Fall 2014

Designing a Regional Trail Network of High Conservation Value Using Principles of Green Infrastructure

Carroll I. Courtenay

Todd R. Lookingbill
University of Richmond, tlooking@richmond.edu

Recommended Citation

Courtenay, Carroll I., and Todd R. Lookingbill. "Designing a Regional Trail Network of High Conservation Value Using Principles of Green Infrastructure." *Southeastern Geographer* 54, no. 3 (Fall 2014): 270-90. doi:10.1353/sgo.2014.0023.

Designing a Regional Trail Network of High Conservation Value Using Principles of Green Infrastructure

CARROLL I. COURTENAY
University of Richmond

TODD R. LOOKINGBILL
University of Richmond

Conservation and recreation planning potentially share many common goals, including the desire to increase landscape connectivity. Trail networks, however, typically develop independently of ecological corridors, with emphasis placed solely on their human services. The failure to align conservation and human use values results in missed opportunities to maximize the benefits of new trail development. This study uses concepts of green infrastructure and tools of connectivity modeling to identify priority locations for a regional trail network in the James River watershed, Virginia U.S.A. The approach uses methods derived from circuit theory to identify potential pathways that meet basic trail design criteria but are also deemed to be of high conservation value. Results are discussed with respect to three separate regions within the watershed, each with distinct planning challenges. The relatively undeveloped headwaters region allows for the greatest flexibility of trail design. In contrast, the narrow watershed boundary in the coastal zone, along with high levels of development, permit limited options for trail placement. As funding for conservation and recreation development is often limited, multi-purpose trails located strategically within densely settled watersheds provide an opportunity for integrated recreation and conservation planning.

La planificación de conservación ambiental y recreación comparten potencialmente abundantes objetivos comunes, incluyendo el deseo de aumentar la conectividad paisajística. Sin embargo, típicamente las redes de senderos se desarrollan independientemente de los corredores ecológicos, enfatizando solamente sus servicios humanos. La falta de alineación entre los valores de conservación ambiental y de usos humanos resulta en una pérdida de oportunidades para maximizar los beneficios del desarrollo de nuevos senderos. Este artículo usa conceptos de infraestructura ecológica y herramientas de modelos de conectividad para identificar lugares prioritarios para una red regional de senderos en la cuenca del río James en Virginia, Estados Unidos. El acercamiento usa métodos derivados de la teoría de circuito para identificar posibles sendas que reúnan los criterios básicos de diseño de senderos pero que también se estimen de alto valor de conservación. Los resultados se analizan con respecto a tres regiones separadas dentro de dicha cuenca, cada una con sus propios desafíos de planificación. El área del nacimiento del río, relativamente poco desarrollada, permite la mayor flexibilidad para el diseño de senderos. Por el contrario, el estrecho límite de la cuenca en la zona costera con su alto nivel de desarrollo permite escasas opciones para el emplazamiento de senderos. Debido a que la *financiación para el desarrollo de conservación y recreación es a menudo limitada, los senderos multiuso situados estratégicamente en áreas fluviales densamente pobladas ofrecen una oportunidad para la planificación integrada de conservación y recreación.*

KEY WORDS: Circuitscape, James River, landscape connectivity, morphological spatial pattern analysis

PALABRAS CLAVE: Circuitscape, James River, conectividad paisajística, análisis morfológido de patrones espaciales

INTRODUCTION

As the population of the United States struggles with issues of obesity, diabetes, and other health concerns related to an increasingly sedentary lifestyle, health professionals have placed greater emphasis on creating a recreational infrastructure to increase physical activity (Cordell 2008; VA DCR 2011; Thomsen et al. 2013). Recreational hiking, biking, and running trails offer an effective strategy to promote community building, exercise, and active transportation (Sandström 2002; Brownson et al. 2006; Tzoulas et al. 2007; Eyler et al. 2008). Relatively small expenditures on new trails systems can fundamentally change the dynamics of a region. In the Portland/Vancouver metropolitan area, for example, an initial investment in a 64 kilometer loop trail (Oregon Metro 1992) stimulated the development of a system of over 480 kilometers of trails used by millions of people each year (Oregon Metro 2013).

The health benefits of regional trail systems to quality of life in local communities have been well documented (Schasberger et al. 2009). A study assessing user demographics, preferences, and economics of the Washington & Old Dominion Trail, a regional trail in northern Virginia (Table 1), found that most users ranked health, recreation, and fitness as their top reasons for trail use (Bowker et al. 2004). Trails encourage healthy lifestyles through physical recreation and transportation (Payne et al. 1998; de Vries et al. 2003;

Table 1. Example trail networks in the vicinity of the study area. The number of regional, multi-use trail networks has been growing worldwide as localities recognize their overlapping recreational, transportation, education, and environmental benefits.

Name	Location	Length	Uses
Washington and Old Dominion Trail (W&OD Trail) (http://www.wodfriends.org/trail.html)	Purcellville to Falls Church, Virginia, USA	72 km	Biking and walking path, bridle trail, active transportation
Greater Philadelphia Regional Trail Network (http://www.pecpa.org/southeast-pa-regional-trail-network)	Southeastern Pennsylvania, USA, New Jersey, USA, and Delaware, USA	644 km	Multi-use paths, on-street bikeways, recreation, active transportation
Chesapeake & Ohio Canal National Historical Park (C&O Canal) (http://www.nps.gov/choh/index.htm)	Cumberland, West Virginia, USA to Georgetown, Washington DC, USA	297 km	Footpath, camping, ranger-guided programs

Fenton 2005). Outdoor experiences also support mental health through reduced stress and crime rates, greater community support systems, opportunities for psychological relaxation and renewal, and improved mental focus (Forsyth and Musacchio 2005; Schmalz et al. 2013). A recent cost-benefit analysis estimated direct medical benefits of $2.94 for every $1.00 investment in trail development (Wang et al. 2005).

New trails provide additional benefits to communities beyond promoting physical and mental health. For example, active transportation on trail systems reduces air pollution and transportation costs (Shafer et al. 2000). Trails also attract tourists and bring money to local businesses through increased visitor traffic (Bowker et al. 2004). These benefits often translate into increased property values (Campbell and Munroe 2007; Beeton 2010). Educational benefits associated with trails include greater access to and understanding of the environment, and trails offer the opportunity for interpretative signage and exhibits (Schasberger et al. 2009; Thomsen et al. 2013).

Trails offer relatively untapped potential benefits for conservation. On one hand, new trails can attract new visitors, which in turn can degrade natural resources, especially when providing visitor access to unique habitats that are home to endangered species (Manning 2001). However, new approaches to managing protected lands have focused on how outdoor recreation can be used to promote conservation. As one example, the National Park Service's Healthy Parks Healthy People program is examining ways in which park resources can be better leveraged to encourage multiple objectives of conservation, education, and physical activity (Thomsen et al. 2013). The boom in interest in development of recreational trails creates an opportunity to couple recreation and conservation planning.

The traditional paradigm of conservation planning has been to separate and exclude humans from ecologically important areas (Miller and Hobbes 2002). Isolating people from conservation activities can be counter-productive. Combining recreational trail and park planning can increase community awareness of and ownership in environmental conservation (Miller and Hobbes 2002). At Minute Man National Historical Park, for example, a multi-use trail connecting two historical sites has greatly increased community use of the park and exposed visitors to its diverse natural, cultural, and educational resources (Thomsen et al. 2013). Through increased awareness of natural surroundings, a conservation ethos can be formed (Forsyth et al. 2004). In Baltimore, Maryland, it was found that the Gwynn Falls watershed trail was instrumental to catalyzing local citizen support of riparian restoration projects (Groffman et al. 2003). Giving citizens the chance to experience nature in their own communities exposes them to the natural resources in their area, and makes them more likely to connect to, advocate for, and take action to protect those resources (Miller and Hobbes 2002; Forsyth et al. 2004).

With limited funding for both recreation and conservation, linking these two goals can provide a rich return on investment. The integration of regional trail networks with ecocorridors is consistent with the overarching tenets of Green Infrastructure (GI) design to promote ecosystem and human health, and the most successful implementations of GI networks often incorporate multi-purpose corridors (Tzoulas et al. 2007). For example, the GI network developed in Angelina County, Texas, was designed not only to preserve important ecosystem processes and services, but also to help build the county's nature-based tourism industry (Amundsen et al. 2009). Using GI networks as a basis for a recreational trail system offers the opportunity to promote ecological conservation in a way that may be compatible with human use (Tzoulas et al. 2007).

Broadly defined, GI consists of interconnected networks of core (large, intact areas of natural habitat) and corridor (smaller, connecting bridges of habitat) green spaces that help to enhance ecosystem services and conserve ecosystem functions (Benedict and McMahon 2001; Tzoulas et al. 2007). The GI definition highlights the important dual role of GI networks: providing ecosystem services to local communities, such as water filtration, stormwater control, and air purification (de Groot et al. 2002; Tzoulas et al. 2007); and supporting critical ecological processes, such as species migration, dispersal, and recolonization (Hargrove et al. 2000; Saura and Pascual-Hortal 2007; Kong et al. 2010). Protection of core areas of mature, heterogeneous habitat is a well-documented conservation tool in the battle to offset the many adverse effects of habitat fragmentation (Tewksbury et al. 2002; Hooper, et al. 2005; Opdam et al. 2006; Tzoulas et al. 2007). A recent meta-analysis indicates that corridors can enhance species movement between core areas by as much as 50 percent compared to unconnected core areas (Gilbert-Norton et al. 2009). The facilitated movement of plant and animal species through corridors potentially benefits ecosystems in many ways, including increases in genetic diversity as species population sizes increase (Bengtsson et al. 2002; Tewksbury et al. 2002; Haddad & Tewksbury 2005). Natural corridors have been found to be more effective for species movement than created corridors, suggesting that protecting existing habitat is more important than creating new habitat (Gilbert-Norton et al. 2009). Thus, GI networks that target intact habitat corridors tend to best preserve healthy ecosystem functions (Tzoulas et al. 2007).

There is, however, no uniform process for developing GI plans, which are highly dependent on scale and geography (Benedict and McMahon 2001). In addition, there are discouragingly few options for implementing those GI plans that have been developed. In the current climate of budget cuts and funding shortfalls, leveraging the energy behind new trail creation to maximize benefits for both community and ecosystem health seems a wise strategy. The purpose of this study is to use principles of GI and the latest approaches in spatial pattern analysis and connectivity modeling as a coarse filter to identify potential locations for new trails in the James River watershed, Virginia, U.S.A. The analysis yields general rules of thumb for trail planning in different regions of the watershed and locates specific priority areas for more detailed consideration of trail placement. Finally, existing trails being considered for inclusion in the James River Heritage Trail system are assessed for their ecological value. The result is a spatially explicit strategy for creating a connected trail network of high ecological value, in order to facilitate the alignment of conservation and recreational planning.

METHODS

Study Area

The James River watershed encompasses 26,511 square kilometers within three physiographic provinces of the state of Virginia (Figure 1). Making up approximately a quarter of the state, the James River watershed includes parts of 39 counties and 19 cities and is home to one-third of all Virginia residents. At 547 kilometers, the James River is Virginia's longest river, one of the nation's longest rivers contained entirely in one state, and Virginia's largest tributary to the Chesapeake Bay (VA DCR 2005). The watershed is historically and ecologically significant as the site of the first permanent English settlement in the Americas, one of the last confirmed strongholds for the endangered Atlantic sturgeon, and one of the best examples of bald eagle recovery on the continent (Watts et al. 2008; Balazik et al. 2012).

The James River Heritage Trail (JRHT) is envisioned as an interconnected network of trails within the James River watershed (VA DCR 2011). Much of the JRHT will comprise existing trails, including some paved, on-road bike lanes located near the banks of the James River. Currently in the conceptual planning stages, the Virginia Department of Conservation and Recreation is leading a coordinated approach among dozens of interested parties in the James River watershed to define the trails. Stakeholder concerns include: water quality, historic preservation, habitat conservation, working lands, navigation, commercial use, private property rights, public recreation, safety, and stewardship (VA DCR 2011). Although recreation is the primary goal of the JRHT network, once completed, the trails will act as managed corridors to protect and enhance natural resources throughout this historic watershed (VA DCR 2011). The creation of the trail network, therefore, provides an exceptional opportunity to align conservation priorities with recreation planning.

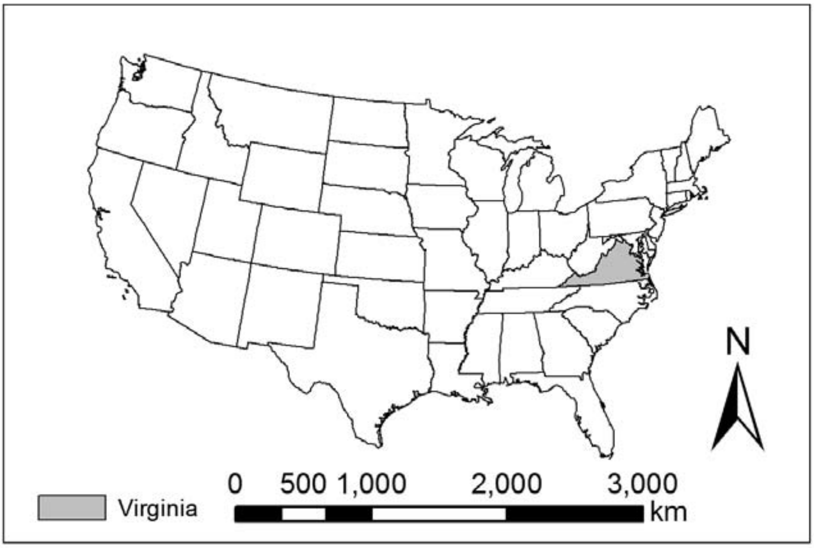
Identification of Priority Landscape Components

Two types of GI assessments, the state-produced Virginia Natural Landscape Assessment and a morphological spatial pattern analysis, were used to identify priority green spaces in the James River watershed. Information from these two assessments were combined with (1) data on current protected lands from the United States Protected Areas Database and (2) an analysis of river proximity to rank pixels on the landscape by their conservation value. All analyses were done in ArcGIS 10.

Virginia National Landscape Assessment

The Virginia Natural Landscape Assessment (VaNLA) is Virginia's official statewide GI plan. Residential and commercial development are the main causes of habitat loss and fragmentation in the state. VaNLA uses geospatial analysis to identify, prioritize, and link remaining natural lands in the state (VA DCR 2007).

Ecological cores were identified using satellite imagery and defined as areas of natural land cover (e.g., forests, marshes, and dunes) of at least 40.5 hectares



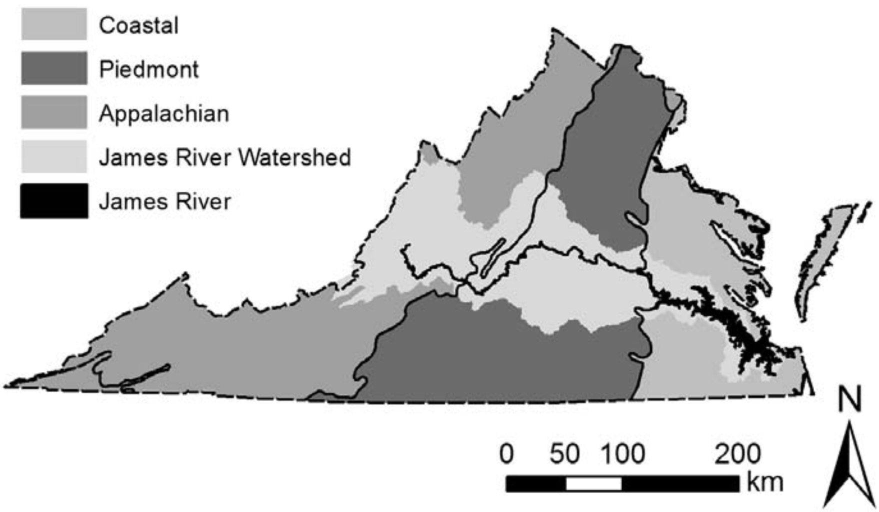


Figure 1. The James River watershed, located within the Commonwealth of Virginia, encompasses 26,511 square kilometers. The watershed is comprised of a mountainous headwater region, an agriculturally intensive piedmont region, and a highly developed coastal area.

(100 acres) in size. Over 50 attributes were assigned to each ecological core based on rare species and habitats, environmental diversity, species diversity, patch characteristics, patch context, and water quality benefits (VA DCR 2007). The ecological attributes were then integrated into an ecological integrity score, ranging from C1 (outstanding) to C5 (general), which represents a prioritization ranking for conservation. For the purpose of this analysis, we focused only on C1 and C2 cores. Landscape corridors that connect these cores were identified through least-cost path analysis (Adriaensen et al. 2003; VA DCR 2007). The input data layers used in VaNLA, as well as the final GI maps, are publically available and can be downloaded from the Virginia Department of Conservation and Recreation website: (http://www.dcr.virginia.gov/natural_heritage/vclnavnla.shtml).

Morphological Spatial Pattern Analysis

New, standardized methods have recently been proposed for prioritizing GI at regional scales (Wickham et al. 2010). Morphological spatial pattern analysis (MSPA) uses structural components of natural landcover to develop networks of core and corridor areas by categorizing the landscape into discrete structural classes (e.g., Core, Islet, Perforation, Edge, Loop, Bridge, and Branch) (Vogt et al. 2007). Focusing only on structural connectivity, where connections of intact habitat physically exist, we produced a simplified MSPA layer using GUIDOS 1.3. (http://forest.jrc.ec.europa.eu/download/software/guidos/).

Landcover data from the 2001 National Landcover Dataset (NLCD; Homer et al. 2007) for the James River watershed were first reclassified into a binary map of 'Foreground' (forest and wetland classifications) and 'Background' (all other landcover classifications). Next, an MSPA was run to reclassify the 'Foreground' landcover class into the seven structural classes identified above. For this analysis, Core patches greater than or equal to 101 hectares (250 acres) were used as the ecological cores. Corridors were created from remaining Core areas combined with the Edge and Bridge classes, two of the other MSPA classes that represent landscape connections and lands immediately contiguous to Core patches, respectively. The more inclusive, structurally defined MSPA rankings provided a complement to the more strictly defined, functional priority areas derived from the VaNLA assessment.

United States Protected Areas

United States Protected Areas (PAs) are lands designated and managed to preserve biological diversity and to serve other natural, recreational, and cultural uses (PAD-US 2009). Over one million square kilometers of land are protected in the United States, which includes national parks and forests, city parks, state beaches and parks, land trust preserves, county open space reserves, and other types of land holdings owned or protected under conservation easement by an agency or non-governmental organization (Protected Area Database 2009).

For this study, PA data were downloaded from the Protected Areas Database of the United States (www.protectedlands.net). Only PAs with International Union for Conservation of Nature (IUCN) classifications I and II were used in the analysis in order to focus on areas set aside to protect large-scale ecological processes.

Priority Surface

We combined the VaNLA, MSPA, and PA data layers to generate a priority surface for the study region that weighted lands based on perceived ecological value (Table 2). The surface also took into account proximity to the river as a stated goal of the JRHT. Each 30-meter pixel in the watershed was classified in the following manner. PAs were assigned the highest weights (100) because they are widely recognized as areas of significant ecological value and are generally open to the public. By contrast, VaNLA and MSPA cores and corridors were delineated without consideration of public access or stewardship. The functionally-defined VaNLA land designations, which take into account characteristics such as species diversity and water quality attributes, were assigned higher scores than their MSPA counterparts, which were based solely on the spatial structure of forest and wetlands on the landscape. VaNLA Cores were assigned weights of 50 and MSPA Cores were assigned weights of 25. Consistent with VaNLA methodology, corridors were weighted lower than core areas (VA DCR 2007). VaNLA Corridors were assigned weights of 10 and MSPA Corridors assigned weights of 5. All other land in the watershed was assigned a value of 1.

To address JRHT goals for the trail network, greater importance was given to land centered around the historic James River. A 100-meter buffer was created around the river. Like the MSPA designations, this buffer region was not ground-truthed or accompanied by any ancillary data, but the buffer width of 100 meters was chosen to be consistent with recommended riparian corridor widths for conservation purposes (Bentrup 2008). The buffer also serves the aesthetic goal of enhancing visual interest by increasing the value of land near the water. Pixels within the buffer were multiplied by 100 (Table 2).

Connectivity Assessment

We analyzed the connectivity of the priority surface using Circuitscape (http://www.circuitscape.org). Circuitscape uses algorithms from electronic circuit theory to predict patterns of movement across

Table 2. Priority weighting scheme. An inverse cost-surface was created by assigning values based on priority to different landscape designations, then multiplying those values by a scale based on the pixel's distance from the James River's edge. PAs and VaNLA components were considered to be higher importance, as they are already recognized as conservation planning tools by the Commonwealth of Virginia.

Land Designation	Value
Protected Areas (PAs)	100
VaNLA Cores	50
MSPA Cores	25
VaNLA Corridors	10
MSPA Corridors	5
Other	1

X

Distance from River	Value
< 100 meters	100
>100 meters	1

heterogeneous landscapes (McRae et al. 2008). The approach builds upon other least-cost path approaches by simultaneously considering all possible routes across the landscape and allowing movement to be dispersed among multiple potential pathways. Conductance maps were interpreted as potential pathways for the JRHT that efficiently flow through multiple locations of high natural resource value.

Each cell on the priority surface was treated as a node and potential conductance to neighboring cells was based on first-order, four-neighbor rules (McRae and Shah 2011). High value cells on the priority surface were considered high importance for the JRHT, therefore the grid was coded in conductances to allow greater ease of current movement through higher priority pixels (McRae and Shah 2011). Using the all-to-one mode, multiple iterations were run and connectivity was calculated between pairs of focal nodes (McRae and Shah 2011): one pair located at the mouth and headwaters on the north side of the James River, and a second pair located on the south side of the river. The two Circuitscape output maps were then combined to assess effective conductances for the entire watershed.

Evaluation of Ecological Conductance Network

The evaluation of model outputs included analysis of areas of high conservation value on the priority surface, areas of high conductance, zonal statistics of conductance for counties and subwatersheds, and conductance potential of existing trails. The James River watershed was analyzed as a whole, at the level of counties and independent cities, and at the small watershed level (fifth and sixth order hydrologic units). Existing trails being considered for inclusion in the JRHT conceptual plan were analyzed to determine their relative importance to the overall plan based on ecological conductance.

County-level Evaluation

Zonal statistics (maximum, mean, and standard deviation) of potential conductance were evaluated on the county and independent city level. Partitioning of resources and prioritization of planning efforts at this scale will be critical to the successful implementation of any regional plan, as there are 58 counties and independent cities located within the James River watershed.

Watershed-level Evaluation

Nongovernmental organizations, neighborhood associations, and other local-scale entities are increasingly exerting their influence on natural resource management (Kaplowitz et al. 2012). The scale of the overall analysis matches the focal extent of several large watershed organizations (e.g., James River Association, Chesapeake Conservancy). The relative importance to conductivity of all fifth and sixth order hydrologic units within the James River watershed were also quantified and compared. The 67 fifth order hydrologic units range in size from 16,000 hectares to 100,000 hectares, while the 298 smaller sixth order hydrologic units range from 4,000 hectares to 16,000 hectares (VA DCR 2012).

RESULTS

Prioritization of Landscape Components

Each 30-meter grid cell was scored by combining existing protected areas

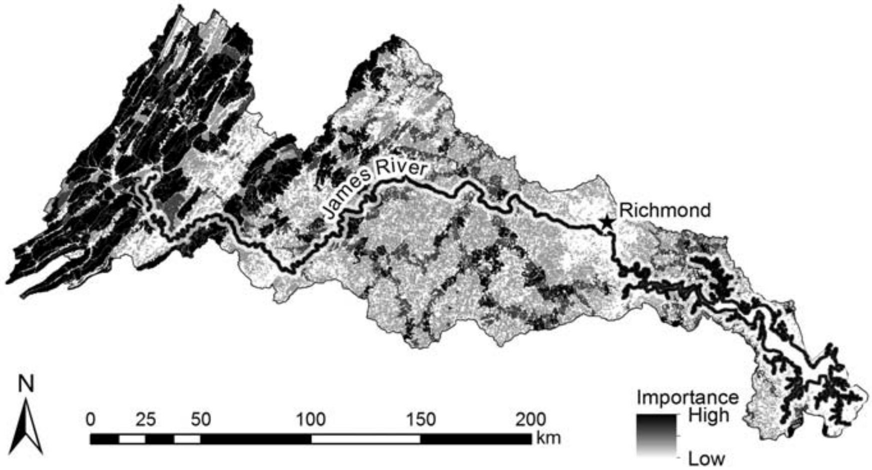


Figure 2. Map of priority ranks. Importance was calculated by combining the different landscape designations and weighting by proximity to the James River.

(PAs) with the proposed conservation areas from two green infrastructure networks (VaNLA and MSPA) and information about proximity to the James River. Areas of *high priority* occurred where highly ranked PAs, VaNLA components, and MSPA components overlapped, close to the river's banks. The upper headwaters portion of the watershed, which includes parts of Shenandoah National Park and George Washington National Forest, had the highest concentration of these high priority areas (Figure 2). Areas of *low priority* included much of the middle-watershed Piedmont section, which is dominated by agricultural and some urban land uses. The coastal section of the watershed had several patches of high priority, such as the Great Dismal Swamp, Hog Island State Waterfowl Refuge, and the Naval Weapons Station at Yorktown, but generally had lower value than the upper portion of the watershed in the Appalachian Mountains.

Landscape Connectivity

At the basin scale, the Circuitscape analysis highlighted the lack of connectivity between relatively high value lands in the headwater region and high values lands in the coastal section of the watershed (Figure 3). There were clear, preferred conductance pathways among the large, high-value protected lands in the upper section of the James River watershed. In the middle section of the watershed, however, the lack of green space created a series of bad routing options, resulting in a braided network of moderately connected paths. The more clearly delineated pathways in the lower section of the watershed resulted from the watershed's narrowing boundary. There is only a small amount of land through which the paths could pass, meaning the Circuitscape analysis forced flow through highly developed land in some cases. Although these lands might have been assigned lower values in the priority surface mapping, they

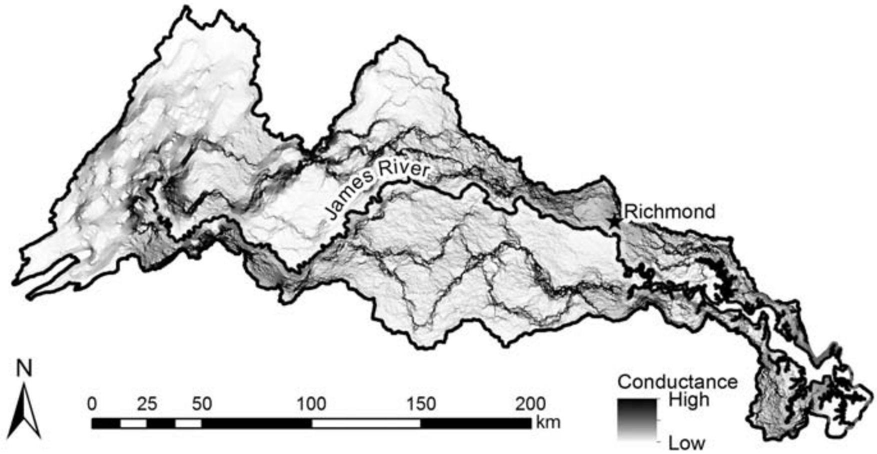


*Figure 3. Conductance map created through Circuitscape. The connectivity analysis was based on the landscape priority surface (***Figure 2***).*

were assigned high conductance in the analysis because they represented what were the best routes through this narrow, highly populated section of the watershed.

County-level Prioritization

Differences in conductivity among counties in the upper, middle, and lower sections of the James River watershed reflect their varying physical geographies and land use (Figure 4**)**. The location identified as having the highest conductance was in the headwater region, in Botetourt County. This metric demonstrates the importance of Botetourt County to the overall plan and reflects the spatial constraints created by the steep slopes and mixed land use in this region of the basin. Counties and independent cities within the middle section of the James River watershed generally had low mean conductances with correspondingly low variance, which highlights the poor connectivity options through the central Piedmont region. In the Coastal Plain, many cities and counties had high variance among pixels. The cities of Hampton, Williamsburg, and Newport News had the highest mean values of all counties and cities analyzed. However, they also had the highest internal variance; therefore, careful planning would be required within these cities to locate new trails that could also serve as potential wildlife corridors.

Watershed-level Prioritization

To address potential issues associated with using politically-derived county and city boundaries as the basis for regional prioritization and planning, we compared the fifth and sixth order hydrologic units within the James River watershed in terms of their Circuitscape conductance (Figure 5). This assessment also allowed us to directly contrast prioritization schemes based on two hierarchically nested scales of analysis. The differences in conductance values between fifth and sixth order hydrologic units can be seen

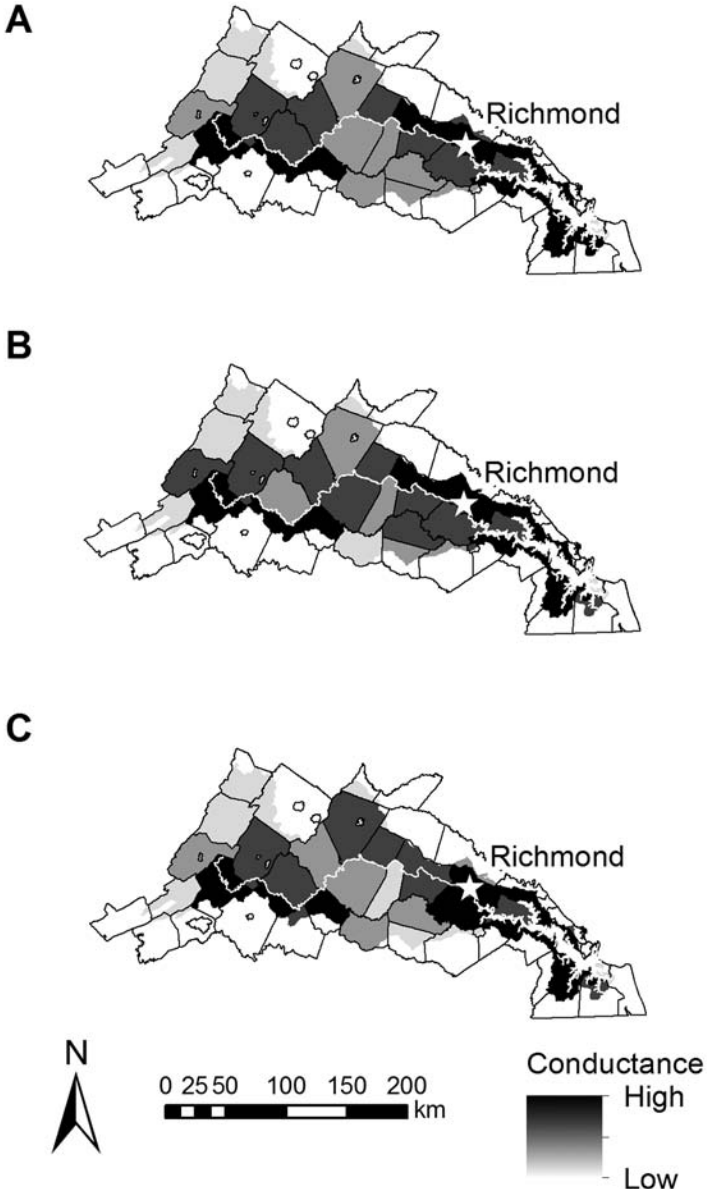


Figure 4. County-level assessment of conductance. White parts of counties are outside the watershed boundary and not included in the analysis. **A)** *Mean conductance;* **B)** *Standard deviation of conductance; and* **C)** *Maximum conductance values of counties and independent cities are provided for the James River watershed based on the Circuitscape analysis.*

near Richmond, Virginia. Sites of high conductance at the larger scale did not consistently have high conductance at the finer scale (map insets in Figure 5). In other words, just because a fifth order hydrologic unit was deemed to be of high conductance, did not mean that all constituent sixth order watersheds were also of high conductance value. Instead, some of these smaller watersheds were of much higher value than others. In contrast, areas of low conductance at coarse scale generally also had low conductance at finer scale. From a trail placement perspective, this implies that large regions of low conductance can be excluded from the trail planning process. However, areas of high conductance require further study to assess the best positioning of trails given the fine-scale environmental variability and additional recreational and logistical concerns that must be considered in the final implementation.

Table 3. The mean and standard deviation trail conductance values (unitless) for a sampling of trails in the James River watershed based on the Circuitscape analysis. Trails are sorted based on the mean conductance value of trail pixels.

Trail Name	Trail Value	
	Mean	St. Dev.
City Point Beach Trail	163.4	46.3
On-Road Bike Route	10.9	58.0
Appalachian Trail	5.3	7.9
Proposed Cumberland-Appomattox Route	2.6	0.6
Proposed Seaboard Coastline Trail	1.7	19.6
Proposed Blue Ridge Railway Trail	1.5	2.7
Chessie Trail	1.0	0.6

Evaluation of Existing Trails

Existing trails are an important part of the JRHT conceptual plan and show how existing recreational infrastructure can be an important resource in facilitating connectivity between ecological core habitats. Trail type varies from hiking trails to on-road bike paths and paved pedestrian walkways. The conductance values were also highly variable among trails (Table 3). Those trails that were most important to the conductance network can be classified into two broad categories: long trails that pass through large regions and intersect prime lands for conservation, and shorter trails that cross through *choke points* in highly urbanized areas.

The Appalachian Trail was one of the higher ranked trails in the watershed. However, most of the trail is not located immediately adjacent to the James River. Instead, the high value of this trail was derived from the fact that along its great length it runs through several high priority conservation lands. The state's on-road bike route was also ranked relatively high. The bike route is one of the most extensive existing recreational assets in the James River watershed, often following the James River closely, and therefore was ranked high despite not consistently passing through ecologically important areas. The variance in values along this trail was also very high. The highest ranked trail, the City Point Beach Trail, is located in the urban, lower section of the James River watershed where other potential pathways are limited. Small trails such as this one in the narrow coastal zone, along with the existing large regional hiking and biking trails, form a solid foundation for the future JRHT network.

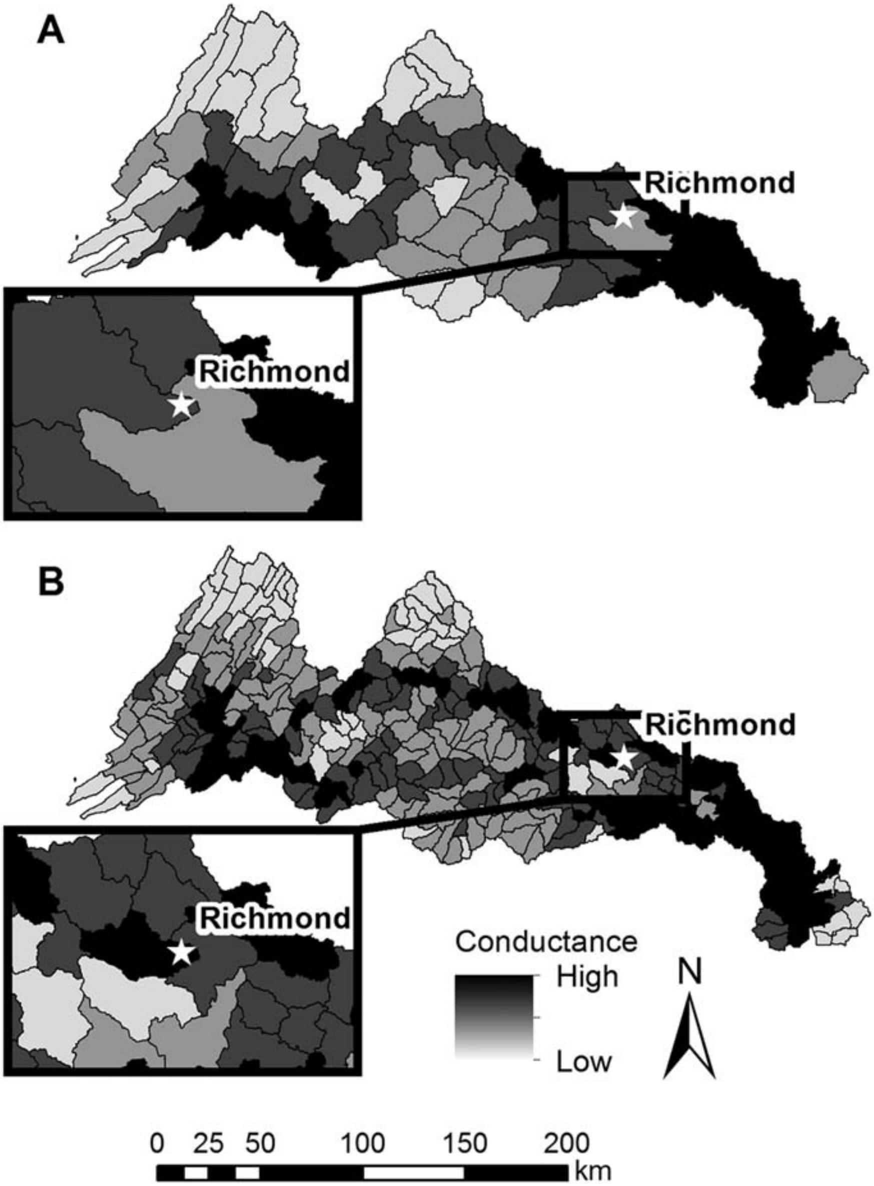


Figure 5. Mean values of conductance of **A)** *fifth order hydrologic units and* **B)** *sixth order hydrologic units based on the Circuitscape analysis. Insets highlight area of contrast between the two scales.*

DISCUSSION

This study demonstrates how concepts of green infrastructure and ecological connectivity modeling can be used as a basis to target and connect ecologically important areas for multi-use trail development, in order to promote both ecological conservation and recreational use. At the basin level, the results identify specific regions to focus trail development. The trails would meet the broad requirements of the recreational trail system, by providing an extensive, interconnected pathway within the vicinity of the historic James River. By removing these lands from the threat of potential development, the trails would also provide a valuable function as potential wildlife corridors and riparian buffer areas.

The detailed location of trails would ultimately need to incorporate many additional considerations related to other recreational goals, priorities, and logistical constraint. As part of a more intensive *boots-on-the-ground* planning with local stakeholders, areas of high conductance could be reanalyzed at much finer scale with the Circuitscape priority-surface calibrated to consider factors such as trail intent, user perceptions, land ownership, and physical characteristics not evident at the basin level (Figure 6). The method is highly scalable and can be tailored to varying situations and goals by selecting from numerous potential recreation and ecological spatial variables. It is entirely reasonable to expect that in refining our model outcomes for actual trail implementation, some areas of low ecological value would be added into the network and some locations of high ecological value would be excluded. For example, trails could be designed to skirt sites with known occurrences of disturbance sensitive species.

The James River watershed provides a useful case study for the application of these tools because the James River Heritage Trail has stated goals of aligning recreation and conservation values. The geography of the watershed also reflects a common pattern in the southeastern United States of protected montane headwaters feeding substantial agricultural areas and terminating in highly urbanized coastal zones. The diverse geography and patterns of development found in the James River watershed illustrate some of the challenges that come with multi-use trail creation.

Large parks and mountainous geography characterize the headwater region of the James River watershed. As a result, the region has remained relatively undeveloped with large tracts of forest of high conservation value. While riparian pathways are prioritized within our analysis, the Circuitscape tool allows planners the flexibility to take advantage of already-developed trails, logistical opportunities, and exceptional ecological habitats, even when these options are not immediately adjacent to the river, by providing information on multiple potential routings.

The highly modified agricultural and urban landcover characteristic of the middle section of the James River watershed led to the identification of a series of poor trail options for traversing the Piedmont region. From a planning perspective, this region provides the greatest challenge to creating a connected, multi-purpose trail network that incorporates existing core and corridor habitats. The trail network in this region of the watershed may be better

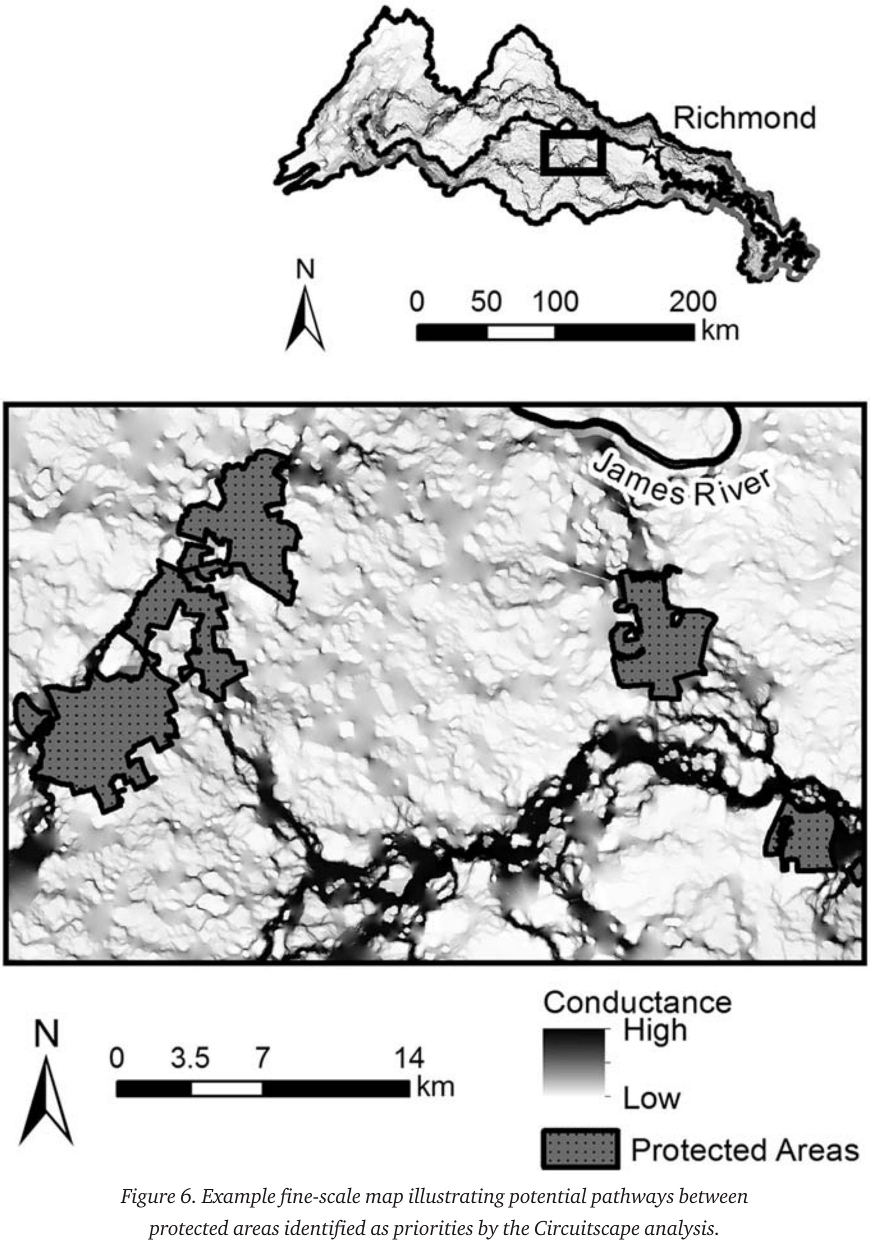


Figure 6. Example fine-scale map illustrating potential pathways between protected areas identified as priorities by the Circuitscape analysis.

envisioned as restoration rather than conservation. Instead of protecting sites of currently high ecological value, new trails could be designed to reclaim neglected riparian corridors, reestablish needed nutrient retention functions, and mitigate non-point source pollution from entering the river.

Several of the cities located in the region have already begun linking the recreational, health, and traffic benefits of trails with efforts to restore ecologically sensitive floodplains. Richmond, for example, has its own GI plan, the Richmond Region Green Infrastructure Assessment Project (RRGIAP) (Green Infrastructure Center 2010) that includes numerous parks and trails within the James River corridor. The scale of our analysis was focused on larger tracts of land consistent with the statewide GI approach, and did not take into account these smaller green spaces. This disconnect between city and state GI planning is unfortunately too common, and our analysis highlights the essential role that city planning can play in bridging regional gaps, especially in highly modified landscapes.

The narrower watershed boundary and constraints imposed by development in the coastal region allowed for fewer trail options. In these cases, leveraging existing trails will often be required due to high competition for land. Spatial pattern and connectivity analysis can help determine the potential contribution of current trails to the overall trail network conductance (Table 3). Particularly in urban areas, riparian trails offer unique opportunities for integrating stormwater control and habitat restoration. Instead of investing substantial funds in new trail development, resources may be better allocated towards simple modifications of existing trails and adjacent areas to treat urban runoff and restore ecological functions. In future studies of the unrealized opportunities for existing trails to provide a broader array of services, attributes such as trail type should also be taken into consideration. Paved bike trails, for example, could be converted to pervious surfaces to provide additional water quality benefits.

In summary, unique trail planning recommendations emerged from the analysis for each of the three physiographic provinces within the James River watershed. Planning in the relatively undeveloped Appalachian Mountains can take advantage of the large areas of high conservation value in the region. In the agriculturally intensive Piedmont region, which also contains the urban and suburban sprawl of the state's capital city, new riparian trails can be thought of as restoration opportunities rather than conservation strategies. In the highly developed Coastal Plain, funding may be better utilized by improving existing trails of high conductance rather than investing in new ones.

CONCLUSION

Applications of efficient, cost-effective methods in spatial analysis offer innovative ways to leverage new trail projects to contribute to conservation needs. The James River Heritage Trail (JRHT) is envisioned as an interconnected network of trails that would benefit both the recreational and environmental resources of the largest watershed in the Commonwealth of Virginia. At a coarse level, the goals of the JRHT trail network are simply to create a coherent system of trails between the Appalachian Mountains and Chesapeake Bay that, when possible, are located in close proximity to the river. These goals leave considerable flexibility to incorporate additional objectives, including the protection of habitat of high ecological value.

This case study used an integrated workflow of spatial analysis tools to identify potential locations for the trail system based on existing protected areas (PAs), Virginia's proposed GI network (VaNLA), and a GI network developed using morphological spatial pattern analysis (MSPA). A conductance map of high ecological value sites was developed using methods from circuit theory. The results identified three distinct regional challenges to trail planning using GI as a guide that correspond to the three unique physiographic regions within the watershed. The basin-scale model also provided a baseline map of potential priority pathways and identified specific counties and sub-watersheds for finer-scale assessment of potential placement of trails based on local stakeholder input, recreational priorities, and logistical constraints. Combining conservation and recreational goals is a way to stretch limited funding and engage communities directly in the protection of their natural resources.

ACKNOWLEDGEMENTS

We would like to thank the Virginia Department of Conservation and Recreation, Jennifer Wampler, and Joe Weber for their support supplying data and answering questions about the James River Heritage Trail. We would also like to thank the University of Richmond Spatial Analysis Laboratory, Kim Klinker, and Justin Madron for helpful feedback throughout this project.

REFERENCES

Adriaensen F., Chardon J.P., De Blust G., Swinnen E., Villalba S., Gulinck H., and Matthysen E. 2003. The application of 'least-cost' modelling as a functional landscape model. *Landscape and Urban Planning* 64(4):233–247.

Amundsen, O., Allen, W., and Hoellen, K. 2009. "Green infrastructure planning: Recent advances and applications" (PAS Memo – ISSN 2169–1908). American Planning Association. Accessed 25 April 2014 at http://www.planning.org/pas/memo/open/may2009/.

Balazik, M.T., IcIninch, S.P., Garman, G.C., and Latour, R.J. 2012. Age and growth of Atlantic sturgeon in the James River, Virginia, 1997–2011. *Transactions of the American Fisheries Society* 141(4):1084–1080.

Beeton, S. 2010. Regional community entrepreneurship through tourism: The case of Victoria's rail trails. *International Journal of Innovation and Regional Development* 2(1):128–148.

Benedict, M.A., and McMahon, E.T. 2001. "Green infrastructure: Smart conservation for the 21st century." Sprawl Watch Clearinghouse. Accessed 25 April 2014 at www.sprawlwatch.org/greeninfrastructure.pdf.

Bengtsson, J., Engelhardt, K., Giller, P., Hobbie, S., Lawrence, D., Levine, J., Vilà, M., and Wolters, V. 2002. Slippin' and slidin' between the scales: The scaling components of biodiversity-ecosystem function relations. In *Biodiversity and Ecosystem Functioning: Synthesis and Perspectives*, eds. M. Loreau, S. Naeem, P. Inchausti, 209–220. Oxford: Oxford University Press.

Bentrup, G. 2008. *Conservation buffers: design guidelines for buffers, corridors, and greenways*. USDA General Technical Report SRS-109, Southern Research Station, Asheville, NC.

Bowker, J.M., Bergstrom, J.C., Gill, J., and Lemanski, U. 2004. *The Washington & Old Dominion trail: An assessment of user demographics, preferences, and economics* (Final Report). Virginia Department of Conservation. Accessed 25 April 2014 at http://www.srs.fs.usda.gov/recreation/WOD.pdf.

Brownson, R., Haire-Joshu D., and Luke, D. 2006. Shaping the context of health: A review of environmental and policy approaches in the prevention of chronic diseases. *Annual Review of Public Health* 27:837–842.

Campbell, H.S., and Munroe, D.K. 2007. Greenways and greenbacks: The impact of the Catawba regional trail on property values in Charlotte, North Carolina. *Southeastern Geographer* 47(1):118–137.

Cordell, K.H. 2008. The latest trends in nature-based outdoor recreation. *Forest History Today* Spring:4–11.

de Groot, R.S., Wilson, M.A., and Boumans, R.M.J. 2002. A typology for the classification, description, and evaluation of ecosystem functions, goods, and services. *Ecological Economics* 41(3):393–408.

de Vries, S., Verheij, R.A., Groenewegen, P.P., and Spreeuwenberg, P. 2003. Natural environments—healthy environments? An exploratory analysis of the relationships between greenspace and health. *Environmental Planning* 35(10):1717–1731.

Eyler, A.A., Brownson, R.C., Evenson, K.R., Levinger, D., Maddock, J.E., Pluto, D., Troped, P.J., Schmid, T.L., Carnoske, C., Richards, K.L., and Steinman, L.E. 2008. Policy influences on community trail development. *Journal of Health Politics, Policy, and Law* 33(3):407–427.

Fenton, M. 2005. Battling America's epidemic of physical inactivity: Building more walkable, livable communities. *Journal of Nutrition Education and Behavior* 37(2):S115–S120.

Forsyth, D.R., Garcia, M., Zyzniewski, L.E., Story, P.A., and Kerr, N.A. 2004. Watershed pollution and preservation: The awareness–appraisal model of environmentally positive intentions and behaviors. *Analyses of Social Issues and Public Policy* 4:115–128.

Forsyth, A., and Musacchio, L. 2005. *Designing small parks: A manual addressing social and ecological concerns.* John Wiley & Sons Inc, New York.

Gilbert-Norton, L., Wilson, R., Stevens, J.R., and Beard, K.H. 2009. A meta-analytic review of corridor effectiveness. *Conservation Biology* 24(3):660–668.

Green Infrastructure Center. 2010. "The Richmond region green infrastructure assessment." Accessed 25 April 2014 at www.gicinc.org/Richmond.html.

Groffman, P.M., Bain, D.J., Yesilonis, I.C., and Sipperer, W.C. 2003. Down by the riverside: Urban riparian ecology. *Frontiers in Ecology and the Environment* 1(6):315–321.

Haddad, N.M., and Tewksbury, J.J. 2005. Low-quality habitat corridors as movement conduits for two butterfly species. *Ecological Applications* 15(1):250–257.

Hargrove, W.W., Hoffman, F.M., and Efroymson, R.A. 2004. A practical map-analysis tool for detecting potential dispersal corridors. *Landscape Ecology* 20(4):361–373.

Homer, C., Dewitz, J., Fry, J., Coan, M., Hossain, N., Larson, C., Herold, N., McKerrow, A., VanDreil J.N., and Wickham, J. 2007. Completion of the 2001 national land cover database for the conterminous United States. *Photogrammetric Engineering & Remote Sensing* 73(4):337–341.

Hooper, D., Chapin, F., Ewel, J., Hector, A., Lavorel, S., Lawton, J., Lodge, D.M., Loreau, M., Naeem, S., Schmid, B., Setälä

H., Symstad, A.J., Vandermeer, J., and Wardle, D.A. 2005. Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. *Ecological Monographs* 75(1):3–35.

Kaplowitz, M.D., Lupi, F., and Arreola, O. 2012. Local markets for payments for environmental services: Can small rural communities self-finance watershed protection? *Water Resources Management* 26:3689–3704.

Kong, F., Yin, H., Nakagoshi, N., and Zong, Y. 2010. Urban green space network development for biodiversity conservation: Identification based on graph theory and gravity modeling. *Landscape and Urban Planning* 95(1–2):16–27.

Manning, R., 2001. Programs that work. Visitor experience and resource protection: a framework for managing the carrying capacity of National Parks. *Journal of Park and Recreation Administration* 19:93–108.

McRae, B.H., Dickson, B.G., Keitt, T.H., and Shah, V.B. 2008. Using circuit theory to model connectivity in ecology and conservation. *Ecology* 89(10):2712–2724.

McRae, B.H., and Shah, V.B. 2011. "Circuitscape User Guide." The University of California, Santa Barbara. Accessed 25 April 2014 at http://circuitscape.org.

Miller, J.R., and Hobbes, R.J. 2002. Conservation where people live and work. *Conservation Biology* 16(2):330–337.

Opdam, P., Steingrover, E., and van Rooij, S. 2006. Ecological networks: A spatial concept for multi-actor planning of sustainable landscapes. *Landscape and Urban Planning* 75(3–4):322–332.

Oregon Metro. 1992. *Metropolitan Greenspaces: Master Plan*. Prepared by Oregon Metro. Accessed 25 April 2014 at http://library.oregonmetro.gov/files//doc10_794_metropolitan_greenspaces_master_plan.pdf.

———. 2013. *Portland Metropolitan Trail Accomplishments*. Prepared by Oregon Metro. Accessed 25 April 2014 at http://library.oregonmetro.gov/files/trails_accomplishments_report_2013.pdf.

Payne, L., Orsega-Smith, B., Godbey, G., and Roy, M. 2005. Local park use and personal health among older adults: An exploratory study. *Journal of Park and Recreation Administration* 23(2):1–20.

Protected Areas Database—U.S. (PAD-US) Partnership. 2009. *A Map for the future, creating the next generation of protected area inventories in the United States* (Final Report). Accessed 25 April 2014 at http://www.protectedlands.net/images/PADUS_FinalJuly2009LowRes.pdf.

Sandström, U.G. 2002. Green infrastructure planning in urban Sweden. *Planning Practice & Research* 17(4):373–385.

Saura, S., and Pascual-Hortal, L. 2007. A new habitat availability index to integrate connectivity in landscape conservation planning: Comparison with existing indices and application to a case study. *Landscape and Urban Planning* 83(2–3):91–103.

Schasberger, M.G., Hussa, C.S., Polgar, M.F., McMonagle, J.A., Burke, S.J., and Gegaris, A.J., Jr. 2009. Promoting and developing a trail network across suburban, rural, and urban communities. *American Journal of Preventative Medicine* 37(2):S336–S344.

Schmalz, D.L., Hallo, J.C., Griffin, S.F., Kusch, M., and Arce, M. 2013. Development of a Healthy Parks Healthy People strategic plan for Hot Springs National Park. *Park Science* 30(2):37–43.

Shafer, C.S., Lee, B.K., and Turner, S. 2000. A tale of three greenway trails: User perceptions related to quality of life. *Landscape and Urban Planning* 49(3–4):163–178.

Tewksbury, J.J., Levey, D.J., Haddad, N.M., Sargent, S., Orrock, J.L., Weldon, A., Danielson, B.J., Brinkerhoff, J., Damschen, E.I., and Townsend, P. 2002. Corridors affect plants, animals, and their interactions in fragmented landscapes. *Proceedings of the National Academy of Sciences of the United States of America* 99(20):12923–12926.

Thomsen, J.M., Powell, R.B., and Allen, D. 2013. Park health resources: Benefits, values, and implications. *Park Science* 30(2):30–36.

Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kazmierczak, A., Niemela, J., and James, P. 2007. Promoting ecosystem and human health in urban areas using green infrastructure: A literature review. *Landscape and Urban Planning* 81(3):167–187.

Virginia Department of Conservation and Recreation (VA DCR). 2005. "Chesapeake Bay nutrient and sediment reduction tributary strategy for the James River, Lynnhaven and Poquoson coastal basins." Accessed 25 April 2014 at http://www.dcr.virginia.gov/water_quality/documents/tsjamesall032805.pdf.

———. 2007. *Virginia natural landscape assessment 2007*. Prepared by the Virginia Department of Conservation and Recreation. Accessed 25 April 2014 at http://www.dcr.virginia.gov/natural_heritage/vclnavnla.shtml#assess.

———. 2011. *James River Heritage Trail* (Conceptual Plan). Prepared by the Virginia Department of Conservation and Recreation with assistance from the National Park Service Rivers, Trails, and Conservation Assistance Program. Accessed 25 April 2014 at http://dcr.cache.vi.virginia.gov/recreational_planning/documents/jrht__draftplan.pdf.

———. 2012. *Stormwater management*. Prepared by the Virginia Department of Conservation and Recreation. Accessed 25 April 2014 at http://www.dcr.virginia.gov/stormwater_management/hu.shtml.

Vogt, P., Riiters, K.H., Estreguil, C., Kozak, J., Wade, T.G., and Wickham, J. D. 2007. Mapping spatial patterns with morphological image processing. *Landscape Ecology* 22(2):171–177.

Wang, G., Macera, C.A., Scudder-Souci, B., Schmid, T., Pratt, M., and Buchner, D. 2005. Cost-benefit analysis of physical activity using bike/pedestrian trails. *Health Promotion Practice* 6(2):174–179.

Watts, B.D., Terres, G.D., and Byrd, M.A. 2008. Recovery of the Chesapeake Bay bald eagle nesting population. *Journal of Wildlife Management* 72(1):152–158.

Wickham, J.D., Riiters, K.H., Wade, T.G., and Vogt, P. 2010. A national assessment of green infrastructure and change for the conterminous United States using morphological image processing. *Landscape and Urban Planning* 94(3–4):186–195.

CARROLL COURTENAY is a graduate of the University of Richmond in Richmond, VA, 23173, with a double major in Geography and Environmental Studies. Email: carroll.courtenay@richmond.edu. Her research interests include land conservation, green infrastructure, and landscape connectivity.

TODD LOOKINGBILL is an Assistant Professor of Geography and the Environment at the University of Richmond, Virginia, 23173. Email: tlooking@richmond.edu. His research interests in landscape ecology include connectivity modeling, invasive species management, and natural resource assessment methods for battlefields and other mixed- use national parks within the Mid-Atlantic and Southeast United States.