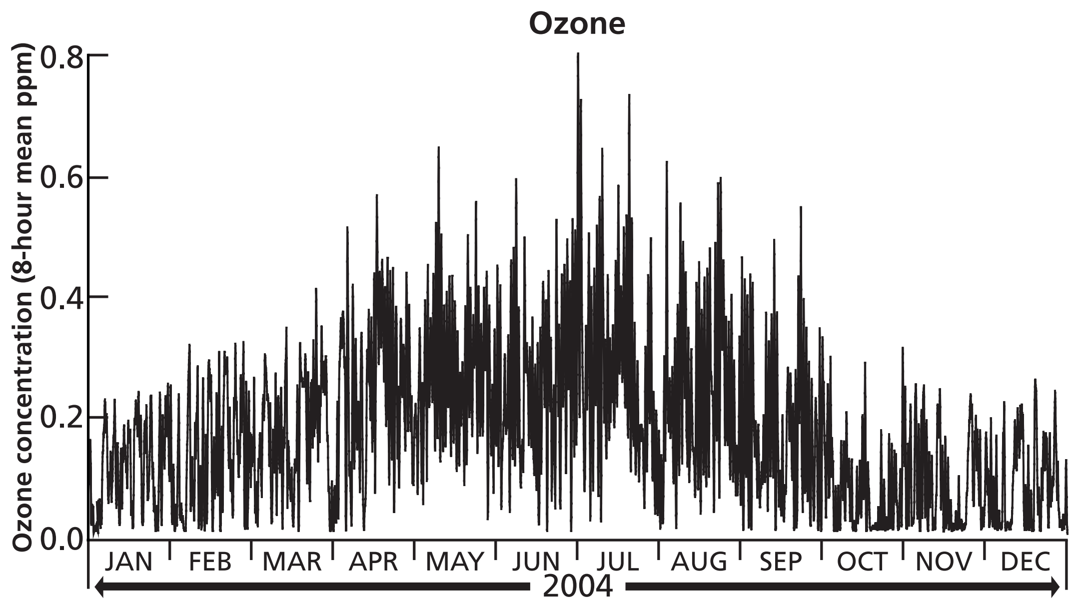
Air Quality Data

The vital signs in the 'Air Quality and Climate' vital sign category consist of regional air quality measurements on a variety of parameters. Air pollution is an increasingly important urban concern. The NCRN is one of the most urban networks in the I&M Program. Nearly all of the NCRN parks are located within the Potomac River watershed. Between 2000 and 2008, the watershed population increased 8 percent (ICPRB 2008). More than 80 percent of the population in the Potomac watershed is located in the Washington DC metropolitan area. The pollutants emitted by the increased urban population can degrade air quality and decrease visibility (NPS 2004). Pollutants of concern include ground-level ozone, mercury, and nitrogen and sulfur compounds. The NCRN is monitoring these pollutants to protect human and ecological health, to maintain cultural resources, and to provide scenic vistas.

Ground-level ozone concentrations are monitored in most National Parks in conjunction with national air quality monitoring networks (NPS 2004). The ozone data for Rock Creek Park are collected at McMillan Reservoir in Washington D.C. and are part of the Clean Air Status and Trends Network (CASTnet). In April 2004, EPA designated the Washington D.C. area as a 'moderate' nonattainment area under the Clean Air Act (MWCOG 2007; EPA 1990). This is an improvement from the 1992 "serious" nonattainment designation (MWCOG 2007). According to the State Implementation Plan (MWCOG 2007), air quality in the Washington D.C. metropolitan region continues to improve while ozone emissions are decreasing.

Ozone concentration is collected hourly at McMillan Reservoir and a mean value is calculated over running eight-hour periods. There are approximately 9,000 data points within 1 year. Ozone concentration is generally higher in the summer than in the

Figure A.1. Ozone concentration measured at McMillan Reservoir.



winter (Figure A.1). However, there is high variability within a single month and from period to period.

Anthropogenic emissions and natural sources of nitrogen and sulfur can have negative effects on NPS resources. The nitrates and sulfates emitted by automobiles, power plants, industries, agriculture and fires combine with rainfall to create what is known as "acid rain" (NPS 2005b). Atmospheric deposition is the process by which these and other chemicals are deposited on the earth's surface via rainfall or other means. Wet deposition is a measure of the amounts of these chemicals deposited on the Earth's surface by rain and snow. The National Atmospheric Deposition Program (NADP) is a cooperative effort among numerous governmental organizations, academic institutions, and private organizations. The NADP collects composite weekly samples from each of its sites, which are analyzed in part for pH, sulfate, nitrate, ammonium, and calcium (NPS 2005b).

Annual concentrations of wet nitrate and sulfate deposition from 1984 to 2002 were variable from year to year (Figure A.2, Figure A.3), however they have been consistently

Figure A.2. Annual wet nitrate deposition measured at the National Atmospheric Deposition Network White Rock substation site (MD03).

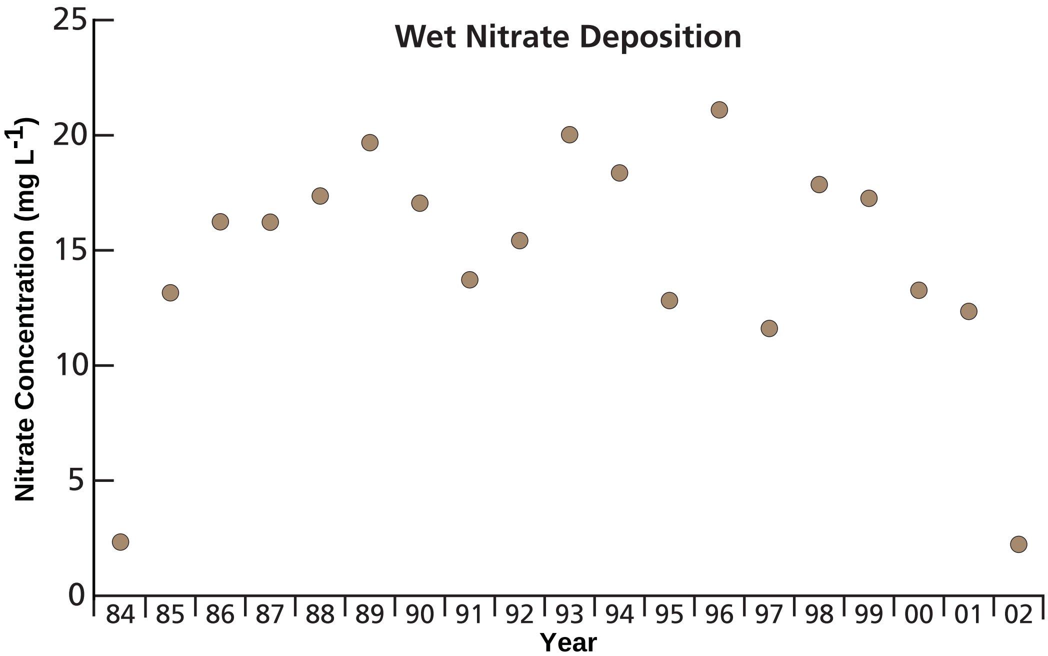
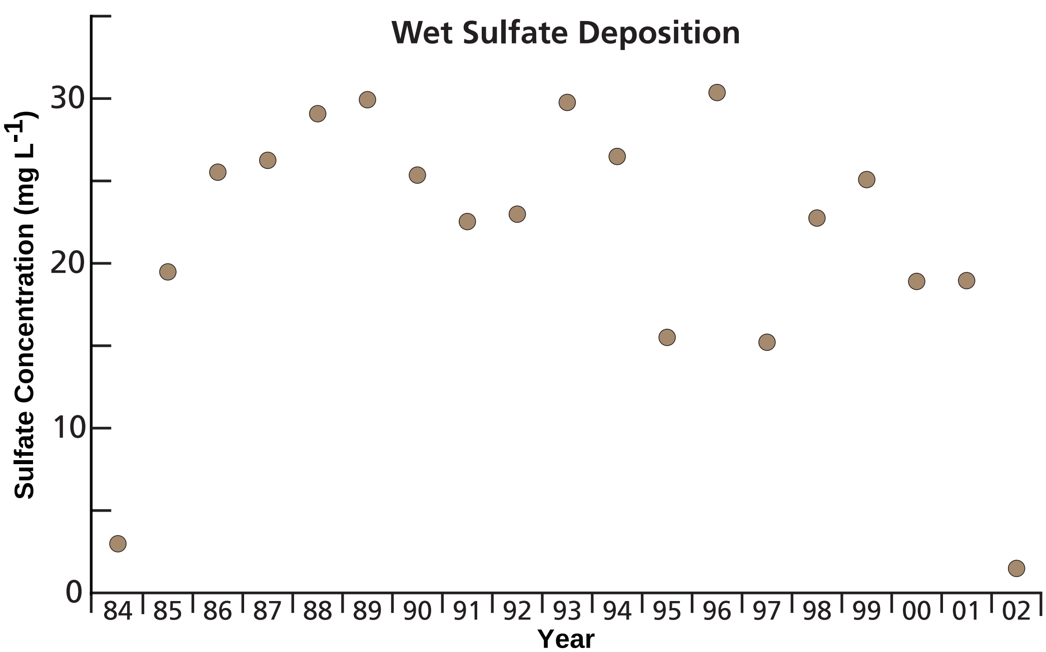


Figure A.3. Annual wet sulfate deposition measured at the National Atmospheric Deposition Network White Rock substation site (MD03).



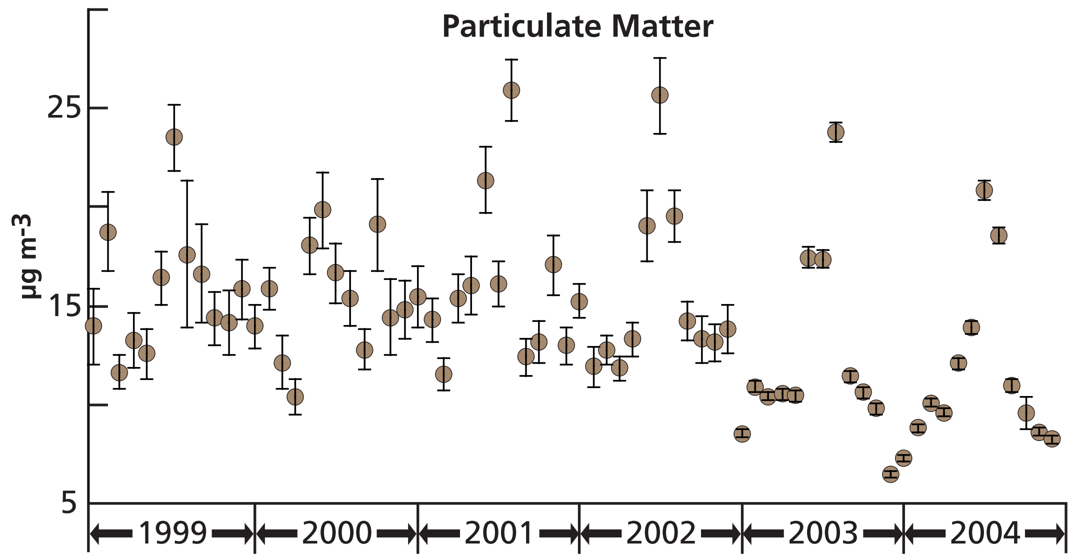
high. The sulfate concentration generally has been higher than nitrate concentration for the years shown.

Airborne particulate matter is a concern for human and wildlife health because it can damage the cardiovascular system. Moreover, increased particulate matter can decrease visibility in National Parks. The particulate matter consists of microscopic solids and liquid drops (EPA 2003) that can include acids, organic chemicals, metals, soil, dust, and allergens (EPA 2003). Particulate matter is divided into two categories: 'fine particles' ($PM_{2.5}$) which are particles 2.5 micrometers in diameter or smaller, and 'inhalable coarse particles' (PM_{10}) which are particles between 2.5 micrometers and 10 micrometers in diameter (EPA 2003, EPA 2006a). $PM_{2.5}$ is associated with haze and smoke, whereas PM_{10} is associated with windblown dust (EPA 2003).

From 1999 through 2004, mean monthly fine particulate matter ($PM_{2.5}$) concentration ranged from about 5 to 25 µg m^{-3} (Figure A.4). Sampling intensity increased for 2003 and 2004 from 300 to 500 samples, to more than 8,000 samples, which is reflected in the standard error decrease. Measurements were made at the southeast end of McMillan Reservoir, Washington D.C. (Site ID 0043). Summer months generally have higher atmospheric particulate matter than winter months.

Mercury is a concern for human and wildlife health as a result of consumption of fish containing methylmercury (Mason et al. 2000). Atmospheric deposition of mercury, two-thirds of which is anthropogenically-derived, is the main source of mercury to aquatic systems (Hammerschmidt & Fitzgerald 2006; Mason et al. 2000). In addition, methylmercury accumulation in fish populations has been linked to atmospheric mercury deposition (Hammerschmidt & Fitzgerald 2006). Long-term sediment core studies have suggested that mercury deposition has decreased since 1990 (Mason

Figure A.4. Monthly particulate matter measured at McMillan Reservoir.



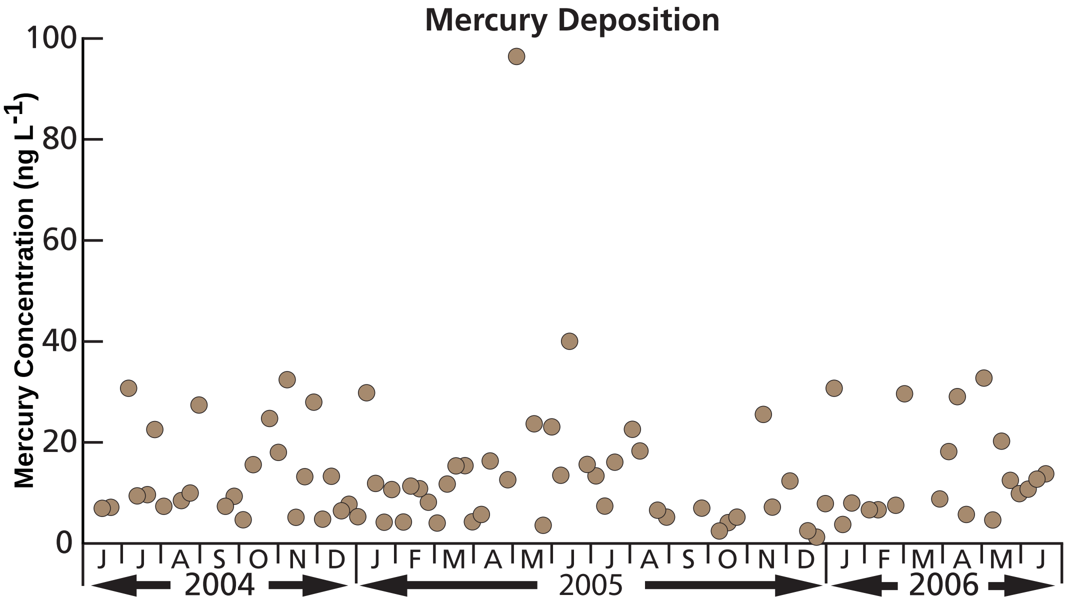
et al. 2000); however, long-term atmospheric mercury measurements are needed to confirm this trend.

The NCRN uses data collected at Beltsville, Maryland by the Mercury Deposition Network (MDN), a part of the NADP. Although there is no obvious pattern in the weekly mercury deposition measurements. Mercury deposition is generally high (Figure A.5).

Water Quality Data

The vital signs in the 'Water Quality and Hydrology' category consist of chemical, physical, and biological measurements of various watercourses throughout the NCRN. Many of the streams in the Potomac region are in a degraded state due to current and historical landscape modification (Hilderbrand et al. 2007, Roth et al. 1999). The current condition of park streams is strongly influenced by the condition of the surrounding watershed (Defries et al. 2007). Unfortunately, many of the streams that run through the small NCRN parks originate outside of park lands. The threats to water quality, physical habitat and biological communities include residential and urban development, agriculture, sediment and acid precipitation; most of which enter the

Figure A.5. Weekly mercury deposition measured in Beltsville, Maryland by the Mercury Deposition Network.



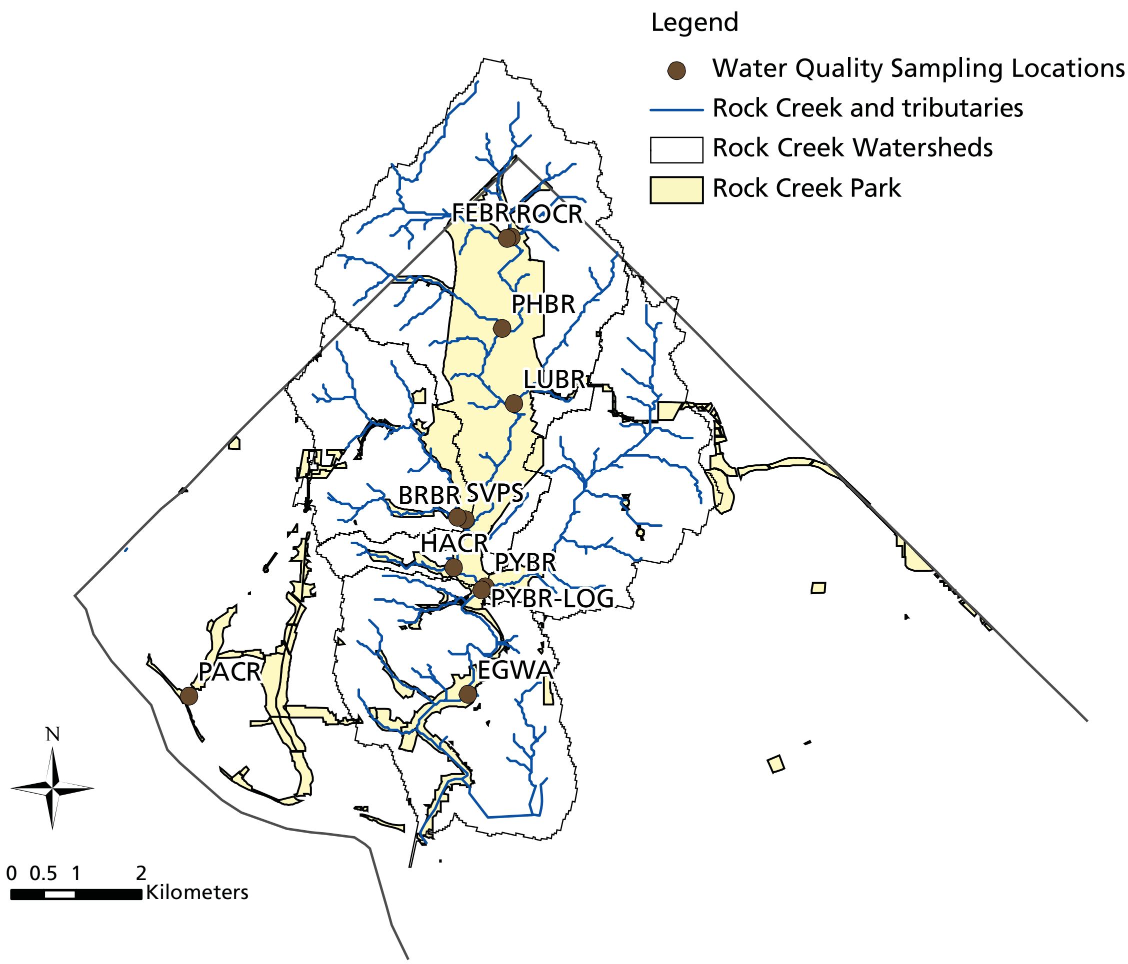
park from outside sources (Hilderbrand et al. 2007). Water resources are important in NCRN parks because streams and rivers are a dominant landscape feature. Visitor experience is heavily influenced by the water quality and many biotic communities reach the edge of their geographic range in the Potomac basin (Hilderbrand et al. 2007).

Most of the water quality data is collected at 10 sampling sites within Rock Creek Park (Table A.1, Figure A.6). Measurements are conducted at these sites monthly. Under the Water Chemistry vital sign the NCRN measures pH, dissolved oxygen concentration, specific conductance, water temperature, acid neutralizing capacity, and salinity. Under the Nutrient Dynamics vital sign the NCRN measures ammonium concentration, nitrate concentration, and phosphorus concentration. All of these metrics provide a good overview of the water quality for a given water body and are fundamental for water quality monitoring programs.

Table A.1. Water quality measurement site legend for all graphs.

ROCR:	Rock Creek
FEBR:	Fenwick Branch
PHBR:	Pinehurst Branch
LUBR:	Luzon Branch
BRBR:	Broad Branch
PYBR:	Piney Branch
HACR:	Hazen Creek
EGWA:	Edgewater Stables
SVPS:	Soapstone Stream
PACR:	Palisades Creek

Figure A.6. Water quality monitoring sampling locations in Rock Creek Park.



Various legislation and NPS mandates require that the NCRN monitor water quality in the parks. Decreased water quality can result in increased phytoplankton biomass, taste and odor problems, and increased drinking water treatment costs (Tsegaye et al. 2006). One of the largest threats to water quality is land use change (Tsegaye et al. 2006), which is ubiquitous in a watershed that had a population increase of 8 percent in the last decade. Therefore, the NCRN is monitoring water chemistry to identify key sources of pollution, to determine if streams can withstand regional acidity inputs, and to assess stream condition (Norris & Fisher 2006). Water quality measures consist of physical and chemical properties of the water that can be directly measured to determine site specific pollutants and stressors.

The pH of Rock Creek is generally consistent throughout the year (Figure A.7). Variation between sites is greater than variation between seasons. Some sites showed decreased pH during winter and spring 2006 while others showed elevated pH during spring 2006.

Dissolved oxygen concentration shows a seasonal pattern with high winter concentrations and low summer concentrations (Figure A.8). This is due to the seasonal growth patterns in the northern hemisphere. Dissolved oxygen concentration is generally good throughout the park.

Figure A.7. Monthly pH measurements taken at 10 sites within Rock Creek Park.

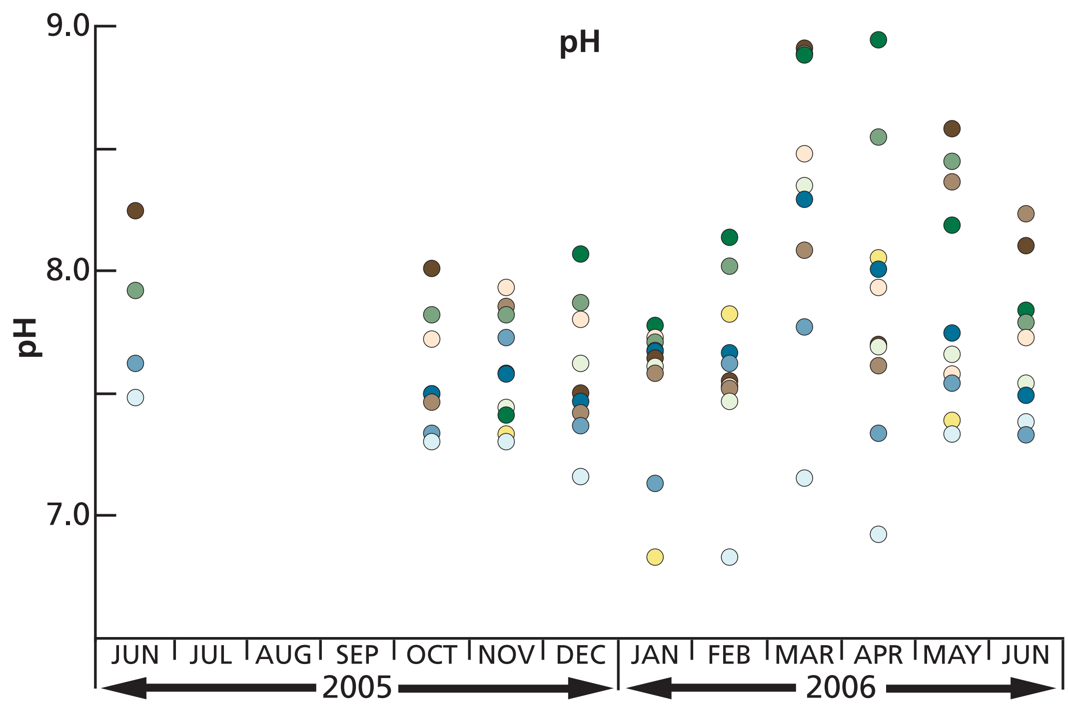
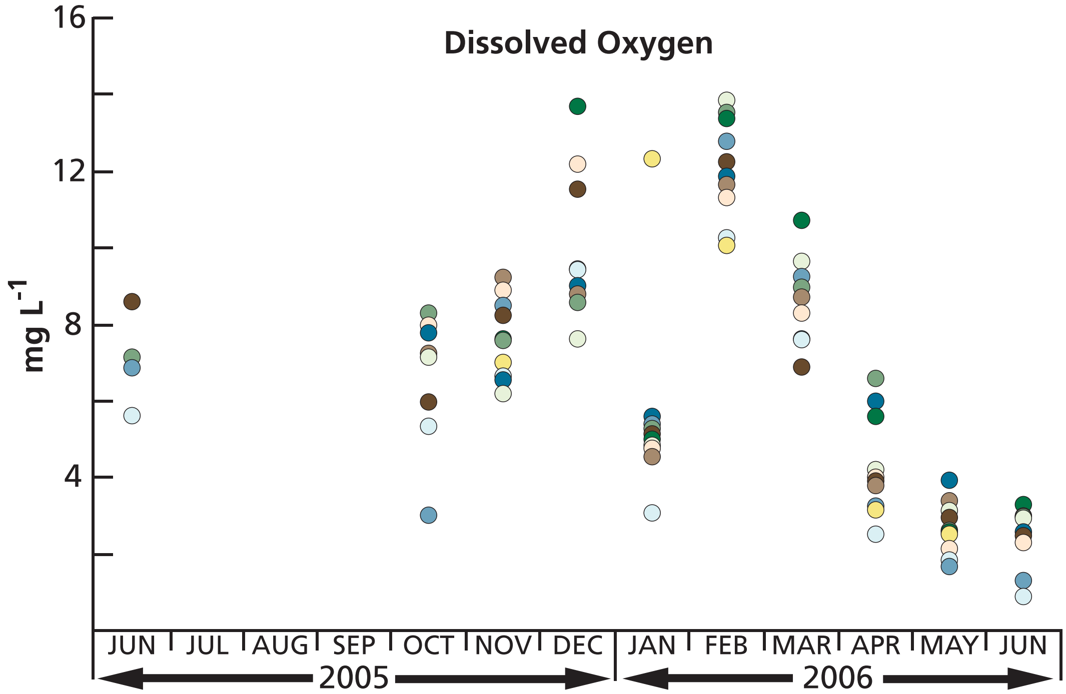


Figure A.8. Monthly dissolved oxygen concentration measurements taken at 10 sites within Rock Creek Park.



Specific conductance is high throughout the sampling period (Figure A.9). There are spikes in specific conductance in the winter months of December and February. This potentially is due to winter road salting entering the waterways.

Water temperature shows a clear seasonality, with lower water temperatures in winter and higher in summer (Figure A.10). This is consistent with the seasonal climate of the region. Rock Creek is well-shaded along its entire length, therefore summer temperatures are generally cool.

Acid neutralizing capacity shows high variability among sites (Figure A.11), however all sites have good acid neutralizing capacity. Good acid neutralizing capacity provides a buffer for streams that may be susceptible to acidification.

Salinity is generally high in Rock Creek, with spikes in the winter months (Figure A.12). These spikes may be due to road salting events. The background salinity is moderately high in some locations.

Figure A.9. Monthly specific conductance measurements taken at 10 sites within Rock Creek Park.

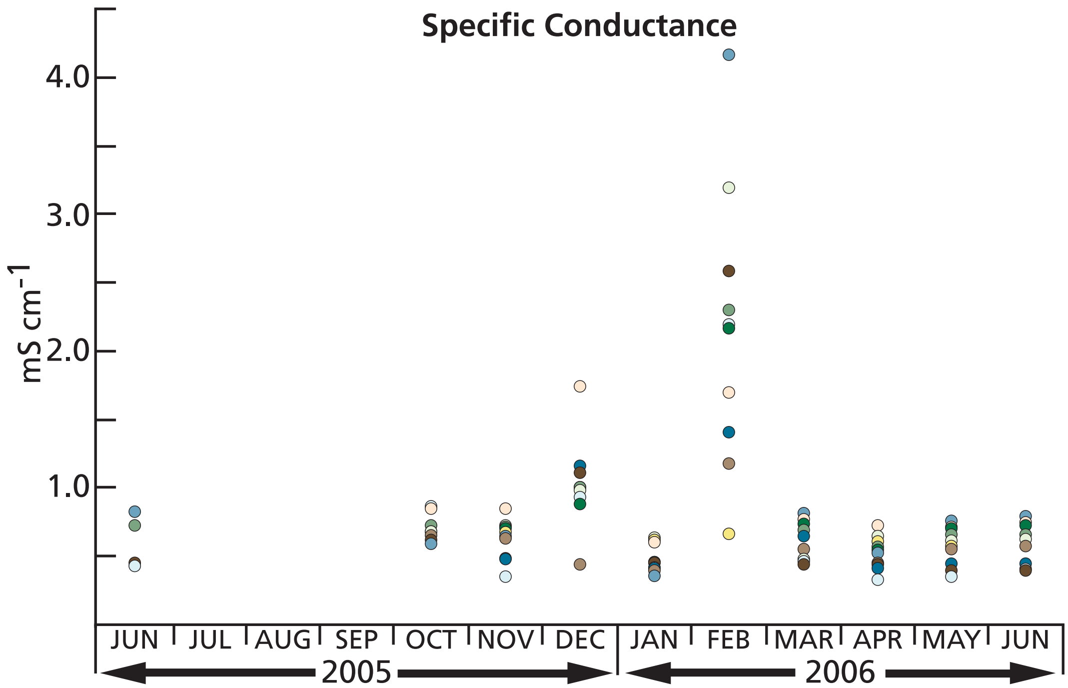


Figure A.10. Monthly water temperature measurements taken at 10 sites within Rock Creek Park.

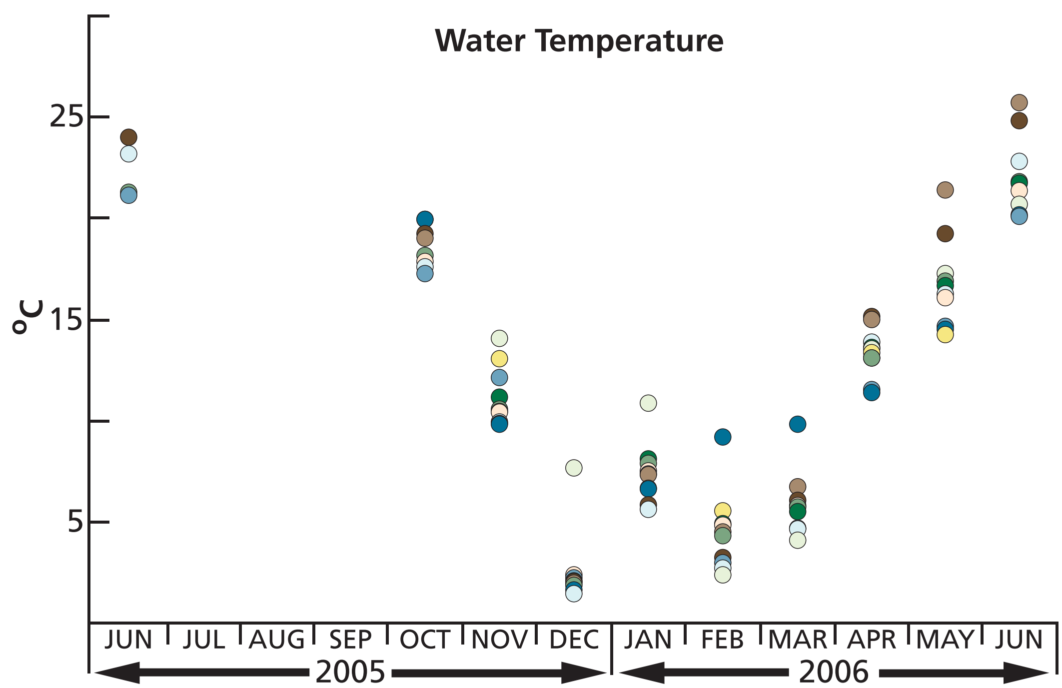


Figure A.11. Monthly acid neutralizing capacity measurements taken at 10 sites within Rock Creek Park.

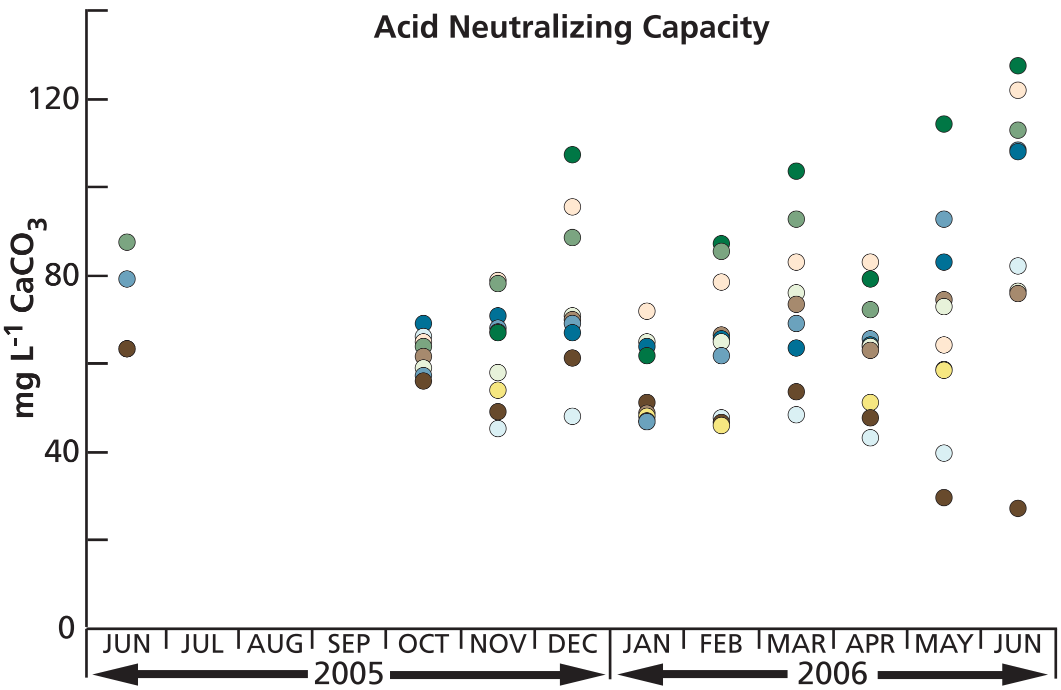
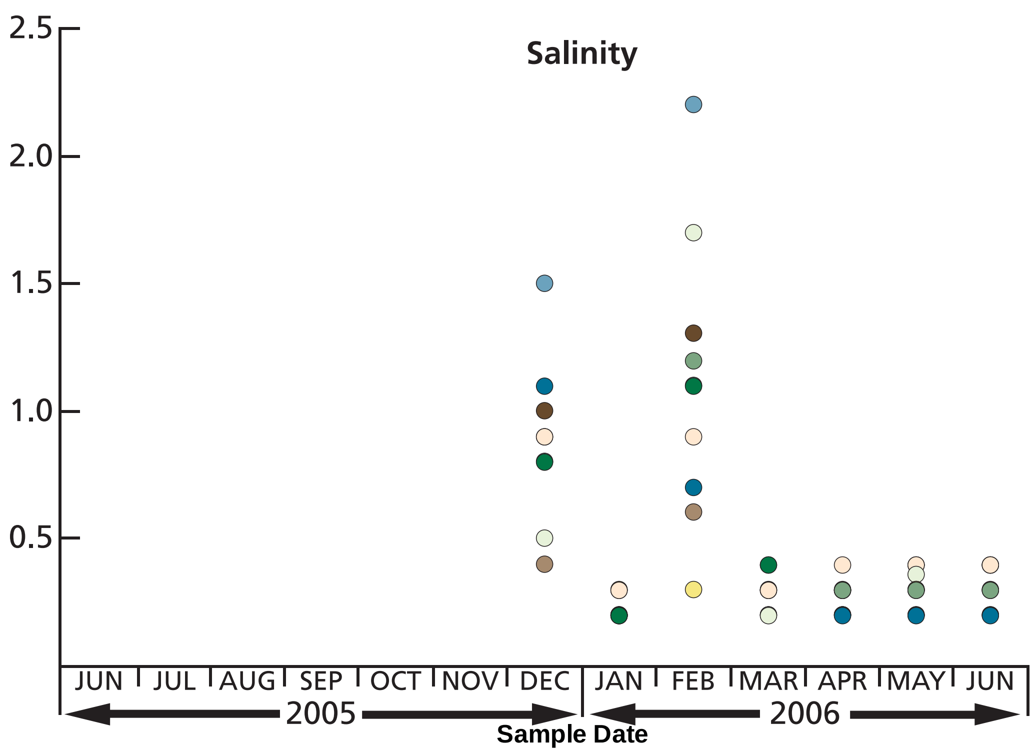


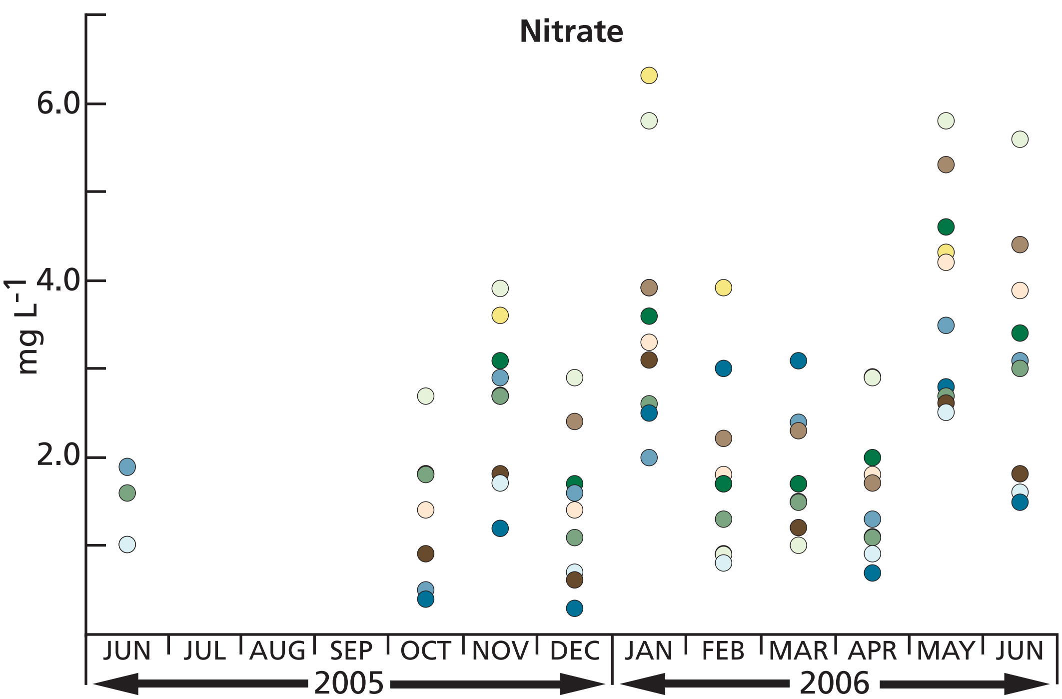
Figure A.12. Monthly salinity measurements taken at 10 sites within Rock Creek Park.



Surrounding land use heavily influences the nutrient concentrations in a stream. Approximately 35% of river reaches in the United States violate the Clean Water Act, much of it related to nutrient pollution (EPA 1996, EPA 2001a). In particular, runoff from agriculture contributes 50 to 70% of the nitrogen, phosphorus, and sulfur pollution nationwide and runoff from urban centers contributes 5 to 15% of nationwide pollution (EPA 1996, EPA 2001a). The NCRN is measuring nutrient concentrations to assess the variance of nutrients, to assess the trends within and between watersheds and stream orders, and to assess stream condition (Norris & Fisher 2006).

Nitrate concentration shows high between site variability and there does not seem to be a seasonality to the measurements (Figure A.13). Nitrate concentration is generally high throughout the year. The high nitrate concentration is potentially leading to eutrophication of Rock Creek and receiving water bodies.

Figure A.13. Monthly nitrate concentration measurements taken at 10 sites within Rock Creek Park.



Ammonium concentrations are generally low in Rock Creek Park (Figure A.14). There are a few isolated peaks, but the concentration is not indicative of a problem as concentrations remain low overall.

Phosphorus concentrations are consistently high throughout the park (Figure A.15). There may be a seasonality pattern associated with the monitoring data with lower phosphorus concentrations in the winter months; however, there is not enough data to determine if this is a true pattern.

In addition to the physical and chemical methods, biota can serve as a method for measuring water quality. Resident biota are sensitive to continuous chemical and physical stressors as well as episodic events that a monitoring regime may not record (Hilderbrand et al. 2007). Assessment of these biotic assemblages may be more likely to capture the full extent of anthropogenic impacts on the water resources than physical and chemical monitoring alone (Hilderbrand et al. 2007).

Figure A.14. Monthly ammonium concentration measurements taken at 10 sites within Rock Creek Park.

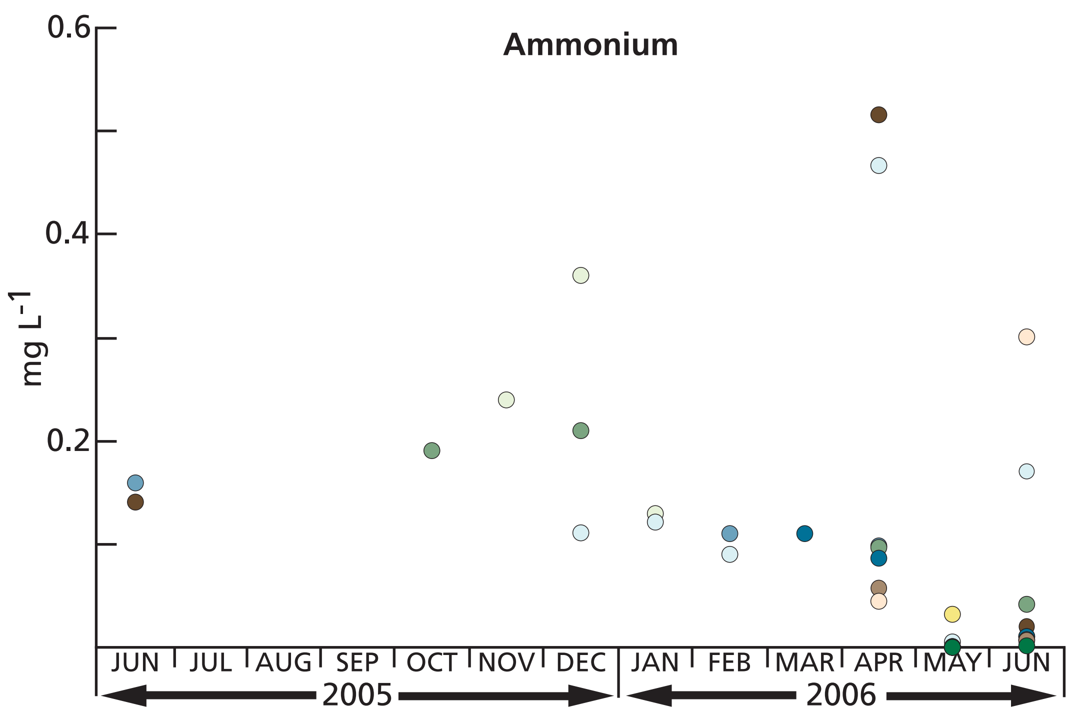
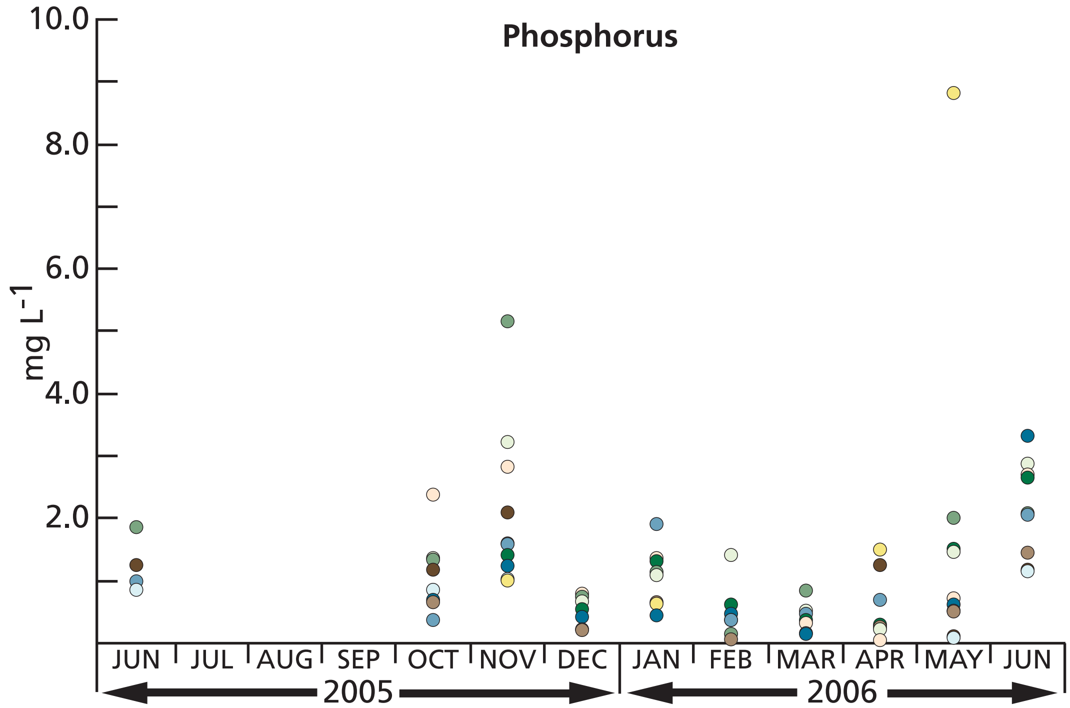


Figure A.15. Monthly phosphorus concentration measurements taken at 10 sites within Rock Creek Park.



In particular, the NCRN is measuring the Benthic Index of Biotic Integrity (IBI) and the Fish IBI to determine current conditions and track long-term trends in water resource, and to determine species composition and functional groups (Hilderbrand et al. 2007). Both fish and benthic IBI are in poor condition (Table A.2, Roth et al. 1999). Fish IBI is considered a 'Biodiversity' measure, however it is included here for ease of presentation.

In addition to the physical water parameters, stream health can be judged based on physical habitat parameters. These parameters are useful for assessing site condition, the state of the watershed, and the abiotic environment (Hilderbrand et al. 2007). The

Table A.2. Benthic IBI, Fish IBI, and PHI measured in Rock Creek Park.

Metric	Value
Benthic Index of Biotic Integrity	2.11
Fish Index of Biotic Integrity	2.78
Physical Habitat Index	61.32

NCRN is measuring the Physical Habitat Index (PHI) to determine current conditions and track long-term trends in water resource condition (Hilderbrand et al. 2007). Rock Creek Park PHI is in fair condition (Table A.2, Roth et al. 1999).

Biodiversity Data

The NCRN parks play an important ecological role in the region's highly urbanized landscape. Many of the parks were established for cultural or recreational reasons; however, the parks are some of the last remaining refugia for plant and animal species (NPS 2006a). These refugia are threatened by exotic plants, deer overabundance, and the impacts of urbanization. The Biodiversity vital signs characterize both the resources and threats associated with these natural areas.

Invasive exotic herbaceous plant species are monitored as part of the forest monitoring program (Table A.3). These plants are measured at forest monitoring locations (Figure A.16). Of the species found, Rock Creek Park has the most cover of *Alliaria petioloata* (Garlic mustard), and *Hedera helix* (English ivy). A total of 8 species have been found in Rock Creek Park. Some species have been found at multiple sites.

Invasive exotic shrub and tree species also are measured in Rock Creek Park (Table A.4, Table A.5). These species are measured in the forest monitoring plots (Figure 20). The most prevalent shrub species, *Viburnum sieboldii* (Siebold's arrowwood), has 23 individuals at one monitoring plot (Table A.4). There are two exotic trees, both of which are found in the same monitoring plot. The *Acer platanoides* (Norway maple) is the larger of the two trees (Table A.5).

Insect pest species are also monitored at the forest monitoring plots in Rock Creek Park (Figure A.16). No insect pest species have been found during the monitoring conducted in the park.

Table A.3. Invasive exotic herbaceous plant species found in Rock Creek Park

Site	Year	Species	Mean % Cover
ROCR-0092	2006	*Alliaria petioloata*	33 ± 10
		Ampelopsis brevipedunculata	2 ± 1
		Duchesnea indica	0.1 ± 0.1
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
ROCR-0186	2007	*Hedera helix*	40 ± 13
		Alliaria petioloata	2 ± 1

Figure A.16. Forest monitoring plot locations in Rock Creek Park.

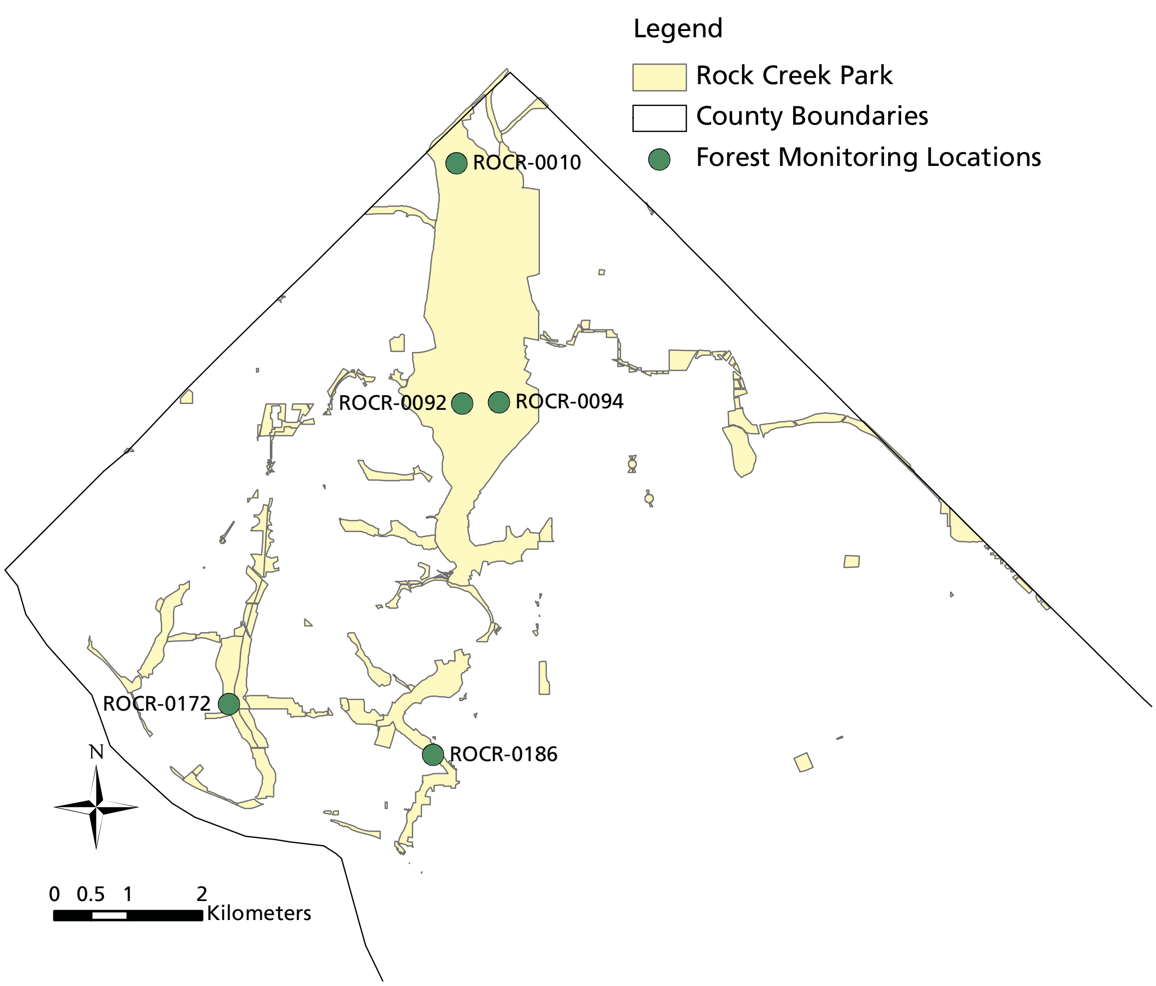


Table A.4. Invasive exotic shrub species found in Rock Creek Park.

Site	Year	Species	Sum Basal Area	# of Shrubs
ROCR-0094	2006/2007	*Euonymus alatus*	45.36	1
ROCR-0172	2006/2007	*Viburnum plicatum*	185.50	2
ROCR-0186	2006/2007	*Viburnum sieboldii*	405.18	23

Table A.5. Exotic invasive tree species found in Rock Creek Park

Site	Year	Species	Sum Basal Area	# of Trees
ROCR-0186	2007	*Acer platanoides*	289.53	1
ROCR-0186	2007	*Malus sieboldii*	81.71	1

Forest vegetation is important throughout the NCRN as it is the predominant vegetation cover in many of the parks (Schmit et al. 2006). Many parks in the region have a mandate in their founding legislation to manage forest resources. In addition to these legislative requirements, park forests are important ecologically as they help to filter nutrients and sediment, stabilize soils, and moderate flooding of streams and rivers (NPS 2006a). Forests can also contribute to regional air quality by removing pollutants, fixing carbon, and buffering traffic and other noise pollution (NPS 2006a). NCRN is measuring forest vegetation to track overall forest condition, impacts of deer browsing, invasion of exotic species, impacts of surrounding urban development, and impacts on streamside vegetation due to channel and bank erosion (Schmit et al. 2006). Forest monitoring locations are shown in Figure A.16. Seedling density is low in Rock Creek Park (Table A.6). The small number of seedlings will result in forest that is unable to regenerate. As older trees die there will be few trees replacing them.

The NCRN parks lie in an area that, prior to human settlement, was predominantly forested (Dawson 2006). The rapid urbanization of the NCR results in forest loss, fragmentation and degradation which in turn results in impacts on forest dwelling bird species (Jones et al. 2000). Because the NCRN parks are some of the last patches of forest remaining in the region, the parks are important for conservation of forest

Table A.6. Seedling density measured at forest monitoring locations in Rock Creek Park.

Site	Year	Seedlings	Seedlings ha^{-1}	# Species
ROCR-0010	2006	0	0	0
ROCR-0092	2006	2	1667	1
ROCR-0094	2006	4	3333	3
ROCR-0172	2007	3	2500	2
ROCR-0186	2007	0	0	0

dwelling bird species (Dawson 2006). Over 80 bird species have been recorded to nest in NCRN forests, including 19 species that have been deemed important for conservation efforts (Dawson 2006). The NCRN is monitoring landbirds to obtain annual estimates of abundance of forest-nesting bird species and to estimate long-term trends in abundance across the network.

In 2003, five sensitive species were observed in Rock Creek Park (Figure A.17 , Table A.7). Each site had up to four species observed (Figure A.17). The specific species observed are shown in Table A.7.

For more than 25 years, White-Tailed Deer abundance has been recognized as a threat to the abundance and diversity of native trees and herbaceous vegetation (Bates 2006). High densities of white-tailed deer have negative effects on tree species composition and forest regeneration (Tilghman 1989, Bates 2006). These changes also affect small mammals, songbirds, and eventually even the deer themselves (Horsley et al. 2003, Bates 2006). The NCRN is measuring White-Tailed Deer to identify key trigger points for implementing management practices to manipulate the deer population and to document trends in deer population (Bates 2006). The deer density from 2000-2005 is shown in Figure A.18. The deer density has been high throughout the sampling period.

Ecosystem Pattern and Process Data

Figure A.17 Bird sampling locations for Rock Creek Park.

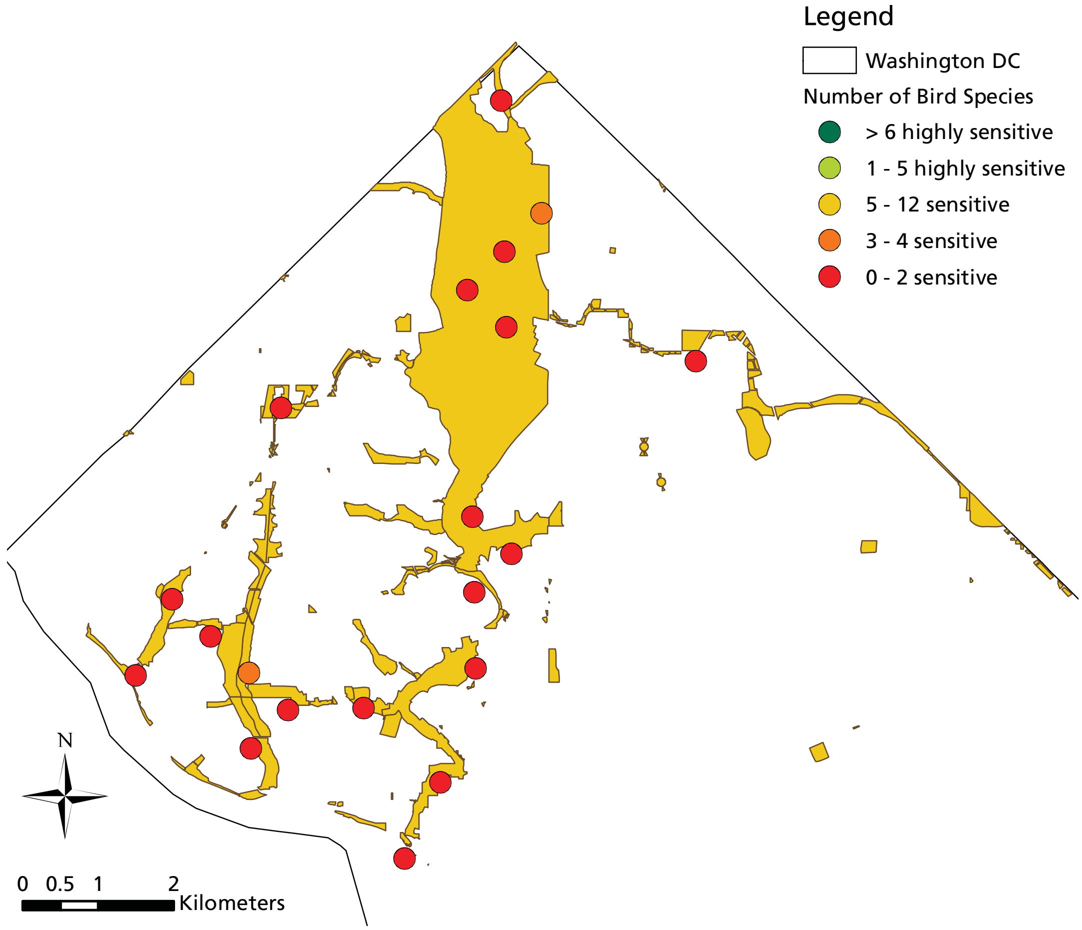
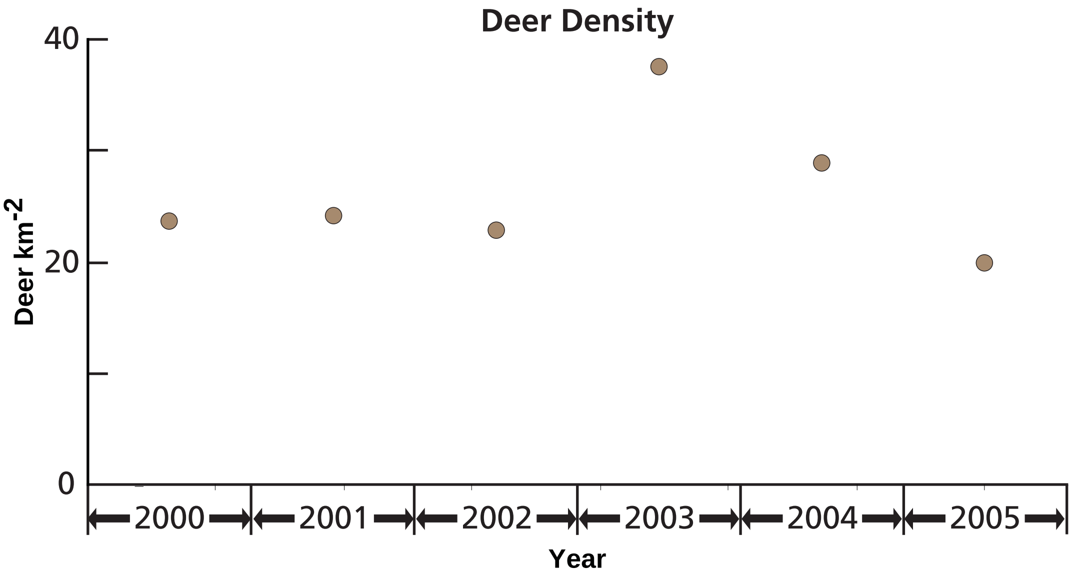


Table A.7. Sampling results for highly sensitive (HS) and sensitive (S) forest interior dwelling bird species.

			# of Observations		
Common Name	Status	Code	1993	1994	2003
Black-and-White Warbler	HS	BAWW		2	
American Redstart	HS	AMRE		2	
Louisiana Waterthrush	HS	LOWA		1	
Kentucky Warbler	HS	KEWA		1	
Hooded Warbler	HS	HOWA		2	
Hairy Woodpecker	S	HAWO	4	5	
Pileated Woodpecker	S	PIWO	7	4	
Acadian Flycatcher	S	ACFL	14	23	7
Red-Eyed Vireo	S	REVI	28	35	5
Veery	S	VEER	8	8	3
Wood Thrush	S	WOTH	19	29	5
Northern Parula	S	NOPA	1	2	
Ovenbird	S	OVEN	7	2	
Scarlet Tanager	S	SCTA	2	2	1

Figure A.18. Annual deer density measured within Rock Creek Park.



Ecosystem Pattern and Processes Vital Signs show how land use within and surrounding a park affects habitat and water quality. Urban land use, the matrix in which most of the NCRN parks are embedded, can severely degrade both habitat and water quality (Wang et al. 2001). More specifically, using remotely sensed information, the NCRN is measuring how disturbance, fragmentation, buffers and land cover change affect the abundance of rare, threatened and endangered (RTE) species, biodiversity, exotic plant invasions, terrestrial habitat, water quality, and stream habitat (Townsend et al. 2006). All Ecosystem Pattern and Processes metrics are measured twice, within the Fed Fee boundary (interior) and in an area that contains the park and a buffer that is five times the area of the park (exterior).

The park is generally in good condition based on the ecosystem pattern and process data (Table A.8). The park has about 10 percent of the impervious surface that the park and buffer have. The park has almost 3 times the amount of forested landcover than the buffer. The connectivity of the park is longer than the connectivity outside the park. This suggests that remnant forest patches within the buffer are allowing for further connectivity than the park boundary alone.

Table A.8. Ecosystem Pattern and Process metric data for Rock Creek Park.

Metric	Inside Park	Outside Park
Critical Dispersal Threshold Distance	340 m	270 m
Percent Cover of Impervious Surface	4.6%	44.9%
Percent Area of Dominant Landcover	71%	24%

Appendix B: Further Threshold Information

Air Quality Thresholds

Ozone (1 metric)

Ground-level ozone is regulated under the Clean Air Act and the EPA is required to set standard concentrations for ozone (EPA 1990). This standard, the National Ambient Air Quality Standard (NAAQS), is intended to protect public health (primary standard) and to prevent damage to the environment (secondary standard). The NAAQS standard is exceeded when the three-year average of the fourth-highest daily maximum 8-hour average ozone concentrations exceeds 0.08 parts per million (ppm) (EPA 1997a). For the integrated assessment, this standard was simplified to 0.08 ppm $(8\text{-hour})^{-1}$ for all 8-hour periods within the monitoring year.

Wet Deposition (2 metrics)

Wet deposition is not regulated by any government agency. Wet deposition monitoring will assist resource managers in determining ecosystem effects and critical loads for their particular park. The NPS Air Resources Division has estimated that natural background deposition of nitrogen and sulfur in the Eastern United States is 0.05 kg ha^{-1} y^{-1} (NPS 2005b). All historical and current measurements of deposition indicate that deposition exceeds this background level. Dupont et al. (2005) suggest that wet deposition target load for freshwater Canadian lakes of 10 kg ha^{-1} y^{-1} for both sulfate and 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). The target load suggested by Dupont et al. (2005) is used as the threshold for nitrate and sulfate deposition in this assessment.

Visibility and Particulate Matter (1 metric)

Particulate matter is regulated under the Clean Air Act and the EPA is required to set air quality standards for particulate matter (EPA 1990). The NAAQS primary and secondary standard for fine particulate matter ($PM_{2.5}$) is exceeded when the three-year average of the annual average $PM_{2.5}$ concentration is greater than or equal to 15 μg m^{-3} (EPA 1997b, EPA 2006a). For the integrated assessment, this standard was simplified to an annual standard of 15 μg m^{-3} for the monitoring year.

Mercury Deposition (1 metric)

The EPA regulates methylmercury concentration in fish tissue in order to protect human health. High doses of methylmercury in humans results in mental retardation, cerebral palsy, deafness, blindness, and sensory and motor impairments. In addition to human health concerns, some studies suggest links between behavioral effects and methylmercury concentrations in organisms, especially high trophic level predators (e.g. Hammerschmidt and Fitzgerald 2005; Evers et al. 1998); however, little work has been done to determine a methylmercury concentration threshold for ecological effects. The EPA Ambient Water Quality Criterion (AWQC) for protection of human health for methylmercury concentration in fish tissue is 0.3 mg methylmercury (kg fish)$^{-1}$ (EPA 2001b). The threshold used for mercury deposition in this assessment is based on scientific evidence connecting mercury deposition to fish tissue methylmercury concentration. Meili et al. (2002) calculate an annual critical mercury deposition value of 2 ng Hg L^{-1} to prevent fish tissue concentration below a threshold of 0.5 methylmercury (kg fish)$^{-1}$. Using their same calculation and substituting the EPA criterion value results in a threshold of 1.2 ng Hg L^{-1} y^{-1}.

Water Quality Thresholds

Water Chemistry (6 metrics)

Some of the thresholds in the Water Chemistry vital sign are based on regulatory values. These thresholds are based on Washington D.C. Municipal water quality standards. The District of Columbia Municipal Regulations 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 dissolved oxygen concentration is required to be greater than 5 mg L^{-1} from February 1 through May 31 and above 3.2 mg L^{-1} from June 1 through January 31 (DCMR 2005). The regulated range for pH is greater than 6.0 and less than 8.5 (DCMR 2005). In all cases, water temperature is regulated to be less than 32.2°C (DCMR 2005).

There is an additional threshold for dissolved oxygen that indicates loss of fisheries, loss of biodiversity, and alteration of food webs (Diaz 2001). The threshold of 2 mg L^{-1} is the level of hypoxia, or the point at which various animals suffocate (Diaz 2001).

The Specific Conductance threshold is based on the Maryland Department of Natural Resources Maryland Biological Stream Survey (MBSS) program after their first round of sampling (1995-1997). Analysis of the data has shown that freshwater fish are sensitive to high levels of conductivity (pers. comm. Ray Morgan). These analyses suggest that a threshold of 250 microSiemens per centimeter ($\mu S\ cm^{-1}$) is protective of freshwater fish health (pers. comm. Ray Morgan).

The Acid Neutralizing Capacity (ANC) threshold was developed by the MBSS program after their first round of sampling (1995-1997). The MBSS data was used to detect stream degradation 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 (IBI) 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 ueq L^{-1} (Roth et al. 1999; Hilderbrand et al. 2007). This can be converted into a threshold of 10 mg L^{-1} using the conversion factor 20 μeq L^{-1} is equal to 1 mg L^{-1}.

Salinity in drinking water is regulated by EPA under the National Secondary Drinking Water Regulations. These regulations control contaminants in drinking water and are non-enforceable. The Secondary Maximum Contaminant Level (SMCL) for salinity is 250 mg L^{-1} (EPA 2002b). This is not a biological threshold, however this value has been suggested as an acceptable threshold by experts (pers. comm. Ray Morgan). Therefore, the salinity threshold for this assessment is less than 0.25.

Nutrient Dynamics (3 metrics)

One of the thresholds for the Nutrient Dynamics vital sign is based on District of Columbia Municipal Regulations. The regulations require ammonia concentration to be below a certain concentration based on a table of pH versus temperature (DCMR 2005). In order to simplify this threshold, the lowest value on the table was chosen to determine the threshold. This value is 0.442 mg L^{-1}. In many cases this value may be too restrictive; however, based on the results of the assessment it is not highly restrictive for Rock Creek.

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). The same threshold is used in this assessment.

There is an additional nitrate threshold developed as part of the EPA Ecoregional Nutrient Criteria. These criteria were developed to prevent eutrophication nationwide and are not regulatory (EPA 2000; EPA 2002a). The criteria are developed as baselines for specific geographic regions. Rock Creek Park is located in Ecoregion IX or the Southeastern Temperate Forested Plains and Hills region (EPA 2000). The ecoregional reference condition value for nitrogen is 0.69 mg L^{-1}(EPA 2000). While this value is not specifically for nitrate, it is more restrictive than the MBSS threshold and is used in the assessment as a nitrate threshold.

The phosphorus threshold also is found in the Ecoregional Nutrient Criteria is 36.56 µg L^{-1} (EPA 2000). There is a secondary more restrictive phosphorus threshold that is based on Bayesian changepoint analysis of a dosing study in the Florida Everglades. The ecological exceedence threshold developed through the dosing study is 15 µg L^{-1} (Richardson et al. 2007). A third phopshorus threshold was developed based on the data collected in Chapter 3 of this thesis. The threshold developed is 0.2 mg L^{-1} and is based on the 85th percentile of the monitoring data.

Aquatic Macroinvertebrates (1 metric)

The Aquatic Macroinvertebrates threshold is based on the MBSS interpretation of the benthic 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 1 indicates that the benthic assemblage is less than the 10th percentile of reference value, a score of 3 indicates that the assemblage is in the 10th to 50th percentile, and a score of 5 indicates that the assemblage is in the 50th percentile or higher. An IBI score of 3 indicates a site is considered to be comparable 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 statistically different from the reference sites (Roth et al. 1999, Hilderbrand et al. 2007). Therefore the threshold for Aquatic Macroinvertebrates is an IBI less than 3, which indicates that a site is in degraded condition (Roth et al. 1999).

Physical Habitat Index (1 metric)

The PHI threshold was developed by the MBSS program after their first round of sampling as described for the ANC threshold. The MBSS determined that a PHI score of less than 42 (out of 100) indicated stream degradation (Roth et al. 1999; Hilderbrand et al. 2007).

Biodiversity Thresholds

Invasive Exotic Plants (2 metrics)

There are two metrics under the invasive exotic plants vital sign: percent cover of herbaceous species and woody vines and density of target exotic shrubs and trees. The threshold for both of these metrics is based on the best professional judgment of NCRN staff. This threshold is less than five percent cover (pers comm. NCRN I&M).

Forest Insect Pests (1 metric)

The presence of pest species metric has a management threshold. This threshold is less than 1 percent of park area (pers comm. NCRN I&M). This threshold is low because many of these pest species require immediate management action if they are found within park boundaries.

Forest Vegetation (1 metric)

NCRN is measuring tree and shrub basal area, plant species composition and richness, abundance and basal area of individual tree and shrub species per plot, cover of exotic understory plants per plot, cover of individual exotic herbaceous understory species per plot, and amount of coarse woody debris per plot. Of these metrics, a threshold was developed for seedling regeneration for this vital sign. Other metrics are covered under other vital signs or do not have enough data to develop meaningful thresholds. The threshold for seedling regeneration is based on rates of successful tree regeneration under low conditions of deer herbivory (McWilliams et al. 1995; Carter & Fredericksen 2007; Marquis et al. 1992). Based on the rates of successful tree regeneration, the threshold for Seedling Regeneration is a seedling density greater than 31,875 seedlings ha^{-1}. A more restrictive desired condition threshold of 55,000 seedlings ha^{-1} is also found in the literature (McWilliams et al. 1995). Recent thresholding work done in the NCRN has used a professional judgment threshold of 5,000 seedlings ha^{-1} for a lower undesired condition bound (Lookingbill et al. In Review).

Fishes (1 metric)

The fish threshold is based on the MBSS interpretation of the fish IBI. The IBI scores range from 1-5 and are calculated by comparing the site's fish assemblage to the assemblage found at minimally impacted sites (Hilderbrand et al. 2007). An IBI score of 1 indicates that the benthic assemblage is less than the 10th percentile of reference value, a score of 3 indicates that the assemblage is in the 10th to 50th percentile, and a score of 5 indicates that the assemblage is in the 50th percentile or higher. An IBI score of 3 indicates a site is considered to be comparable 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 statistically different from the reference sites (Roth et al. 1999, Hilderbrand et al. 2007). Therefore the threshold for Fish is an IBI less than 3, which indicates that a site is in degraded condition (Roth et al. 1999).

Amphibians (1 metric)

A threshold has been developed for the proportion of area occupied by adult amphibians. Because the amount of data collected to date is not enough to accurately characterize the amphibian population, best professional judgment was used in the development of this threshold. The threshold for the proportion of area occupied is between 20 and 80 percent (pers comm. L. Bailey & E. Grant).

Landbirds (1 metric)

The landbirds threshold for Rock Creek Park is based on the State of Maryland's guide for forest interior dwelling bird species (FIDS). FIDS are bird species that require large forested areas in which to reproduce and thrive (Jones et al. 2000). State regulations require that all landowners with FIDS must protect and conserve those large forested tracts, or 'critical areas' (Jones et al. 2000). The presence of sensitive FIDS is used as an indicator of high-quality forest interior habitat. Using the bird survey data interpretation section of the guidance, a ranking scale of FIDS habitat was created (Jones et al. 2000). 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). Presence of six or more highly area-sensitive species indicates exceptional forest interior habitat (Jones et al. 2000). The other 12 FIDS are less area-sensitive, however they still require large forest tracts for stable populations. A forest that contains fewer than 4 of these species is considered marginal or low quality habitat (Jones et al. 2000). The numerical values assigned to these assemblages for this assessment are arbitrary, however they represent the continuum of habitat quality represented by the forest-living bird species.

White-Tailed Deer (1 metric)

White-tailed deer density prior to European settlement was estimated to be between 3.1 and 7.7 deer km^{-2}. The current deer density in the NCRN is between 18 and 75 deer km^{-2}. Based on deer enclosure studies, tree species diversity and regeneration decline at deer densities greater than 8 deer km^{-2} (Tilghman 1989, Horsley et al. 2003). Therefore the threshold used for the NCRN parks is less than 8 deer km^{-2}.

Ecosystem Pattern and Process Thresholds

Land Cover/Land Use (4 metrics)

The threshold for Percent Area of Dominant Land Cover is based on information obtained through the use of neutral models. Neutral models are standardized “landscapes” that produce landscape patterns in the absence of landscape processes (Gardner et al. 1987). In studying these neutral models, landscape characteristics change most rapidly at a critical percent area of 0.5928 (Gardner et al. 1987). This critical percentage is also the value at which the largest cluster of dominant landscape type will span the entire map (Gardner et al. 1987). In addition, at percent areas greater than the critical percent, the clusters will have a fractal dimension approaching 2, whereas when the percent area is less than the critical percent, clusters will have a fractal dimension less than 2 (Gardner et al. 1987). A second threshold of ecological change was found at between 10 and 30 percent forest cover (Radford et al. 2005). This lower threshold is important, but not as protective as the neutral model threshold. Therefore, the threshold for Interior and Exterior Percent Area of Dominant Land Cover is rounded up from 59.28 percent to 60 percent.

Critical Dispersal Threshold Index (D_{crit}) is a measure of the connectivity of park units and of the park with the adjacent landscape. D_{crit} is a measure of the gap crossing ability of a particular species. At the point that the distance between habitat patches is greater than the gap crossing ability, the landscape is considered functionally fragmented for that particular species (Ferrari et al. 2007). At distances less than D_{crit}, the species of interest does not view the landscape as fragmented into separate patches. For each park, D_{crit} is the distance at which 75 percent of patches are connected. The threshold for this metric has been determined with respect to the dispersal capabilities of small mammals and tree seed dispersal. Corry & Nassauer (2005) list dispersal distances for a number of small mammals as ranging from 60 to 500 meters. He & Mladenoff (1999) list dispersal distances for tree seeds ranging from 40 to 5000 meters, with most in the 100 to 400 meter range. Based on these dispersal ranges a value of 360 meters was chosen as the threshold for D_{crit}.

Impervious surface is a landscape condition metric that has a high correlation with water quality impacts from non-point source runoff (Arnold & Gibbons 1996). There are two general thresholds for percent impervious surface: 10 percent and 30 percent (Arnold & Gibbons 1996). According to Arnold & Gibbons (1996), there are three broad categories of stream health, protected (< 10 percent impervious), impacted (10 to 30 percent impervious), and degraded (> 30 percent impervious). Most researchers agree that there is a threshold for impervious surfaces around 10 percent (Scheuler 1994; Booth & Jackson 1997; May et al. 1997; Wang et al. 2001, Morse et al. 2003). Therefore, the threshold used for this scorecard is less than 10 percent impervious surface.

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