A Habitat-Based Framework for Communicating Natural Resource Condition

Tim J. B. Carruthers,1 Shawn L. Carter,2 Todd R. Lookingbill,3 Lisa N. Florkowski,1 Jane M. Hawkey,1 and William C. Dennison1

1 Integration and Application Network, University of Maryland Center for Environmental Science, P.O. Box 775, Cambridge, MD 21613, USA
2 US Geological Survey, National Climate Change & Wildlife Science Center, Reston, VA 20192, USA
3 Department of Geography and the Environment, University of Richmond, 28 Westhampton Way, Richmond, VA 23173, USA

Correspondence should be addressed to Todd R. Lookingbill, tlooking@richmond.edu

Received 8 December 2011; Accepted 7 January 2012

Academic Editors: D. Gerten and D. Sánchez-Fernández

Progress in achieving desired environmental outcomes needs to be rigorously measured and reported for effective environmental management. Two major challenges in achieving this are, firstly, how to synthesize monitoring data in a meaningful way at appropriate temporal and spatial scales and, secondly, how to present results in a framework that allows for effective communication to resource managers and scientists as well as a broader general audience. This paper presents a habitat framework, developed to assess the natural resource condition of the urban Rock Creek Park (Washington, DC, USA), providing insight on how to improve future assessments. Vegetation and stream GIS layers were used to classify three dominant habitat types, Forest, Wetland, and Artificial-terrestrial. Within Rock Creek Park, Forest habitats were assessed as being in good condition (67% threshold attainment of desired condition), Wetland habitats to be in fair condition (49% attainment), and Artificial-terrestrial habitats to be in degraded condition (26% attainment), resulting in an assessed fair/good condition (60% attainment; weighted by habitat area) for all natural resources in Rock Creek Park. This approach has potential to provide assessment of resource condition for diverse ecosystems and provides a basis for addressing management questions across multiple spatial scales.

1. Introduction

One of the key challenges of large-scale monitoring programs is to develop integrated and synthetic data products that can translate a multitude of diverse data into a format that can be readily communicated to decision-makers, policy developers, and the public [1–3]. Such timely syntheses of ecosystem condition can provide feedback to managers and stakeholders, so that the effectiveness of management actions as well as future management goals can be determined at multiple scales [4].

1.1. Integrative Indices and Report Cards. One approach to synthesizing data has been the development of multimetric indices to summarize the status of a community, such as stream fish, and then draw inferences on the status of the supporting ecosystem [5]. Metrics such as the fish index of biotic integrity (FIBI) and the benthic IBI have been widely applied, both internationally and regionally (e.g., streams in Maryland, USA). IBI metrics are seen as providing greater insight into ecosystem condition than physical measurements (e.g., water quality) alone, as biological communities provide an integrated summary of ecosystem condition over time [6–8]. However, in the absence of a rigorous process for integrating data on diverse biotic communities and other ecosystem components and for communicating results to decision-makers, these indices and bioindicators have had limited effectiveness in improving ecosystem management [9].
Environmental score cards or report cards are seen as an important tool for this type of integrated assessment, to move beyond simply identifying ecosystem change and on to applying monitoring data to ecosystem management [10, 11]. In some cases, assessments of multiple metrics using threshold-based environmental report cards have been used to compare estuaries at broad spatial scales [12–15]. At the local level, however, most environmental assessments still tend to focus on a few, specific resources rather than providing an integrated overview of site conditions.

1.2. Consideration of Scale in Integrated Assessments. An important consideration in determining the appropriate spatial and temporal scale of an integrated assessment is identifying the characteristic scales of variability in the ecological resources, as well as in the potential stressors to those resources.

Environmental processes typically show a direct relationship between temporal and spatial scales, with fine-scale spatial processes happening rapidly and broad-scale processes happening slowly [16, 17]. Many stressors also follow this pattern, with local impacts such as point-source inputs being short term and concentrated in small areas while global impacts such as climate change occur slowly over large spatial scales [18] (Figure 1). Less intuitive, and more difficult to measure, are shifting baselines such as nutrient increases, where gradual changes occur at even small spatial scales [19] and extreme events such as hurricanes where stressors can impact large areas in a very short period of time (Figure 1). In some cases, the aggregation of multiple small-scale stressors can also produce larger-scale impacts (Figure 1). Time versus space plots (Stommel diagrams) have been used extensively [17, 20] to illustrate these scaling relationships for different organisms and processes in oceanic [21] and terrestrial [16] environments.

1.3. Monitoring Data Collected at Multiple Scales. Integrative monitoring programs typically collect data on different variables at a variety of spatial and temporal scales. The spatial scale of measurement is important to consider for effectively combining metrics into integrated assessments of resource condition. A large number of metrics can be measured over small spatial scales for relatively little expense (e.g., biodiversity and water quality), so it is often useful to aggregate these metrics to get a more stable measure of condition (Figure 2). Aggregation can be accomplished by the mathematical combination of multiple metrics, for example, into a water quality index [22, 23] or the benthic index of biotic integrity (BIBI) [24]. Metrics providing information at very large spatial scales are often considered individually within an integrated assessment because they are typically more difficult or costly to obtain or represent one number for a large area such as percent impervious surface [25] (Figure 2).

The temporal scale of metric measurement is also important to consider for data synthesis. Metrics that change over short temporal scales can be measured at high frequency, although interpreting the high data variance can be challenging; in one example, rolling averages have been developed for ozone [26]. For metrics related to long-term trends, measures of central tendency are often suitable; long-term monitoring of land cover change often relies on key spatial pattern indices such as mean patch size, for example [27]. Matching the scale of observation to the scale of environmental change remains a central challenge in ecology [28]. Not only careful metric selection but also a strong framework to integrate diverse metrics, collected at different spatial and temporal scales, can assist in the interpretation of trends in natural resource condition and explanation of linkages between condition and diverse stressors.

1.4. Aim. The aim of this study was to integrate a series of available monitoring metrics to assess the current resource condition of habitats within Rock Creek Park and to identify ways to improve future assessments of resource condition.

2. Methods

2.1. Study Site. Rock Creek Park is located on approximately 710 hectares in the District of Columbia, USA, at the downstream end of a highly urban and continually developing Piedmont river valley [29]. The Park was established in 1890 at a significant time in the development of what would later become the National Park System. As a result, the protective prescription for the Park called for regulations to “provide for the preservation from injury or spoliation (plundering) of all timber, animals, or curiosities within said park, and their retention in their natural condition, as nearly as possible” [30, 31]. Therefore, determination of key habitats and assessment of resource condition is particularly...
relevant to the management of Rock Creek Park, a unit within the National Park Service.

2.2. Determination of Assessment Scale. The first step in the assessment process was to identify the spatial and temporal scale for assessment. Relevant scales for integrated assessments of natural resource condition may vary from 100s of meters, for example, within a managed land such as a national park or between subwatersheds, to 1000s of kilometers, for regional or even global-scale comparisons. Different data and approaches have been applied at these different scales [22, 32, 33]. In consultation with Park management staff, the assessment scales were determined based on potential management questions and interpretation as well as data availability. The spatial extent for the assessment was established as the current Park boundary (classified as the Fee Boundary) and the temporal extent is an eight-year period from 2000 to 2008.

2.3. Identification of Habitats. Many ecological classification systems exist, based on such features as vegetation communities [34, 35] or land cover [36]. In the current assessment, a classification defined by the International Union for the Conservation of Nature (IUCN) was used, to facilitate potential comparisons to other ecological systems [37]. The IUCN habitat classification includes 16 habitat types at the highest level, including both terrestrial and aquatic habitats, desert, forest, and subterranean cave habitats.

To determine the habitat types present within Rock Creek Park, a classified vegetation base map, from the National Capital Region (NCR) Inventory and Monitoring Program (I&M), was aggregated into general habitat types: beach/mixed oak, beach/tulip poplar, beach/white oak, chestnut oak, loblolly pine/mixed oak, tulip poplar, Virginia pine/oak, and sycamore/green ash were classified as “Forest habitat”; streams, seeps, and springs were classified as “Wetland (inland) habitat”; and canopy gap, meadow, mowed lawn, and mowed lawn with trees and shrubs were classified as “Artificial-terrestrial habitat”. Although discussions with resource managers originally determined a longer list of habitats (e.g., multiple forest types), available data density did not allow assessment at this level of precision, so the higher level habitat classification (three habitats) was used for condition assessment calculations.

2.4. Selection of Metrics. Within the habitat assessment framework, metrics were chosen to establish a definition of the conceptual range of habitat condition, from desired to degraded, which were applicable to management goals and objectives (Figure 3). Data were obtained from multiple sources: National Park Service (NPS) Inventory and Monitoring (I&M) Program, Montgomery County (Maryland, USA), US Environmental Protection Agency, and
Degraded forest habitat has high numbers of exotic shrubs and trees, high % of impervious surface, and large deer populations. Native seedling regeneration and diversity of forest-dwelling bird species are low in patch forest with high occurrence of insect pests.

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

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

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

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

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

Figure 3: Conceptual description of habitat desired and degraded condition based upon reliable and interpretable metrics for each habitat type.
Table 1: Sources of data used in the Rock Creek Park resource condition assessment.

| Metrics (by habitat) | Agency | Reference/source | Sites | Samples | Period          |
|----------------------|--------|------------------|-------|---------|----------------|
| **Forest**           |        |                  |       |         |                |
| Exotic tree/shrub density | NPS I & M | [38, 39]       | 3     | 4       | 2006-2007     |
| Presence of forest pest species | NPS I & M | [38, 39]       | 3     | 3       | 2005-2007     |
| Presence of forest interior dwelling species (FIDS) of birds | DC Birdscape II; NPS I & M | [40, 41] | Park | 3 | 2003-2008 |
| Deer density         | NPS I & M | [42]            | Park  | 8       | 2000-2007     |
| Native seedling regeneration | NPS I & M | [38, 39]       | 5     | 5       | 2006-2007     |
| Critical connectivity (Dcrit; within Park) | UMCES; NPS | [27] | Park | 1 | 2001-2002 |
| Proportion of impervious surface (within Park) | UMCES; NPS | NCRN I & M | Park | 1 | 2000 |
| **Wetland (inland)**|        |                  |       |         |                |
| Total phosphorus     | NPS I & M | [43]            | 13    | 230     | 2005-2007     |
| Salinity             | NPS I & M | [43]            | 13    | 219     | 2005-2007     |
| Aqueous nitrate      | NPS I & M | [43]            | 13    | 234     | 2005-2007     |
| Dissolved oxygen     | NPS I & M | [43]            | 13    | 241     | 2005-2007     |
| Benthic index biological integrity (BIBI) | NPS I & M, Montgomery County | [44] | Montgomery County, DEP | 6 | 6 | 2000-2004 |
| Proportion of area occupied (PAO) by amphibians | NPS I & M | [45] | Park | 9 | 2005-2007 |
| Physical habitat index (PHI) | NPS I & M, Montgomery County | [44] | Montgomery County, DEP | 3 | 8 | 2000-2004 |
| **Artificial-terrestrial** |        |                  |       |         |                |
| Deer density         | NPS I & M | [42]            | Park  | 8       | 2000-2007     |
| Proportion of impervious surface (within Park) | UMCES; NPS | NCRN I & M | Park | 1 | 2000 |
| PM2.5 concentration  | IMPROVE | http://vista.cira.colostate.edu/improve/ | 3     | 15      | 2000-2004     |
| Ozone                | EPA & NPS ARD | http://www.epa.gov/castnet/ | 2     | 8       | 2000-2003     |
| Wet SO$_4^2+$ deposition | NADP | http://nadp.sws.uiuc.edu/ | 3     | 10      | 2000-2007     |
| Total NO$_3$ deposition (cultivated) | NADP | http://nadp.sws.uiuc.edu/ | 3     | 10      | 2000-2007     |
| Hg deposition        | MDN-NADP | http://nadp.sws.uiuc.edu/mdn/ | 1     | 86      | 2004-2006     |

DEP: Department of Environmental Protection; EPA: US Environmental Protection Agency; I & M: Inventory and Monitoring; MBSS: Maryland Biological Stream Survey; MDN: Mercury Deposition Network; NADP: National Atmospheric Deposition Program; NCRN: National Capital Region Network; NPS: National Park Service; UMCES: University of Maryland Center for Environmental Science.

All metrics are used within the NPS I&M program and hence have been through a stringent process of protocol development as well as careful assessment for responsiveness to ecosystem changes [3]. Seven metrics were used to assess each habitat and two metrics (deer population and percentage of impervious surface) were used in the assessment of both Forest and Artificial-terrestrial habitats, resulting in a total of 19 separate data sets. Data used for the assessment of Rock Creek Park were collected between 2000 and 2008, with data density ranging from one park-level value at one time (e.g., impervious surface, critical connectivity) to 241 total measurements (e.g., dissolved oxygen, monthly measures from 13 sites) (Table 2).

Five of the indicators used to assess ecosystem condition of Forest habitats were measures of biodiversity, with two indicators of ecosystem processes (Figures 2 and 3). Of the seven indicators, three are relevant to the measurement of...
Table 2: Summary of thresholds and references used to justify thresholds for the Rock Creek Park habitat-based condition assessment (see Supplementary Materials available online at doi: 10.5402/2012/384892 for threshold justifications).

| Metric (by habitat)                          | Threshold                                      | References/justification                  |
|----------------------------------------------|------------------------------------------------|------------------------------------------|
| **Forest**                                  |                                                |                                          |
| Exotic tree/shrub density                   | <5% (of total basal area)                      | Guideline to commence removal            |
| Presence of forest pest species             | <1% of trees infested                          | [46, 47] see also [48]                   |
| Presence of forest interior dwelling species (FIDS) of birds | >1 "highly sensitive" FIDS | [49] see also [50]                     |
| Deer density                                | Forest: < 8 deer km⁻²                          | [51] see also [52, 53]                   |
| Native seedling regeneration                | >31,875 seedlings ha⁻¹                         | [54–56]                                  |
| Critical connectivity (Dcrit; within Park)   | <360 m                                        | [27, 57, 58]                             |
| Proportion of impervious surface (within Park) | <0.1                                          | [25, 59] see also [60]                   |
| **Wetland (inland)**                        |                                                |                                          |
| Total phosphorus                            | <36.56 µg L⁻¹                                   | [61]                                     |
| Salinity                                    | <0.25 g L⁻¹                                    | [44, 62]                                 |
| Nitrate                                     | <2 mg L⁻¹                                      | [24]                                     |
| Dissolved oxygen                            | June 1–Jan 31: ≥ 3.2 mg L⁻¹ Feb 1–May 31: ≥ 5.0 mg L⁻¹ | [63, 64]                                 |
| Benthic index biological integrity (IBI)    | >3                                             | [24, 44, 65]                             |
| Proportion of area occupied (PAO) by amphibians | 20% < PAO < 80% each spp.                      | Management guideline; see also [66–68]   |
| Physical habitat index (PHI)                | >42                                            | [24, 44]                                 |
| **Artificial-terrestrial**                  |                                                |                                          |
| Deer density                                | Grassland: <20 deer km⁻²                       | [51] see also [52, 53]                   |
| Proportion of impervious surface (within Park) | <0.1                                          | [25, 59] see also [60]                   |
| PM2.5 concentration                         | <15 mg m⁻³                                     | [69–71] see also [72]                    |
| Ozone                                       | <0.075 ppm                                     | [26, 69] see also [72, 73]               |
| Wet SO₄ deposition                          | <10 kg ha⁻¹ yr⁻¹                               | [74, 75] see also [72, 76]               |
| Total NO₃ deposition (cultivated)            | <10 kg ha⁻¹ yr⁻¹                               | [75, 77] see also [72]                   |
| Hg deposition                               | <2 ng L⁻¹                                      | [78–80]                                  |

Recognizing that the quality of a resource within Forest habitats (presence of forest interior dwelling birds, native seedling regeneration, connectivity), while the remaining four (exotic tree/shrub density, presence of pest species, deer density, impervious surface) measure stressors that are likely to directly impact Forest habitats.

Six of the seven indicators used to assess condition of Wetlands habitats were water quality indicators: three indicators of stressors (total phosphorus, salinity, aqueous nitrate) and three indicators of habitat quality for aquatic fauna (dissolved oxygen, benthic IBI, physical habitat index). The remaining indicator (proportion of area occupied by adult amphibians) is a measure of biodiversity and provides information regarding the ecosystem resource value of the habitat. Assessment of Artificial-terrestrial habitat condition was based on indicators in three categories: biodiversity (deer density), ecosystem processes (impervious surface), and air quality (soot, ozone, sulfate deposition, nitrate deposition, mercury deposition) (Figure 2, Table 2).

Recognizing that air quality indicators could be used for any habitat, particularly any terrestrial habitat, they were considered particularly appropriate for use in the predominantly mowed grass characterizing Artificial-terrestrial habitat within Rock Creek Park (Figure 2, Table 2). These open vistas rely most heavily on the resource of high visibility and are likely to be more directly impacted in terms of plant health by high ozone, due to plants being more exposed in open grassland than a closed forest. Wet deposition of sulfate, nitrate, and mercury is more likely to have a negative impact in open areas where transport rate to groundwater and creeks will be greater than areas such as forest where more rainfall is intercepted by plant canopies and where there is greater plant biomass to reabsorb nutrients from soils.

2.5. Definition of Thresholds and Calculation of Condition Assessment. To assess the natural resource condition of Rock Creek Park, thresholds were established for the 19 separate metrics using scientific literature, management goals, regulations, and professional judgment where necessary (Table 2).

In nearly all cases these thresholds were justified ecologically by the scientific literature, even though many of them were set as either management or regulatory thresholds.
Table 3: Summary of Rock Creek Park habitat-based condition assessment.

| Metric (by habitat)                                      | Units                                      | Grand mean | Standard error | Percentage of threshold attainment |
|---------------------------------------------------------|--------------------------------------------|------------|----------------|-----------------------------------|
| Forest: 575 ha (81%)                                    |                                            |            |                |                                   |
| Exotic tree/shrub density                               | % total basal area                         | 16.7       | 10.9           | 70                                |
| Presence of forest pest species                         | % of trees infested                        | 0          | —              | 100                               |
| Presence of forest interior dwelling species (FIDS) of birds | “highly sensitive” FIDS  + “sensitive” FIDS | 2.4        | 1.4            | 100                               |
| Deer density                                            | deer km⁻²                                  | 26.4       | 2.1            | 0                                 |
| Native seedling regeneration                           | seedlings ha⁻¹                            | 6,000      | 3,221          | 0                                 |
| Critical connectivity (Dcrit; within Park)              | m                                         | 340        | —              | 100                               |
| Proportion of impervious surface (within Park)          |                                            | 0.05       | —              | 100                               |
| Wetland (inland): 14 ha (2%)                           |                                            |            |                |                                   |
| Total phosphorus                                        | µg L⁻¹                                    | 929        | 60             | 0                                 |
| Salinity                                                | g L⁻¹                                     | 0.4        | 0.0            | 30                                |
| Aqueous nitrate                                         | mg L⁻¹                                    | 2.6        | 0.1            | 46                                |
| Dissolved oxygen                                        | mg L⁻¹                                    | 7.5        | 0.2            | 87                                |
| Benthic index biological integrity (IBI)                |                                            | 1.5        | 0.2            | 0                                 |
| Area occupied (PAO) by amphibians                       | % area occupied                           | 53.4       | 8.4            | 78                                |
| Physical habitat index (PHI)                            |                                            | 56.8       | 2.5            | 100                               |
| Artificial-terrestrial: 121 ha (17%)                    |                                            |            |                |                                   |
| Deer density                                            | deer km⁻²                                  | 26.4       | 2.1            | 12                                |
| Proportion of impervious surface (within Park)          |                                            | 0.05       | —              | 100                               |
| PM2.5 concentration                                     | mg m⁻³                                    | 14.4       | 0.6            | 27                                |
| Ozone                                                   | ppm                                       | 0.09       | 0.00           | 0                                 |
| Wet SO₄ deposition                                      | kg ha⁻¹ yr⁻¹                              | 18.2       | 0.6            | 0                                 |
| Total NO₃ deposition (cultivated)                       | kg ha⁻¹ yr⁻¹                              | 10.8       | 0.5            | 40                                |
| Hg deposition                                           | ng L⁻¹                                    | 13.5       | 0.3            | 0                                 |

Park percentage of attainment condition assessment is area-weighted by habitat type.

(3. Results)

Three habitats were defined within Rock Creek Park; Forest habitat making up 81% of the total area (575 ha), Wetland habitat 2% (14 ha), and Artificial-terrestrial habitat comprising the remaining 17% of Park area (121 ha) (Figure 4). Within the habitat assessment framework, the threshold attainment scores for individual metrics ranged from 0% attainment (very degraded) to 100% attainment (very good) (Table 3). The overall, area-weighted, habitat-based condition of Rock Creek Park, based on attainment of ecological threshold for 19 metrics, was assessed as fair to good (60% attainment; Table 3, Figure 5).

3.1. Forest Habitats. Forest habitats within Rock Creek Park were assessed to be in good condition (67% attainment of threshold condition; Table 3, Figure 5). These habitats had high deer populations of 26.4 ± 2.1 deer km⁻¹.
Figure 4: Map showing location of the three major habitat types within Rock Creek Park.

Habitats
- Forest (81%)
- Artificial-terrestrial (17%)
- Wetland (inland) (2%)
- DC boundary

3.2. Wetland Habitats. Wetland habitats within Rock Creek Park were assessed to be in fair condition (49% overall attainment of threshold condition; Table 3, Figure 5).

These habitats had a high total phosphorus concentration of 929 ± 60 µg L⁻¹ (mean ± standard error; 0% attainment), a low benthic index of biotic integrity of 1.5 ± 0.2 (0% attainment), and high salinity (0.4 ± 0.0; 30% attainment) and nitrate concentration 2.6 ± 0.1 mg L⁻¹ (46% attainment). The habitats had high dissolved oxygen of 7.5 ± 0.2 mg L⁻¹ (87% attainment), physical habitat index (56.8 ± 2.5; 100% attainment), and proportion of area occupied (PAO) by adult amphibians (53.4 ± 8.4; 78% attainment).

3.3. Artificial-terrestrial Habitats. Artificial-terrestrial habitats within Rock Creek Park were assessed to be in degraded condition (26% attainment of threshold condition; Table 3, Figure 5). While these habitats had just 5% impervious surface within the park (100% attainment), they had degraded condition for NO₃ deposition of 10.8 ± 0.5 kg ha⁻¹ yr⁻¹ (mean ± standard error; 40% attainment) and 14.4 ± 0.6 mg m⁻³ (PM2.5; 27% attainment), respectively, and highly degraded conditions for deer population with 26.4 ± 2.1 deer km⁻¹ (12.5% attainment), ozone concentration (0.09 ± 0.00 ppm), wet SO₄ deposition (18.2 ± 0.6 kg ha⁻¹ yr⁻¹), and mercury deposition (13.5 ± 0.3 ng L⁻¹; all 0% attainment).

4. Discussion

Effective ecosystem management relies on clear, synthetic communication of natural resource condition to managers, decision makers, and the interested public. The habitat
moderate numbers of exotic shrubs and trees, low percentage of impervious surface, and large deer populations. Native seedling regeneration is low, but bird species diversity is high in highly connected forest with low occurrence of insect pests.

Rock Creek Park forest habitats have moderate numbers of exotic shrubs and trees, low percentage of impervious surface, and large deer populations. Native seedling regeneration is low, but bird species diversity is high in highly connected forest with low occurrence of insect pests.

Rock Creek Park forest habitats have intact, shady stream banks, high nutrients, salinity, and oxygen levels with stable populations of amphibians, but degraded populations of benthic invertebrates.

Rock Creek Park artificial-terrestrial habitats have high particulate matter or soot (low visibility), and low impervious surface, but high deer populations, high ozone levels, fair sulfate deposition, and high nitrate and mercury deposition.

Table 3, Figure 5: Summary assessment of natural resources within Rock Creek Park, based upon habitat condition.

**Figure 5: Summary assessment of natural resources within Rock Creek Park, based upon habitat condition.**

The framework developed for the assessment of natural resource condition in Rock Creek Park provides a framework for the synthesis of diverse metrics to allow integrated assessments at multiple spatial and temporal scales, presenting results in a readily understandable and communicable format.

### 4.1. Implications of Rock Creek Park Assessment

An overall fair/good assessment of natural resource condition for the entire Park (60% attainment of ecological threshold condition) reflected the large area of Forest habitat in good condition the relatively small area of Artificial-terrestrial habitat (mostly mowed grasslands) in degraded condition, and the very small area of wetland in fair condition (Table 3, Figure 5).

The assessment of Forest habitat within the Park was good; however, this habitat is clearly challenged by very high deer populations and low native seedling regeneration (Table 3, Figure 5), suggesting that the Forest is susceptible to further degradation. Species richness and abundance of herbs and shrubs have shown measurable reductions at densities as low as 3.7 deer km\(^{-2}\) and are consistently reduced as densities approach 8.0 deer km\(^{-2}\) [81]. Densities of 10–17 deer km\(^{-2}\) inhibited the regeneration of understory species in a large manipulation study, whereas a diverse understory was supported at 3–6 deer km\(^{-2}\) [82]. It is therefore likely that high deer populations recorded for Rock Creek Park (approximately 26 deer km\(^{-2}\)) are related to the low native seedling regeneration (Table 3). Measurement of exotic tree and shrub density was highly variable (Table 3) with a mean value three times the threshold of 5% of total basal area, suggesting patchy but intense infestations. This metric was assessed from only three forest sampling plots (Table 2) and so increased spatial assessment would be valuable to more fully assess the potential impact of exotic plants on forest condition. Forest connectivity was close to the threshold (340 m measured, 360 m threshold; Table 3), suggesting that the Forest is susceptible to further fragmentation within the Park (by roads and trails, etc.), potentially reducing the habitat value for both flora and fauna.

High nutrient concentrations, depauperate benthic stream communities, and high salinity resulted in an assessment rating of fair for Wetland habitats within Rock Creek.
Park (Table 3). Nitrate concentration has been found to be negatively correlated to the integrity of benthic communities [24], and the statewide mean nitrate concentration of 2.45 mg L$^{-1}$ is lower than the mean of 2.6 ± 0.1 mg L$^{-1}$ measured within Rock Creek Park. Rock Creek watershed is also highly urbanized and the integrity of benthic communities has previously been correlated negatively to urbanization within the surrounding watershed [83]. Salinity in Rock Creek and tributaries was greater than 0.25 g L$^{-1}$ in 70% of samples, with salinities reported as high as 1.7 g L$^{-1}$ during winter, when road salting occurs [29]. Although short-term exposure (96 hrs) to salinities as high as 10 g L$^{-1}$ has been found to have little effect on individuals of multiple macro-invertebrate species [84], many studies have reported biotic degradation or species loss and promotion of exotic species at salinities greater than 1.0–1.4 g L$^{-1}$ [85, 86]. There has been a regional (Maryland, USA) increase in salinity over the past 30 years [87], so salinity has high potential to pose an increasing threat to the water quality in Rock Creek, with its highly urbanized watershed.

The degraded assessment for Artificial-terrestrial habitats within the Park resulted from the desired condition being largely based on air quality (Figure 3), with all five metrics of air quality having very low threshold attainment (Table 3). This raises the issue of how to define desired condition, especially for altered habitats that still have ecosystem values. In this case, for example, the Artificial-terrestrial habitats are mostly mowed grasslands—but with best management they could contain meadow areas habitat for insects and buffer areas along streamlines to limit nutrient inputs. This indicates a data gap, as no metrics are currently monitored to address changes in native meadow to mowed grass or extent of these data, which would allow an improved assessment of the natural resource condition of Artificial-terrestrial habitats, atmospheric metrics, which indicate more regional challenges.

4.2. A Habitat Framework Can Assist in the Assessment Process. Scientific understanding of ecosystem processes is often limited to the temporal and spatial scales of the research, requiring clear frameworks to facilitate translation of understanding across scales and application by decision-makers and managers [88]. Assessments of ecosystem status are increasingly being recognized for their value to direct and assess management actions [3, 4]. However, as the spatial scale of impacts becomes larger (e.g., air quality and climate change), the challenge is to develop frameworks that will allow comparison between different locations, or management units, as well as across spatial and temporal scales.

The condition and trend of natural resources can be evaluated over multiple temporal and spatial scales (Figure 1). Global [89] and national [90] level assessments have long been a focus of attention and regional level assessments have become increasingly prominent [23, 91]. At the local level, however, most environmental assessments still tend to focus on a few, specific resources rather than providing an integrated overview of site conditions. The most common framework for conducting ecosystem assessments is a geographic basis, for example, estuaries along a coastline [13] or regions within a larger system [92]. This is ideal when the different regions can be measured with the same metrics and are essentially similar (e.g., all temperate forest, all estuarine habitats, etc.). However, when disparate comparisons are requested (e.g., tropical and temperate estuaries, coastal and mountain landscapes), different ecological drivers may be present and the various communities may interact differently. One approach to dealing with this variability is to assess on a species by species basis; careful choice of indicator species can provide valid assessments of some aspects of an ecosystem [93]. However, an indicator species approach is limited to the range of the particular organism or organisms [94]. To understand, assess, and manage natural resources undergoing change requires a synthetic approach that looks across spatiotemporal scales and associated organizational levels [95, 96]. Hierarchical classification systems for forests [97] and streams [98] have been specifically designed to allow integration of data for broader level assessments. However, forests are not always accurately described by an accounting of individual trees and large basins are not simply a sum of smaller catchments [99], and the presented habitat framework has the potential to effectively bridge these hierarchies of scale.

Acknowledgments

Pat Campbell, John-Paul Schmidt, Marion Norris, Geoff Sanders, and Jeff Runde (CUE/NPS) as well as Sara Stevens (NCBN/NPS), Elizabeth Johnson (NER/NPS), and NCRN park managers provided helpful comments and discussion in the development of these ideas. Staff at Rock Creek Park provided insightful comments and input. Jeff Runde assisted with GIS data synthesis. Funding was facilitated through the Chesapeake Watershed CESU. UMES contribution number is 4611.

References

[1] J. R. Karr and E. W. Chu, “Biological monitoring and assessment: using multiameter indexes effectively,” EPA 235-R97-001, University of Washington, Seattle, Wash, USA, 1997.
[2] M. A. Harwell, V. Myers, T. Young et al., “A framework for an ecosystem integrity report card: examples from south Florida show how an ecosystem report card links societal values and scientific information,” BioScience, vol. 49, no. 7, pp. 543–556, 1999.
[3] S. G. Fancy, J. E. Gross, and S. L. Carter, “Monitoring the condition of natural resources in US national parks,” Environmental Monitoring and Assessment, vol. 151, no. 1–4, pp. 161–174, 2008.
[4] W. C. Dennison, T. R. Lookingbill, T. J. B. Carruthers, J. M. Hawkey, and S. L. Carter, “An eye-opening approach to developing and communicating integrated environmental assessments,” Frontiers in Ecology and the Environment, vol. 5, no. 6, pp. 307–314, 2007.
[5] J. R. Karr, “Assessment of biotic integrity using fish communities,” Fisheries, vol. 6, no. 6, pp. 21–27, 1981.
[6] N. Roth, M. Southerland, J. Chaillou et al., “Maryland biological stream survey: development of a fish index of biotic...
integrity," *Environmental Monitoring and Assessment*, vol. 51, no. 1-2, pp. 89–106, 1998.

[7] N. E. Roth, M. T. Southerland, J. C. Chaillou, P. F. Kazvak, and S. A. Stanko, “Refinement and validation of a fish index of biotic integrity for Maryland streams,” Chesapeake Bay and Watershed Programs: Monitoring and Non-Tidal Assessment CBWP-MANTA-EA-00, 2000.

[8] T. D. Harrison and A. K. Whitfield, “A multi-metric fish index to assess the environmental condition of estuaries,” *Journal of Fish Biology*, vol. 65, no. 3, pp. 683–710, 2004.

[9] S. L. Carter, G. Mora-Bourgeois, T. R. Lookingbill, T. J. B. Carruthers, and W. C. Dennison, “The challenge of communicating monitoring results to effect change,” *The George Wright Forum*, vol. 24, no. 2, pp. 48–58, 2007.

[10] U. S. EPA, “Mid-Atlantic highland streams assessment,” Tech. Rep. EPA903/R-00/015, U.S. Environmental Protection Agency Region 3, Philadelphia, Pa, USA, 2000.

[11] U. S. EPA, “A framework for assessing and reporting on ecological condition: an SAB Report,” Tech. Rep. EPA-SAB-EPEC-02-009, Environmental Protection Agency, Science Advisory Board, Washington, DC, USA, 2002.

[12] J. G. Ferreira, “Development of an estuarine quality index based on key physical and biogeochemical features,” *Ocean and Coastal Management*, vol. 43, no. 1, pp. 99–122, 2000.

[13] J. A. Kiddon, J. F. Paul, H. W. Buffum et al., “Ecological condition of US Mid-Atlantic estuaries, 1997–1998,” *Marine Pollution Bulletin*, vol. 46, no. 10, pp. 1224–1244, 2003.

[14] L. Turner, D. Tracey, J. Tilden, and W. C. Dennison, *Where River Meets Sea: Exploring Australia’s Estuaries*, Cooperative Research Centre for Coastal Zone, Estuary and Waterways Management, Brisbane, Australia, 2004.

[15] S. B. Bricker, B. Longstaff, W. Dennison et al., “Effects of nutrient enrichment in the nation’s estuaries: a decade of change,” *Harmful Algae*, vol. 8, no. 1, pp. 21–32, 2008.

[16] H. R. Delcourt and P. A. Delcourt, “Quaternary landscape ecology: relevant scales in space and time,” *Landscape Ecology*, vol. 2, no. 1, pp. 23–44, 1988.

[17] D. C. Schneider, “The rise of the concept of scale in ecology,” *BioScience*, vol. 51, no. 7, pp. 545–553, 2001.

[18] D. F. Boesch, “Global Warming and the Free State: Comprehensive Assessment of Climate Change Impacts in Maryland,” Report of the Scientific and Technical Working Group of the Maryland Commission on Climate Change, University of Maryland Center for Environmental Science, Cambridge, Mass, USA, 2008.

[19] N. Knowlton and J. B. C. Jackson, “Shifting baselines, local impacts, and global change on coral reefs,” *PLoS Biology*, vol. 6, no. 2, article e54, 2008.

[20] H. Stommel, “Varieties of oceanographic experience,” *Science*, vol. 139, no. 3555, pp. 572–576, 1963.

[21] J. H. Steele, “The ocean ‘landscape’,” *Landscape Ecology*, vol. 3, no. 3, pp. 185–192, 1989.

[22] C. E. Wazniak, M. R. Hall, T. J. B. Carruthers, B. Sturgis, W. C. Dennison, and R. J. Orth, “Linking water quality to living resources in a mid-atlantic lagoon system, USA,” *Ecological Applications*, vol. 17, no. 5, pp. 564–578, 2007.

[23] M. Williams, B. Longstaff, R. Llanso, C. Buchanan, and W. C. Dennison, “Development and evaluation of a spatially-explicit index of Chesapeake Bay health,” *Marine Pollution Bulletin*, vol. 59, no. 1–3, pp. 14–25, 2009.

[24] N. E. Roth, M.T. Southerland, G. Mercurio et al., “State of the streams: 1995–1997 maryland biogical stream survey results,” Tech. Rep. CBWP-MANTA-EA-99-6, Chesapeake Bay and Watershed Programs, Monitoring and Non-Tidal Assessment, 1999.

[25] C. L. Arnold Jr. and C. J. Gibbons, “Impervious surface coverage: the emergence of a key environmental indicator,” *Journal of the American Planning Association*, vol. 62, no. 2, pp. 243–269, 1996.

[26] U. S. EPA, The Clean Air Act. Washington United States Environmental Protection Agency, Washington DC, USA, 2004, http://epw.senate.gov/envlaws/cleanair.pdf.

[27] P. A. Townsend, T. R. Lookingbill, C. C. Kingdon, and R. H. Gardner, “Spatial pattern analysis for monitoring protected areas,” *Remote Sensing of Environment*, vol. 113, no. 7, pp. 1410–1420, 2009.

[28] S. A. Levin, “The problem of pattern and scale in ecology,” *Ecology*, vol. 73, no. 6, pp. 1943–1967, 1992.

[29] T. J. B. Carruthers, L. Carter, L. Florkowski, J. Runde, and W. Dennison, “Rock creek natural resource condition assessment,” Natural Resource Report NPS/NCRN/NRR – 2009/109, National Park Service, Fort Collins, Colo, USA, 2009.

[30] B. Mackintosh, *Rock Creek Park: An Administrative History*, United States Department of the Interior, National Park Service, Washington, DC, USA, 1985.

[31] “An act authorizing the establishing of a public park in the District of Columbia,” in *Proceedings of the 51st United States Congress*, September 1890, Ch. 1001, 26 Stat 492.

[32] R. P. Brooks, T. J. O’Connell, D. H. Wardrop, and L. E. Jackson, “Towards a regional index of biological integrity: the example of forested riparian ecosystems,” *Environmental Monitoring and Assessment*, vol. 51, no. 1–2, pp. 131–143, 1998.

[33] Y. Ding, W. Wang, X. Cheng, and S. Zhao, “Ecosystem health assessment in inner Mongolia region based on remote sensing and GIS,” *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. 37, no. B1, pp. 1029–1034, 2008.

[34] M. Anderson, P. Bourgeron, M.T. Bryer et al., *International Classification of Ecological Communities: Terrestrial Vegetation of the United States. Volume II. The National Vegetation Classification System: List of Types*, The Nature Conservancy, Arlington, Va, USA, 1998.

[35] D. H. Grossman, D. Faber-Langendoen, A. S. Weakley et al., *International Classification of Ecological Communities: Terrestrial Vegetation of the United States. Volume I. The National Vegetation Classification System: Development, Status, and Applications*, The Nature Conservancy, Arlington, Va, USA, 1998.

[36] J. R. Anderson, E. E. Hardy, J. T. Roach, and R. E. Witmer, “A Land use and land cover classification system for use with remote sensor data,” U.S. Geological Survey Professional Paper 964, U.S. Geological Survey, Reston, Va, USA, 1976.

[37] IUCN, “Habitats classification scheme (version 3.0),” International Union for the Conservation of Nature, 2007, http://www.iucnredlist.org/technical-documents/classification-schemes/habitats-classification-schema-ver3.

[38] J. P. Schmit and J. P. Campbell, “National Capital Region Network 2006 forest vegetation monitoring report,” Tech. Rep. NPS/NCRN/NRT/R-2007/046, National Park Service, Fort Collins, Colo, USA, 2007.

[39] J. P. Schmit and J. P. Campbell, “National Capital Region Network 2007 forest vegetation monitoring report,” Tech. Rep. NPS/NCRN/NRT/R-2008/125, National Park Service, Fort Collins, Colo, USA, 2008.

[40] J. Haddidian, J. Saver, C. Swarth et al., “A citywide breeding bird survey for Washington, D.C.,” *Urban Ecosystems*, vol. 1, pp. 87–102, 1997.
[41] D. K. Dawson and M. G. Efford, “National Capital Region Network–Protocol for monitoring forest-nesting birds,” Tech. Rep., National Park Service parks, Fort Collins, Colo, USA, 2006.

[42] S. Bates, “National Capital Region Network 2006 deer monitoring report,” Tech. Rep. NPS/NCR/NRTR-2007/033, National Park Service, Fort Collins, Colo, USA, 2007.

[43] M. Norris, J. P. Schmit, and J. Pieper, “National Capital Region Network 2005-2006 water resources monitoring report,” Tech. Rep. NPS/NCR/NRTR-2007/066, Natural Resource Program Center, Fort Collins, Colo, USA, 2007.

[44] R. H. Hilderbrand, R. L. Raesly, and D. M. Boward, National Capital Region Network–Biological Stream Survey Protocol, 2007.

[45] D. K. Dawson and M. G. Efford, “Birds as a tool in environmental monitoring, “Dist. of Columbia Municipal Regulations. DCMR, “District of Columbia Municipal Regulations. Amendment to chapter 11 of Title 21, sections 1100 to 1106,” 2005, http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/rivers/rivers_9.pdf.

[46] D. M. Norris, J. P. Schmit, and J. Pieper, “The influence of suburban land use on habitat and biotic integrity of coastal Rhode Island streams,” Environmental Monitoring and Assessment, vol. 139, no. 1–3, pp. 119–136, 2008.

[53] J. Bowman, A. Jaeger, and L. Fahrig, “Dispersal distance of seed dispersal when a species is detected imperfectly,” Ecology, vol. 84, no. 8, pp. 2200–2207, 2003.

[54] J. B. Stribling, B. K. Jessup, J. S. White, D. Boward, and M. Hurd, “Development of a benthic index of biotic integrity for Maryland streams. Chesapeake Bay and watershed programs monitoring and non-tidal assessment,” Tech. Rep. CBWP-98-3, 1998.

[55] D. I. MacKenzie, J. D. Nichols, J. E. Hines, and A. B. Franklin, “Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly,” Ecology, vol. 84, no. 8, pp. 2200–2207, 2003.

[56] D. I. MacKenzie, J. D. Nichols, J. E. Hines, and A. B. Franklin, “Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly,” Ecology, vol. 84, no. 8, pp. 2200–2207, 2003.
[74] D. W. Schindler, “Effects of acid rain on freshwater ecosys-
tems,” Science, vol. 239, no. 4836, pp. 149–157, 1988.
[75] J. Dupont, T. A. Clair, C. Gagnon et al., “Estimation of critical
loads of acid for lakes in Northeastern United States and
Eastern Canada,” Environmental Monitoring and Assessment,
vol. 109, no. 1–3, pp. 275–291, 2005.
[76] J. Hendricks and J. Little, Thresholds for regional vulnera-
ibility analysis. National exposure research laboratory. U.S. EPA
(E243-05), 2003, http://www.epa.gov/reva/docs/final_stres-
sor_threshold_table.pdf.
[77] P. Greenfelt and E. Thornelof, “Critical loads of nitrogen—a
workshop report,” Tech. Rep. 41, Nordic Council of Ministers,
Copenhagen. Regional Vulnerability Assessment Program
National Exposure Research Laboratory U.S. EPA (E243-05),
1992, (E243-05).
[78] M. Melli, K. Bishop, L. Bringmark et al., “Critical levels of
atmospheric pollution: criteria and concepts for operational
modelling of mercury in forest and lake ecosystems,” The
Science of the Total Environment, vol. 304, no. 1–3, pp. 83–106,
2003.
[79] C. R. Hammerschmidt and W. F. Fitzgerald, “Methylmercury
in freshwater fish linked to atmospheric mercury deposition,”
Environmental Science and Technology, vol. 40, no. 24, pp.
7764–7770, 2006.
[80] U. S. EPA, “Water quality criterion for the protection of hu-
man health: methylmercury,” Tech. Rep. EPA-823-R-01-001,
United States Environmental Protection Agency, Washington,
DC, USA, 2001.
[81] D. S. DeCalesta and S. L. Stout, “Relative deer density and
sustainability: a conceptual framework for integrating deer
management with ecosystem management,” Wildlife Society
Bulletin, vol. 25, no. 2, pp. 252–258, 1997.
[82] W. M. Healy, “Influence of deer on the structure and compo-
sition of oak forests in central Massachusetts,” in The Science
of Overabundance: Deer Ecology and Population Management,
W. J. McShea, H. B. Underwood, and J. H. Rappole, Eds.,
p. 249–266, Springer, Amsterdam, The Netherlands, 1997.
[83] J. H. Volstad, N. E. Roth, G. Mercurio, M. T. Southerland, and
D. E. Strebel, “Using environmental stressor information to
predict the ecological status of Maryland non-tidal streams as
measured by biological indicators,” Environmental Monitoring
and Assessment, vol. 84, no. 3, pp. 219–242, 2003.
[84] B. J. Blasius and R. W. Merritt, “Field and laboratory in-
vestigations on the effects of road salt (NaCl) on stream ma-
croinvertebrate communities,” Environmental Pollution,
vol. 120, no. 2, pp. 219–231, 2002.
[85] B. T. Hart, P. Bailey, R. Edwards et al., “A review of the salt
sensitivity of the Australian freshwater biota,” Hydrobiologia,
v. 210, no. 1–2, pp. 105–144, 1991.
[86] C. Fiscart, J. C. Moreteau, and J. N. Beisel, “Biodiversity
and structure of macroinvertebrate communities along a
small permanent salinity gradient (Meurthe River, France),”
Hydrobiologia, vol. 551, no. 1, pp. 227–236, 2005.
[87] S. Kaushal, P. Groffman, G. Likens et al., “Increased sali-
ization of fresh water in the Northeastern United States,” Pro-
ceedings of the National Academy of Sciences of the United
States of America, vol. 102, no. 38, pp. 13517–13520, 2005.
[88] J. E. Petersen, V. S. Kennedy, W. C. Dennison, and W. M.
Kemp, Eds., Enclosed Experimental Ecosystems and Scale: Tools
for Understanding and Managing Coastal Ecosystems, Springer,
New York, NY, USA, 2009.
[89] M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden,
and C. E. Hanson, Climate Change 2007: Impacts, Adaptation
and Vulnerability. Contribution of Working Group II to the
Fourth Assessment Report of the Intergovernmental Panel on
Climate Change, Cambridge University Press, Cambridge, UK,
2007.
[90] H. Center, The State of the Nation’s Ecosystems: Measuring
Land, Waters, and Living Resources of The United States, Island
Press, 2008.
[91] B. S. Brown, W. R. Munns Jr., and J. F. Paul, “An approach
to integrated ecological assessment of resource condition: the
Mid-Atlantic estuaries as a case study,” Journal of Environ-
mental Management, vol. 66, no. 4, pp. 411–427, 2002.
[92] F. J. Pantus and W. C. Dennison, “Quantifying and evaluating
ecosystem health: a case study from Moreton Bay, Australia,”
Environmental Management, vol. 36, no. 5, pp. 757–771, 2005.
[93] R. S. Morin, A. M. Leibold, E. R. Luzader, A. J. Lister, K. W.
Gottschalk, and D. B. Twardus, “Mapping host species abun-
dance of three major exotic forest pests,” Research Paper
NE-726, Northeastern Research Station, USDA forest service,
2004.
[94] S. J. Andelman and W. F. Fagan, “Umbrellas and flagships:
efficient conservation surrogates or expensive mistakes?”
Proceedings of the National Academy of Sciences of the United
States of America, vol. 97, no. 11, pp. 5954–5959, 2000.
[95] R. V. O’Neill and R. H. Gardner, “Sources of uncertainty in
ecological models,” in Methodology in Systems Modelling and
Simulations, B. P. Zeigler, M. S. Elzas, G. J. Klij, and T. I. Oren,
Eds., pp. 447–463, North-Holland Publishing, Amsterdam,
The Netherlands, 1979.
[96] T. F. H. Allen and T. B. Starr, Hierarchy: Perspectives for Ecolog-
cal Complexity, The University of Chicago Press, Chicago, Ill,
USA, 1982.
[97] P. Comer, D. Faber-Langendoen, R. Evans et al., Ecological
Systems of the United States: A Working Classification of U.S.
Terrestrial Systems, NatureServe, Arlington, Tex, USA, 2003.
[98] A. N. Strahler, “Quantitative analysis of watershed geomor-
phology,” American Geophysical Union Transactions, vol. 38,
pp. 913–920, 1957.
[99] J. Shaman, M. Stiegitz, and D. Burns, “Are big basins just the
sum of small catchments?” Hydrological Processes, vol. 18, no.
16, pp. 3195–3206, 2004.
Submit your manuscripts at
http://www.hindawi.com