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Research Article

Strategies for Long-Term Monitoring of Riverscour Plant Communities to Inform Science-Based Management

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ABSTRACT

Understanding the condition of natural resources in protected areas is fundamental to their management and preservation. Long-term monitoring can provide crucial data for managers to prioritize management actions and subsequently determine their effectiveness. In five national park units in the eastern United States, the National Park Service Inventory and Monitoring Program monitors rare riverscour communities—open habitats in which sun-loving plants grow over rocky substrates along high-gradient streams. Based on a decade of monitoring experience, we present recommendations for monitoring riverscour communities including sampling methodology, data collection methods, and subsequent management actions. Given increasing stressors from changing climate, invasive species, and altered hydrology, understanding how riverscour communities are changing is increasingly important to their protection.

Index terms: monitoring; national park; riverscour; sampling methods; science-based management

INTRODUCTION

Knowing the condition of natural resources in protected areas is fundamental to their management and preservation. Protected-area managers are confronted with increasingly complex and challenging issues that require a broad-based understanding of the status and trends of vulnerable resources as a basis for making management decisions. Knowledge gaps can be filled by deliberately designed and methodically implemented monitoring programs, which can provide crucial information on (adapted from Fancy et al. 2009):

1. the condition of the resource and reference points for comparisons with other altered or protected environments,
2. early warnings of abnormal conditions in selected resources to help develop effective mitigation measures and reduce costs of management,
3. the dynamic nature of natural systems and trends in selected indicators of those systems,
4. measuring progress toward management goals.

Monitoring provides managers with key information to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of the resources. Natural resource monitoring is most effective and useful when it is directly tied to management actions and objectives (Elzinga et al. 1998).

The National Park Service (NPS) created its Inventory and Monitoring Program to gather necessary information to fulfill the NPS mission of protecting resources "unimpaired for the enjoyment of future generations" (National Park Service Organic Act of 1916, 2014). The NPS Inventory and Monitoring Program allows more than 270 national park system units to implement long-term monitoring of their highest-priority "vital signs"—information-rich attributes that track the overall condition or "health" of park natural resources (Fancy et al. 2009).

The NPS Inventory and Monitoring Program is implemented programmatically through 32 ecoregional "networks," groupings of parks linked by geography and shared natural resource characteristics. Through shared funding and professional staff, the network approach also facilitates collaboration, information sharing, and economies of scale. Two networks, the Appalachian Highlands Network (APHN) and the Eastern Rivers and Mountains Network (ERMN), monitor riverscour plant communities as important vital signs in their parks (Figure 1). The Appalachian Highlands Network encompasses four parks in the Southern Appalachians and Cumberland Plateau across Tennessee, Kentucky, North Carolina, and Virginia, and monitors riverscour in Big South Fork National River and Recreation Area (BISO) and Obed Wild and Scenic River (OBRI). The Eastern Rivers and Mountains Network, which includes nine parks in New York, New Jersey, Pennsylvania, and West Virginia, monitors riverscour in Delaware Water Gap National Recreation Area (DEWA), New River Gorge National Park and Preserve (NERI), and Gauley River National Recreation Area (GARI).

Riverscour communities are "open habitats of stable-substrate zones (bedrock, boulder, cobble), often along high-gradient streams, where periodic high-flow events and edaphic factors inhibit woody vegetation and promote persistent shrub-grassland communities rich in conservative heliophytes" (Estes et al. in prep). Riverscour communities in the eastern United States are shaped by two primary factors: (1) geomorphology, including the underlying bedrock, sedimentary geology, and

Figure 1.—Monitoring network boundaries, parks, and streams where the National Park Service conducts riverscour monitoring. APHN = Appalachian Highlands Network, ERMN = Eastern Rivers and Mountains Network, BISO = Big South Fork National River and Recreation Area, OBRI = Obed Wild and Scenic River, DEWA = Delaware Water Gap National Recreation Area, NERI = New River Gorge National Park and Preserve, GARI = Gauley River National Recreation Area.

landforms in and around the river channel; and (2) flow regime, which is the timing and volume of water that flows through the river (Nilsson and Svedmark 2002; Naiman et al. 2005; Podniesinski et al. 2010). The interaction of these two factors controls what types of substrates or sediments are available for plant growth along the river, the frequency and intensity of scour and droughts, and ultimately what types of riparian plant communities establish and persist.

Riverscour communities occur where relatively stable areas of rock substrate (e.g., bedrock, boulders, or cobbles) have accumulated from mass wasting of gorge walls and/or alluvial processes, including exposing bedrock along the shoreline (Figure 2; Wolfe et al. 2007). Scour-adapted plants root in finer sediments deposited in cracks between the rock substrates. These unique plant communities persist due to patterns of scour and drought that other plants cannot tolerate (Wolfe et al. 2007). Grasses typical of the American tallgrass prairie, such as big bluestem (*Andropogon gerardii*), switchgrass (*Panicum virgatum*), and Indian grass (*Sorghastrum* spp.) have deep root systems that sprout readily after disturbance (Zedler 2007), such as scouring floods. The federally endangered Virginia spiraea (*Spiraea virginiana*) regenerates clones after scour episodes due to its fine fibrous root mass and heavy lateral rhizomes (USFWS 1992). Many of the rare plants in riverscour communities are obligate heliophytes vulnerable to shading if taller trees and shrubs are not removed by regular scour (Cartwright and Wolfe 2016).

Scour by water and/or ice during high flows is an important disturbance that strongly influences the composition and structure of riverscour communities (Wolfe et al. 2007). For rivers in the northeastern United States, ice blocks accumulated during the winter scour river shores in spring when snow melt causes high flows (Breden 1989; DePhilip and Moberg 2013; Edinger et al. 2014). For rivers that flow through gorges or other steep terrain in the southeastern United States, scour occurs during rainstorm events when high water flows and sediments carried therein abrade the river corridor (Cartwright and Wolfe 2016).

Altered flow regimes shift the balance between floods and droughts that maintain riverscour communities and may increase woody plant cover as trees and shrubs encroach into the riverscour (Wolfe et al. 2007). Dams alter flow regimes, changing

Figure 2.—Riverscour monitoring in an Appalachian Acidic Sandstone Rivershore Prairie at Gauley River National Recreation Area (top) and in a Cumberland Riverside Scour Prairie at Big South Fork National River & Recreation Area (bottom).

not only the timing and volume of water, but also the water temperature and the transport of sediment (Parasiewicz 2001; Bennett and McDonald 2006). Climate change can also alter river flow regimes, changing the frequency or intensity of scour events, especially in times of unprecedented storms and droughts. Warmer winter temperatures will reduce winter ice accumulation and spring ice scour that are critical to maintaining riverscour communities in the northeastern United States (Rustad et al. 2012). In addition, multiple anthropogenic stressors impact rivers in the eastern United States such as point and non–point source pollution; acid rain; floodplain and channel alterations from roads, railroads, and bridges; heavily concentrated recreation; municipal water withdrawal and wastewater discharge; and nonnative invasive plants (Podniesinski et al. 2010).

There are many different types of riverscour communities in the eastern United States, and several of these unique vegetation associations are considered globally rare (Sneddon 2010). These communities are hotspots of vascular plant diversity and provide critical habitat for multiple federal- and state-listed plant species, as well as rare insects and other organisms (Vanderhorst et al. 2007; Hudgins et al. 2011; Cartwright and Wolfe 2016). The riverscour communities monitored in APHN and ERMN national parks possess some of the highest ecological integrity (Faber-Langendoen et al. 2016) of the known examples of these globally rare communities and their associated rare plant species (Table 1, Figure 2; Murdock et al. 2013; Perles et al. 2018).

Monitoring Riverscour

Given that riverscour communities are inherently dynamic systems, understanding how they are changing and which changes warrant management intervention is essential to their protection within national parks. The need for long-term monitoring of riverscour communities to determine status and trends is highlighted in the parks' natural resource condition assessments (Mahan 2005; Worsham et al. 2013; Benck et al. 2017; Nadeau et al. 2019).

Successful riverscour monitoring efforts must be designed deliberately, with clearly defined objectives, appropriate sampling design, thorough documentation, and a commitment to implement the monitoring from planning through data analyses and reporting. We highly recommend *Measuring and Monitoring Plant Populations* (Elzinga et al. 1998) for a thorough discussion of plant monitoring since the details of designing and implementing plant monitoring are too complex to fully describe here. We highlight several recommendations for designing and implementing a successful monitoring program, with specific examples from riverscour monitoring.

Clearly Define Monitoring Goals and Objectives: One of the most critical steps in designing a monitoring program is to clearly define the goals and objectives. Are you most concerned about increased woody cover, trends in specific rare plant species, changes in sediment deposition, or other metrics? Thoroughly described objectives guide the remainder of the planning process.

There are two categories of objectives: management objectives that set specific goals for attaining ecological condition, and sampling objectives that set specific goals for the measurement of a value, such as target levels of precision, statistical power, acceptable false-change error rate, or the magnitude of change (Elzinga et al. 1998). Clearly defined management and sampling objectives that complement each other ensure that monitoring information is useful and collected data do not languish unanalyzed. For example, objectives for riverscour monitoring in NERI and GARI are (Perles et al. 2018):

Management objective: Maintain cover of woody plants greater than 1 m in height at $<$50% at each riverscour site.

Sampling objective: Detect 20% change in woody cover greater than 1 m in height over eight years, with a power of 0.80 and an alpha of 0.1.

Important metrics to consider when defining monitoring objectives for riverscour communities include: cover of woody plants, particularly species not adapted to flood disturbance; herbaceous and graminoid cover; substrate composition and

Table 1.—Riverscour communities monitored in national parks, with rarity information.

Park[a]	Riverscour community common name	NatureServe CEGL code[b]	NatureServe G Rank[c]	Number of rare plant species[d]
BISO and OBRI	Cumberland Riverside Scour Prairie	8471	G2	27
DEWA	Northern Riverscour Rock Outcrop	6284	G2	26
GARI	Appalachian Acidic Sandstone Rivershore Prairie	6623	G2	5
NERI	Central Appalachian-Allegheny Calcareous Riverscour Prairie	6283	G3	8

[a] BISO = Big South Fork National River and Recreation Area; OBRI = Obed Wild and Scenic River; DEWA = Delaware Water Gap National Recreation Area; NERI = New River Gorge National Park and Preserve; GARI = Gauley River National Recreation Area.
[b] CEGL = Community Element Global code, assigned and maintained by NatureServe (NatureServe 2021).
[c] G ranks: G2 = globally imperiled, typically having 6–20 known occurrences in the world; G3 = globally vulnerable or rare; typically having 21–100 known occurrences in the world, as assigned by NatureServe (NatureServe 2021).
[d] Number of federally- or state-listed rare plant species documented in the riverscour community in the park(s).

changes in sedimentation; rare plant occurrences; and species richness and cover of native, nonnative, and invasive species.

Identify the Population of Interest and Use Random Assignment to Avoid Bias: Based on your objectives, determine the population you are interested in monitoring. The population may be all riverscour community occurrences within a protected area, or a rare plant species at a single riverscour site. If you are unable to monitor every occurrence of your target, then the entire population must be sampled in an unbiased manner. Including a random or spatially balanced pseudorandom component in the selection of sampling sites allows for unbiased inference to the target population and more reliable and defensible estimates of target variables.

For example, APHN defines a riverscour community as discrete deposits of alluvium (composed largely of rocks and cobbles, but with less than 80% large boulders) that are seasonally flooded, vegetated with a mixture of warm-season perennial grasses and other herbaceous species adapted to full-sun conditions, with very few trees or shrubs that are not flood-adapted. Using this definition, APHN mapped all riverscour occurrences in OBRI, and then used stratified random selection to choose two cobble bars from each stream reach for inclusion in the monitoring protocol.

Since riverscour communities are dependent on high-gradient river flows, accessing the sites often requires boats or long, steep hikes into gorges. Access may be an important factor to consider in the sampling design. Include any access limitations in the description of the population of interest. As a hypothetical example, the monitoring population could include all riverscour communities in the park within 5 km of a put-in and take-out point for boats or within 3 km of a road that provides access along a path with slopes less than 35°. The scope of inference of the monitoring results will not extend to the inaccessible sites that were removed due to logistical constraints.

Choose a Sampling Design That Will Efficiently Meet Your Objectives: Although sampling design decisions depend on site-specific objectives and constraints, there are existing riverscour monitoring protocols that can be adapted or built upon (Murdock et al. 2013; Perles et al. 2018). The use of permanent sampling units (e.g., transects or quadrats) that are revisited over time is recommended for monitoring, because resampling permanent transects or quadrats increases the power to detect trends over time by removing transect-to-transect differences from the change estimates and increasing estimate precision (Urquhart et al. 1998; Fancy et al. 2009). Note that maintaining permanent monuments in highly dynamic riverscour systems presents a challenge; however, some suggested techniques are presented below.

Determine How the Data Will Be Analyzed before They Are Collected: Very small differences in data collection can have profound impacts on the types of analysis that can be conducted. For example, percent cover categories (e.g., <1%, 1–5%, 5–10%) are a common field method for characterizing plant abundance. Such ordered categorical data are not normally distributed; therefore, cumulative link models or ordinal zero-augmented beta models are appropriate analysis approaches (Irvine et al. 2019). Simpler linear or logistic models may be used for aggregated percent cover data (e.g., total cover of native plants, proportion of total cover represented by invasive plants); however, many details of the analytical approach are dependent on the details of how data were collected. Furthermore, the desired precision of your monitoring and sampling objectives should guide the level of precision with which the data are collected.

Clearly Document Everything: Monitoring will only be successful if data collection is consistent over time. Document and archive in an accessible place all details of the sampling methodology, directions to sampling sites, field protocols, data value descriptions/restrictions, etc. Data should be linked to the specific versions of field protocols that were used for their collection. Include explanations for key decisions in determining objectives, sampling design, and field protocols.

National Park Service Approach to Riverscour Monitoring

National Park Service riverscour monitoring protocols have been designed to detect trends in plant community structure and composition, particularly trends in cover of woody plants greater than 1 m tall. Several NPS monitoring objectives focus on detecting shifts in plant community composition, such as cover of invasive plants, abnormal increases in cover by seedlings and saplings of flood-intolerant woody species, as well as shifts in guilds of native species (e.g., grasses, forbs). Changes in deposition of fine sediment, woody debris, and other substrate types, which are crucial to the persistence of riverscour communities, are also monitored.

Field protocols were designed to allow the greatest possible amount of precision during repeated sampling within the constraints of working in areas where annual flooding and impervious substrates make the establishment of permanent monuments difficult. To maintain high precision, transects must

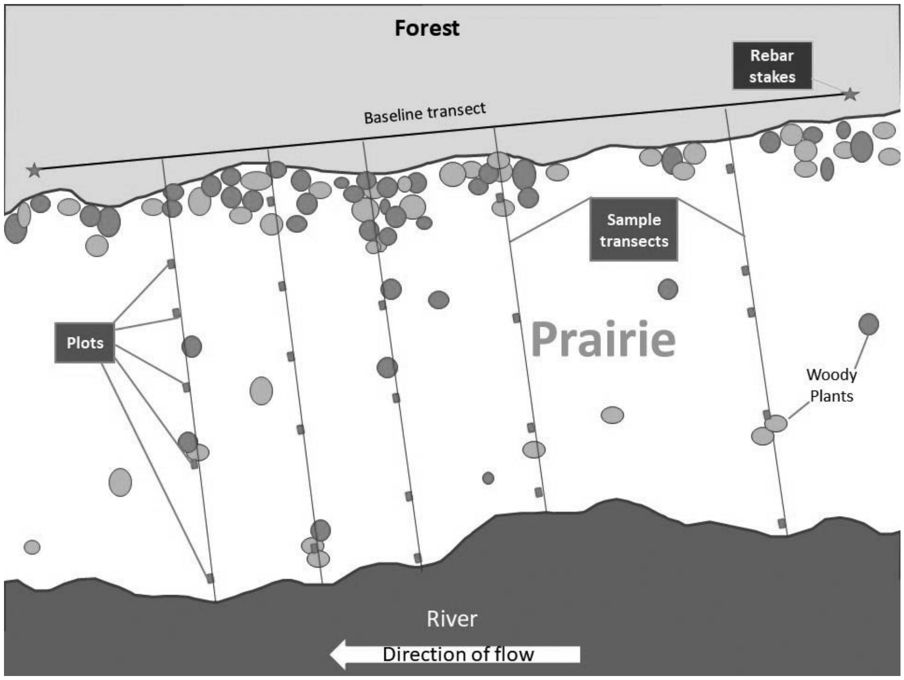

Figure 3.—Sample design for monitoring riverscour communities in two National Park Service Inventory and Monitoring networks.

be placed in the same position during every sample event. At each riverscour site, the sampling transects are located relative to a baseline that spans the site's length parallel to the river, far enough into the forest to be somewhat sheltered from the main force of floods (Figure 3). Origin, terminus, and intermediate locations along the baseline are marked with rebar stakes, as well as tagged and georeferenced witness trees, so that the baseline can be reestablished on subsequent sampling events. The locations of rebar stakes are also documented with GPS waypoints collected to sub-meter accuracy, when possible. This allows the baseline to be permanently monumented with less chance of disturbance. Even the sturdiest markers can easily be washed away if put directly in the riverscour, where trees and boulders crash through during seasonal flood events.

Restricted randomization was used to establish monitoring transects along the baseline to ensure that transects were spatially distributed throughout each site. The baseline was divided into equal-length sections and one monitoring transect was randomly located within each section. Restricted random sampling resulted in good spatial distribution of sampling units throughout the target population and resulted in more precise estimates of density than simple random sampling (Elzinga et al. 1998). Monitoring transects were established using sighting compasses perpendicular to the baseline from the forest to the edge of the river, with park-specific criteria defined to consistently determine the beginning and end points of monitoring transects (Figure 3). The location of each transect relative to the baseline was recorded and replicated during subsequent sampling events. Although there can be 1–2° error with sighting compasses, monitoring transects can be reestablished consistently with thorough training of field staff and careful adherence to standard operating procedures. In dynamic riverscour communities with frequent disturbances that regularly remove aboveground plant material, the level of precision achieved with sighting compasses is sufficient for monitoring. Since the transect terminus is the river's edge, the length of each monitoring transect varies during every sample and is recorded to incorporate into data analyses.

Both NPS networks use the line-intercept method to quantify relative abundance of woody vegetation greater than 1 m tall. This method records the points along the transect where woody cover begins and ends, with species identified for each intercept distance. Percent cover of all woody species is calculated by summing the lengths of the intercepted line segments and dividing by the total transect length. Percent cover can also be calculated for individual species, flood-adapted vs. non-flood-adapted species, or for invasive woody plants.

Plant community composition and substrate are measured differently by the two networks. In APHN parks, the point-intercept method is used to measure cover for plants less than 1 m tall (divided into functional groups of grass, herbaceous species, and woody species), and for nonliving substrate classes (e.g., sand, gravel, cobble, boulder, and woody debris). Two data points are collected using a laser every 50 cm along a transect from the forest canopy edge to the river's edge. The first laser intercept at each point represents the vegetation layer and can be recorded as "open" if no vegetation exists. The last laser intercept at each point represents the substrate layer. Any intercepts between the first and last at each point are ignored for APHN monitoring but could be included if a measure of vegetation density is desired. Cover is calculated by dividing the number of points that intercepted a particular plant or substrate category along the transect by the total number of points measured on the transect.

In ERMN parks, quadrats are placed along the monitoring transects, using restricted randomization. Within each 1 m^2 quadrat, the substrate is characterized and all vascular plant species within the quadrat are recorded using standard percent cover categories. Pilot studies in DEWA (Shank and Shreiner 1999; Perles et al. 2011) determined that a sampling intensity of one quadrat per 152 m^2 of riverscour was adequate to detect statistically significant changes in species richness, abundance and frequency of individual species, and percent cover of key invasive plants. The benefits and challenges of the point-intercept and quadrat methods are discussed in detail in the following section.

Sampling occurs each year in late summer to early fall (August through the first half of October), when grasses and other perennial plants have reached their maximum growth for the season but before senescence. Sampling is planned for times when the river gauge height is low enough to fully expose the riverscour, although analysis of pilot data have shown that river flows can vary considerably without substantially affecting the area of riverscour sampled. The length of the monitoring transects is affected by river gauge height, such that recording monitoring transect length is crucial during each sampling event.

The sampling schedule follows a rotating panel design, in which a subset of riverscour sites is monitored each year, with sites distributed across the rivers' main stems and major tributaries (Stevens and Olsen 2004). The sample panel rotates every 2 y in APHN and every 7 y in ERMN, driven primarily by network capacity for field work. Field crews are composed of two people, one of whom is familiar with the local flora. Once the monitoring protocol is determined and sites are established, monitoring each riverscour site requires 3.5 person-days on average, including all tasks from field season preparation through data analysis and reporting.

Comparison of Sampling Methodologies

Based on previously published studies and our work resampling an extensive riverscour community with both methodologies (Symstad et al. 2006; Perles et al. 2011), the point-intercept and quadrat methods yield similar results for key measures in riverscour monitoring, such as proportion of total cover occupied by native or invasive species, and percent cover of substrate type. Thus, either method could be used for long-term monitoring related to these objectives, if the method was applied consistently. Depending on methodology details, the point-intercept method can be more efficient at detecting trends in plant community structure (e.g., woody vs. graminoid cover) and available substrate, whereas the quadrat method can provide information on shifts in relative abundance of characteristic or dominant plant species, which is useful for objectives focused on specific herbaceous species.

Measuring cover by the point-intercept method is considered the least biased and most objective of the basic cover measures, as point intercepts are not subject to observer variability from canopy gaps or visual cover estimations that are inherent in quadrat sampling (Elzinga et al. 1998). That said, because the point-intercept method assumes that the sampling point is infinitesimally small, but actual sample points have a real (though small) diameter, the point-intercept method inevitably overestimates cover compared to the true value (Winkworth 1955). Kercher et al. (2003) and Miller et al. (2006) found that cover values were consistently lower when measured by the quadrat method than when measured with the intercept method.

The point-intercept method captures significantly fewer plant species than the quadrat method, such that transect species richness is significantly lower for the point-intercept method compared with the quadrat method (Floyd and Anderson 1987; Stohlgren et al. 1998; Kercher et al. 2003; Leis et al. 2003; Symstad et al. 2006; Perles et al. 2011). However, the majority of species missed by the point-intercept method have very low cover (<1%; Symstad et al. 2006; Perles et al. 2011). A practical result of capturing fewer species is that the point-intercept method requires less botanical expertise from observers than the quadrat method. Furthermore, transects sampled with the point-intercept method take less time in the field to complete than transects with quadrats.

If all quadrats within each transect are averaged (i.e., the transect is the permanent sampling unit), the quadrat method requires more transects than point-intercept sampling for the same level of precision (Perles et al. 2011). However, in riverscour communities with strong vegetation gradients from forest to river, the quadrat methodology is advantageous in that quadrats can be grouped by distance from forest or river and analyzed separately. In this case, quadrats are considered the permanent sampling unit, and the quadrat method will have greater power to detect trends and be more operationally efficient than the point-intercept method given the same number of transects (Perles et al. 2011). This approach is useful for sites where, for example, invasive woody shrubs are abundant only near the forest, or a rare plant thrives only near the shoreline.

Analysis of ortho-rectified aerial photography in time series can be useful in monitoring the distribution and extent of available riverscour habitat throughout entire river corridors (as described in Wolfe et al. 2007). While this approach provides a more spatially comprehensive overview of available riverscour habitat in the river corridor, it cannot provide information on the presence of woody, invasive, or rare plants that are the primary focus of the NPS monitoring protocols described herein. Furthermore, the bedrock outcrops, boulders, and cobble bars that provide unique substrates for riverscour communities are stable under current climate conditions (Wolfe et al. 2007), indicating that site-level monitoring from a statistically valid random sample of the river corridor will yield more actionable information for management.

While the APHN and ERMN monitoring provide key information on condition and trends in riverscour communities, they do not specifically target rare plant species, which are often missed by the monitoring transects, and therefore often provide little information on the condition or trends of rare plant populations. Additional sampling methods and design would be required to capture rare species population information such as individual counts or demographic data suitable for population viability analyses. For more information on monitoring rare plant species, see Menges and Gordon (1996) and Palmer (1987).

Monitoring Data Guides Riverscour Management

When deliberately designed and methodically implemented, monitoring riverscour communities produces information crucial to managing and protecting these special habitats. For example, monitoring the Northern Riverscour Rock Outcrops along the Delaware River in DEWA identified 400% increases in cover of invasive shrubs such as autumn olive (*Elaeagnus umbellata*) and honeysuckles (*Lonicera* spp.) (Perles et al. 2011). As a result, park staff and the regional Invasive Plant Management Team are removing and treating the invasive shrubs, conducting the treatments in late winter to reduce impacts on the numerous rare plant species. APHN data from the last 10 y indicated that riverscour communities at BISO and OBRI have been largely stable, without significant encroachment of native or invasive woody species. These results have allowed park staff to focus resources on other management needs, since woody species removal was not needed in the riverscour communities. Monitoring that reveals important resources are in good stable condition can be as valuable in directing limited park resources as monitoring that highlights significant resource declines.

When field staff visit riverscour sites for monitoring, they play a key role in the early detection of and rapid response to invasive plants. During riverscour monitoring in ERMN and APHN parks, field staff search the entire riverscour site for invasive plants, with a focus on a short list of key invasive plants that are likely to appear in the park but have not yet been documented within park boundaries. Invasive plants that are new to the river drainage or to the park are reported to park managers and, when possible, treated promptly as a cost-effective response to prevent the spread of new invasive plants. Thus far, new occurrences of sweet autumn clematis (*Clematis terniflora*), kudzu (*Pueraria montana*), and marsh dewflower (*Murdannia keisak*) have been discovered during riverscour monitoring and promptly treated by NPS staff.

Although designing and implementing long-term monitoring requires investment in time and resources, knowing how riverscour communities are changing is crucial to managing these biodiverse sites and protecting the rare plants and animals that depend on riverscour habitats. Understanding the condition and trends in woody cover, invasive plant abundance, and characteristic native plants empowers natural resource managers to advocate for needed changes to hydrologic regimes on dammed rivers and to target woody species removal effectively. As globally rare communities that support state- and federally-listed species, riverscour communities warrant the effort associated with monitoring, so that data guide their management and the protection of their few remaining locations.

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Evan M. Raskin is the APHN Assistant Data Manager/Biologist and the field crew lead for APHN vegetation monitoring. Based in western North Carolina, Evan has spent the past 11 years with The Nature Conservancy and the National Park Service and has been monitoring riverscours on the Cumberland Plateau since 2014.

LITERATURE CITED

Benck, K.M., K. Allen, A.J. Nadeau, H. Hutchins, A.M. Davis, and A. Robertson. 2017. Natural resource condition assessment: Obed Wild and Scenic River. Natural Resource Report NPS/OBED/NRR—2017/1554. National Park Service, Fort Collins, CO.

Bennett, D., and B. McDonald. 2006. Riparian conditions of the Gauley and Meadow Rivers in Gauley River National Recreational Area, West Virginia. West Virginia Division of Natural Resources Wildlife Resources Section Report, Cooperative Agreement 4000-8-9011.

Breden, T.F. 1989. A preliminary natural community classification for New Jersey. Pp. 157–191 *in* E.F. Karlin, ed., New Jersey's Rare and Endangered Plants and Animals. Institute for Environmental Studies, Ramapo College, Mahwah, NJ.

Cartwright, J.M., and W.J. Wolfe. 2016. Insular ecosystems of the southeastern United States—A regional synthesis to support biodiversity conservation in a changing climate: U.S. Geological Survey Professional Paper 1828. <http://dx.doi.org/10.3133/pp1828>

DePhilip, M., and T. Moberg. 2013. Ecosystem flow recommendations for the Delaware River basin. The Nature Conservancy, Harrisburg, PA.

Edinger, G.J., D.J. Evans, S. Gebauer, T.G. Howard, D.M. Hunt, and A.M. Olivero, eds. 2014. Ecological Communities of New York State. 2nd ed. A Revised and Expanded Edition of Carol Reschke's Ecological Communities of New York State. New York Natural Heritage Program, New York State Department of Environmental Conservation, Albany, NY. <https://www.nynhp.org/ecological-communities/>

Elzinga, C.L., D.W. Salzer, and J.W. Willoughby. 1998. Measuring and Monitoring Plant Populations. Bureau of Land Management. Technical Reference 1730-1, Denver, CO.

Faber-Langendoen, D., W. Nichols, J. Rocchio, K. Walz, and J. Lemly. 2016. An Introduction to NatureServe's Ecological Integrity Assessment Method. NatureServe, Arlington, VA.

Fancy, S.G., J.E. Gross, and S.L. Carter. 2009. Monitoring the condition of natural resources in US National Parks. Environmental Monitoring and Assessment 151:161–174.

Floyd, D.A., and J.E. Anderson. 1987. A comparison of three methods for estimating plant cover. Journal of Ecology 75:221–228.

Hudgins, R., C. Norment, M.D. Schlesinger, and P.G. Novak. 2011. Habitat selection and dispersal of the cobblestone tiger beetle (*Cicindela marginipennis* Dejean) along the Genesee River, New York. American Midland Naturalist 165:304–318.

Irvine, K.M., W.J. Wright, E.K. Shanahan, and T.J. Rodhouse. 2019. Cohesive framework for modelling plant cover class data. Methods in Ecology and Evolution 10:1749–1760.

Kercher, S.M., C.B. Frieswyk, and J.B. Zedler. 2003. Effects of sampling teams and estimation methods on the assessment of plant cover. Journal of Vegetation Science 14:899–906.

Leis, S.A., D.M. Engle, D.M. Leslie, J.S. Fehmi, and J. Kretzer. 2003. Comparison of vegetation sampling procedures in a disturbed mixed-grass prairie. Proceedings of the Oklahoma Academy of Sciences 83:7–15.

Mahan, C.G. 2005. A natural resource assessment for New River Gorge National River. Technical Report NPS/NER/NRTR–2004/002. National Park Service, Philadelphia, PA.

Menges, E.S., and D.R. Gordon 1996. Three levels of monitoring intensity for rare plant species. Natural Areas Journal 16:227–237.

Miller, M.E., D. Witwicki, and R. Mann. 2006. Field-based evaluations of sampling methods for long-term monitoring of upland ecosystems on the Colorado Plateau – 2005 Annual Report: U.S. Geological Survey, Southwest Biological Science Center, Kanab, UT.

Murdock, N., R.L. Smyth, C.W. Nordman, R. Emmott, B. O'Donoghue, and P. Flaherty. 2013. Long-term monitoring protocol for cobble bar communities: Big South Fork National River and Recreation Area (BISO) and Obed Wild and Scenic River (OBRI). Natural Resource Report NPS/APHN/NRR—2013/698. National Park Service, Fort Collins, CO.

Nadeau, A.J., K. Allen, H. Hutchins, and A. Robertson. 2019. Natural resource condition assessment: Gauley River National Recreation Area. Natural Resource Report NPS/GARI/NRR—2019/1859. National Park Service, Fort Collins, CO.

Naiman, R.J., H. Decamps, and M.E. McClain. 2005. Riparia: Ecology, Conservation, and Management of Streamside Communities. Elsevier, New York.

NatureServe. 2021. NatureServe Explorer. NatureServe, Arlington, VA. Accessed 3 Dec 2021 from <https://explorer.natureserve.org/>.

Nilsson, C., and M. Svedmark. 2002. Basic principles and ecological consequences of changing water regimes: Riparian plant communities. Environmental Management 30:468–480.

National Park Service. 1916. National Park Service Organic Act of 1916. 54 U.S.C. § 100101(a) (2014).

Palmer, M.E. 1987. A critical look at rare plant monitoring in the United States. Biological Conservation 39:113–127.

Parasiewicz, P. 2001. Strategy for sustainable management of the Upper Delaware River Basin. Report to Trout Unlimited.

Perles, S.J., K.K. Callahan, and M.R. Marshall. 2011. Long term monitoring of a rare riparian community in the Delaware Water Gap National Recreation Area: Eastern Rivers and Mountains Network. Natural Resource Technical Report. NPS/ERMN/NRTR—2011/495. National Park Service, Fort Collins, CO.

Perles, S.J., D.R. Manning, K.K. Callahan, and M.R. Marshall. 2018. Rare riparian prairie monitoring protocol for the Eastern Rivers and Mountains Network: Protocol narrative version 1.0. Natural Resource Report NPS/ERMN/NRR—2018/1733. National Park Service, Fort Collins, CO.

Podniesinski, G.S., M. Furedi, B.A. Eichelberger, and S.J. Perles. 2010. Conceptual models and recommendations for monitoring riparian plant communities within riverine parks of the Eastern Rivers and Mountains Network. Natural Resource Report NPS/NER/NRR—2010/023. National Park Service, Philadelphia, PA.

Rustad, L., J. Campbell, J.S. Dukes, T. Huntington, K. Fallon Lambert, J. Mohan, and N. Rodenhouse. 2012. Changing climate, changing forests: The impacts of climate change on forests of the northeastern United States and eastern Canada. General Technical Report NRS-99. USDA Forest Service, Northern Research Station, Newtown Square, PA.

Shank, L.K., and J. Shreiner. 1999. Globally threatened calcareous riverside seep and calcareous riverside outcrop communities along the New Jersey shoreline of the Delaware River: Summary of rare plant census, community sampling, and recommended monitoring protocol. Department of Environmental Protection, Division of Parks and Forestry, Office of Natural Lands Management, Trenton, NJ.

Sneddon, L.A. 2010. Global conservation status ranks of state-rare vegetation associations in the Eastern Rivers and Mountains Network. Natural Resource Technical Report NPS/NER/ERMN/NRTR—2010/151. National Park Service, Philadelphia, PA.

Stevens, D.L., and A.N. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99(465):262–278.

Stohlgren, T.J., K.A. Bull, and Y. Otsuki. 1998. Comparison of rangeland vegetation sampling techniques in the central grasslands. Journal of Range Management 51:164–172.

Symstad, A.J., C.L. Wienk, and A. Thorstenson. 2006. Field-based evaluation of two herbaceous plant community sampling methods for long-term monitoring in northern Great Plains national parks. U.S. Geological Survey Open-File Report 2006-1282, Helena, MT.

Urquhart, N.S., S.G. Paulsen, and D.P. Larsen. 1998. Monitoring for policy-relevant regional trends over time. Ecological Applications 8:246–257.

[USFWS] U.S. Fish and Wildlife Service. 1992. Virginia spiraea (*Spiraea virginiana* Britton) recovery plan. Newton Corner, MA.

Vanderhorst, J.P., J. Jeuck, and S.C. Gawler. 2007. Vegetation classification and mapping of New River Gorge National River, West Virginia. Technical Report NPS/NER/NRTR—2007/092. National Park Service, Philadelphia, PA.

Winkworth, R.E. 1955. The use of point quadrats for the analysis of heathland. Australian Journal of Botany 3:68–81. Cited in K.F. Higgins, K.J. Jenkins, G.K. Clambey, D.W. Uresk, S.E. Naugle, J.E. Norland, and W.T. Barker. 2005. Vegetation sampling and measurement. Pp. 523–553 *in* C.E. Braun, ed., Techniques for Wildlife Investigations and Management. The Wildlife Society, Bethesda, MD.

Wolfe, W.J., K.C. Fitch, and D.E. Ladd. 2007. Alluvial bars of the Obed Wild and Scenic River, Tennessee. US Geological Survey, Scientific Investigations Map 2007-2972. USGS, Knoxville, TN.

Worsham, L., G. Sundin, N. Nibbelink, G. Grossman, and M. Mengak. 2013. Natural resource condition assessment for Big South Fork National River and Recreation Area. Natural Resource Report NPS/BISO/NRR—2013/619. National Park Service, Fort Collins, CO.

Zedler, P.H. 2007. Fire effects on grasslands. Pp. 397–439 *in* E.A. Johnson and K. Miyanishi, eds., Plant Disturbance Ecology: The Process and the Response. Elsevier, Oxford, UK.