Interactive Conservation Planning and Design Phase I for the Appalachian Landscape Conservation Cooperative

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September 2015

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Executive Summary

Systematic conservation planning is well suited to address the many large-scale biodiversity conservation challenges facing the Appalachian region. However, broad, well-connected landscapes will be required to sustain many of the natural resources important to this area into the future. If these landscapes are to be resilient to impending change, it will likely require an orchestrated and collaborative effort reaching across jurisdictional and political boundaries. The first step in realizing this vision is prioritizing discrete places and actions that hold the greatest promise for the protection of biodiversity. Once these opportunities are identified, they must be placed into a multi-scaled prioritization framework that facilitates the collaborative work of conservation planning practitioners who will be implementing the plan.

We identify five conservation design elements covering many critical ecological processes and patterns across the Appalachian LCC geography. These elements include large interconnected regions as well as the broad landscapes that connect them. We also map small areas that are likely to contain larger ecological significance than their size would suggest. We provide examples of multi-scale aquatic and terrestrial conservation targets that are represented by our design elements. All of the elements are assessed in regards to the three major landscape level threats in the geography (i.e., climate stability, energy development, and urbanization via housing density). Since cultural resources are an additional important piece of conservation design, we include a conceptual framework for mapping these resources across the entire geography to be integrated in a future iteration of the conservation design.

Although conservation planning is firmly rooted in ecology and biology, and informed by other fields such as landscape genetics and climatology, the success of the entire enterprise is wholly dependent on human communities. A successful conservation plan provides public land managers, NGOs, and private landowners the ability to incorporate its data into their own land use decisions. In order for these entities to find plans useful they must be encouraged to participate and the plan must by dynamic, iterative, and well informed by stakeholders. The LCC system provides a great model for bringing these parties together to form a unique and comprehensive conservation vision across the region.

Recommendations:

- Broadly and strategically communicate the utility of landscape-level conservation planning to the many stakeholders in the region.
- Select subgeographies from LCC-wide plan to focus conservation outreach and efforts building a support base and better design for next iteration of plan.
- Articulate use-cases and interpretive materials for organizations interested in using the conservation plan.
- Fund multi-scaled spatial analyses and data creation to fill data gaps and better represent the complexity across the geography.
- Align conservation plan with other 'big thinkers' such as NGOs and other LCCs to extend the utility of the plan.
- Reiterate multi-scaled vision of conservation across the region. Local planning remains extremely important but LCC should provide utility beyond the local and inform those efforts with a broader context where possible.
- Expand technical team expertise to include emerging science and data products.

Background

Less than 14% (77,000 km^2) of lands within the Appalachian LCC are currently under some level of protection against development. Most of this protected land is managed for multiple land uses leaving its long-term utility for biodiversity conservation largely unclear. The remaining 86% of lands are predominantly under private ownership. However, land-use planning decisions at multiple levels of government influence private lands conservation. In recent decades there has been an increasing effort to marry multiple levels of land use decision-making and jurisdictions with conservation biology to spatially prioritize conservation actions (Pierce et al. 2005, Theobald et al. 2005). The science of systematic conservation planning exemplifies this marriage (Margules and Pressey 2000). Although focusing more specifically on biodiversity conservation, the scientific framework can be used to help land-use planners minimize impacts of utilitarian decisions.

Conservation planning is concerned with spatially identifying and prioritizing lands and waters important for functioning ecosystems and biodiversity. It is a sophisticated discipline utilizing geographic information systems and large ecological datasets to generate spatially explicit, scenario-based maps of conservation potential (Tress and Tress 2003). These scenarios can balance social, economic, and regulatory constraints while optimizing representation of temporal and spatial processes, which need to be managed to maximize biodiversity conservation. The planning process itself, as well as final products, helps practitioners prioritize where and when to take conservation action. Successful conservation planning processes are typically interactive, iterative, and inclusive of multiple stakeholder and local expert inputs (Reyers et al. 2010). These steps are critical to the transparency and adoption of models produced by the planning exercise (Reed 2008). This process includes generating actual conservation targets with discrete goals that are important to regiona1 cooperators (e.g., the App LCC Steering Committee).

Importantly, conservation planning reaches far beyond setting aside reserves and protected areas. These efforts alone have been recognized to be insufficient for protecting biodiversity into the future (Newmark 1985, Scott et al. 2001). Thus, conservation planning includes the evolutionary and ecological processes that give rise to new diversity (Hunter Jr 1990). In order to capture these phenomena, a multi-scaled, functional network of lands and water is required (Pressey et al. 2007). This network must accommodate perturbations in species gene flow, effects from disturbance, climatic shifts, and migrations (Dobson et al. 1999, Anderson and Ferree 2010, Beier and Brost 2010).

To address the large-scale changes occurring on the landscape in the last several decades many conservation planners are focusing on coarse-filter planning approaches. These approaches focus on ecosystem and evolutionary functions as opposed to individual species conservation (Anderson and Ferree 2010, Beier and Brost 2010). These ideas have scientific merit but likely need to be complimented with fine-filter planning to aid in local conservation, to represent the mandates from multiple stakeholders, and to conserve important keystone species (Fjeldsa 2007, Brost and Beier 2012). Coupling coarse-filter data products with species distributions, thought to represent major ecological communities, is one multi-scaled method of planning.

However, conservation biology, in large part, practices the precautionary principle and representing multiple spatial and temporal scales in each plan is considered best practice (Tingley et al. 2014)

As the science of conservation planning has grown, so have the number of options for modeling approaches, software packages, and data availability. Most systematic exercises are able to use these approaches in similar ways and data products are largely interchangeable between methods. However, it is extremely important to formalize the conservation questions and methods to answering those questions in a mathematically addressable problem. Understanding how software and data contribute to that solution is likely more important than which software is used to solve the problem. Likewise, making the process and products inclusive, transparent, repeatable, and iterative gives the process a higher chance success.

The geography of the Appalachian LCC encompasses a large and complex region both ecologically and socially. Changes in forest cover and topography, due to mining and agriculture over the past few centuries and current forest management (e.g., fire), have produced complex challenges for landscape conservation (Brown et al. 2005). Its ancient geological history combined with lack of glaciation through many parts, and recent (-12000 years) land use history set the stage for diversity (Delcourt and Delcourt 1998). There is no single conservation planning approach that will adequately capture all the conservation needs, concerns, and ecological problems for this region. However, there are approaches that will simplify regional conservation planning for the Appalachian LCC geography. Many lessons can be and have been learned from previous and ongoing conservation planning efforts within the Appalachians and in neighboring LCCs. For example, in the Northern Appalachians, systematic large-landscape conservation planning has been ongoing for almost a decade (Trombulak et al. 2008) and several of the products developed for this exercise have been refined, expanded, and made available for future planning efforts.

The incorporation of social and cultural concerns inside a systematic conservation plan is an emerging research interest within the field of conservation planning. Cultural resources are often another integral piece to facilitate plan ownership and neglecting this component can hinder plan implementation (Bryan et al. 2010). However, capturing what exactly constitutes a cultural resource and to whom does it carry significance can be extremely challenging. Identification of resources is only the first hurdle as assessing and quantifying significance of them is largely a value judgment that varies across time and space. However, applying existing social science frameworks to minimize subjective valuations while providing a transparent mechanism for mapping cultural resources across the landscape can broaden the appeal of conservation planning.

The overreaching goal of this project was to develop a first iteration regional conservation plan and design using a traditional systematic planning framework accompanied by a proposed method to include cultural landscapes in future planning. A secondary goal of the project was to select a subgeography within the LCC to model aquatic integrity at a much finer spatial scale and compare those results to the coarser LCC-wide plan. The third goal was to use science-driven technical outputs and translate them into a design phase for public dissemination. Using available data and modeling approaches that are well represented in the literature, we developed candidate scenarios and conservation targets and presented them to multiple expert-driven technical teams. We utilized these teams to make three major revisions over a period of 6 months to both scenarios and targets. Site selection, threats analysis, and landscape connectivity maps were developed specifically for phase I but many additional datasets were leveraged from other Appalachian LCC funded projects (Fig. 1). We also utilized data made available through the Data Needs Assessment and prioritized articulated science needs in developing new data (Table 1). The phase I results were presented to the Appalachian LCC steering committee in July 2015.

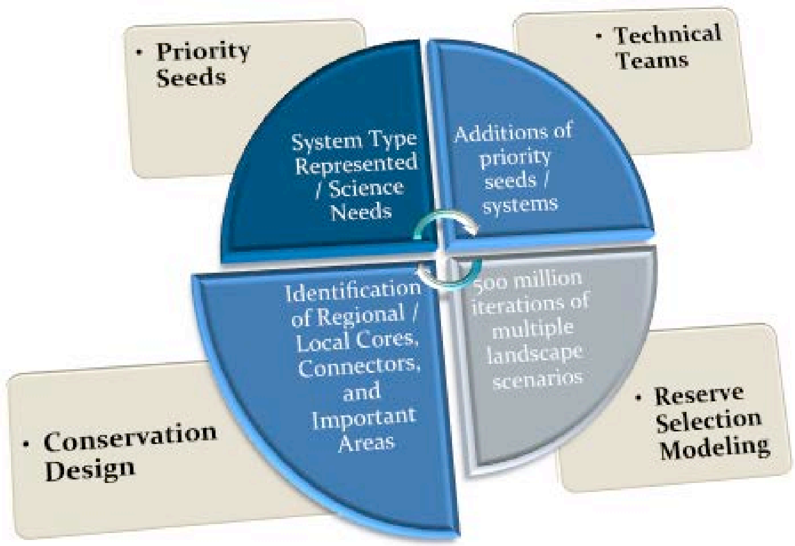


Figure 1. Phase 1 conservation planning / design process relying on four primary cyclical components.

Thematic Area	Priority Rank	Goal	Seed
Aquatic	1 – Aquatic Classification / Ecological Flows	Aquatic Communities / Hydrological Relationships	High/Low elevation headwaters: TN River Basin Macroinverts and Fish IBI
Terrestrial	2 – Resource Extraction	Forecast footprint	Energy Forecasts used in Threats Assessment
Terrestrial	4 – Forests	Species / habitat trends	Lowland Mature, high canopy forests / Spotted Skunk / Bird SDMs
Terrestrial / Aquatic	4 – Wetlands	Identify Threats to regionally important wetlands	PFO/PSS / Acidic Fens vs. Threat Analysis
Terrestrial	4 - Open-land Natural Communities (grasslands / shale barrens)	Inventory and evaluate regional importance	Early Successional SDMs / Share Barrens
Climate	5 – Vulnerability	Multi-scale Vulnerability Assessment	Resilient Landscapes / Climate Exposure Index

Table 1. The highest scoring science needs articulated by the Appalachian LCC along with 'seed' priority resources derived to addresses these needs in conservation planning Phase I.

Assembling and Interacting with Technical Teams for Priority Resource Selection

Following the 2014 App LCC Steering Committee meeting, a call for nominations of technical expertise was announced to committee members in September. These teams were focused on two primary themes: (1) subject-area expertise on major taxonomic groups represented by the species of greatest conservation need throughout the region (e.g., freshwater mussels, herpetofauna, birds), and (2) systems-level expertise focusing on physiographic regions or cultural resources. These teams were assembled to be as representative of the LCC spatially and taxonomically as possible. Technical team rosters were filled in January 2015.

The Clemson research team advanced 'seed' priority resources assembled with input from LCC staff with the goal of representing key ecosystems or processes to begin a discussion in earnest with the technical teams. These selections were made after an evaluation of feasibility (e.g., data cost, availability, alternative surrogates, missing ecosystems) and top articulated science needs from 2012. These 'seed' resources were brought before the technical teams on March 9th in a series of 3 webinars. After a round of input and revisions the Clemson team held a joint webinar for all technical team members of March 16th. After another round of input and revision the team was brought together for a final time in Phase I on June 8th after which final revisions were made to the conservation targets and scenarios.

Following the last webinar the research team deployed a 4-question survey to guide the final discrete conservation goals that were applied to the targets. These questions and responses are summarized in Appendix A.

Phase I Priority Resources

Twenty resources were selected spanning three spatial scales (coarse, meso, and fine) to capture landscape pattern and process (Table 2). In addition, several targets were extended into the year 2030 to provide added confidence for resources into the future. The Appalachian Mountains are filled with a variety of terrestrial and aquatic ecosystems unique to the world but many are being threatened due to human encroachment and development. While it is impossible to successfully model entire ecosystems with measurable benchmarks, these ecosystems can be monitored and modeled using representative species that are unique to those communities. Below is a review of the selected resources (ecosystem themes) and their corresponding representative species or ecosystem index.

Early Successional Habitat

Shrub/Scrub: Golden-winged Warbler

The golden-winged warbler (*Vermivora chrysoptera*) is a distinctive small Nearctic-Neotropical migratory songbird that breeds in early successional, high elevation forests in the Appalachian region (Confer et al. 2011). This species is widely considered to be among the most critically threatened non-federally listed vertebrates in North America showing an annual decline of 2.6% across its range since 1966 (Sauer et al. 2011). Golden-winged warbler (GWWA) populations are declining in part due to competition and hybridization with blue-winged warblers (*Vermivora cyanoptera*; Vallender et al. 2009), but also due to the loss of primary habitat which consists of early successional areas such as old fields, reclaimed strip mines, scrub oak barrens, bogs, power lines, and openings in mature deciduous forest (Confer et al. 2011).
Recent evidence suggests threats due to genetic hybridization with blue-winged warblers (BWWA) could similarly be linked to altered habitat regimes and loss of early successional habitat. It is estimated the GWWA and BWWA have not been geographically isolated for at least the last 1.5 million years, thus it is likely that elevational and habitat barriers partitioned the two species historically (Gill 1980, King et al. 2015). In particular, GWWA are more closely linked to higher elevation (>600 m) habitat with greater grass and herbaceous components and low density of shrub/woody species (Gill 1980, Buehler et al. 2007). Further, it is estimated that habitat patches of at least 10 -50 ha are needed to support several breeding pairs (Confer 1992). Thus, an overall decline in these early successional habitat types that are fire-associated could further explain the increased contact rates and hybridization between the two species (King et al. 2015). Managing for and protecting these habitats may also help sustain populations of American woodcock, ruffed grouse, eastern whip-poor-will, as well as mammals such as the Appalachian cottontail, snowshoe hare, and white-tailed deer.

Young Forest: Eastern spotted Skunk

The eastern spotted skunk (*Spilogale putorius*), once regarded as a fairly common furbearer throughout much of the Appalachians, is estimated to have undergone >90% decline across its range since the 1950's (Gompper and Hackett 2005). While the cause of the decline and general species ecology is poorly understood, recent field data from Arkansas suggests that eastern spotted skunks not only select for forests with dense understory structure (Lesmeister et al. 2009), but have higher risk of mortality when moving between these patches and into areas of open understory (Lesmeister et al. 2010). In the Appalachian region, while sightings have been rare (e.g., only 21 sightings have been reported in South Carolina in the past 30 years), a majority of eastern spotted skunk confirmed sightings have occurred in high elevation protected forests, particularly within patches of early successional forests or mature forests with dense understory (Jachowski et al. in prep). Thus, collectively it is likely that a key component to eastern spotted skunk habitat use is dense understory often associated with early successional forested habitats.

Facultative Generalist: Prairie warbler

The prairie warbler (*Dendroica discolor*) is a Nearctic-Neotropical migratory songbird that summers in large patches of open habitat in the Appalachian region. Pre-European colonization and associated deforestation, the species was absent or rare from much of its current breeding range which extends across most of the eastern US and in into the central hardwood region of the Midwestern US (Nolan et al. 1999). Similar to other early successional associated species, prairie warblers have declined in abundance over the past 50 years due to loss of early successional habitats and are listed by the U.S. Fish and Wildlife Service as a Bird of Conservation Concern in portions of its range. During the summer breeding season prairie warblers are known to inhabit a variety of unforested habitats in the Appalachian region ranging from palustrine swamps to reclaimed strip mines. The species typically nests in small trees in open shrubland or grassland habitat that are > 20 m from forest edge (Nolan et al. 1999). Territory size varies due to a host of site-specific conditions (population density, patch shape/size, habitat type, etc.), but is known to range from 0.2 to 3.5 ha per individual male (Nolan et al. 1999). As a result, managing for this species could similarly benefit other early successional grassland associated species of conservation concern like the eastern meadowlark, Henslow's sparrow, and mammals such as deer and elk.

Mature, Lowland Forest Types

Wood Thrush

The wood thrush (*Hylocichla mustelina*) is a charismatic medium-sized migratory songbird, characteristic to mature, lowland forests throughout the Appalachians. Its population has decreased by more than 50% in the past 50 years and is on the 'State of the Birds' Watch List. This decline is attributed, at least in part, to high rates of nest predation and parasitism associated with forest fragmentation (Peak et al. 2004). Mature forest fragments < 80 ha in size and riparian buffer strips < 530 m wide have been associated with extremely rates of nest and fledgling mortality (Donovan et al. 1995, Peak et al. 2004). Thus, the wood thrush is sensitive to mature forest fragmentation and an appropriate indicator for other mature forest-dependent species vulnerable to edge effects such as other similar neotropical migrants, and terrestrial and aquatic herpetofauna.

High-Elevation Forests

Golden-winged warbler

As discussed above, golden-winged warblers are associated with high elevation, early successional habitats. Golden-winged warblers generally occur at elevations > 600 m; a factor that limits hybridization with blue-winged warblers that prefer lower elevations (Welton 2003). A preference for higher elevations is particularly concerning in the Southern Appalachians where anecdotal evidence suggests that populations are retreating to higher elevations due to climate change (Buehler et al. 2007). The preference for high elevation, early successional forest attributes suitable for golden-winged warblers likely also benefits several other species of conservation concern including the eastern spotted skunk, snowshoe hare, and fisher.

Red Spruce

Red spruce (*Picea rubens* Sarg.) and Fraser fir (*Abies fraseri*) dominated forests have been declining across much of their range in the eastern US and Canada over the last 100 years (White and Cogbill 1992, White et al. 2012). In the early 1900's red spruce were particularly impacted by intensive targeted logging and poor management of this valuable timber resource (Hayes et al. 2007). Since the mid 1900's, the Fraser fir component of this forest type has been particularly impacted by the arrival of an exotic insect, the balsam woolly adelgid (*Adelges piceae*; Boyce and Martin 1993). Collectively, declines within the Appalachian region have occurred to such an extent that red spruce and Fraser fir dominated forests are ranked as the second most endangered ecosystem in the US (Noss et al. 1995). Remnants of this forest community only occur in distinct, high elevation patches that are home to several endangered species, including the Carolina northern flying squirrel (*Glaucomys sabrinus coloratus*), spruce-fir moss spider, and rock gnome lichen (*Gymnoderman lineare*; Rentch et al. 2010). While many of these remnant populations are currently within protected areas, in the southern Appalachians in particular there are concerns over lack of radial growth in red spruce and predictions of further contraction of their range in the future due to climate change (McLaughlin et al. 1987, Koo et al. 2015).

Cave/Karst

Aquatic: Group Richness

In certain areas throughout the Appalachian region limestone has eroded into extensive karst formations that comprise unique habitat for aquatic species within associated underground streams and pools. While the diversity and distribution of these highly adapted and often endemic aquatic species are not well known, these areas are known to be biodiversity hotspots for conservation (Hobbs 2012). For example, in cave systems of Tennessee alone, over 200 described species are known to exist in caves, many of which are endemic troglobionts (cave-obligate species) (Niemiller and Zigler 2013). This includes a diverse array of salamanders, fish, and invertebrate, including several rare or threatened species such as the Madison cave isopod (*Antrolana lira*) and Berry cave salamander (*Gyrinophilus gullineatus*). Due to the poor distributional knowledge and likely high level of regional endemism of species in this system, no individual species serves as a useful landscape-level surrogate. Therefore, overall species richness can be a useful proxy for measuring success of conservation in this system.

Terrestrial: Group Richness

The erosion of karst formations has created sinkholes, underground streams, and caves that similarly provide unique and often critical habitat for terrestrial species. These include several federally listed species including the Townsend's big-eared bat (*Corynorhinus townsendii*) and Indiana bat (*Myotis sodalis*). In addition to bats, cave systems are known to host hundreds of additional terrestrial troglobionts that have received much less detailed study regarding their biology and conservation status (Niemiller and Zigler 2013). Therefore, similar to aquatic systems mentioned above, group richness of a karst formation is likely the most appropriate proxy for prioritizing karst formations of conservation concern.

Unfragmented Forests

Black Bear

Black bears (*Ursus Americanus*) are large, omnivorous carnivores that are highly adaptable and can occur in a wide diversity of forested habitats. From near extirpation in the early- to mid-1900's, black bear populations have recovered to currently occupy portions of each state in the Appalachian region. However, due to human-bear conflict and high harvest rates, bears typically occur at lower densities in highly fragmented habitats near human development (Powell et al. 1997). For example, black bear populations in the large protected areas in the mountains of western North Carolina likely serve as a source to nearby portions of North and South Carolina where bears are heavily harvested and serves as a population sink (Powell et al. 2002). Further, black bears maintain large home ranges, necessitating the conservation of large tracts of continuous forest to serve as travel corridors to maintain population connectivity and gene flow (Larkin et al. 2006, Kindall and Manen 2007). Therefore, while a game animal and not of direct conservation concern, black bears serve as a suitable proxy for the availability of unfragmented land – a trait likely similarly important for maintaining populations of other large mammals with large movement capacities such as elk and fisher.

Forested Wetlands

PFO – NWI

We classified all forested wetlands (PFO and NWI cowardin classifications) as important and did not use a surrogate species for this category.

High Elevation Streams And Rivers

High Elevation: 3rd order headwater stream >3,000 ft.

All 3rd order headwater streams > 3,000 ft. (914 m) were classified as important headwater streams and did not require use of a surrogate species.

Highest Elevation: Brook trout

The eastern brook trout (*Salvelinus fontinalis*) is the only native trout species over most of the eastern US and in the Appalachian region primarily persist only in the pristine, cool streams, rivers, lakes and ponds. Declines and extirpations across their range have occurred due to historical land use practices, changes in water quality, increases in water temperature, spread of exotic fish species, fragmentation of habitat, and natural stochastic events (Hudy et al. 2008). As a result, it is estimated that eastern brook trout have been extirpated from 28% of subwatersheds within their former range, and have been greatly impacted (> 50% decline) in 35% of subwatersheds in the eastern US (Hudy et al. 2008).

Given their ecological and economic/recreational value, considerable efforts have been made to conserve existing populations, and hatchery-produced brook trout have been released to establish or re-establish populations. These efforts to improve water quality and increase connectivity of stream segments for brook trout have similarly had beneficial impacts on associated stream biota that are disturbance-sensitive (VanDusen et al. 2005). Therefore, high quality habitat for brook trout likely also represents pristine (i.e., high dissolved oxygen, low pollution, along with consistently cool temperatures and moderate pH values) and diverse mid-elevational aquatic systems of conservation concern in the Appalachian region (Steedman 1988, Stranko et al. 2008).

Low Elevation Shallow Streams And Rivers

Low: Eastern Hellbender

The Eastern hellbender *(Cryptobranchus alleganiensis alleganiensis)* is a large, fully-aquatic salamander whose distribution is limited to relatively pristine, swiftly flowing shallow streams and rivers with rocky substrate. Their current range extends from New York to northern Georgia, and as far west as Missouri. The species can grow up to 74 cm in length, and live for up to 30 years (Taber et al. 1975). Hellbenders select habitat based on the availability of rock crevices in cool, mid-elevation streams less than 762 m (Petranka 2007, Bodinof et al. 2012). They breed once annually, with females depositing eggs in a rock crevice that is guarded by a male who subsequently cares for the eggs until they hatch and disperse (Nickerson and Mays 1973).

The Eastern hellbender has observed range-wide declines (up to 77% in some areas (Wheeler et al. 2003)) to the point of being listed as endangered in multiple states, and petitioned for listed as endangered under the U.S. Endangered Species Act (Foster et al. 2009, Burgmeier et al. 2011). Siltation due to runoff is likely a major factor in their decline due to loss of rock crevices (Nickerson and Mays 1973). In addition, similar to brook trout, causes of declines can be linked to declines in water quality (temperature, dissolved oxygen, flow, etc.) (Nickerson and Mays 1973). There is also evidence that predation by non-native fishes and human harvest, either as by-catch or for the pet trade, can also impact hellbender populations (Nickerson and Briggler 2007, Gall and Mathis 2010). Collectively, these factors have resulted in many isolated populations of hellbenders, that are typically of older age class individuals (Unger et al. 2013) – suggesting that due to low recruitment the species will continue to decline across many portions of its current range. The sensitivity of Eastern hellbenders exhibit to declines in sedimentation and these other disturbances, and their potential longevity, make this species serve as excellent sentinels of mid-elevation (< 3,000 feet) stream health.

Lowest: Aquatic integrity index

The Appalachian region contains high aquatic diversity but many aquatic species have suffered range contraction and population decline due to various anthropogenic stressors. Because key environmental drivers for aquatic species differ from those for terrestrial species and landscape-level approaches protect a wide array of individual species, aquatic habitat will be assessed based on GIS-derived environmental characteristics such as land use, habitat connectivity (e.g. dams), surficial geology, and elevation. The idea is to identify the key least impacted aquatic habitat or watershed (i.e. best habitat) while taking into account inherent spatial heterogeneity that occurs within the study area (e.g. aquatic ecoregion).

Special Systems or Places

Acidic Fens/Bogs

Bogs and Fens are major types of wetland peat mires that are typically fed by mineral-rich ground or surface water (fens) or precipitation (bogs). These ecosystems typically offer few plant nutrients and are dominated by grasses and sedges. However, due to the unique suite of environmental conditions they are known to host very distinct assemblages of flora and fauna which have high degrees of endemism (Keddy 2010).

Cove Forests: Typic Foothills, Typic Montane, Rich Montane

Cove forests are deciduous communities unique to the Appalachian Mountains typically located in mid to low elevations in protected landscape positions. These forests are thought to buffer stream headwaters occurring in concave landforms. In the southern Appalachian mountains there are large areas of old growth supported a large diversity of both plants and animals including salamanders, birds, and small mammals (Braun 1950).

Rock Outcrops

There are many types of rocky outcroppings scattered across the LCC geography including boulderfields, rocky summits, granitic domes, acidic cliffs, and mafic cliffs in western North Carolina alone (Shafale and Weakley 1990). These ecoystems are known to support rare plant communities including more than 40 rare plant species in parks alone (Spira 2001) and other species of conservation concern throughout the region (e.g., Allegheny Woodrat, Spotted Skunk, Green Salamander)

Shale Barrens

Occurring throughout the Central Appalachians from West Virginia to Pennsylvania, share barrens are typically hot, dry, and rocky ecosystems. They occur at mid to low elevations (240 – 760 m) on steep slopes (~ 30 degrees) with south to west aspects creating unique conditions for vegetation. These harsh conditions host a suite of rare plant species but the dominant tree cover includes chesnut oak, Virginia pine, and white ash (Keener 1983).

Resilient Landscapes (Climate)

Climate Exposure (Stability) Index

In areas where climate has remained relatively stable through the glacial-interglacial climate changes of the Quaternary, it is suspected that taxa have survived in areas of regionally adverse conditions. These areas of historical climate refugia may still be operating today across smaller time horizons. In recent decades species richness and endemism have been found to be related to local, historic climatic stability (Araújo et al. 2008, Médail and Diadema 2009, Sandel et al. 2011). Representing areas in a conservation design that are projected to remain stable into the middle of the 21st century may help capture these unique refugia.

Most Resilient Sites

One way land trusts and public agencies are trying to plan for climate change is by increasing the focus and protection on and of resilient landscapes. This effort focuses on factors that facilitate the persistence of species and processes in discrete places. Largely a coarse-filter effort, resilient landscapes captures multiple biogeophysical settings to sustain long-term ecological functions that are the underpinnings of species diversity. The three central tenants of this work are complexity of the landscape, permeability to ecological flows, and resilience to disturbance (Anderson et al. 2012).

Table 2. Conservation targets selected in phase I of conservation design.

Conservation Target	Scale	Conservation Target	Scale
Eastern Hellbender	*Fine*	*Eastern Spotted Skunk*	*Fine*
Golden-winged Warbler	*Fine*	*Red Spruce*	*Fine*
Cove Forests: Typic Foothills	*Coarse*	*Prairie Warbler*	*Coarse*
Cove Forests: Typic Montane	*Coarse*	*AcidicFens / Bogs*	*Coarse*
Cove Forests: Rich Montane	*Coarse*	*Forested Wetlands*	*Fine*
Shale Barrens	*Coarse*	*Climate Vulnerability Index*	*Coarse*
Rocky Outcrops	*Coarse*	*Moderate gradient, warm headwaters*	*Meso*
Cave Obligates (Aquatic Rich)	*Coarse*	*Roadless forest blocks >75% canopy*	*Coarse*
Cave Obligates (Terr. Rich)	*Coarse*	*Resilient Landscapes*	*Meso*
Brook Trout	*Fine*	*High-elevation Headwaters*	*Coarse*

Phase I Modeling Inputs

Species Distributions Models

Brook Trout

The model was acquired from Tyler Wagner (USGS) (DeWeber & Wagner, 2014). Model outputs were composed of Ecological Drainage Units (EDUs), each of which was assigned a resulting mean predicted occurrence probability

The study region was determined by the Eastern Brook Trout Joint Venture (EBTJV) and represents the native range of the species on the East Coast. The polygons of interest were derived from the NHD plus dataset, with local catchments located at least 90% within the study region boundary. Presence data was taken from fish sampling records collected from state agencies and the Multistage Aquatic Resources Information System (MARIS), and these points were joined to the nearest stream segment. Environmental data was derived from the NLCD, predicted water temperature from air temperature and a neural network ensemble model, landscape attributes such as network soil permeability, local developed land, and network agriculture, and mean soil permeability in each EDU.

The model was constructed using a hierarchical logistic regression, which account for the hierarchical data structure and spatial autocorrelation, using stream reach predictors to create a formula to generate occurrence probabilities (DeWeber & Wagner, 2014). Using the R Statistical Software, the area under the receiver operating curve

(AUC), as well as classification accuracy, sensitivity, specificity, and Cohen's kappa statistic were used to assess the quality of the model. The mean AUC value for the model was 0.79 and output demonstrated a number of very specific geographic extents that appear to be highly suitable habitat.

Hellbender Species

Hellbender presence data was acquired from NatureServe and limited to points dating from 1980 to the present, with individual points adapted from the available data. Geospatial data was acquired from the U.S. Geological Survey's National Land Cover Database (NLCD) and the Horizon Systems Corporation National Hydrography Dataset (NHD) Version 2. The study was conducted over the extent of the Appalachian LCC. Environmental variables of consideration were determined through literature review and expert advice on the species (Personal correspondence, Quinn, 2009).

Hellbender presence data was sub-sampled to reduce spatial bias. Pseudo-absence points were also calculated to be within 1 km of the position of the presence points. NLCD data was reclassified to identify the key variables of investigation. NHD v2 data was applied to the attribute tables of flowline shapefiles, then rasterized to a 1km buffer around each line at a 90m resolution. The feature class data was converted into a raster to be analyzed by the statistical platform (Quinn, 2009). The data was assembled in a script-based MAXENT modeling framework inside R Statistical Software, based on the maximum-entropy approach for species habitat modeling (Baldwin, 2009, Hijmans & Elith, 2013). This statistical package provides a prediction on the occupancy of a given species, given the inputs of presence data and influential environmental variables. This allows the user to produce spatial results that predict species occupancy, as well as evaluate the quality and confidence in the model (Merow et al., 2013). Multiple environmental parameters were tested to produce the model with the greatest confidence and representation of the environmental conditions most suitable for the species, given the available data and understanding of the species (Table 3). The mean AUC value for the model was 0.92 and output demonstrated possible undiscovered Hellbender habitat throughout the region.

Table 3. Environmental variables predicting hellbender occurrence.

Attribute	Source	Metric	Status
Drainage	NHDPlusV2	Average annual volume of water passing through stream segment	Included
Flow Levels	NHDPlusV2	Average annual volume of water passing through a stream segment (f3/sec)	Included
Strahler's Stream Order	NHDPlusV2	Strahler's stream order category based on upstream tributary number	Included
Annual Precipitation	NHDPlusV2	Average annual precipitation received by a stream segment's catchment	Included
Water Temperature	NHDPlusV2	Average annual temperature for each stream segment's catchment	Tested
Slope	NHDPlusV2	Slope of Flowline	Tested
Percent Barren	NLCD	Percent Barren land per catchment of each stream segment	Tested
Percent Crop	NLCD	Percent Crop land per catchment of each stream segment	Tested
SARP	NLCD	Southeast Aquatic Resource Partnership - measure of stream side deveient within 100m of each stream segment	Considered
Alkalinity	-	Alkalinity of each drainage unit	Considered
Dams	-	Proximity to dam structure	Considered
Stream Substrate	-	Average distance between cobble-boulder particles within habitat patches	Considered
Landscape Integrity	-	Contiguous undeveloped landscape rankings at a raster level based upon distance from nearest disturbance	Considered

Spotted Skunk

Spotted Skunk presence data acquired from James L. Fowler IV and limited to points dating from 1980 to the present, with individual points adapted from the available data. Geospatial data acquired from the U.S. Geological Survey's National Land Cover Database (NLCD) and Digital Elevation Model (DEM), NASA Earth Observation Systems, NASA Socioeconomic Data and Applications Center (SEDAC), and the Naturalness Index from Theobald et al. 2010 and 2012. The study was conducted over the extent of the Appalachian LCC. Environmental variables of consideration were determined through literature review and expert recommendations on the species (Lesmeister et al., 2009, Nichols et al., 2008).

Spotted Skunk presence data was sub-sampled to reduce spatial bias. Pseudo-absence points were also calculated to be within 30 km of the position of the presence points. NLCD data was reclassified to identify the key variables of investigation. Environmental variables were compiled in ArcGIS to create a matching extent and spatial resolution**.** Data was assembled in a script-based MAXENT modeling framework inside

R Statistical Software, based on the maximum-entropy approach for species habitat modeling (Baldwin, 2009, Hijmans & Elith, 2013). This statistical package provides a prediction on the occupancy of a given species, given the inputs of presence data and influential environmental variables. This allows the user to produce spatial results that predict species occupancy, as well as evaluate the quality and confidence in the model (Merow et al., 2013). Multiple environmental parameters were tested to produce the model with the greatest confidence and representation of the environmental conditions most suitable for the species, given the available data and understanding of the species (Table 4). Using the R Statistical Software, the area under the receiver operating curve (AUC) was used to assess the quality of the model. The mean AUC value for the model was 0.76 and output demonstrated approximate locations of possible and emerging Spotted Skunk habitat.

Table 4. Environmental variables predicting spotted skunk occurrence.

Attribute	Source	Metric	Status
Elevation	USGS	Digital Elevation Model (meters)	Included
Distance to Road	TIGER	Euclidian Distance in meters	Included
Naturalness	-	Index of naturalness based on human and forested areas	Included
Tree Cover	NLCD	Percent Forest Cover at 1km resolution	Tested
NDVI	MODIS	Annual Mean NDVI	Tested
Human Footprint Index	SEDAC	Proxy for level of possible human influence/contact	Tested
Habitat Type	NLCD	Age and Type of Habitat Vegetation	Considered
Understory Cover	-	Amount of understory cover	Considered
Stand Size	-	Average size of stand per unit area	Considered
Stand Age	-	Average age of stand per unit area	Considered

Golden-Winged Warbler

The model was acquired from Dolly Crawford (Ashland University), which was included in Chapter 3 of the 2012 conservation plan (Roth et al., 2012). Model was composed of cells of predicted Golden-Winged Warbler occurrence across the study region

The study region was determined by the expert opinion derived by the technical team regarding the core breeding populations of Golden-Winged Warbler presence and assigned to the Great Lakes Conservation Region and Appalachian Conservation Region. Within these areas, certain extents are recommended for Golden-Winged Warbler conservation, as they are priority species in those regions and do not promote the invasion of Blue-Winged Warbler, a known hybridization risk. Population location data was determined through estimates developed by the Partners in Flight, which uses extrapolation of the North American Breeding Bird Survey. Environmental data was used to represent the elevation, forest type and cover, tree communities, and distance to local Blue-Winged Warbler populations

Ecosystem Models

Unfragmented Forested Areas

Data was acquired from the TIGER Road Shapefiles and the USGS (DEM and NLCD). The processed data layers were compiled in the ArcGIS environment. The study was conducted over the extent of the Appalachian LCC.

TIGER Roads were collected for all of the constituent states in the Appalachian LCC and divided into polygons for each area between road lines. These areas were then subset to those above 1 km^2 in area and those in areas below 650m elevation. The NLCD was reclassified to those cells of forest and non-forest, and this data was summarized via Zonal Statistics to summarize the percent area forest in each polygon block. Blocks with 75% or greater forest area were reclassified as a Boolean to generate the forested regions of interest.

Cove Forests

Three types of cove forests were filtered in GIS from NatureServe’s Ecological Systems in conjunction with other publically available environmental data (e.g., elevation and landforms). Elevation thresholds for creating filters were derived from Kricher (1988). Rich montane cove forests were derived from steep slope, cool aspects between 610 to 1,400 m of elevation on cove associated ecological systems. Typic montane forests were derived from cove / footslope aspects between 300 – 1,370 m of elevation on associated ecological systems. Likewise typic foothills cove forests were derived from cove / footslope warm aspects and moist flats at elevations below 610 m on associated ecological systems.

Shale Barrens, Acidic Fens / Bogs, and Rock Outcrops

Three special ecosystems were filtered from existing publically available geospatial data. Fens and Bogs were filtered from the National Wetlands Inventory and paired with elevations where these ecosystems are commonly found (mostly above 900 m). Rocky Outcroppings and shale barrens were filtered from NatureServe's ecological systems again paired with elevation thresholds.

Climate and Resilience Models

Climate Exposure

Quantifying projections of climate change exposure across a landscape is a key component in realizing and managing vulnerability. Climate change exposure is defined as the nature and magnitude of climate change that a species, system, or landscape may experience (Glick *et al*. 2011). For the Appalachian LCC, we generated a single multivariate index of mid-century climate change exposure for use in a Marxan conservation prioritization modeling effort being undertaken by Clemson University. The exposure metric chosen for this research describes mid-century future departure from 20th century baseline climate variability. Using historical variability as a baseline to measure the magnitude of projected change is more ecologically relevant (than calculating change in degrees or mm) because inter-annual variability is related to species ecological resilience and therefore changes outside this range should be highlighted (Klausmeyer *et al.* 2011; Ackerly *et al.* 2010; Baettig *et al*. 2007).

The statistic used to characterize exposure is Mahalanobis distance, which is similar to previous distance metrics used in climate change exposure mapping (Williams *et al*. 2007 & Diffenbaugh *et al*. 2013). Mahalanobis distance is a dissimilarity metric that represents magnitude of change for a set of climate variables, relative to their baseline variability (Fig. 2). This metric also incorporates the correlation between those variables by calculating the principal components of the input climate dataset before calculating a standard Euclidean distance. By incorporating correlation between variables, this metric highlights areas in the Appalachia LCC that are outside the range of variability – in terms of magnitude of change as well as novel combinations of climate variables. This metric is calculated for each 1km pixel across the study area and then mapped characterizing spatial variation of climate change across the landscape.

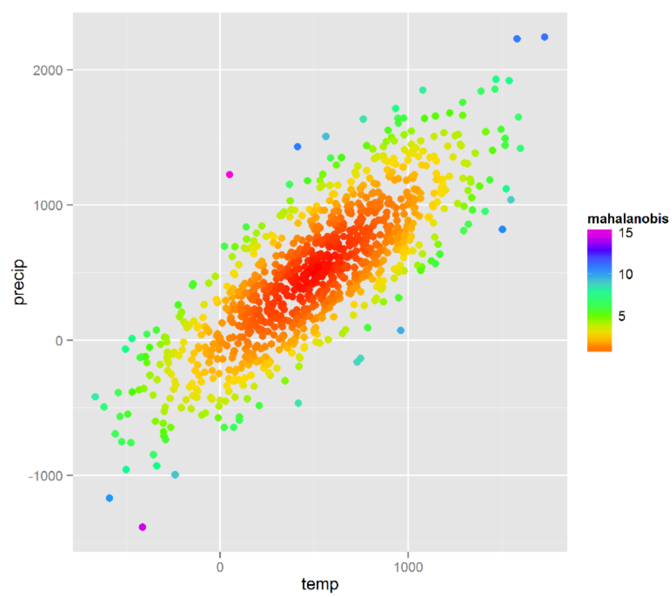


Figure 2: Hypothetical 2-dimensional illustration for Mahalanobis distance calculation for one pixel, showing Mahalanobis distance in color where each of the points represent one year in a time series. The red points in the center are years that were typical of the baseline climate and therefor have a low Mahalanobis distance index, whereas the magenta points have the highest values and represent highly unusual departure from the baseline mean.

Climate exposure was measured using the Climate North America dataset downscaled at 1km resolution, which includes historical and projected future time series from 1901-2100 (Hamann *et al*. 2013). The climate variables chosen to be included in the multivariate exposure metrics were mean annual temperature (MAT) and annual climate moisture deficit (CMD). Climate moisture deficit is derived from the sum of the monthly difference between atmospheric evaporative demand and precipitation and is used as an indicator of drought (Wang *et al.* 2012).

The baseline period used to measure change was a 30-year average of 1950-1979. This time period was chosen because historical weather station density is higher during this time period, reducing error and uncertainty in interpolated climate surfaces. Analysis of future change was based on an ensemble of 15 general circulation models (GCMs) from the latest IPCC 5th Assessment Report (IPCC, 2014), for the mid-century projection (2041-2070, referred to as the 2050s) for one emission scenario (representative conservation pathway 4.5). RCP 4.5 is considered an intermediate emissions scenario with a mean global temperature increase of 1.5 degrees Celsius.

Mid-century change is projected to exceed baseline variability for a significant portion of the Appalachia LCC study area (Fig. 3). The climate change exposure index shows areas of low elevation to be highly exposed to climate change. Areas of low exposure are highlighted in the Valley and Ridge in West Virginia and southern Blue Ridge mountains in Eastern North Carolina. Targets were directly set for areas expected to undergo the least departure from baseline (2 standard deviations below the mean).

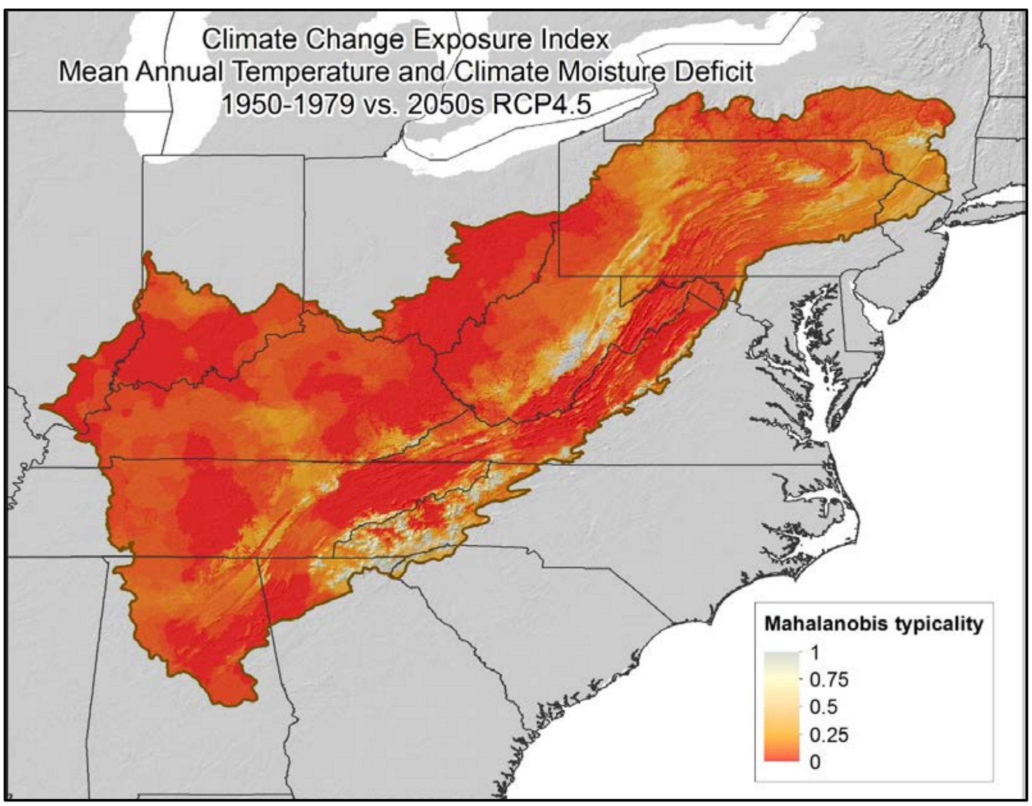


Figure 3. Depicts climate exposure metric using Mahalanobis distance. First, we calculate the Mahalanobis distance between the baseline mean value and each individual year in the baseline. Then we calculate the percentile of the Mahalanobis distance for the future mean relative to the Mahalanobis distances for the baseline. This gives us a value between 0 and 1 telling us what proportion of years in the baseline had climates that were more extreme than the future mid-century time period. A 0 means that the recent mean was more unusual than every year in the baseline, suggesting a massive departure from baseline climate conditions; a 1 means that the recent mean climate wasn't more extreme than any of the individual baseline years, which indicates little or no change.

Resilience

Landscape resilience was estimated at 90 m spatial resolution by The Nature Conservancy for the North and Southeastern U.S. based on geophysical settings, elevation, landforms, wetland density, landscape complexity, local connectedness, regional linkages (Anderson et al. 2012). The two regional efforts were married into one seamless data product and conservation targets were set directly on all resilient areas with scores higher than 2 standard deviations above the mean (standardized by ecoregions).

Reserve Selection Algorithm: Marxan

Spatial optimization in conservation planning helps practitioners achieve multi-objective decision making while balancing all conservation targets and goals simultaneously. One well-defined and common problem is known as the 'minimum set problem'. The solution to this problem is found where planning units must meet all objectives for the least possible cost. It is suited to answer common conservation planning questions (e.g., what are the current gaps in the protected areas network or how much area is required to achieve conservation objectives and where are these areas located?). There are multiple methods and algorithms designed to aid practitioners in answering these kinds of questions. Phase I conservation design utilized a software program designed in Queensland Australia named *Marxan* (Ball et al. 2009). The software can be used free of charge and provides systematic and repeatable support for designing reserve networks. The package is also widely used worldwide in over 60 countries and by 600 organizations.

Some of the strengths of *Marxan* include; transparent and inclusive target / goal setting, extreme flexibility to conservation targets, constraints on planning unit space and cost, the current status of each planning unit, and the evaluation of multiple conservation scenarios. Given there are both strengths and weaknesses to any software, it is important to note weaknesses and supplement those areas with additional solutions. One of the biggest weaknesses in *Marxan* is how it deals with landscape connectivity. Because this is a well documented problem, Phase I of the conservation design modeled connectivity using circuit theory first developed in the software packaged *Circuitscape* (Shah and McRae 2008). The connectivity outputs were integrated into *Marxan* in two primary ways. Firstly, the cost that constrained the minimum set problem was set by inverse of connectivity outputs (i.e., degree of fragmentation). Secondly, connectivity targets were explicitly included for a large landscape mover (American Black Bear).

Three major goal scenarios were modeled using all aforementioned conservation targets and technical team guidance: (1) mean goal levels compiled directly from technical team input; (2) internationally recognized goal levels articulated by the Aichi biodiversity targets for 2020; and (3) all conservation goals set at a flat 50%. All scenarios were carefully examined for ability to achieve targets and to create a connected network. For the sake of this report, only scenario 1 will be discussed in detail. There are two primary outputs from these models. The first output is made up of the minimum number and optimal arrangement of planning units (1km hexagons) to achieve targets and goals. The second output is often referred to as ‘irreplaceability’. This output is used to describe how many times a planning unit was selected over 100 repetitions of 500 million iterations each. The irreplaceability can be thought of as the level of importance to the overall design of each planning unit.

Landscape Connectivity: Circuit Theory

To model connectivity across the entire LCC geography at a spatial grain (270 m) that could inform the overall conservation design required use of custom circuit theory-based software developed by Clemson researchers to be executed on a supercomputer. First, a black bear habitat permeability map was constructed using land cover data, traffic density (AADT), bridges and underpasses, and protected area data. Landcover resistances and reductions to resistance can be found in Appendix B. Secondly, the custom software was employed to derive a 'wall-to-wall' solution by buffering the LCC boundary by 100 km and creating random points along the perimeter of this buffer (Koen et al. 2014). These points were then connected using pairwise methodology and the output was re-clipped to the LCC geography (Fig. 4).

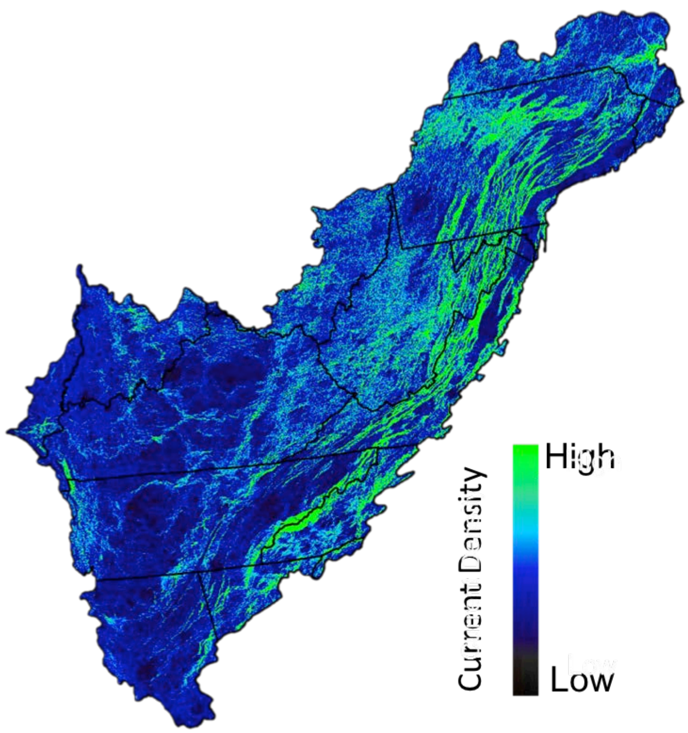


Figure 4. Landscape Connectivity for the Appalachian LCC. The model was parameterized for the American Black Bear at 270 m spatial resolution.

Sub-geography Aquatic Integrity Index Model Development

The southeastern USA is an aquatic diversity hotspot globally, as represented by high diversity and endemism of freshwater fish, mussels and crayfish (Williams et al. 1993; Warren & Burr 1994; Taylor et al. 1996). Aquatic diversity is particularly high in the Tennessee River Basin (TRB), but this unparalleled diversity has been negatively impacted by an array of anthropogenic activities such as habitat loss and fragmentation, altered flow regimes by impoundments, and invasive species. Regional-scale conservation planning is necessary to maintain and restore aquatic diversity in TRB and mapping the current condition of aquatic diversity is a critical step in informed decision making and planning.

Biotic integrity is a commonly used measure of the condition of aquatic resources. Biotic integrity is defined as "the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region" (Karr et al. 1986). An index of biotic integrity (IBI) integrates information on aquatic assemblages (e.g. species richness, functional diversity and evenness) and provides a quantitative (numerical) assessment of aquatic resources using biological data.

Spatial variation in biotic integrity was modeled based on environmental data available at the NHD (National Hydrograph Dataset) Plus catchment scale in TRB. The use of NHD Plus catchments as the spatial grain of analysis was driven by the need to characterize spatial variation that is fine enough to be useful for regional conservation planning that covers a broad spatial extent of TRB. NHD Plus catchment data were used to model spatial variation in fish and benthic macro-invertebrate assemblages, and spatial patterns of biotic integrity differed between these two taxa. Drivers and maps of biotic integrity are provided for fish and macro-invertebrates separately, in order to inform regional-scale conservation in TRB. Detailed methods and results of this modeling effort are available in Appendix C.

Conservation Design Elements Phase I

In order to move from complex model outputs to a network design that can be easily communicated and to facilitate end-user engagement there were 3 goals developed: (1) produce generalized regions with specific conservation functions related to multi-scale process relevant to decision making both locally and regionally; (2) prioritize there regions by overall threats assessment; and (3) provide names for areas that have natural and cultural resonance and foster a ‘sense of place’. To achieve these goals there were 5 conservation design elements integral to the overall network (Fig. 5).

The largest design element is made up of ‘regionally connected cores’. These cores are broad areas of regional significance (i.e., irreplaceability) that have high internal landscape connectivity. Five regional cores were mapped and named:

1. Shawnee-Peabody-Land Between the Lakes Regional Core
2. Southern Blue Ridge – Upper Tennessee River Basin Regional Core
3. Central Appalachian – Alleghany Regional Core
4. Heart’s Content – Northwest Pennsylvania Regional Core
5. Delaware Water Gap – Catskills Regional Core

In addition to regional cores, there were eight ‘locally connected cores’. These areas are locally significant (irreplaceable) and also have high internal local connectivity:

1. Cumberland Plateau – Chattanooga Local Core
2. Daniel Boone Local Core
3. Nashville Basin Local Core
4. Hoosier – Interior Low Plateau Local Core
5. Mammoth Cave – Campbellsville Local Core
6. Cumberland Gap – Big South Fork – Chickamauga Local Core
7. Southern Finger Lakes – Alleghany Plateau Local Core
8. Lower Tennessee – Bankhead – Wheeler Local Core

There were two major types of linkages identified that are likely providing additional connectivity between regionally connected cores and within locally connected cores. ‘Regional linkages’ are region scale corridors that connect large cores. Three were mapped:

1. Northern Cumberland – Blue Ridge Linkage (Connecting S. Blue Ridge to Central Appalachian Core to the north).
2. Southern Cumberland – Blue Ridge Linkage (Connecting S. Blue Ridge to Central Appalachian Core to the south)

3. Northern Sandstone Ridges Linkage (Connecting Central Appalachian – Alleghany Regional Core to Delaware Water Gap – Catskills Regional Core)

The second type of major linkage was found bridging Valley and Ridge topography and connecting mountainous regions with the low plateaus in an east – west orientation. Four such linkages were mapped:

1. Big South Fork-Cumberland River E-W Linkage
2. Cumberland-Interior Low Plateau E-W Linkage
3. Ohio River E-W Linkage
4. Flint Creek-Plateau Escarpment E-W Linkage

Lastly, the conservation design exercise highlighted ‘Local Build Outs’. These smaller, isolated areas are locally significant and were produced in two primary ways: (1) build outs acted as buffers around existing protected areas suggesting that many conservation values around the protected area are not fully protected; and (2) small areas that had unique conservation value regionally but are under no current protection. Thirty-six of these areas were mapped but there are many that scale to the 1 km hexagon level.

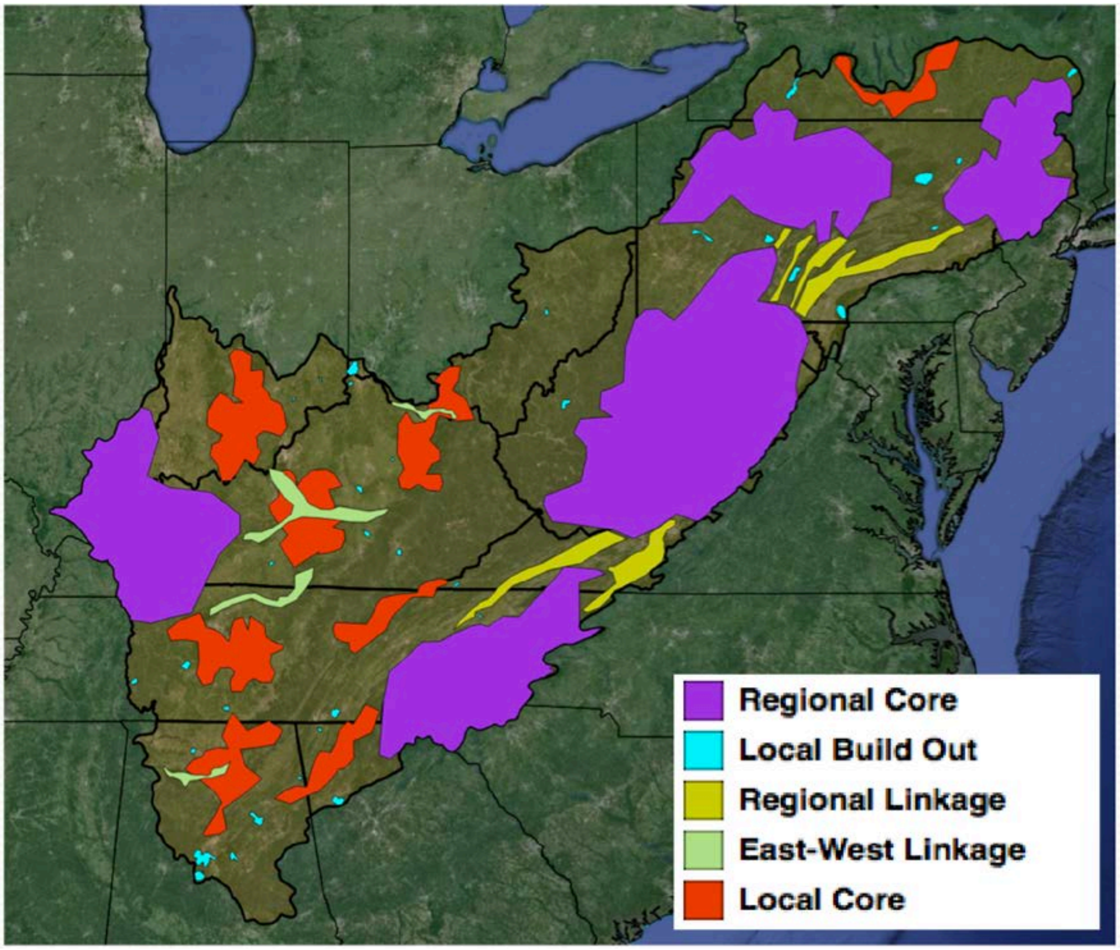


Figure 5. Coarse-scale depiction of conservation design for the Appalachian LCC with five design elements.

Interpreting Importance of Each Design Element: Multi-scale

All elements were examined at across broad, regional extents for significance across the LCC geography. Many additional elements will be locally important. For example, local build-outs were digitized at 1:4 million and altering this scale will illuminate significant localized areas. In addition, local build outs are likely functioning differently as many are buffering existing protected areas while others are completely unprotected. While conservation significance is scalable to each 1 km hexagon, there are 592,000 for the entire LCC. Thus, one practical way to examine output is by summarizing each design element by one or in a combination of the following ways;

conservation target, landscape connectivity, irreplaceability, or by modeled threat to the underlying area. One example is provided below:

Northeast of Chattanooga, Tennessee one local build out appears along ridgelines east of the Tennessee River (Fig. 6). Surrounding areas of significance are all contributing to an existing GAP status 1 or 2 protected area. A quick investigation of this area reveals its mean irreplaceability score is 73 out of a possible 100 if all hexagons were selected at every iteration. There also appears to be a pinch point of habitat connectivity running directly through this area in a northeast to southwest orientation. Conservation targets represented in the area include; forested wetlands, low elevation headwater streams, prairie warbler habitat, and possible hellbender habitat. This area received a relatively low threat score in the threats analysis (discussed below) but remains important for its regional significance.

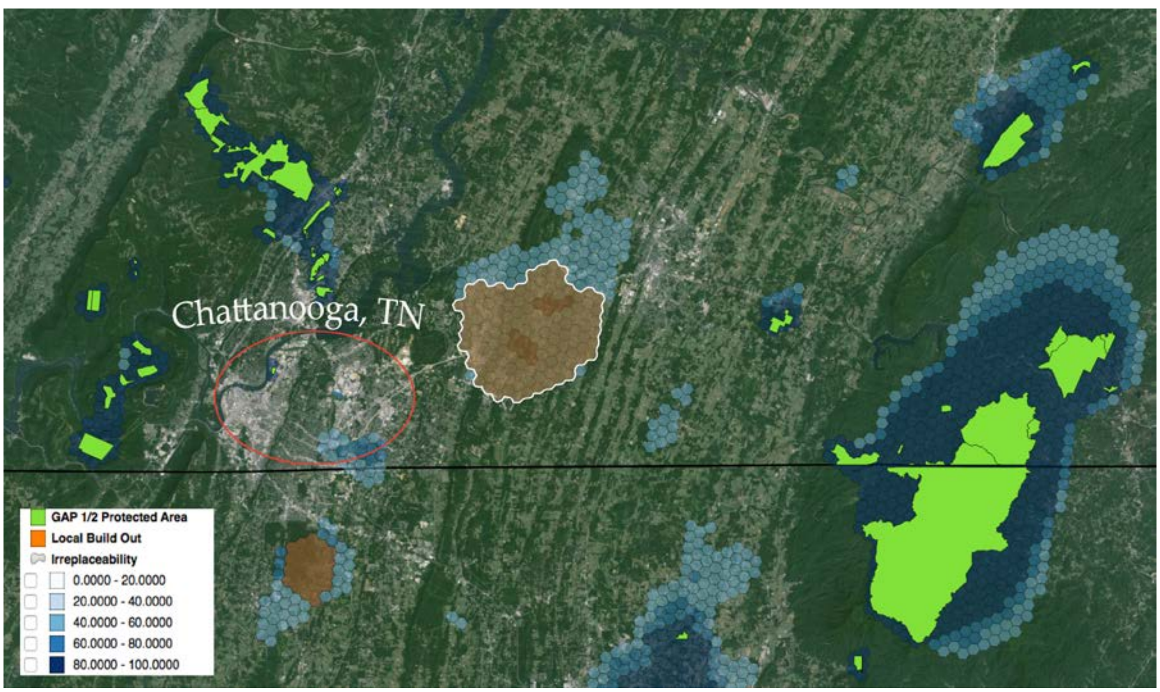


Figure 6. Local build outs surrounding Chattanooga, TN examined for conservation significance and connectivity.

In addition, the subgeography aquatic integrity example may also be examined within the context of the larger LCC-wide conservation design. The Tennessee River basin contained all five conservation design elements and thus provides a great opportunity to investigate the multi-scaled utility of the conservation design (i.e., marriage of regional scale terrestrial targets with catchment scale aquatic integrity). Fish and benthic macro-invertebrate data contributed unique information in ranking aquatic integrity across catchments. These two taxonomic groups have different sets of strengths and weaknesses in their application to biological monitoring (Karr & Chu 1999). It is thus important that both IBI and EPT scores are taken into consideration in regional-scale conservation planning, when data are available. The most distinctive difference between IBI and EPT models was manifest in Duck and Buffalo River basins. The IBI model predicted high scores for these basins whereas the EPT model predicted low scores. Duck and Buffalo Rivers are known to contain exceptional fish, mussel and snail assemblages, and this exceptional aquatic diversity is reflected in high IBI scores despite the fact that these drainages are far from pristine in regards to anthropogenic disturbances. In the meantime, both IBI and EPT models identified southern Appalachian Mountains as maintaining high integrity.

Spatial patterns of IBI and EPT scores can be used in informing regional conservation planning. Both IBI and EPT maps (Figs. 7 & 8) show spatial clusters of high and low score areas. These clusters can be considered as high-priority areas for protection or restoration. Another application may be to identify smaller pockets of representative aquatic ecosystem types. Because IBI and EPT scores were driven by indicators of anthropogenic disturbances (e.g. percent forest, population density), catchments with higher degrees of human footprints tend to receive lower scores. However, this does not necessarily mean that those catchments are less important from a conservation planning perspective. In this sense, our IBI and EPT models may be best used in combination with other aquatic ecosystem classification schemes. For example, hydrologic classifications of lotic systems (e.g. McManamay et al. 2014) can be used to identify areas that contain high IBI or EPT scores in each major hydrologic group for designating a representative network of important areas for conservation planning.

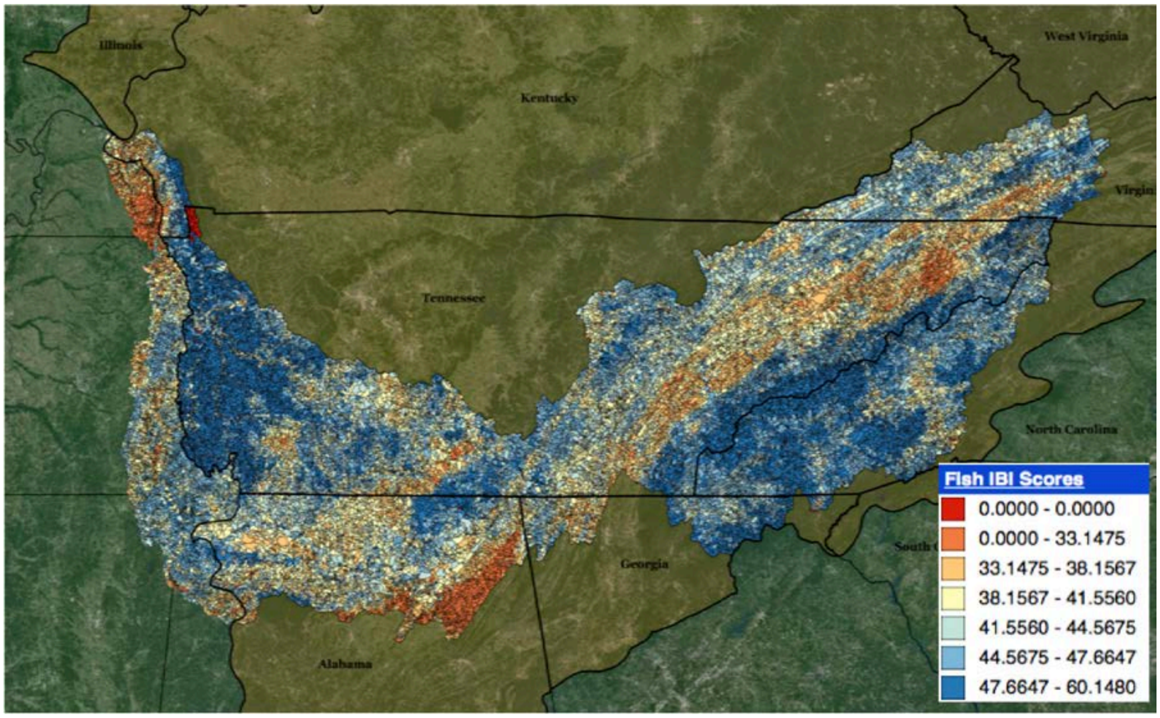


Figure 7. Tennessee river basin classified by predicted IBI scores from biological fish data at NHD Plus catchment scale.

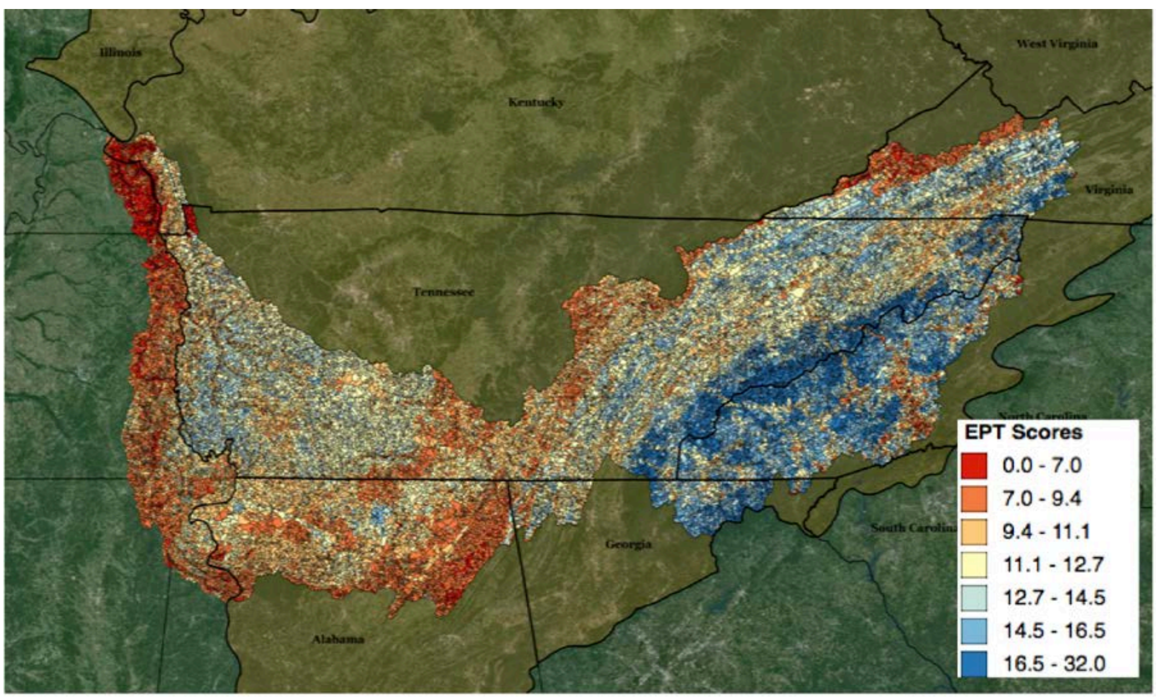


Figure 8. Tennessee river basin classified by predicted EPT scores from biological macroinvertebrate data at NHD Plus catchment scale.

Threats Analysis and Prioritization

The final steps in geographic prioritization include assessing landscape-level threats to both the priority resources and to the conservation design itself. The Appalachian LCC geography is known to support some of the richest natural gas and coalfields in the United States and thus energy development is among the top land use change threats in the region. In addition, many subregional areas are undergoing rapid urbanization that is likely to fragment habitats for many plants and animals (Terando 2014). Moreover, these land use change and intensification trends are likely interacting with a rapidly changing climate to produce deleterious effects for biodiversity conservation (Urban 2015).

These overreaching landscape threats were modeled into the year 2030 to assess the robustness of the conservation design and to help prioritize conservation efforts over the next 15 years. Energy development models were produced by The Nature Conservancy for the LCC that project three main types of use (gas, wind, coal) throughout the geography (Dunscomb et al. 2014). These projections were based on random forest models and compiled into one energy development index for this project. Housing density was projected at the census block level group by researchers at the University of Wisconsin (Hamer et al 2004, Radeloff et al. 2010). Finally, the climate exposure index was created by NatureServe and described in detail above. The three threats (Climate Exposure, Housing Density, Energy Development) were combined into one cumulative threats assessment ranging in intensity from 0-3. A conservative approach was taken to all models where the highest probability of development, climate departure, or housing density (p > 75%) was assigned a score of 1 and lower probabilities a score of 0. The scores for each threat were then summed and overlaid onto the conservation design along with landscape connectivity. A simple matrix was applied to compare irreplaceability to threat in order to prioritize conservation action (Fig. 9)

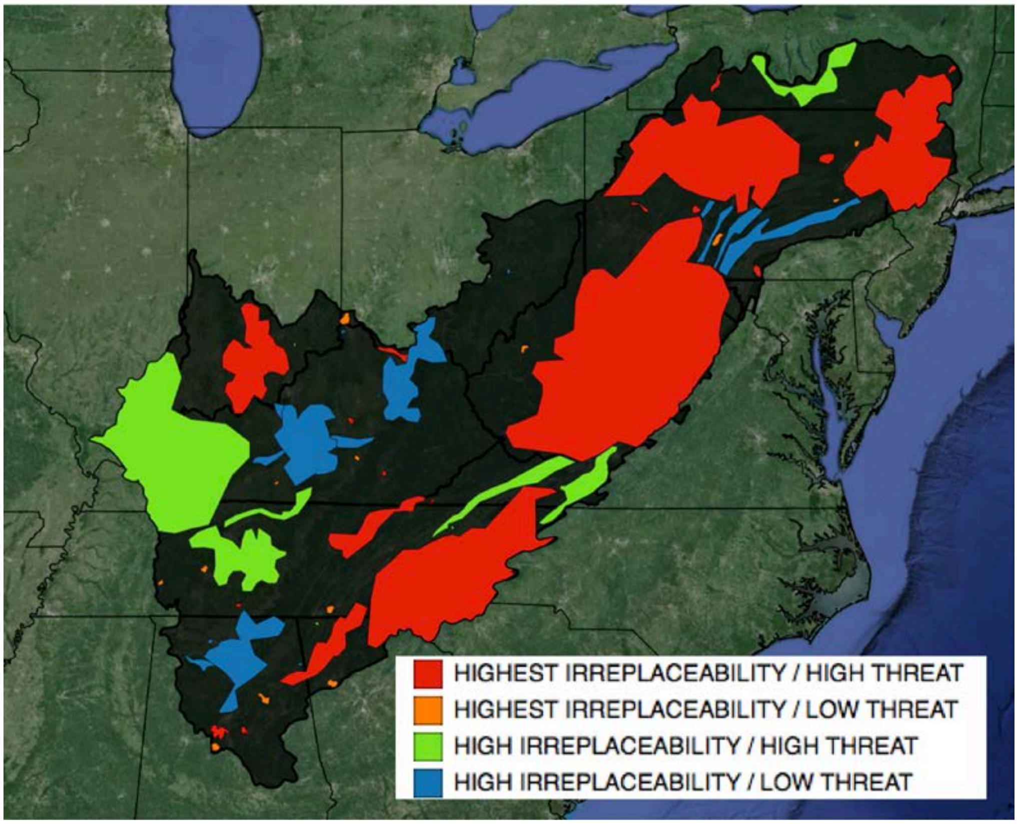


Figure 9. Landscape threats assessment overlaid on conservation design Phase I. An intuitive threat versus irreplaceability matrix was applied to help prioritize conservation action. Many of the regional cores are under the highest threat while hosing many unique areas of conservation targets. Local build outs are less threatened but highly irreplaceable.

Cultural Resources: A framework for mapping cultural resources in landscape conservation planning

Cultural resources were not directly incorporated into the landscape conservation design in Phase I but attempts were made to discuss how they may be incorporated in the future. While existing approaches to mapping cultural resources begin to capture the complexity of values that people hold for places and landscapes, these methods present some shortcomings across the Appalachian LCC geography. Geographic scale is a clear issue as a consistent assessment is needed across the entire geography and yet people tend to attribute greater value closer to where they live and work. Sampling also presents problems, as values will vary depending on the interests of who is being surveyed.

Mapping cultural resources within the greater conservation planning effort will require a methodology that can incorporate the general values that humans assign to places while dealing with issues of scale and feasibility. Considering the large area the region covers and the diversity of culture, mapping methods that seek local input would be both expensive and subject to inconsistent knowledge. A more generalized view will allow for greater consistency and be a more feasible task.

In order to create an assessment of cultural resources we propose using a method similar to that used by the GAP analysis program to classify land stewardship (Jenning, 2000). This system would avoid pitfalls that could arise from the relative valuation of importance that different groups hold for the landscape. The focus will be on measurable distinctions of management at landscape sites as an interpretation of the value of that place. This approach would also allow for the capture of resources beyond only those cataloged within the National Register programs. By considering different levels of management, places of state and local cultural value can be accounted for as well.

Cultural Resource Stewardship Categories

Classification will be based on the agency or group that manages the physical site, moving from a National level down to the local, non-governmental organization (NGO), and community (Fig 10). This framework translates the assigned level of management into an interpretation of the audience that the site may be important to.

Classifications:

1 - National - these would be sites in the landscape that have been designated and/or managed by National agencies. The interpretation is that they are of importance to all citizens of the country.

2 - State - these would be sites in the landscape that have been designated and/or managed by State agencies. The interpretation is that they are of importance to all citizens of a particular state.

3 - Local - these would be sites in the landscape that have been designated and/or managed by County or City agencies. The interpretation is that they are of importance to all citizens of a particular city or county.

4 - NGO/Nonprofit - these would be sites in the landscape that have been designated and/or managed by nonprofit organizations. The interpretation is that they are of importance to a particular group of citizens who hold certain values in common.

5 - Community -these would be sites in the landscape that have been designated and/or managed by a community of people. The interpretation is that they are of importance to members of a local community.

These categories are not a measure of higher or lower importance, but indicate the public that sites are oriented toward, from the broad (national) to narrow (community). Sites to be included will be lands that are public or semi-public (i.e. has a relationship with the public). They will also be lands that fit into the existing concept of cultural ressources and values. These characteristics would be:

- Recreation/Tourism
- Spiritual/Religious
- Aesthetic/Scenic
- Heritage/Historic

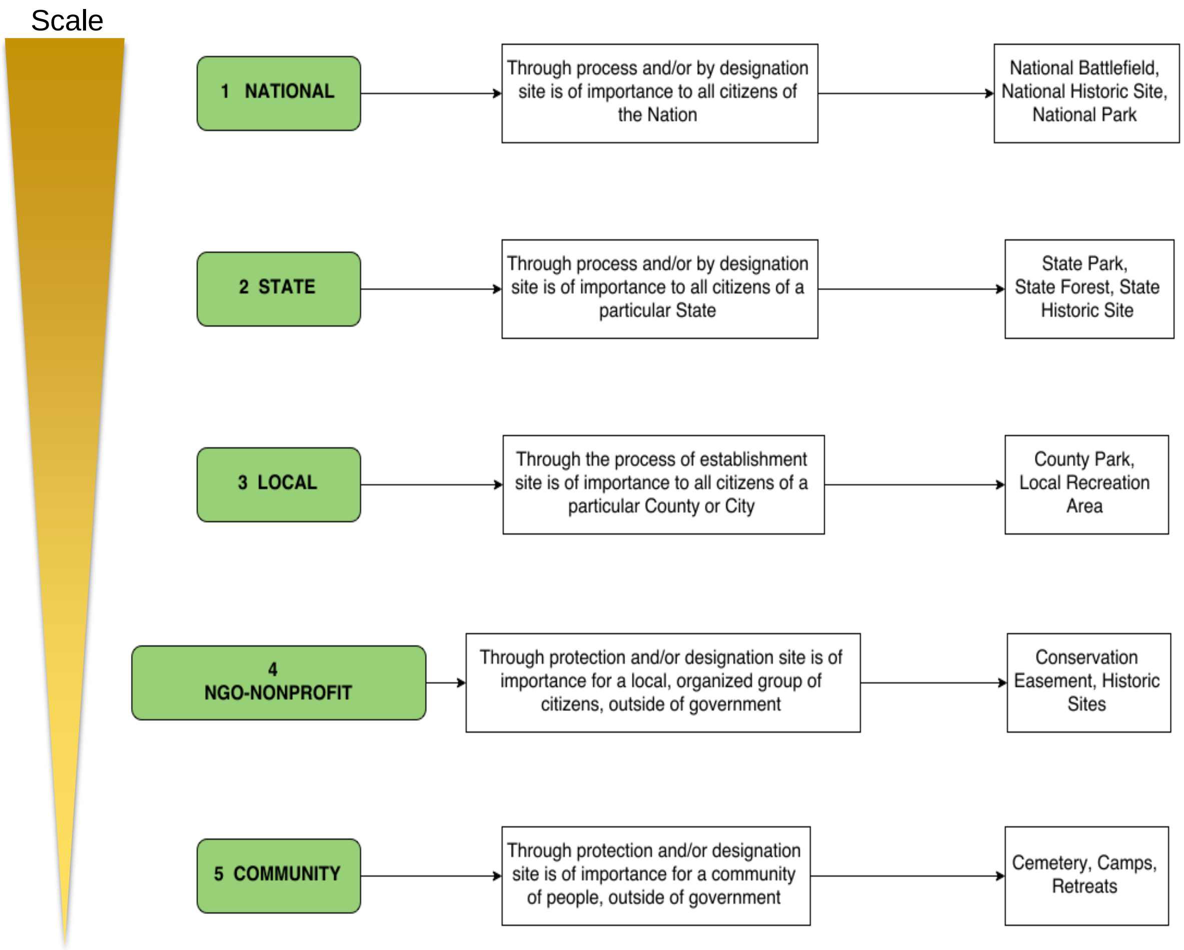


Figure 10. Proposed classification framework for cultural Resources.

This framework will include places within the existing cultural resource geography of the National Register. Additionally, it will seek to integrate places of local and contemporary cultural values that contribute to the many benefits people received from the greater ecosystem. This data can be incorporated into conservation planning as an additional layer of information to enrich the outputs that aid in decision making.

Some types of designations cover multiple sites or general areas. Large area cultural designations, such as National Heritage Areas (NHA), would be evaluated based on whether they are spatially specific and capture particular places, or whether they are more general areas. Large, all-encompassing designations would not be included if they are blanket coverages (i.e. Tennessee Civil War National Heritage Area).

This approach will allow for cultural resources to be integrated into spatial planning tools, avoiding relative valuation that would arise across a large area. State, local, and community resources will also be included to enrich the existing national level data, creating a representative picture of places important to the people and culture of the region.

Strengths

•Expands inputs beyond historical sites

•Avoids valuation based on relative importance related to stakeholder groups

•More efficient use of resources using available data

Limitations

•Data availability at less formal levels may not be as consistent

•Based on the assumption of management policy decisions being a proxy for values

•Will not be 100%, especially at lower levels

Additional context, a review of existing methods to map cultural resources, and one case study for inclusion of cultural resources is included in Appendix D.

Conclusions for Conservation Design Phase I

The Appalachian LCC encompasses some of the most unique aquatic and terrestrial ecosystems in North America. Many of these ecosystems are of global significance and yet are undergoing increased pressures for land cover conversion. These stressors coupled with climate change are creating complex challenges for conservation planners. While local planners often rightfully focus on proximal problems, many of the same problems are occurring at increasing spatial scales and need to be addressed across nested scales and broad geographies. Using the most current and appropriate science, this provides the LCC with a unique opportunity to offer a unifying conservation planning vision to both local and regional planners inside the geography.

Conservation planning science offers us a new paradigm under which to analyze conservation decisions across spatial and temporal scales. Data availability and computing power have made it possible to place localized decisions into larger ecological and future landscape contexts (Leonard et al. 2012). With modern planners scaling up their thinking about how human impacts will influence future landscapes, bolder and bigger thinking is required to implement these plans (Noss et al. 2012, Theobald 2010, Trombulak and Baldwin 2010). Effective conservation planning requires stakeholder engagement at every level. Although extremely important, participation goes beyond simple target and goal settings and extends into parameterizing models, communicating local ecological knowledge, and incorporating conservation values. Collaborative and nested networks of experts need to examine outputs and refine data inputs that match operational scales with planning scales.

Most of the ecological processes and patterns associated with biodiversity will not be conserved by public land alone. With most of the LCC geography in private ownership, it is critically important that conservation planning outputs help land trusts and NGOs in their conservation efforts given similar conservation goals. This requires outreach and engagement with those communities to better understand data needs and to amalgamate conservation visions. The LCC can bring together spatial modelers, ecologists, biologists, land use planners, land trusts, and public land managers who can work together in a conservation planning and design exercise to accomplish region-wide biodiversity conservation. Because roles and responsibilities of the players involved in such exercises, along with shifting political and economic climates, are highly dynamic, conservation planning must be iterative and amenable to new conceptual frameworks and data.

Appendix A. Survey results from technical team guidance to the conservation design research team.

Question 1: How would you like to see 'cost' incorporated in the design

	1	2	3	4	Total	Score
Landscape Fragmentation (Inverse of Connectivity)	13	4	3	0	20	3.5
Human Modification Index	3	8	7	2	20	2.6
Cumulative Threats Index	3	5	4	8	20	2.15
Census Block Median Household Income	1	3	6	10	20	1.75

Question 2: Please rank how you'd like to see landscape connectivity incorporated into the design (1= most desired)

Answered 20 : Skipped 0

	1	2	3	Total	Score
Implicitly in Solution (Cost)	9	4	7	20	2.1
Explicity in Solution (Targets & Goals)	7	6	7	20	2
Post-hoc	4	10	6	20	1.9

Question 3: What top % of the existing resource would you like to see in a prioritized framework?

	5%	10%	20%	30%	40%	50%	> 50 %
Young Forest	9	2	3	2	0	0	2
Grasslands	5	4	4	4	1	0	2
Shrub / Scrub	5	4	4	3	1	0	1
Mature Lowland Forest	1	4	5	3	0	2	3

High-Elevation Stream Integrity	2	0	3	6	1	2	3
Low-Elevation Stream Integrity	4	2	4	2	0	3	3
Forested Wetlands	1	2	5	2	1	4	2
Unfragmented Forests	2	3	2	1	3	4	4
High-Elevation Forests	1	0	6	3	2	3	3
Cave/Karst aquatic richness	2	2	2	4	3	2	2
Cave/Karst terrestrial richness	2	2	3	3	4	2	2

Question 4: How Important ins the inclusion of the below resource for the LCC's design?

	Low	Moderate	High	Not Sure	Total	Score
Cove Forests	0	6	13	1	20	2.68
Balds (Heath & Grassy)	0	6	12	2	20	2.67
Rocky Outcrops	1	11	7	1	20	2.32
Glades	4	6	10	0	20	2.3
Wet Prairie	2	9	5	4	20	2.19
Acidic Fens	5	5	7	3	20	2.12
Shale Barrens	5	7	5	2	19	2

Appendix B. Landcover and traffic density resistance values along with reduction in resistance values used in landscape connectivity circuit theory modeling.

Land Cover Class	Resistance
Open Water	41
Open Space Developed	50
Low Intensity Developed	44
Medium Intensity Developed	64
High Intensity Developed	88
Barren Terrain	41
Deciduous Forest	2
Evergreen Forest	5
Mixed Forest	3
Shrub/Scrub	8
Grass/Herbaceous	25
Pasture/Hay	29
Cultivated Crops	25 (5)
Woody Wetlands	13 (3)
Emergent Herbaceous Wetlands	20

asd

Traffic Range (Vehicles/day)	Resistance
0-500	2
500-1,400	9
1,400-5,000	25
5,000-14,000	50
14,000-35,000	73
35,000+	89

Category	Resistance Reduction
Railroad Bridges	40%
Pedestrian Bridges	30%
Other Bridges	50%
Water Bridges (8-20m)	60%
Water Bridges (over 20m)	40%
Wildlife Crossings	10%

Appendix C. Detailed methods and results for modeling aquatic integrity across NHD Plus catchments in the Tennessee River Basin

Summary

1. Tennessee River Basin (TRB) harbors exceptional aquatic diversity, but it has been impacted negatively by anthropogenic disturbances. Characterizing drivers and spatial patterns of aquatic integrity would serve regional conservation planning effort such as Appalachian Landscape Conservation Cooperative.
2. This study used available biological and environmental data to map aquatic integrity in TRB. I modeled spatial variation in fish Index of Biotic Integrity (IBI) scores, and family richness of Ephemeroptera, Plecoptera and Trichoptera (EPT) in relation to National Hydrograph Dataset (NHD) Plus catchment characteristics using a linear mixed-effect modeling approach.
3. IBI and EPT scores were driven by different sets of environmental covariates, and each metric provided independent assessment of biotic integrity. For example, human population density had negative effects on both scores, but percent forestland affected only EPT scores. The EPT model had a better fit than the IBI model and was more responsive to catchment-scale human disturbances.
4. Statistical models were used to predict IBI and EPT scores for 57,477 NHD Plus catchments within TRB and two clusters of areas with high biotic integrity were identified. Both IBI and EPT models identified southern Appalachian Mountains as retaining high biotic integrity, and Duck and Buffalo River basins were characterized as having high scores in the IBI model.
5. The products of this study can be used to inform regional conservation planning by identifying high priority areas for protection and restoration. This study focused on TRB for its exceptional aquatic diversity, but a similar approach could be used to include the entire Appalachian Landscape Conservation Cooperative region.

Methods

In order to relate biological data with environmental data in the TRB, environmental and biological data were compiled from NPD Plus version 1 and fish IBI and benthic macro-invertebrate data collected by the Tennessee Valley Authority (TVA). Given the broad spatial extent of the study area (i.e. TRB), it was conceivable that the relationship between environmental and biological data would vary among locations within the study area. Accordingly, this spatial heterogeneity was accounted for in mixed-effect models by treating ecoregions as a random effect.

Environmental data

Environmental data were derived from NHD Plus version1 for 57,477 catchments within TRB (http://www.horizon-systems.com/NHD Plus/NHD PlusV1_home.php). Ninety environmental covariates were available for catchments. Given the large number of available covariates, they were screened prior to statistical analysis. First, simple linear regression was fit between each environmental covariate and each biological integrity index (i.e. fish and bugs – see next section). A covariate was removed from further analysis if Pearson's correlation coefficient was less than 0.3 in absolute value (Pearson's $|r| < 0.3$) for both biological indices. A total of 16 covariates were retained for further analysis in this first step. Second, collinearity among the 16 covariates was examined in a pair-wise manner. When two covariates were highly correlated with each other at Pearson's $|r| > 0.5$, the covariate with the largest mean absolute correlation from pair-wise analysis was dropped. At this step, seven covariates were retained. They included minimum elevation (hereafter 'minelevraw' following NHD Plus terminology), percent crop area within catchment ('cropsp'), percent forest within catchment ('forp'), percent wetland upstream cumulative ('wetlandpc'), total estimated phosphorous inputs within catchment ('P_kgdenc'), population density within upstream stream network ('popdensc'), and percent carbonate bedrock geology upstream cumulative ('brock1pc'). Summary statistics and histogram were examined for each covariates (Table 1); 'brock1pc' was removed from further analysis because 29% of NHD Plus catchments received a value of zero and the effect of this covariate on biological integrity was not easy to interpret.

Covariates were standardized by mean divided by standard deviation (*z*-score transformation) for statistical analysis. Covariates that were not normally distributed were transformed before standardization in order to alleviate excessive influence of few uncommon observations; cropsp was square root transformed, and wetlandpc and popdensc were log transformed.

Biological data

Biological data included fish and benthic macro-invertebrate assemblage information collected by TVA between 2000 and 2014. TVA calculated fish IBI scores and number of the families within the Orders Ephemeroptera, Plecoptera and Trichoptera (EPT) to characterize the health of streams (i.e. aquatic integrity). IBI and EPT scores were modeled as response variables in statistical analysis.

IBI was composed of 12 metrics that described taxonomic and ecological properties of a fish assemblage. These metrics were: (1) Number of native species, (2) Number of native darter species, (3) Number of native sunfish species (minus *Micropterus* spp.), (4) Number of native sucker species, (5) Number of intolerant species, (6) Percent of individuals as tolerant species, (7) Percent of individuals as omnivores and stoneroller species, (8) Percent of individuals as specialized insectivores, (9) Percent of individuals as piscivores, (10) Catch rate (abundance), (11) Percent of individuals as hybrids, and (12) Percent of individuals with anomalies. Each metric was scored by adjusting expected criteria by ecoregion and received a score of 1, 3 or 5. The IBI score for a sample was a sum of scores of 12 metrics, thus ranging from 12 to 60.

EPT scores represented the number of families in the Orders Ephemeroptera, Plecoptera and Trichoptera; these taxonomic groups contain a number of species that are sensitive to anthropogenic disturbances (Kerans and Karr 1994). EPT score ranged from 2 to 24 (mean = 11) among NHD Plus catchments.

IBI and EPT scores were available for 1,357 samples (Fig. C1), but some sites were sampled in more than one years and some NHD Plus catchments contained more than one sites. I calculated the mean IBI and EPT scores in catchments with more than one scores. Accordingly, these scores were available at 471 catchments out of 57,477 catchments delineated within TRB (< 1 %). Correlation between observed IBI and EPT scores was weak (Pearson $r = 0.40$) (Fig. 2), necessitating examination of both scores in the analysis.

Statistical analysis

IBI and EPT scores were modeled as a function of environmental covariates at the spatial grain of NHD Plus catchments for TRB. Because a suite of environmental covariates was available, my approach entailed multiple linear regression. In addition, an initial analysis indicated that linear models would not account for spatial autocorrelation in model residuals (results not shown). Thus, mixed-effect linear models were used to account for spatial heterogeneity in regression coefficients by using Level III ecoregions as a random effect. Data and statistical analysis were conducted in Program R (R Development Core Team 2015).

A set of mixed-effect models was built with different random-effect structures using ‘lmerTest’ function in package ‘lme4’ (Kuznetsova et al. 2015) in Program R. The top-down approach of Zuur et al. (2009) was used and models initially included all six environmental covariates as fixed effects. Random-effect structures were represented by specifying only the intercept as a random effect, and then adding each covariate as a random effect in a different model. Only one covariate was used as a random effect because correlation among random effects of covariate terms was high (Pearson’s $|r| > 0.5$). Competing models were compared using an information theoretic approach (Akaike’s Information Criteria: AIC) where lower AIC values indicate better models and the model with the lowest AIC value was identified as the optimal random-effect structure. Covariates with little explanatory power were removed based on *P*-value of coefficient estimates. Calculation of *P*-values in mixed-models is an approximation (Kuznetsova et al. 2015). Thus, a conservative *P*-value of 0.10 was used so as not to eliminate more covariates than necessary. The model that resulted from this selection procedure was then checked for residual structures by plotting residual values against model fitted values, ecoregion and each of environmental covariates included in the model. Residual plots were visually checked to confirm that residuals do not depend on these factors.

The selected model for IBI and EPT scores was used to predict these scores for all NHD Plus catchments within TRB. Predicted scores were spatially plotted and the relationships between predicted IBI and EPT scores were also compared.

Results

Spatial variation in IBI and EPT scores was explained by slightly different sets and effect sizes of environmental covariates. The best random-effect structure of the IBI model included intercept and percent wetland (‘wetlandpc’) as random effects and the AIC value of this model was > 2 smaller than the next best model (Table C1). Percent forest (‘forp’) was removed from this model due to its non-significant *P*-value ($P = 0.58$). Phosphorous and population density were the strongest drivers of IBI scores (Table C2). Elevation and percent wetland had positive effects on IBI scores (Table C3). For random-effect terms, standard deviation of intercept was 3.17 (mean effect = 42.53) and that of percent wetland was 2.37 (mean = 0.79). The large standard deviation of percent wetland relative to its overall mean (fixed) effect indicated that the effect of wetland varied greatly among ecoregions.

The best random-effect structure of the EPT model was represented by including intercept and population density (‘popdensc’) as random effects. Similar to IBI, the AIC value of the next best EPT model was > 2 (13.48) (Table C2), indicating that the top model had by far the best support. EPT scores were driven most strongly by elevation (positive effect) and population density (negative) (Table C2). Standard deviation of random-effect terms was 1.85 for intercept (mean effect = 10.26) and 0.90 for population density (mean = -1.61).

Observed and predicted IBI scores were modestly correlated with other each (Pearson r = 0.50) (Fig. 3). The EPT model had a better fit than the IBI model, and observed and predicted EPT scores were highly correlated with each other (Pearson r = 0.76) (Fig. 3). The differences in spatial patterns between IBI and EPT scores were evident when predicted scores were mapped across NHD Plus catchments in TRB. The IBI model identified two areas of TRB as possessing high IBI scores; one area was located in the southern Appalachian Mountains and the other cluster was in the northwestern part of the TRB (Duck and Buffalo River basins). Predicted EPT scores showed a different spatial pattern in that the southern Appalachian Mountains area retained the highest scores, but Duck and Buffalo River basins received lower scores.

Table C1. Summary of six NHD Plus covariates used for statistical analysis.

Abbreviation	Unit	Mean	Median	2.5 percentile	97.5 percentile
minelevraw	meter	283	217	109	656
cropsp	percent	7	1	0	44
forp	percent	49	48.2	5	95
wetlandpc	percent	2	1	0	12
P_kgdenc	kg/year per km^2	575	512	34	1,562
popdensc	#/km^2	28	13	2	145

Table C2. Rankings of linear mixed models based on random-effect structures. Models are ordered by AIC values, from the lowest to the highest. All covariates include minimum elevation (‘minelevraw’), percent crop area within catchment (‘cropsp’), percent forest within catchment (‘forp’), percent wetland upstream cumulative (‘wetlandpc’), total estimated phosphorous inputs within catchment (‘P_kgdenc’), population density within upstream stream network (‘popdensc’)

(a) IBI

Fixed effects	Random effects	AIC values	Δ AIC
All covariates	Intercept, wetlandpc	3167.74	0.00
All covariates	Intercept, forp	3170.07	2.33
All covariates	Intercept, popdensc	3173.54	5.80
All covariates	Intercept	3174.73	6.99
All covariates	Intercept, P_kgdenc	3175.81	8.07
All covariates	Intercept, cropsp	3176.62	8.88
All covariates	Intercept, minelevraw	3177.64	9.90

(b) EPT

Fixed effects	Random effects	AIC values	Δ AIC
All covariates	Intercept, popdensc	2283.03	0.00
All covariates	Intercept, wetlandpc	2296.51	13.48
All covariates	Intercept	2299.00	15.97
All covariates	Intercept, minelevraw	2300.76	17.73
All covariates	Intercept, P_kgdenc	2302.53	19.50
All covariates	Intercept, forp	2302.73	19.70
All covariates	Intercept, cropsp	2302.97	19.94

Table C3. Estimated fixed effects in the top IBI and EPT model. The IBI model included intercept and “wetlandpc” as random effects and the EPT model included intercept and “popdensc” as random effects (Table C2).

(a) IBI

Parameters	Mean	SE	*t*-value	*P*-value*
Intercept	42.53	1.35	31.42	< 0.01
Elevation (‘minelevraw’)	0.87	0.51	1.71	0.09
Phosphorous (‘P_kgdenc’)	-1.71	0.41	-4.21	< 0.01
Crop (‘cropsp’)	-1.14	0.41	-2.81	0.01
Wetland (‘wetlandpc’)	0.79	1.10	0.72	0.52‡
Population density (‘popdensc’)	-1.69	0.37	-4.53	< 0.01

* *P*-value is based on Satterhwaite’s approximation

‡ Wetland was retained in the final model because its inclusion resulted in the best random-effect structure.

(b) EPT

Parameters	Mean	SE	*t*-value	*P*-value*

Intercept	10.26	0.72	14.31	< 0.01
Elevation (‘minelevraw’)	1.61	0.23	7.86	< 0.01
Forest (‘forp’)	0.68	0.17	3.96	< 0.01
Phosphorous (‘P_kgdenc’)	-0.29	0.16	-1.77	0.08
Crop (‘cropsp’)	-0.38	0.18	-2.09	0.04
Wetland (‘wetlandpc’)	-0.69	0.18	-3.80	< 0.01
Population density (‘popdensc’)	-1.61	0.43	-3.76	0.01

* *P*-value is based on Satterhwaite’s approximation

Fig. C1 Map of the Tennessee River Basin (shaded by grey) showing survey locations for which IBI or EPT scores were available (purple dots). State borders are shown in black lines.

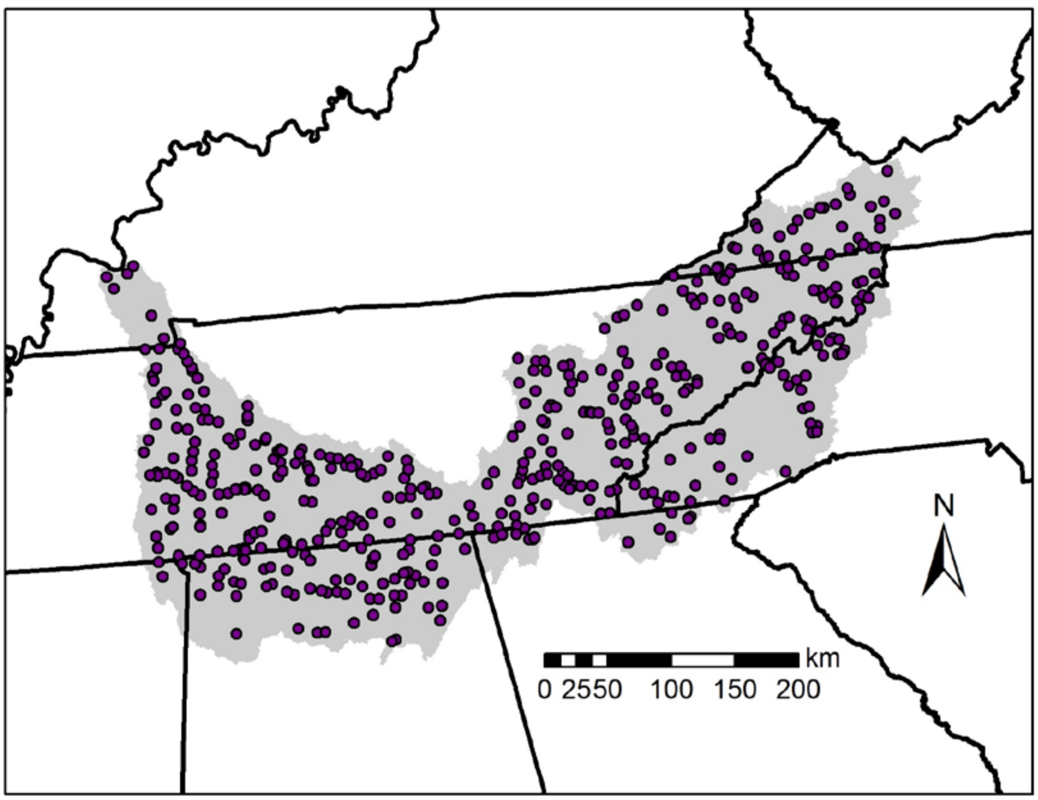


Fig. C2 A plot of observed IBI and EPT scores (Pearson $r = 0.40$). Each dot represents an NHD Plus catchment for which both scores were available.

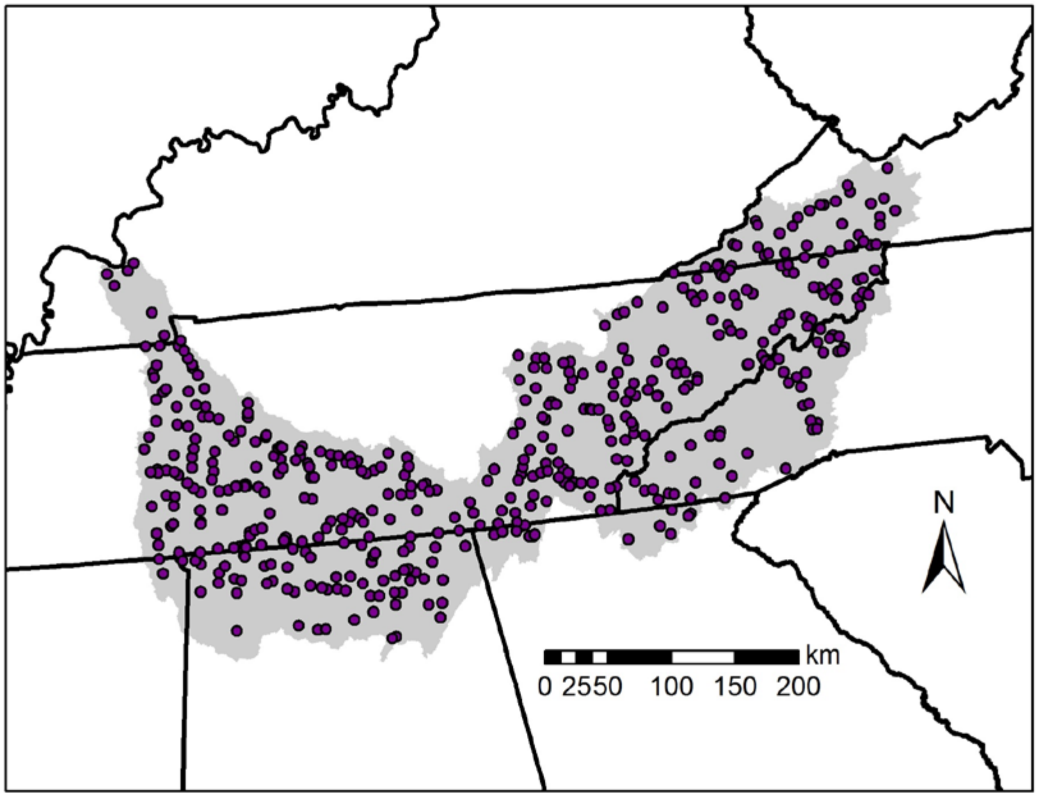
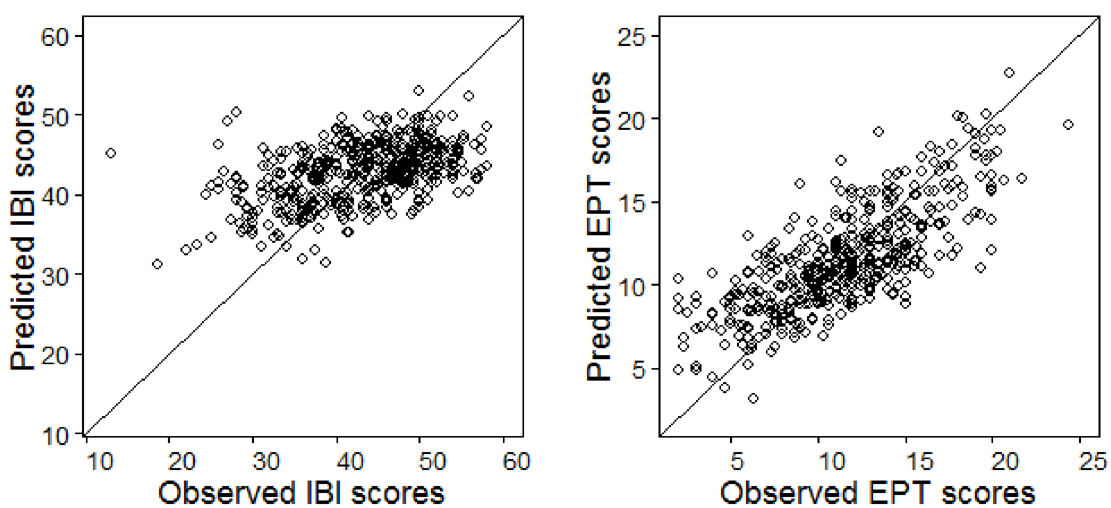


Fig. C3 Relationships between observed and predicted scores in IBI and EPT. Each dot represents an NHD Plus catchment for which biological data are available. Pearson $r = 0.50$ in the IBI plot (left) and 0.76 in the EPT plot (right).



Appendix D. Detailed review of existing methods to map cultural resources and case study for inclusion of cultural resources into landscape conservation design.

Introduction

In addition to history are the contemporary values that people hold for places that contribute to their culture and livelihoods. Together the past and present describe cultural resources across scales, from the local community to the nation. While other attributes of the landscape, such as clean water or biodiversity, may be easier to quantify and map, cultural resources involve more intangible and elusive ideas that are associated with emotional and psychological responses of people to locations and events, such as sense of place or inspiration (Schaich, Bieling, Plieninger, 2010).

Defining cultural resources is an important starting point and provides the scope of what components of the landscape will be considered. Cultural resources have been defined by a number of groups and agencies that protect portions of our national heritage. The National Park Service states that these resources are “physical evidence or place of past human activity” (National Park Service). Sites and buildings are just some of the resources the NPS has been charged with protecting under the National Historic Protection Act of 1966. A number of NPS programs have been created to catalog and protect cultural resources, ranging from objects to landscapes (see notes for list of programs).

Cultural resources have also been defined as “a tangible entity or a cultural practice of a cultural system that is valued by or significantly representative of a culture or that contains significant information about a culture” (Page, Gilbert, & Dolan, 1998). This definition illustrates that beyond historical significance, cultural resources are representative and valued by particular groups. What is considered a cultural resource will vary depending on the perspective of different groups. Importance may be placed on locations, buildings, or structures relative to the interest of stakeholders. This will also differ across scales, from the local to the national level.

Values play a key role in the specification of cultural resources. Values, defined as “a set of positive characteristics or qualities perceived in cultural objects or sites by certain individuals or groups" (de la Torre and Mason, 2002), can be historic, social, or economic. The variety of values and significance that groups associate with different locations, such as scenic or spiritual values, contribute to the difficulty of including cultural resources in conservation planning. Since there is human history and experience in almost all places built and natural, nearly every place may have cultural value (Phillips, 1998). How places and structures are valued will change with different stakeholders, with more or less importance given depending on who is being asked.

Determining a practical method for incorporating cultural resources into conservation planning will require the consideration of cultural values while focusing on measurable attributes of the landscape. In this document we will:

•Review previous work in mapping cultural resources and values
•Propose a framework for classifying cultural resource sites
•Outline an example of how this method may be implemented

The overarching purpose of creating a new framework is to provide a clear and straightforward mechanism for mapping cultural resources across the landscape, avoiding more subjective valuations that differ depending on stakeholder groups. Through mapping these resources, historical and cultural importance can be included in the larger conservation plan and broaden the appeal of conservation efforts.

Approaches to Mapping Cultural Resources

Including cultural resources in conservation planning requires there to be some attribute that can be measured and mapped. Identifying the locations of historic structures or sites only provides information about the geography of the past. The importance of these places is a matter of the values that different groups might hold. These cultural values describe our relationship to the past and how that heritage exists in today's world.

Cultural values also include aspects beyond just historical importance. Features of the landscape can be associated with scenic beauty, sense of place, or recreation. The ranges of values, assigned to parts of the landscape, have been mapped in different ways in an effort to incorporate them into the overall assessment of ecosystems.

In this section we will present some existing approaches to mapping cultural resources and their associated values in the landscape. Techniques have varied from general concepts to data driven assessments based on economic value. Each approach will be described and strengths and weaknesses provided.

Mapping historical sites and structures

Programs focused on historic preservation present a definition of cultural resources as structures and places of significance to the nation's past. The location of these places has been mapped across the county. Typically the inclusion of cultural resources in planning has been limited to those buildings and sites included in the National Register of Historic Sites. This dataset is maintained by the NPS and managed through its Cultural Resource Division.

The National Register program represents sites, structures, and districts that have gone through a process of designation, which includes nomination, research, and documentation of the site's historic importance (National Register, n.d.). The program was initiated after the National Historic Preservation Act in 1966. The NPS continues to digitize information from paper records for the National Register Programs and this dataset is freely available. This process helps ensure that the places included in the Register are of value to the Nation's history and culture.

Spatial data on historic sites is a straightforward means of cataloging places of cultural value. This approach avoids relative values about a site's importance by using a process of designation, but only captures cultural resources deemed of "significance in American history" (National Park Service, 1995). Additionally, the focus on historical sites does overlook more contemporary sites that contribute to the livelihood and culture of an area.

Strengths

•Rigorous process of designation and documentation

•Broad representation of national heritage

Weaknesses

•Scale is at the national level only

•Limited view of cultural resources as historical sites, landscapes, and buildings

•A singular perspective provided by data from one specific program (National Register)

Mapping values in the watershed

During the late 1990's an effort was made to measure and then map the values people attributed to their communities. The focus was on the natural and built environment, the ecosystem health of these neighborhoods, and the linkage between these and quality of life. The value framework used was developed by Stephen Kellert and seeks to detail the relationship between humans and their natural environment. This framework describes the range and strength of values that people may hold toward nature in general, a particular location, or a part of the ecosystem such as a particular species (Kellert, 2012). The typology includes both positive and negative relationships (Table D 1).

Typology of values in nature

Aesthetic	Physical appeal and attraction to nature
Dominionistic	Mastery and control of nature
Humanistic	Emotional attachment to nature
Moralistic	Moral and spiritual relation to nature
Naturalistic	Direct contact with and experience of nature
Negativistic	Fear of and aversion to nature
Scientific	Study and empirical observation of nature
Symbolic	Nature as a source of metaphorical and communicative thought
Utilitarian	Nature as a source of physical and material benefit

Table D1 - Typology of values in nature

The Greater New Haven Watershed Project involved surveying residents within watersheds, resulting in value measurements that can be mapped to the subwatershed level. The subwatersheds corresponded to neighborhoods and were evaluated on ecosystem health, socioeconomic conditions, and quality of life factors. For each neighborhood a graph could be made showing its measure on a variety of items. Areas could then be compared to see the relationship between environmental and social condition.

The study was of a relatively small watershed in Connecticut but involved a large amount of resources to collect both ecological and social data. While it may not be feasible on a larger scale, the results show how a healthy ecosystem contributes to physical features that people value. These landscape features also contribute to benefits that people identify with in the places they live (Figure D1). This place identity is a key factor in the cultural value that sites have for local residents.

The Greater New Haven study was an early precedent that linked environmental and landscape values to a specific geography (subwatersheds). This work also informed future studies of spatially representing environmental and cultural values. The mapping effort documented the more intangible aspects of cultural resources and allows them to be mapped and included in spatial analysis.

Strengths

•Provides a detailed measure of values related to place and environment

•Allows for mapping environmental values, in this case at the watershed level

•Involves local knowledge and interpretation of environmental condition into assessments

•Obtains a robust sample of people in the watershed

Weaknesses

•Resource intensive - requires extensive survey and sampling procedures

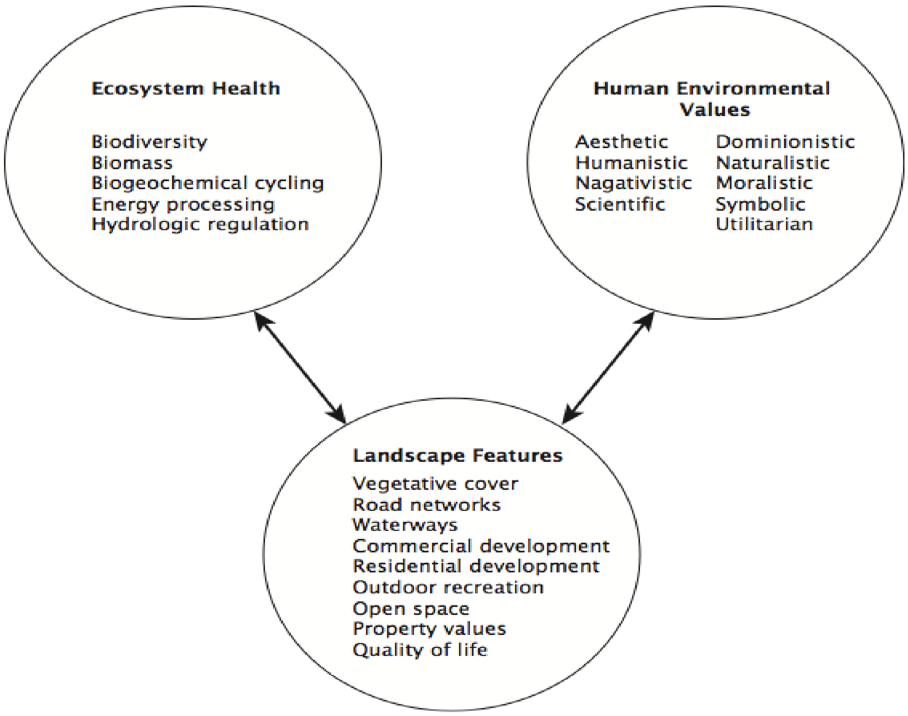


Figure D1. Relationship Framework. Values are not linked to specific cultural resources but instead to a broader landscape

Public Participatory Geographic Information Systems (PPGIS)

PPGIS began in the late 1990's but has seen most of its development since 2000. The main impetus was to incorporate more public participation in land management decision making (Brown and Kyttä, 2014). To augment existing ecological and forestry knowledge managers sought a way to represent the input from public stakeholders in the spatial planning tools they used.

The values that are mapped in PPGIS originate from a framework suggested by Ralston and Coufal that could be integrated into forest planning. These values seek to capture aspects of forest management that were missing from existing multiple use strategies (1991). These are:

1. Life support values - Soils, Water, Natural Processes
2. Economic values - Raw materials, Timber, Utility
3. Scientific values - Knowledge of ecology
4. Recreational values - Consumptive and non-consumptive recreation, Rejuvenation
5. Esthetic values - Sense of the sublime, enjoyment from scenery
6. Wildlife values - Animals of the forest, Concept of wildness
7. Biotic Diversity values - Variety of species
8. Natural history values - Antiquity, Continuity, Identity, Process
9. Spiritual values - Sacred space, Transcendence
10. Intrinsic values - Values of the forest outside of human utility

This set of values has been extended by adding aspects of the landscape such as special places, historic value, or sense of place (Brown & Raymond, 2007). Table D2 includes terms and definitions that have been used in PPGIS studies.

Terms and Definitions

Aesthetic	Scenic qualities
Recreation	Places that provide outdoor recreation opportunities
Economic	Places that provide income and employment opportunities
Wilderness	Wild, uninhabited or relatively untouched by human activity
Biological	Places that provide a variety of plants, wildlife or other living organisms
Heritage	Values placed on maintaining historically important landscapes or species
Future	Places that provide opportunity for future generations to know and
Learning	Places to learn about the natural environment through interpretation and

Intrinsic	Places valuable for their own sake
Therapeutic	Places to feel better physically and/or mentally
Spiritual	Places that are sacred, religious, or special for spiritual reasons
Life-Sustaining	Places that help produce, preserve, or renew air, soil, and water
Social	Areas that provide opportunity for social interaction
Historical/Cultural	Places that represent history or that allow for passing on of tradition and way of life
Marine	Places that support marine life
Subsistence	Places that provide resources or food for people
Special Places	Places special to the individual
Family Connection	Places important to maintaining family connections
Sense of Place	Connection that people feel with recognized feature of the environment
Cultural Diversity	The role that ecosystems play in enhancing cultural diversity
Community	People's role in schools, fire-fighting, land stewardship and forming sense
Economic viability	Concern for income and employment security

Table D2. (Brown, 2004; MEA, 2005; Brown, 2009; Brown & Raymond, 2010; Brown & Weber, 2012; Brown & Brabyn, 2012; Lowery & Morse, 2013; Brown, 2013)

PPGIS uses techniques that solicit stakeholder input to map a variety of values within a defined geographic area. The method has been used in scenarios from national forest planning (Brown, 2009) to assessing sense of place (Brown & Raymond, 2007). The process typically asks participants to place dots or markers on locations that they associate with a given set of values. The dots are then analyzed with GIS software to produce maps of density for each of the values assessed.

In some more recent use, participants have been asked to instead draw polygons or areas that they associate with values such as recreation. These maps consist of many overlapping polygons revealing areas of intensity for landscape values (Lowery & Morse, 2014).

Participants in PPGIS studies can be sought via traditional survey methods like paper or electronic mailings. Additional input can also be received from internet mapping applications built specifically for PPGIS (Fig. D2). Links to this type of interface can be passed along via other communication routes. The sample size is typically an issue with these studies. While mail surveys can be targeted to a broad population, response rates have been low, reducing the ability to draw general conclusions from the data. With internet-based surveys it is difficult to know who exactly is participating. This uncertain sample means that it is difficult to say if the results are representative or the views of a particular group.

There have been some larger scale projects that have involved PPGIS and these highlight other challenges related to how people view large landscapes. Data from a study in New Zealand indicated that the results were skewed towards people placing more values close to where they lived, following the theory of spatial discounting that suggests a higher number of positive values near a person's home (Hannon, 1994; Brown, Reed, & Harris, 2002). Similar research has indicated that people do not think on a regional or ecoregional scale, but have a better concept of their local area (Ardoin, 2009). This outcome lessens the ability of PPGIS to be used to assess large, multi-state regions such as Appalachia.

The PPGIS approach refines the location of cultural values that people hold to specific places. Through the mapping process particular values can be identified with distinct locations in the landscape, though the question of whose values they are might remain. PPGIS provides a means of spatially identifying cultural information and adding this into the planning process.

Strengths

- Allows stakeholders to participate in value assignments
- Can capture specific values at specific places
- Enriches planning through additional information provided by the public and the inclusion of local knowledge

Weaknesses

- Scale is an issue. Theory of spatial discounting - people will associate greater value closer to where they live
- Difficult to assign multiple values to same place
- Values are defined in survey and may not capture unique cultural perspectives
- Values may not be as specific as a single data point, intention of respondent may be unclear

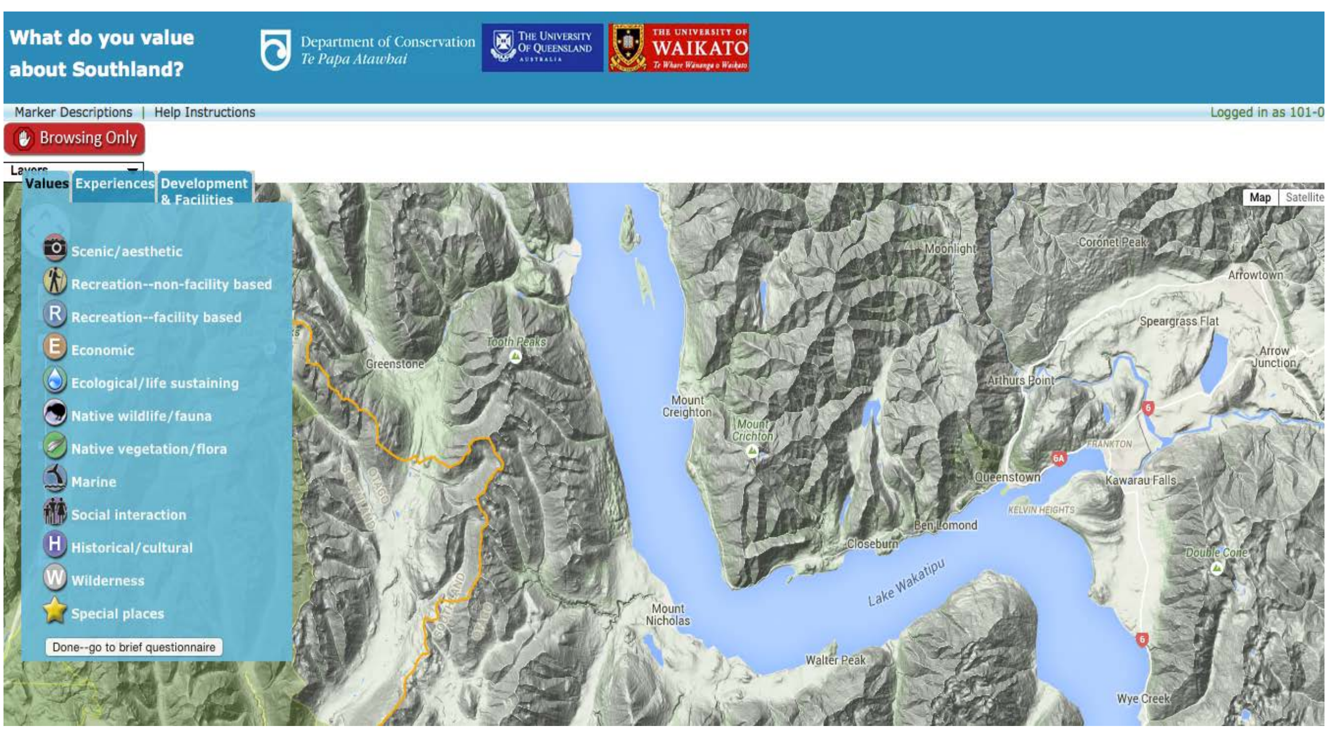


Figure D2 - Internet based mapping interface

Economic Valuation Mapping

Efforts at mapping the benefits of cultural resources have also used methods based on assigning monetary value to places. Economic value is seen as a substitute for the non-market or intangible values people hold for their environment. Work at placing economic value on cultural resources has typically focused on those aspects that can be assessed through traditional measures of economic impact, such as tourism and recreation. This can be done through techniques such as contingent valuation and travel cost.

Contingent valuation (CV) is a method that attempts to assign monetary value to the environment amenities. The premise is to determine the benefits and costs associated with certain actions based on the preferences of the individual. This method directly asks what a person would be willing to pay for an environmental good or service based on a given scenario. Willingness to pay asks respondents what would be an acceptable amount to pay to protect certain resources. This type of surveying seeks to identify preferences that people hold for certain places or resources (Arrow et al., 1993; de Groot, Wilson, & Bouman, 2002).

Contingent valuation has been used in a number of surveys and legal proceedings but is heavily criticized (Chee, 2004). There are issues of bias based on how the survey is constructed, whether values are open-ended, and how people react to hypothetical scenarios (Hanemann, 1994). Despite its shortcoming, the CV method has been employed in assessing the value of environmental features and determining damages from environmental accidents.

Travel cost is a method for determining value of recreation and tourism sites based on the cost associated with visiting those sites. In a recreation example this method would account for costs such as travel, equipment, licenses, etc. Travel costs are subject to the judgment of those doing the analysis as some boundary must be set for what to include.

Using travel cost can distort the value of places as sites close to population centers will be visited more, increasing the total monetary value. The method is less suited to sites that are less frequently visited, like wilderness, or less tangible characteristics of the landscape, such a scenic or livelihood values (Chee, 2004).

With contingent value and travel cost an economic number can be assigned to sites of environmental or cultural value. These monetary amounts can be mapped to sites, summarized and even transferred to other, similar locations to assess value where data is limited (Troy and Wilson, 2006).

Economic valuation can provide a measurable assessment to places that cannot easily be valued by typical policy tools. While the amounts determined are considered to be objective, the idea of placing a price on history or culture is controversial, especially when the resource is not replaceable. This method is also more applicable to smaller scale studies where respondents have knowledge to be able to make specific value judgments.

Strengths

• Can assign economic value to places of environmental or cultural importance

• Fits into traditional economic thinking and planning practices

Weaknesses

• Results can be varied depending on method and quality of surveying

• Assigning a monetary number to intangible attributes is controversial

Social Indicators

Local culture can also be viewed through the social condition of a place. Cultural resources, like other ecosystem benefits, can contribute to the well-being of residents in an area. A method of measuring and mapping well-being is through the use of social indicators. Demographic, health, cultural, or political data can be determined for populations and mapped, providing information for conservation planning efforts (Stephanson & Mascia, 2014). More recently a number of indexes have been developed that include cultural measures such as number of protected sites, number of cultural organizations, or creative businesses (i.e. WNC Vitality Index). While these include cultural aspects in the overall evaluation of a region, the items measured typically are indicative of cultural offerings or events and less associated with the traditional definition of cultural resources.

In measuring the human side of ecosystems social indicators can describe the contemporary state, accounting for aspects of society that interact with and impact natural systems. This is one part of how people relate to their environment, but does not provide a measure of the values people hold about place. In attempting to include cultural resources in conservation planning, and be of interest to a broad audience, both present and past values need to be incorporated.

Strengths

• Includes the social condition in conservation planning

• Captures current state of the human component of ecosystems

Weaknesses

• Focused more on outcomes of economic, education, or health policy

• Doesn't capture intangible values that might lie outside of already designated cultural sites

By trying to represent the views people hold about places, these approaches to mapping cultural resources and values illustrate the difficulty of including values in planning. Some methods try to capture an objective measure of values, while others lean more on public participation to describe the amount significance held for the landscape. Components of these techniques can be applied to specific sites or to more general areas, resulting in varying amounts of each characteristic (i.e. high utilitarian value and low aesthetic). Each method has its strengths and weaknesses that can help inform an approach that could be effectively applied on a regional scale.

Case Study Example

To illustrate how this framework might be implemented, a cultural resource layer was created for the area around Chattanooga, TN. This city lies within the Tennessee River Basin and has a number of significant historical and cultural sites (Map 1).

Sources		**Data**
Tennessee GIS Data Server	tngis.org	Background data for state
University of Tennessee at Chattanooga	geoportal.utc.edu	Infrastructure, Recreation, Open Space
The Commission for Environmental Cooperation	www.cec.org	Terrestrial Protected Lands
ESRI		Cultural data
The Nature Conservancy	www.tnclands.tnc.org	Conserved lands
Land Trust for Tennessee	landtrusttn.org	Land Trust properties
National Conservation Easement Database	conservationeasement.us	Conservation Easements
National Park Service	irma.nps.gov	National Register, National Parks
USGS	gapanalysis.usgs.gov/padus/	PAD-US

Table D3 - Data Sources

Process

The process for compiling this dataset included:

- Search for data (Table D3)

- Check quality
- Clean and organize
- Classify
- Combine
- Produce outputs

In this case all data was found in available and accessible datasets. Across the LCC there may be more searching or creation of datasets required to reach consistency of data at each classification level.

In this example all lands that serve cultural resource functions are identified in the Chattanooga area (Map 3). These are classified according to the framework outlined above. To translate the amount of cultural resources across the area, sites are aggregated to a 5km hexagon grid through an additive procedure. Some alternative methods are presented that can represent the data:

- Raw number - additive, sum up number of sites
- Absence/Presence - 0,1
- Weighted sum based on classification (Map 4)
    - Inverse weighting - 1 – 0.2
- Cultural Resource Diversity Index - based on Simpson's Index of Diversity

Issues

The accuracy of datasets varied with some containing more detail than others. Additionally, there were features repeated between some datasets. These required cleaning to avoid double counting features in the aggregation. Coverage of sites that serve cultural functions was adequate across the study area. The community level (5) was the least represented in the data. In future use this level may require more investigation to identify additional features.

Data Gaps

This example showed that there are gaps at the county level, particularly with historical sites. This data may be found with State level historical sites if they are obtained in the future. Additional data may be found through listings, such as spiritual retreats, music festivals, or farmers markets. This case illustrates that even state level data may include gaps. For example, there were many broken links for data from the TN Department of Environment. While this data was found elsewhere, this may not always be the case. Necessary datasets most likely exist within organizations but would require inquiry to obtain. Across the LCC states it is possible that there will be inconsistent availability of data that will require communication with the appropriate agencies.

Possible Input Dataset Sources

NPS

National Register of Historic Sites (Needs attention)

USGS, USFS, FWS

Landscape data, Protected areas

States

State departments of natural resources, environment, etc.

State Offices of Historic Preservation (data not easily available)

State Historical Sites

Counties

Parks, historical sites

(Many counties have GIS data, not always freely available)

NGO/Nonprofit

National Conservation Easement Database

Trust for Public Land

The Nature Conservancy

Land Trusts

National Trust for Historic Preservation

(Determining which lands are protected for cultural, rather than solely ecological, reasons may be fuzzy)

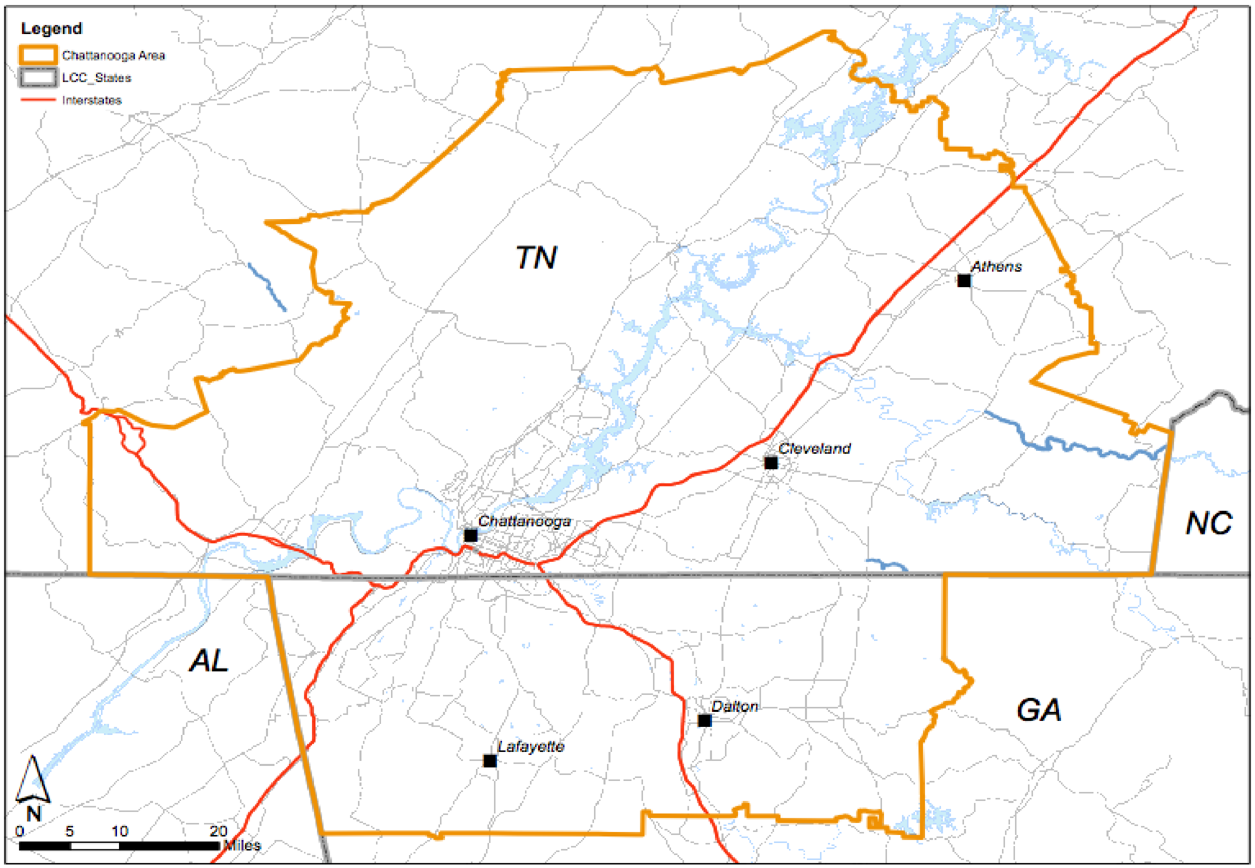
ESRI

Parks and cultural sites (recreation, cemeteries, etc.) are available for US

(Licensing issues for use in planning? This would need verification)

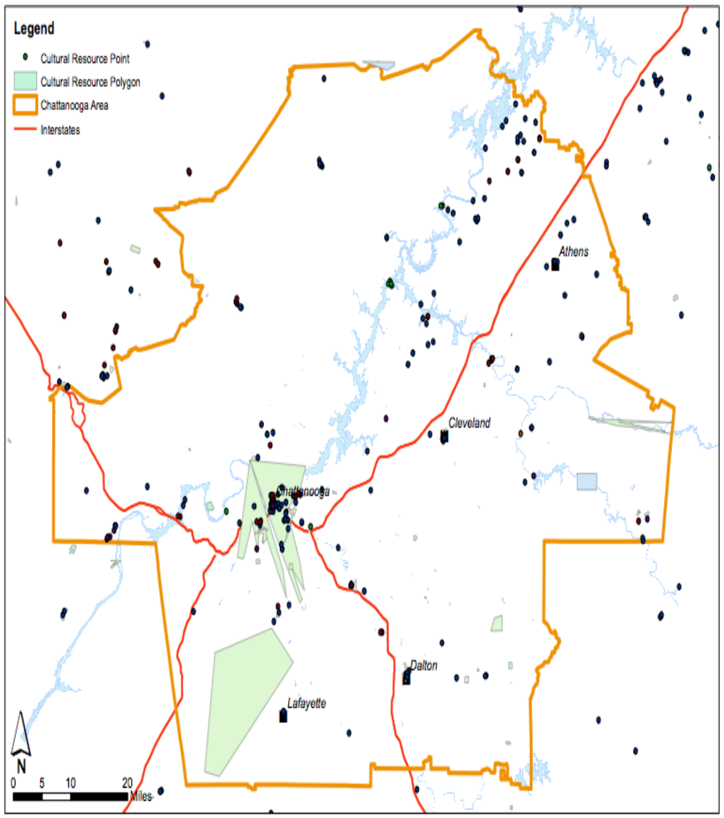
Map 1.

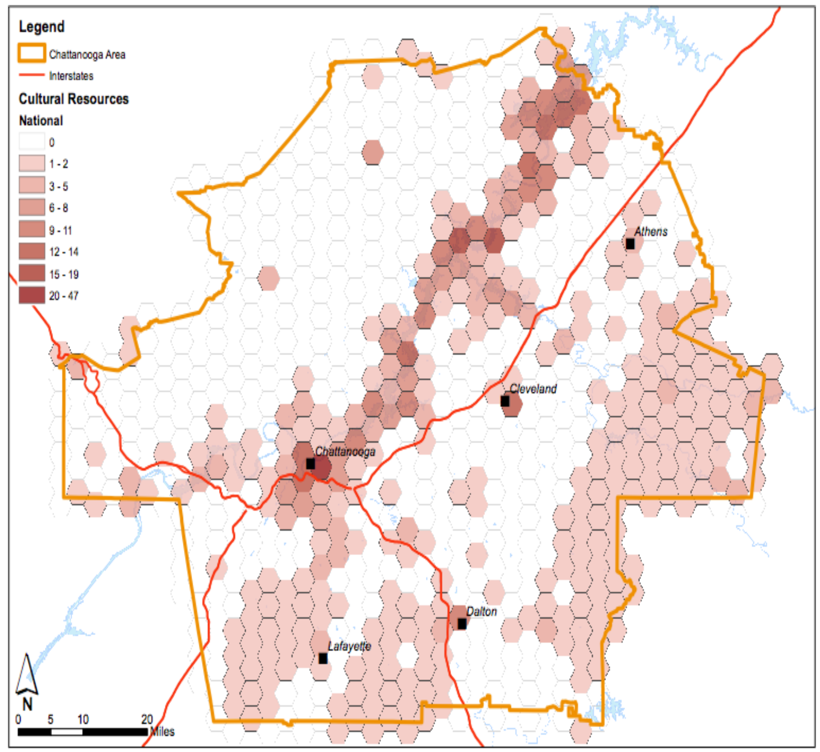
Chattanooga Area – locator



Map 2. Data from National Register of Historic Sites

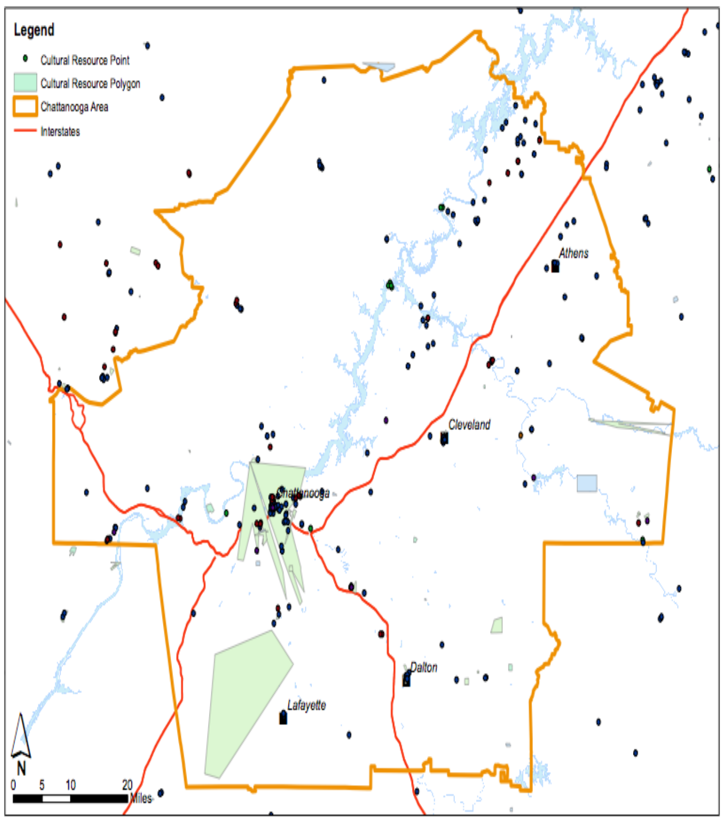
Only National category data aggregated to hexagonal grid (5km)

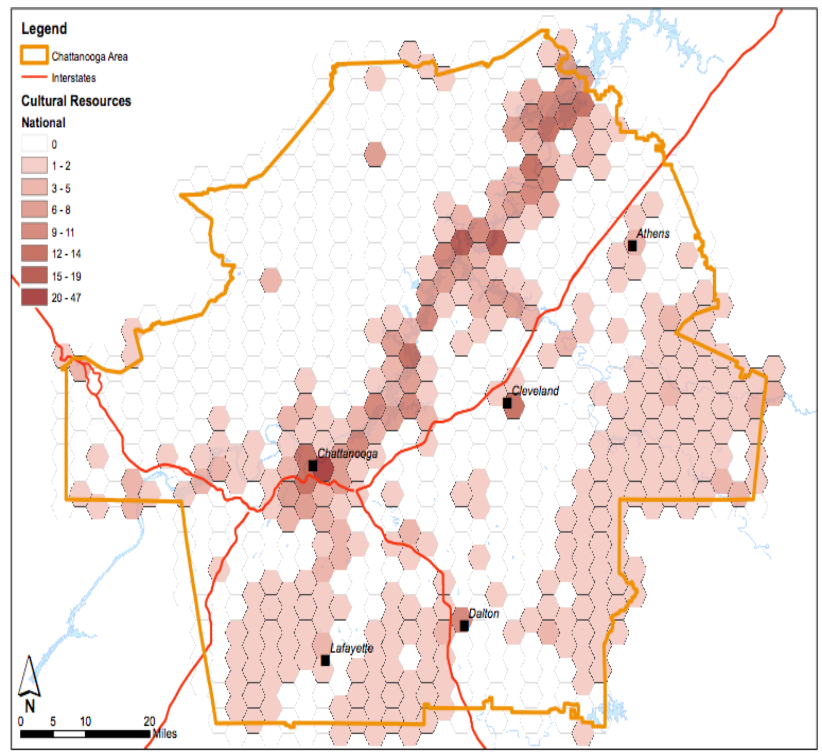




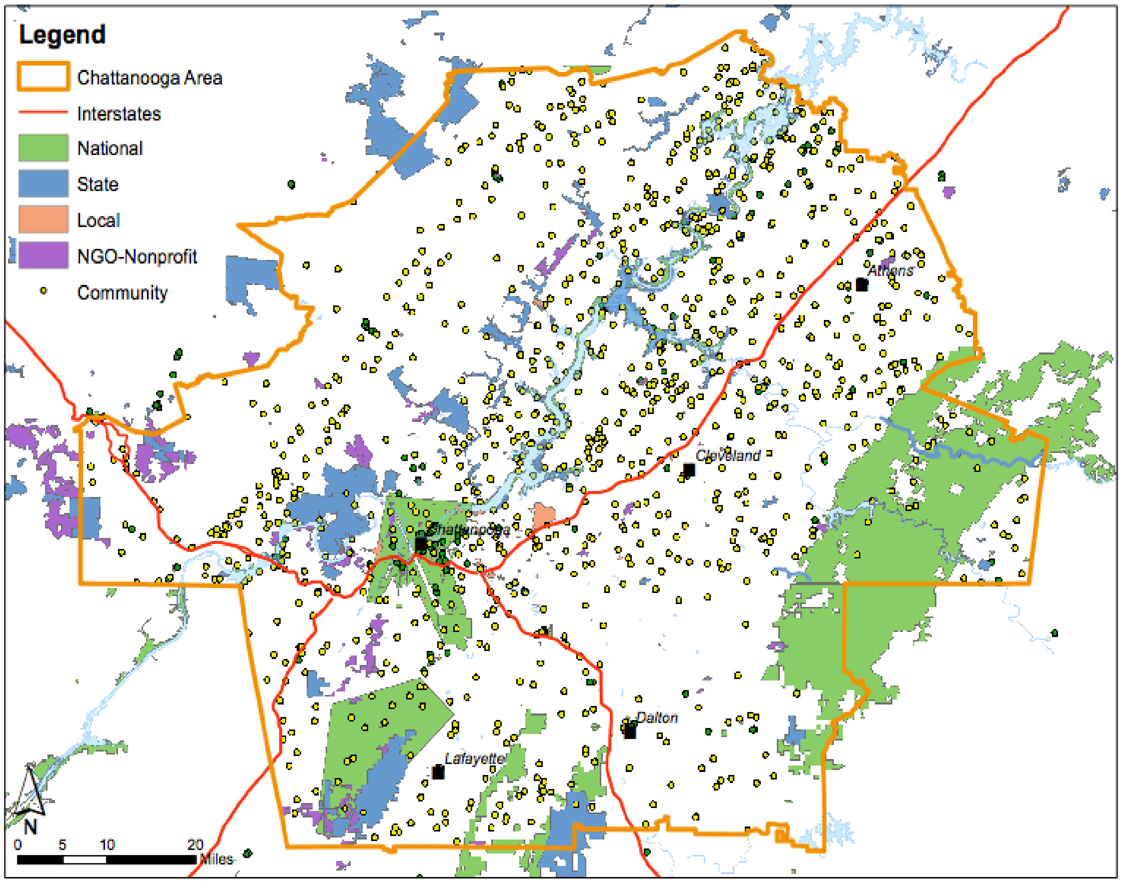
Map 2. Data from National Register of Historic Sites

Only National category data aggregated to hexagonal grid (5km)

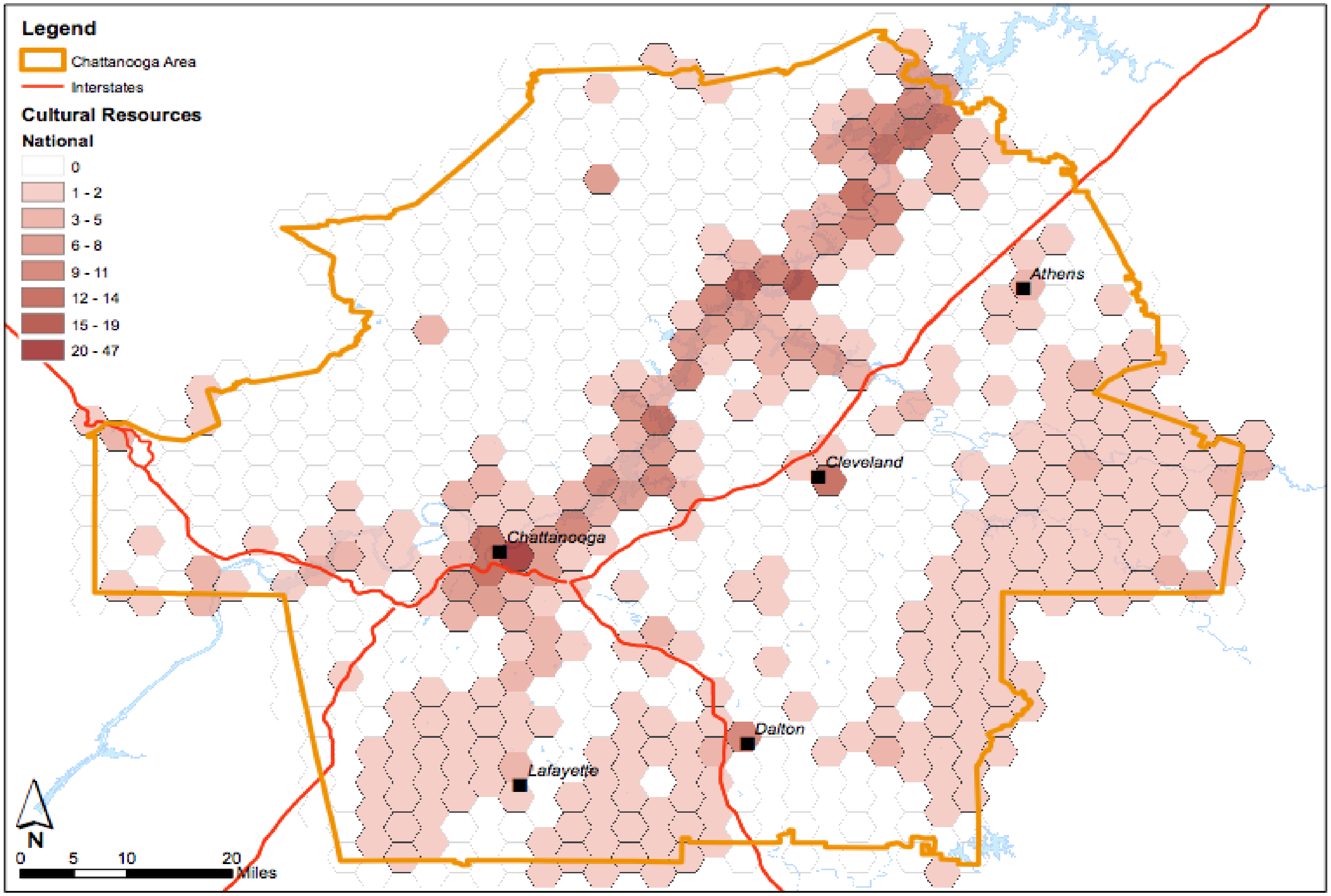




Map 3. All cultural sites identified for area of interested. Classified according to proposed framework.



Map 4. Cultural resources aggregated to a hexagonal grid based on weighted sum. Cultural resources aggregated to hexagonal grid (5km). Cultural resource features per cell are a weighted sum based on: ∑ *(1/Class x number of features)*. A higher value would indicate a greater amount of cultural resources.



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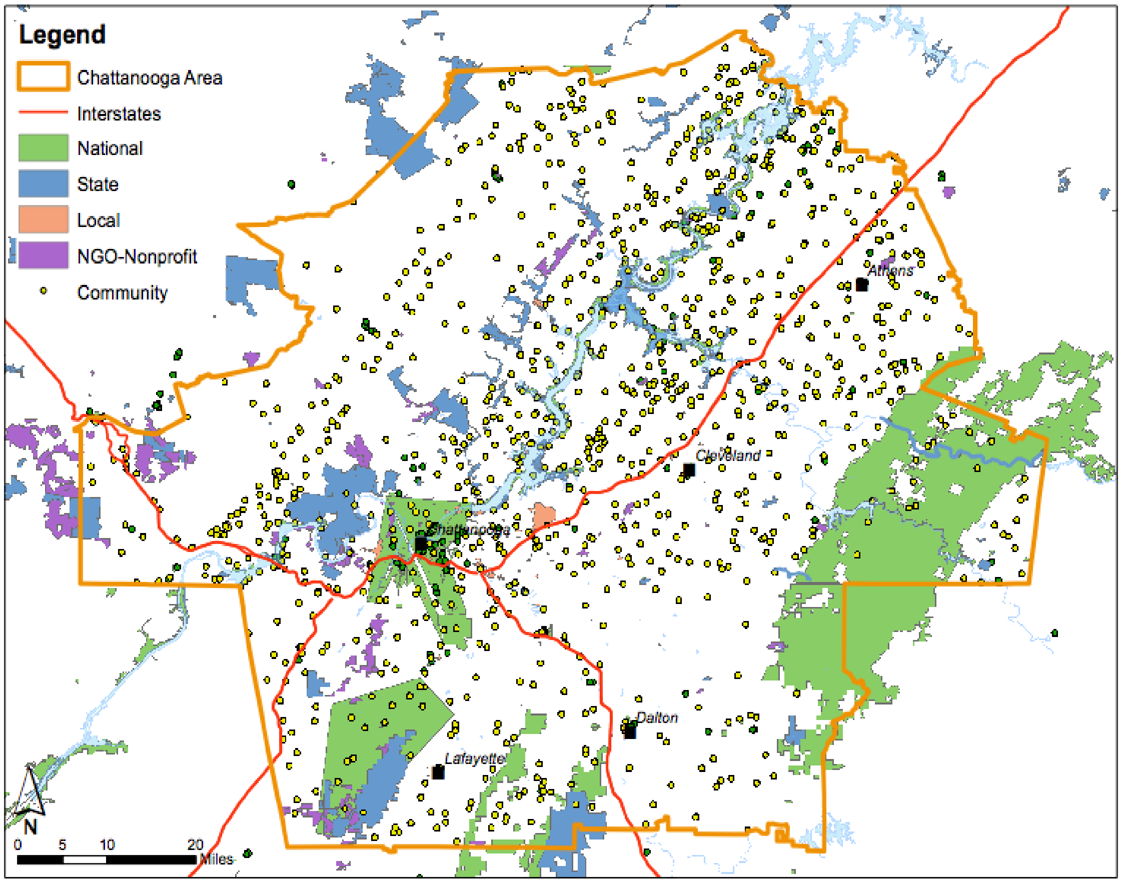

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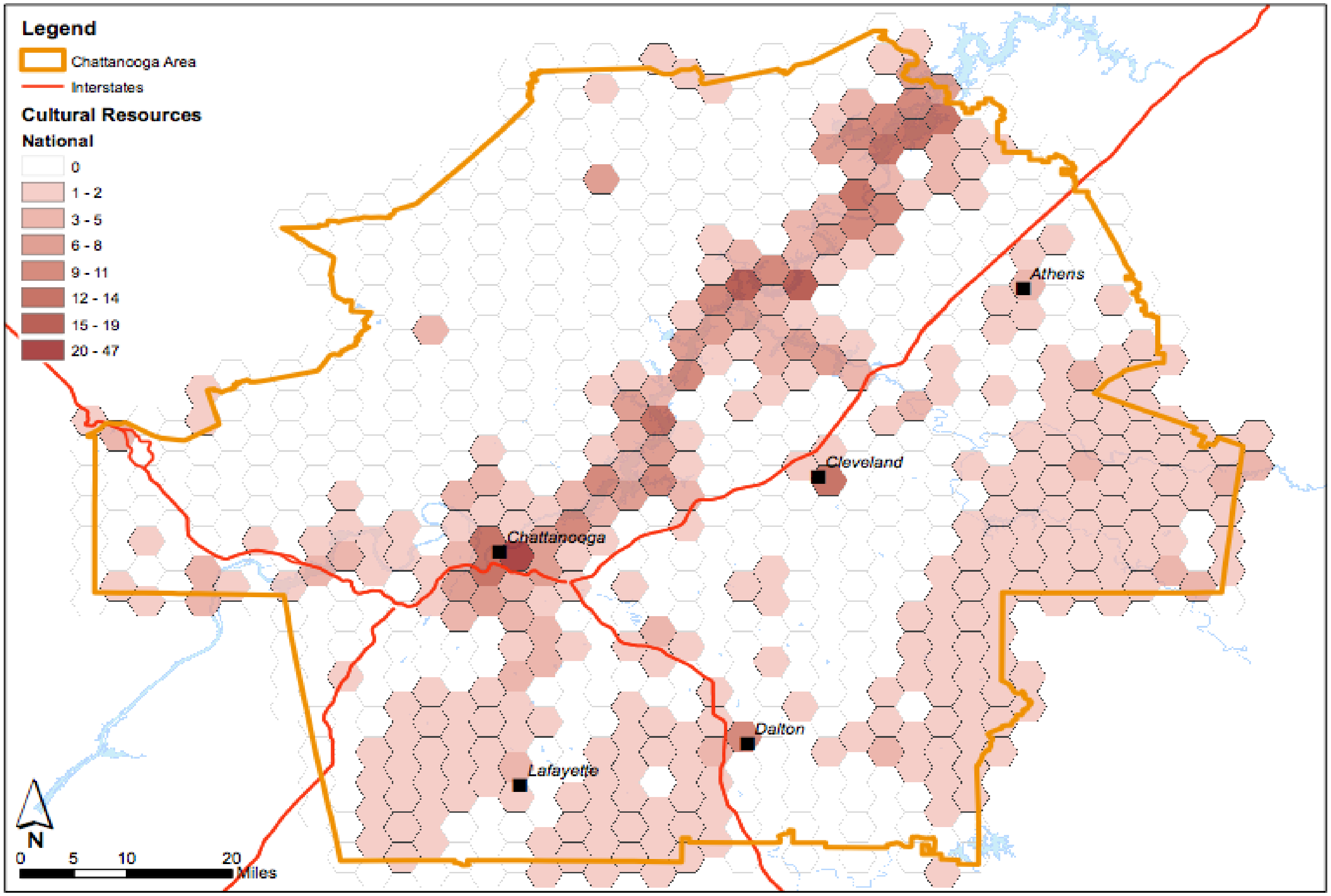

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Appendix A. Survey results from technical team guidance to the conservation design research team.

Question 1: How would you like to see 'cost' incorporated in the design

	1	2	3	4	Total	Score
Landscape Fragmentation (Inverse of Connectivity)	13	4	3	0	20	3.5
Human Modification Index	3	8	7	2	20	2.6
Cumulative Threats Index	3	5	4	8	20	2.15
Census Block Median Household Income	1	3	6	10	20	1.75

Question 2: Please rank how you'd like to see landscape connectivity incorporated into the design (1= most desired)

Answered 20 : Skipped 0

	1	2	3	Total	Score
Implicitly in Solution (Cost)	9	4	7	20	2.1
Explicity in Solution (Targets & Goals)	7	6	7	20	2
Post-hoc	4	10	6	20	1.9

Question 3: What top % of the existing resource would you like to see in a prioritized framework?

	5%	10%	20%	30%	40%	50%	> 50 %
Young Forest	9	2	3	2	0	0	2
Grasslands	5	4	4	4	1	0	2
Shrub / Scrub	5	4	4	3	1	0	1
Mature Lowland Forest	1	4	5	3	0	2	3

High-Elevation Stream Integrity	2	0	3	6	1	2	3
Low-Elevation Stream Integrity	4	2	4	2	0	3	3
Forested Wetlands	1	2	5	2	1	4	2
Unfragmented Forests	2	3	2	1	3	4	4
High-Elevation Forests	1	0	6	3	2	3	3
Cave/Karst aquatic richness	2	2	2	4	3	2	2
Cave/Karst terrestrial richness	2	2	3	3	4	2	2

Question 4: How Important ins the inclusion of the below resource for the LCC's design?

	Low	Moderate	High	Not Sure	Total	Score
Cove Forests	0	6	13	1	20	2.68
Balds (Heath & Grassy)	0	6	12	2	20	2.67
Rocky Outcrops	1	11	7	1	20	2.32
Glades	4	6	10	0	20	2.3
Wet Prairie	2	9	5	4	20	2.19
Acidic Fens	5	5	7	3	20	2.12
Shale Barrens	5	7	5	2	19	2

Appendix B. Landcover and traffic density resistance values along with reduction in resistance values used in landscape connectivity circuit theory modeling.

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Land Cover Class	Resistance
Open Water	41
Open Space Developed	50
Low Intensity Developed	44
Medium Intensity Developed	64
High Intensity Developed	88
Barren Terrain	41
Deciduous Forest	2
Evergreen Forest	5
Mixed Forest	3
Shrub/Scrub	8
Grass/Herbaceous	25
Pasture/Hay	29
Cultivated Crops	25 (5)
Woody Wetlands	13 (3)
Emergent Herbaceous Wetlands	20

Traffic Range (Vehicles/day)	Resistance
0-500	2
500-1,400	9
1,400-5,000	25
5,000-14,000	50
14,000-35,000	73
35,000+	89

Category	Resistance Reduction
Railroad Bridges	40%
Pedestrian Bridges	30%
Other Bridges	50%
Water Bridges (8-20m)	60%
Water Bridges (over 20m)	40%
Wildlife Crossings	10%

Appendix C. Detailed methods and results for modeling aquatic integrity across NHD Plus catchments in the Tennessee River Basin

Summary

1. Tennessee River Basin (TRB) harbors exceptional aquatic diversity, but it has been impacted negatively by anthropogenic disturbances. Characterizing drivers and spatial patterns of aquatic integrity would serve regional conservation planning effort such as Appalachian Landscape Conservation Cooperative.
2. This study used available biological and environmental data to map aquatic integrity in TRB. I modeled spatial variation in fish Index of Biotic Integrity (IBI) scores, and family richness of Ephemeroptera, Plecoptera and Trichoptera (EPT) in relation to National Hydrograph Dataset (NHD) Plus catchment characteristics using a linear mixed-effect modeling approach.
3. IBI and EPT scores were driven by different sets of environmental covariates, and each metric provided independent assessment of biotic integrity. For example, human population density had negative effects on both scores, but percent forestland affected only EPT scores. The EPT model had a better fit than the IBI model and was more responsive to catchment-scale human disturbances.
4. Statistical models were used to predict IBI and EPT scores for 57,477 NHD Plus catchments within TRB and two clusters of areas with high biotic integrity were identified. Both IBI and EPT models identified southern Appalachian Mountains as retaining high biotic integrity, and Duck and Buffalo River basins were characterized as having high scores in the IBI model.
5. The products of this study can be used to inform regional conservation planning by identifying high priority areas for protection and restoration. This study focused on TRB for its exceptional aquatic diversity, but a similar approach could be used to include the entire Appalachian Landscape Conservation Cooperative region.

Methods

In order to relate biological data with environmental data in the TRB, environmental and biological data were compiled from NPD Plus version 1 and fish IBI and benthic macro-invertebrate data collected by the Tennessee Valley Authority (TVA). Given the broad spatial extent of the study area (i.e. TRB), it was conceivable that the relationship between environmental and biological data would vary among locations within the study area. Accordingly, this spatial heterogeneity was accounted for in mixed-effect models by treating ecoregions as a random effect.

Environmental data

Environmental data were derived from NHD Plus version1 for 57,477 catchments within TRB (http://www.horizon-systems.com/NHD Plus/NHD PlusV1_home.php). Ninety environmental covariates were available for catchments. Given the large number of available covariates, they were screened prior to statistical analysis. First, simple linear regression was fit between each environmental covariate and each biological integrity index (i.e. fish and bugs – see next section). A covariate was removed from further analysis if Pearson's correlation coefficient was less than 0.3 in absolute value (Pearson's $|r| < 0.3$) for both biological indices. A total of 16 covariates were retained for further analysis in this first step. Second, collinearity among the 16 covariates was examined in a pair-wise manner. When two covariates were highly correlated with each other at Pearson's $|r| > 0.5$, the covariate with the largest mean absolute correlation from pair-wise analysis was dropped. At this step, seven covariates were retained. They included minimum elevation (hereafter 'minelevraw' following NHD Plus terminology), percent crop area within catchment ('cropsp'), percent forest within catchment ('forp'), percent wetland upstream cumulative ('wetlandpc'), total estimated phosphorous inputs within catchment ('P_kgdenc'), population density within upstream stream network ('popdensc'), and percent carbonate bedrock geology upstream cumulative ('brock1pc'). Summary statistics and histogram were examined for each covariates (Table 1); 'brock1pc' was removed from further analysis because 29% of NHD Plus catchments received a value of zero and the effect of this covariate on biological integrity was not easy to interpret.

Covariates were standardized by mean divided by standard deviation (*z*-score transformation) for statistical analysis. Covariates that were not normally distributed were transformed before standardization in order to alleviate excessive influence of few uncommon observations; cropsp was square root transformed, and wetlandpc and popdensc were log transformed.

Biological data

Biological data included fish and benthic macro-invertebrate assemblage information collected by TVA between 2000 and 2014. TVA calculated fish IBI scores and number of the families within the Orders Ephemeroptera, Plecoptera and Trichoptera (EPT) to characterize the health of streams (i.e. aquatic integrity). IBI and EPT scores were modeled as response variables in statistical analysis.

IBI was composed of 12 metrics that described taxonomic and ecological properties of a fish assemblage. These metrics were: (1) Number of native species, (2) Number of native darter species, (3) Number of native sunfish species (minus *Micropterus* spp.), (4) Number of native sucker species, (5) Number of intolerant species, (6) Percent of individuals as tolerant species, (7) Percent of individuals as omnivores and stoneroller species, (8) Percent of individuals as specialized insectivores, (9) Percent of individuals as piscivores, (10) Catch rate (abundance), (11) Percent of individuals as hybrids, and (12) Percent of individuals with anomalies. Each metric was scored by adjusting expected criteria by ecoregion and received a score of 1, 3 or 5. The IBI score for a sample was a sum of scores of 12 metrics, thus ranging from 12 to 60.

EPT scores represented the number of families in the Orders Ephemeroptera, Plecoptera and Trichoptera; these taxonomic groups contain a number of species that are sensitive to anthropogenic disturbances (Kerans and Karr 1994). EPT score ranged from 2 to 24 (mean = 11) among NHD Plus catchments.

IBI and EPT scores were available for 1,357 samples (Fig. C1), but some sites were sampled in more than one years and some NHD Plus catchments contained more than one sites. I calculated the mean IBI and EPT scores in catchments with more than one scores. Accordingly, these scores were available at 471 catchments out of 57,477 catchments delineated within TRB (< 1 %). Correlation between observed IBI and EPT scores was weak (Pearson $r = 0.40$) (Fig. 2), necessitating examination of both scores in the analysis.

Statistical analysis

IBI and EPT scores were modeled as a function of environmental covariates at the spatial grain of NHD Plus catchments for TRB. Because a suite of environmental covariates was available, my approach entailed multiple linear regression. In addition, an initial analysis indicated that linear models would not account for spatial autocorrelation in model residuals (results not shown). Thus, mixed-effect linear models were used to account for spatial heterogeneity in regression coefficients by using Level III ecoregions as a random effect. Data and statistical analysis were conducted in Program R (R Development Core Team 2015).

A set of mixed-effect models was built with different random-effect structures using 'lmerTest' function in package 'lme4' (Kuznetsova et al. 2015) in Program R. The top-down approach of Zuur et al. (2009) was used and models initially included all six environmental covariates as fixed effects. Random-effect structures were represented by specifying only the intercept as a random effect, and then adding each covariate as a random effect in a different model. Only one covariate was used as a random effect because correlation among random effects of covariate terms was high (Pearson's $|r| > 0.5$). Competing models were compared using an information theoretic approach (Akaike's Information Criteria: AIC) where lower AIC values indicate better models and the model with the lowest AIC value was identified as the optimal random-effect structure. Covariates with little explanatory power were removed based on *P*-value of coefficient estimates. Calculation of *P*-values in mixed-models is an approximation (Kuznetsova et al. 2015). Thus, a conservative *P*-value of 0.10 was used so as not to eliminate more covariates than necessary. The model that resulted from this selection procedure was then checked for residual structures by plotting residual values against model fitted values, ecoregion and each of environmental covariates included in the model. Residual plots were visually checked to confirm that residuals do not depend on these factors.

The selected model for IBI and EPT scores was used to predict these scores for all NHD Plus catchments within TRB. Predicted scores were spatially plotted and the relationships between predicted IBI and EPT scores were also compared.

Results

Spatial variation in IBI and EPT scores was explained by slightly different sets and effect sizes of environmental covariates. The best random-effect structure of the IBI model included intercept and percent wetland ('wetlandpc') as random effects and the AIC value of this model was > 2 smaller than the next best model (Table C1). Percent forest ('forp') was removed from this model due to its non-significant *P*-value ($P = 0.58$). Phosphorous and population density were the strongest drivers of IBI scores (Table C2). Elevation and percent wetland had positive effects on IBI scores (Table C3). For random-effect terms, standard deviation of intercept was 3.17 (mean effect = 42.53) and that of percent wetland was 2.37 (mean = 0.79). The large standard deviation of percent wetland relative to its overall mean (fixed) effect indicated that the effect of wetland varied greatly among ecoregions.

The best random-effect structure of the EPT model was represented by including intercept and population density (‘popdensc’) as random effects. Similar to IBI, the AIC value of the next best EPT model was > 2 (13.48) (Table C2), indicating that the top model had by far the best support. EPT scores were driven most strongly by elevation (positive effect) and population density (negative) (Table C2). Standard deviation of random-effect terms was 1.85 for intercept (mean effect = 10.26) and 0.90 for population density (mean = -1.61).

Observed and predicted IBI scores were modestly correlated with other each (Pearson r = 0.50) (Fig. 3). The EPT model had a better fit than the IBI model, and observed and predicted EPT scores were highly correlated with each other (Pearson r = 0.76) (Fig. 3). The differences in spatial patterns between IBI and EPT scores were evident when predicted scores were mapped across NHD Plus catchments in TRB. The IBI model identified two areas of TRB as possessing high IBI scores; one area was located in the southern Appalachian Mountains and the other cluster was in the northwestern part of the TRB (Duck and Buffalo River basins). Predicted EPT scores showed a different spatial pattern in that the southern Appalachian Mountains area retained the highest scores, but Duck and Buffalo River basins received lower scores.

Table C1. Summary of six NHD Plus covariates used for statistical analysis.

Abbreviation	Unit	Mean	Median	2.5 percentile	97.5 percentile
minelevraw	meter	283	217	109	656
cropsp	percent	7	1	0	44
forp	percent	49	48.2	5	95
wetlandpc	percent	2	1	0	12
P_kgdenc	kg/year per km^2	575	512	34	1,562
popdensc	#/km^2	28	13	2	145

Table C2. Rankings of linear mixed models based on random-effect structures. Models are ordered by AIC values, from the lowest to the highest. All covariates include minimum elevation (‘minelevraw’), percent crop area within catchment (‘cropsp’), percent forest within catchment (‘forp’), percent wetland upstream cumulative (‘wetlandpc’), total estimated phosphorous inputs within catchment (‘P_kgdenc’), population density within upstream stream network (‘popdensc’)

(a) IBI

Fixed effects	Random effects	AIC values	Δ AIC
All covariates	Intercept, wetlandpc	3167.74	0.00
All covariates	Intercept, forp	3170.07	2.33
All covariates	Intercept, popdensc	3173.54	5.80
All covariates	Intercept	3174.73	6.99
All covariates	Intercept, P_kgdenc	3175.81	8.07
All covariates	Intercept, cropsp	3176.62	8.88
All covariates	Intercept, minelevraw	3177.64	9.90

(b) EPT

Fixed effects	Random effects	AIC values	Δ AIC
All covariates	Intercept, popdensc	2283.03	0.00
All covariates	Intercept, wetlandpc	2296.51	13.48
All covariates	Intercept	2299.00	15.97
All covariates	Intercept, minelevraw	2300.76	17.73
All covariates	Intercept, P_kgdenc	2302.53	19.50
All covariates	Intercept, forp	2302.73	19.70
All covariates	Intercept, cropsp	2302.97	19.94

Table C3. Estimated fixed effects in the top IBI and EPT model. The IBI model included intercept and “wetlandpc” as random effects and the EPT model included intercept and “popdensc” as random effects (Table C2).

(a) IBI

Parameters	Mean	SE	*t*-value	*P*-value*
Intercept	42.53	1.35	31.42	< 0.01
Elevation (‘minelevraw’)	0.87	0.51	1.71	0.09
Phosphorous (‘P_kgdenc’)	-1.71	0.41	-4.21	< 0.01
Crop (‘cropsp’)	-1.14	0.41	-2.81	0.01
Wetland (‘wetlandpc’)	0.79	1.10	0.72	0.52‡
Population density (‘popdensc’)	-1.69	0.37	-4.53	< 0.01

* *P*-value is based on Satterhwaite’s approximation
‡ Wetland was retained in the final model because its inclusion resulted in the best random-effect structure.

(b) EPT

Parameters	Mean	SE	*t*-value	*P*-value*

Intercept	10.26	0.72	14.31	< 0.01
Elevation (‘minelevraw’)	1.61	0.23	7.86	< 0.01
Forest (‘forp’)	0.68	0.17	3.96	< 0.01
Phosphorous (‘P_kgdenc’)	-0.29	0.16	-1.77	0.08
Crop (‘cropsp’)	-0.38	0.18	-2.09	0.04
Wetland (‘wetlandpc’)	-0.69	0.18	-3.80	< 0.01
Population density (‘popdensc’)	-1.61	0.43	-3.76	0.01

* *P*-value is based on Satterhwaite’s approximation

Fig. C1 Map of the Tennessee River Basin (shaded by grey) showing survey locations for which IBI or EPT scores were available (purple dots). State borders are shown in black lines.

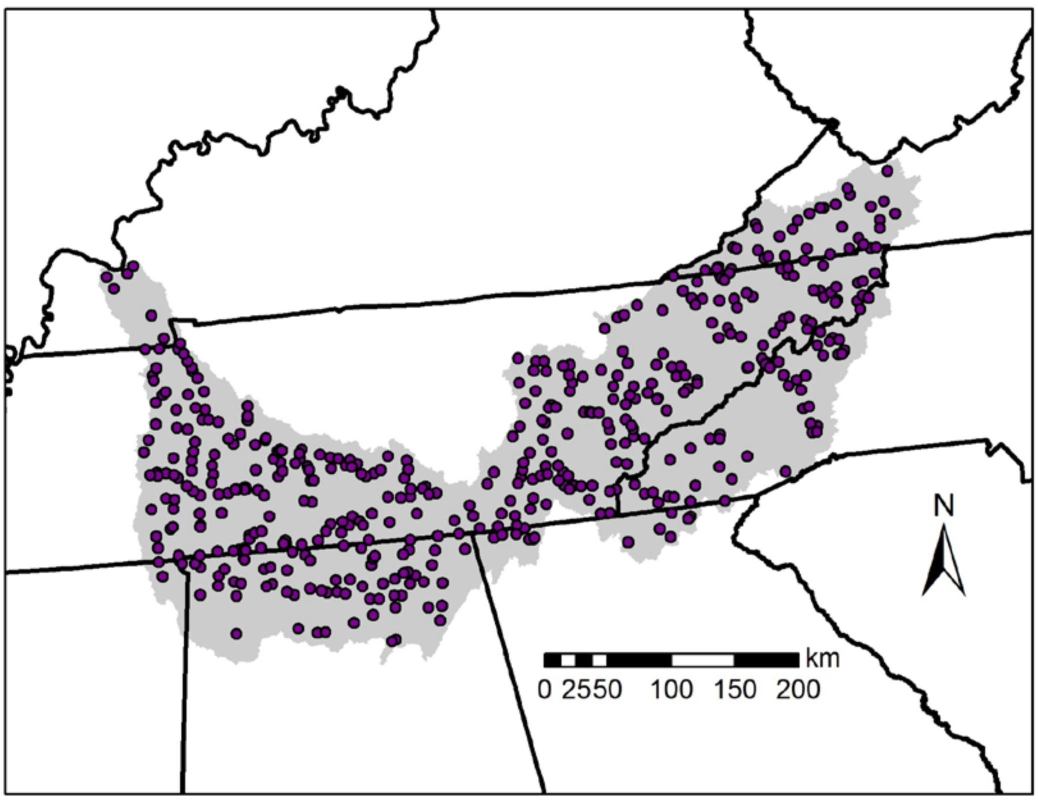


Fig. C2 A plot of observed IBI and EPT scores (Pearson $r = 0.40$). Each dot represents an NHD Plus catchment for which both scores were available.

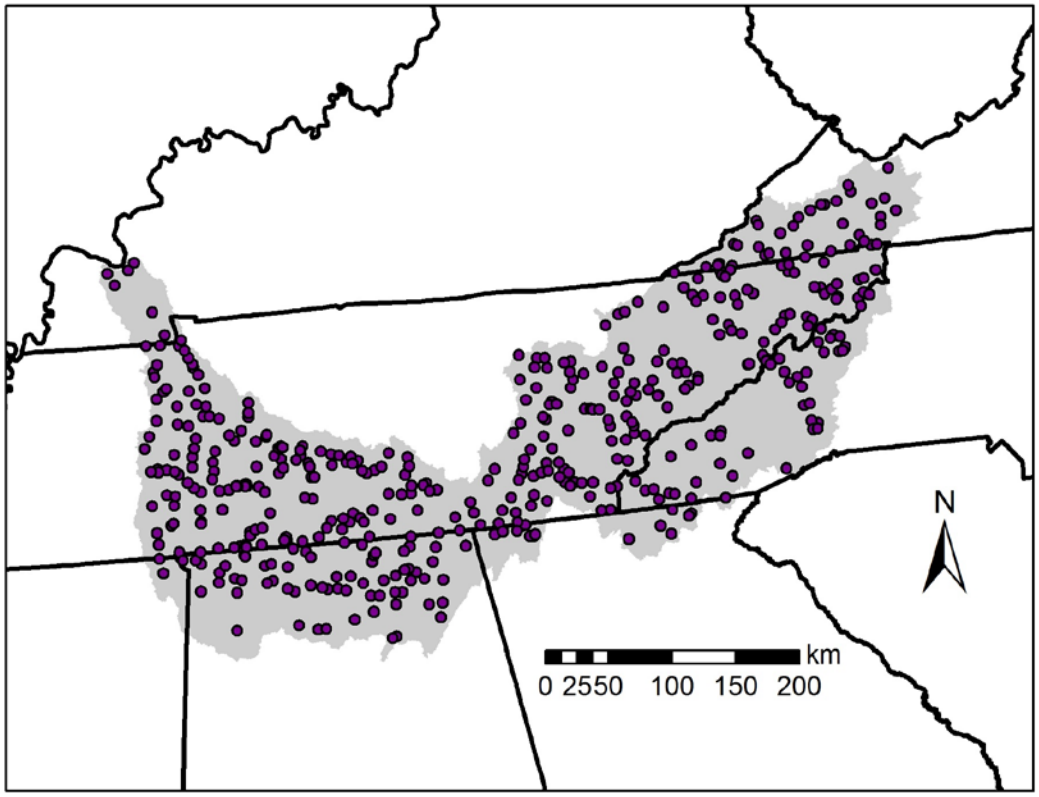
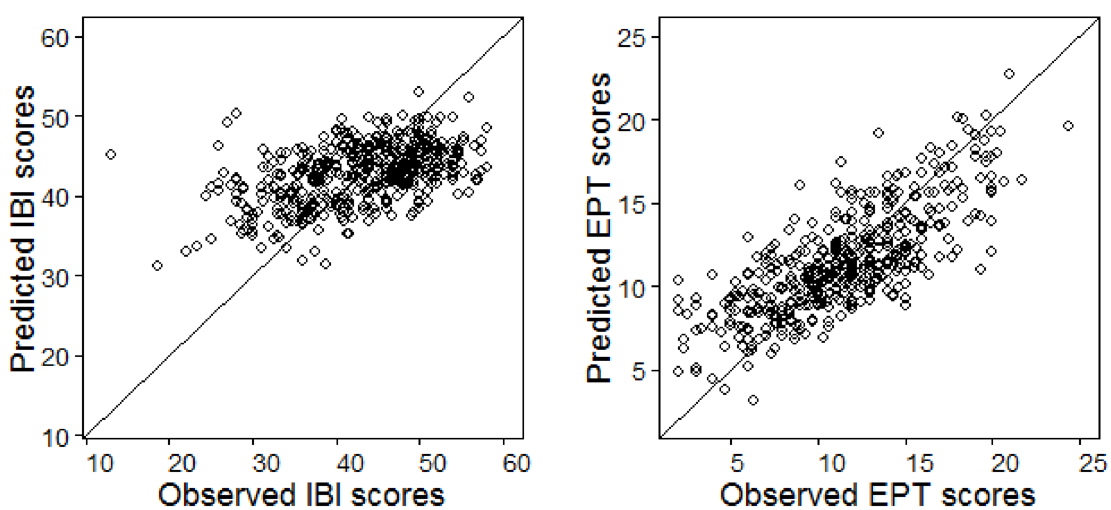


Fig. C3 Relationships between observed and predicted scores in IBI and EPT. Each dot represents an NHD Plus catchment for which biological data are available. Pearson $r = 0.50$ in the IBI plot (left) and 0.76 in the EPT plot (right).



Appendix D. Detailed review of existing methods to map cultural resources and case study for inclusion of cultural resources into landscape conservation design.

Introduction

In addition to history are the contemporary values that people hold for places that contribute to their culture and livelihoods. Together the past and present describe cultural resources across scales, from the local community to the nation. While other attributes of the landscape, such as clean water or biodiversity, may be easier to quantify and map, cultural resources involve more intangible and elusive ideas that are associated with emotional and psychological responses of people to locations and events, such as sense of place or inspiration (Schaich, Bieling, Plieninger, 2010).

Defining cultural resources is an important starting point and provides the scope of what components of the landscape will be considered. Cultural resources have been defined by a number of groups and agencies that protect portions of our national heritage. The National Park Service states that these resources are “physical evidence or place of past human activity” (National Park Service). Sites and buildings are just some of the resources the NPS has been charged with protecting under the National Historic Protection Act of 1966. A number of NPS programs have been created to catalog and protect cultural resources, ranging from objects to landscapes (see notes for list of programs).

Cultural resources have also been defined as “a tangible entity or a cultural practice of a cultural system that is valued by or significantly representative of a culture or that contains significant information about a culture” (Page, Gilbert, & Dolan, 1998). This definition illustrates that beyond historical significance, cultural resources are representative and valued by particular groups. What is considered a cultural resource will vary depending on the perspective of different groups. Importance may be placed on locations, buildings, or structures relative to the interest of stakeholders. This will also differ across scales, from the local to the national level.

Values play a key role in the specification of cultural resources. Values, defined as “a set of positive characteristics or qualities perceived in cultural objects or sites by certain individuals or groups" (de la Torre and Mason, 2002), can be historic, social, or economic. The variety of values and significance that groups associate with different locations, such as scenic or spiritual values, contribute to the difficulty of including cultural resources in conservation planning. Since there is human history and experience in almost all places built and natural, nearly every place may have cultural value (Phillips, 1998). How places and structures are valued will change with different stakeholders, with more or less importance given depending on who is being asked.

Determining a practical method for incorporating cultural resources into conservation planning will require the consideration of cultural values while focusing on measurable attributes of the landscape. In this document we will:

•Review previous work in mapping cultural resources and values
•Propose a framework for classifying cultural resource sites
•Outline an example of how this method may be implemented

The overarching purpose of creating a new framework is to provide a clear and straightforward mechanism for mapping cultural resources across the landscape, avoiding more subjective valuations that differ depending on stakeholder groups. Through mapping these resources, historical and cultural importance can be included in the larger conservation plan and broaden the appeal of conservation efforts.

Approaches to Mapping Cultural Resources

Including cultural resources in conservation planning requires there to be some attribute that can be measured and mapped. Identifying the locations of historic structures or sites only provides information about the geography of the past. The importance of these places is a matter of the values that different groups might hold. These cultural values describe our relationship to the past and how that heritage exists in today's world.

Cultural values also include aspects beyond just historical importance. Features of the landscape can be associated with scenic beauty, sense of place, or recreation. The ranges of values, assigned to parts of the landscape, have been mapped in different ways in an effort to incorporate them into the overall assessment of ecosystems.

In this section we will present some existing approaches to mapping cultural resources and their associated values in the landscape. Techniques have varied from general concepts to data driven assessments based on economic value. Each approach will be described and strengths and weaknesses provided.

Mapping historical sites and structures

Programs focused on historic preservation present a definition of cultural resources as structures and places of significance to the nation's past. The location of these places has been mapped across the county. Typically the inclusion of cultural resources in planning has been limited to those buildings and sites included in the National Register of Historic Sites. This dataset is maintained by the NPS and managed through its Cultural Resource Division.

The National Register program represents sites, structures, and districts that have gone through a process of designation, which includes nomination, research, and documentation of the site's historic importance (National Register, n.d.). The program was initiated after the National Historic Preservation Act in 1966. The NPS continues to digitize information from paper records for the National Register Programs and this dataset is freely available. This process helps ensure that the places included in the Register are of value to the Nation's history and culture.

Spatial data on historic sites is a straightforward means of cataloging places of cultural value. This approach avoids relative values about a site's importance by using a process of designation, but only captures cultural resources deemed of "significance in American history" (National Park Service, 1995). Additionally, the focus on historical sites does overlook more contemporary sites that contribute to the livelihood and culture of an area.

Strengths

•Rigorous process of designation and documentation

•Broad representation of national heritage

Weaknesses

•Scale is at the national level only

•Limited view of cultural resources as historical sites, landscapes, and buildings

•A singular perspective provided by data from one specific program (National Register)

Mapping values in the watershed

During the late 1990's an effort was made to measure and then map the values people attributed to their communities. The focus was on the natural and built environment, the ecosystem health of these neighborhoods, and the linkage between these and quality of life. The value framework used was developed by Stephen Kellert and seeks to detail the relationship between humans and their natural environment. This framework describes the range and strength of values that people may hold toward nature in general, a particular location, or a part of the ecosystem such as a particular species (Kellert, 2012). The typology includes both positive and negative relationships (Table D 1).

Typology of values in nature

Aesthetic	Physical appeal and attraction to nature
Dominionistic	Mastery and control of nature
Humanistic	Emotional attachment to nature
Moralistic	Moral and spiritual relation to nature
Naturalistic	Direct contact with and experience of nature
Negativistic	Fear of and aversion to nature
Scientific	Study and empirical observation of nature
Symbolic	Nature as a source of metaphorical and communicative thought
Utilitarian	Nature as a source of physical and material benefit

Table D1 - Typology of values in nature

The Greater New Haven Watershed Project involved surveying residents within watersheds, resulting in value measurements that can be mapped to the subwatershed level. The subwatersheds corresponded to neighborhoods and were evaluated on ecosystem health, socioeconomic conditions, and quality of life factors. For each neighborhood a graph could be made showing its measure on a variety of items. Areas could then be compared to see the relationship between environmental and social condition.

The study was of a relatively small watershed in Connecticut but involved a large amount of resources to collect both ecological and social data. While it may not be feasible on a larger scale, the results show how a healthy ecosystem contributes to physical features that people value. These landscape features also contribute to benefits that people identify with in the places they live (Figure D1). This place identity is a key factor in the cultural value that sites have for local residents.

The Greater New Haven study was an early precedent that linked environmental and landscape values to a specific geography (subwatersheds). This work also informed future studies of spatially representing environmental and cultural values. The mapping effort documented the more intangible aspects of cultural resources and allows them to be mapped and included in spatial analysis.

Strengths

•Provides a detailed measure of values related to place and environment

•Allows for mapping environmental values, in this case at the watershed level

•Involves local knowledge and interpretation of environmental condition into assessments

•Obtains a robust sample of people in the watershed

Weaknesses

•Resource intensive - requires extensive survey and sampling procedures

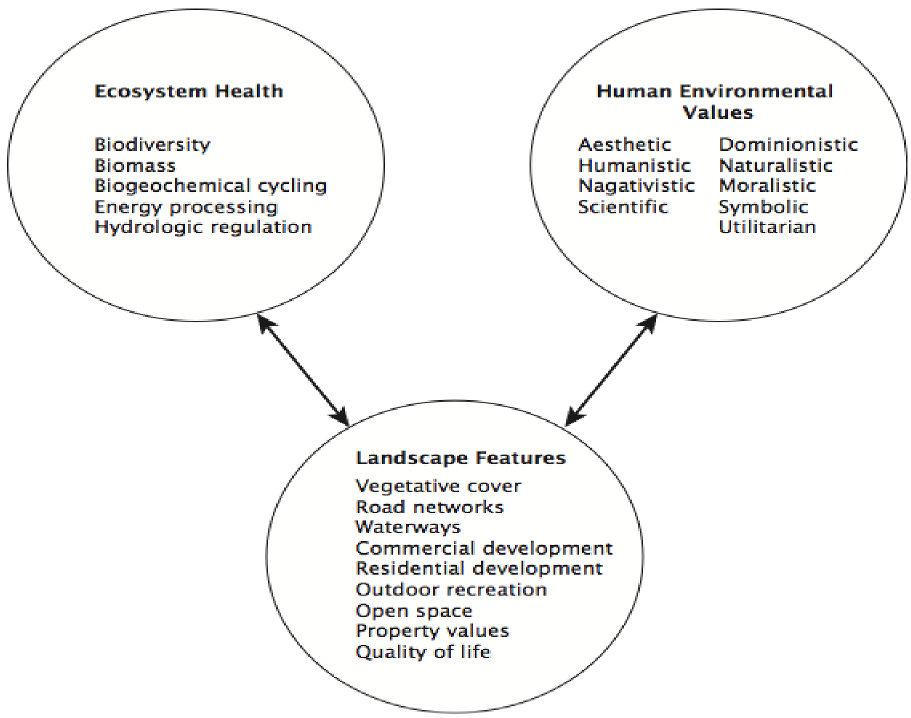


Figure D1. Relationship Framework. Values are not linked to specific cultural resources but instead to a broader landscape

Public Participatory Geographic Information Systems (PPGIS)

PPGIS began in the late 1990's but has seen most of its development since 2000. The main impetus was to incorporate more public participation in land management decision making (Brown and Kyttä, 2014). To augment existing ecological and forestry knowledge managers sought a way to represent the input from public stakeholders in the spatial planning tools they used.

The values that are mapped in PPGIS originate from a framework suggested by Ralston and Coufal that could be integrated into forest planning. These values seek to capture aspects of forest management that were missing from existing multiple use strategies (1991). These are:

1. Life support values - Soils, Water, Natural Processes
2. Economic values - Raw materials, Timber, Utility
3. Scientific values - Knowledge of ecology
4. Recreational values - Consumptive and non-consumptive recreation, Rejuvenation
5. Esthetic values - Sense of the sublime, enjoyment from scenery
6. Wildlife values - Animals of the forest, Concept of wildness
7. Biotic Diversity values - Variety of species
8. Natural history values - Antiquity, Continuity, Identity, Process
9. Spiritual values - Sacred space, Transcendence
10. Intrinsic values - Values of the forest outside of human utility

This set of values has been extended by adding aspects of the landscape such as special places, historic value, or sense of place (Brown & Raymond, 2007). Table D2 includes terms and definitions that have been used in PPGIS studies.

Terms and Definitions

Aesthetic	Scenic qualities
Recreation	Places that provide outdoor recreation opportunities
Economic	Places that provide income and employment opportunities
Wilderness	Wild, uninhabited or relatively untouched by human activity
Biological	Places that provide a variety of plants, wildlife or other living organisms
Heritage	Values placed on maintaining historically important landscapes or species
Future	Places that provide opportunity for future generations to know and
Learning	Places to learn about the natural environment through interpretation and

Intrinsic	Places valuable for their own sake
Therapeutic	Places to feel better physically and/or mentally
Spiritual	Places that are sacred, religious, or special for spiritual reasons
Life-Sustaining	Places that help produce, preserve, or renew air, soil, and water
Social	Areas that provide opportunity for social interaction
Historical/Cultural	Places that represent history or that allow for passing on of tradition and way of life
Marine	Places that support marine life
Subsistence	Places that provide resources or food for people
Special Places	Places special to the individual
Family Connection	Places important to maintaining family connections
Sense of Place	Connection that people feel with recognized feature of the environment
Cultural Diversity	The role that ecosystems play in enhancing cultural diversity
Community	People's role in schools, fire-fighting, land stewardship and forming sense
Economic viability	Concern for income and employment security

Table D2. (Brown, 2004; MEA, 2005; Brown, 2009; Brown & Raymond, 2010; Brown & Weber, 2012; Brown & Brabyn, 2012; Lowery & Morse, 2013; Brown, 2013)

PPGIS uses techniques that solicit stakeholder input to map a variety of values within a defined geographic area. The method has been used in scenarios from national forest planning (Brown, 2009) to assessing sense of place (Brown & Raymond, 2007). The process typically asks participants to place dots or markers on locations that they associate with a given set of values. The dots are then analyzed with GIS software to produce maps of density for each of the values assessed.

In some more recent use, participants have been asked to instead draw polygons or areas that they associate with values such as recreation. These maps consist of many overlapping polygons revealing areas of intensity for landscape values (Lowery & Morse, 2014).

Participants in PPGIS studies can be sought via traditional survey methods like paper or electronic mailings. Additional input can also be received from internet mapping applications built specifically for PPGIS (Fig. D2). Links to this type of interface can be passed along via other communication routes. The sample size is typically an issue with these studies. While mail surveys can be targeted to a broad population, response rates have been low, reducing the ability to draw general conclusions from the data. With internet-based surveys it is difficult to know who exactly is participating. This uncertain sample means that it is difficult to say if the results are representative or the views of a particular group.

There have been some larger scale projects that have involved PPGIS and these highlight other challenges related to how people view large landscapes. Data from a study in New Zealand indicated that the results were skewed towards people placing more values close to where they lived, following the theory of spatial discounting that suggests a higher number of positive values near a person's home (Hannon, 1994; Brown, Reed, & Harris, 2002). Similar research has indicated that people do not think on a regional or ecoregional scale, but have a better concept of their local area (Ardoin, 2009). This outcome lessens the ability of PPGIS to be used to assess large, multi-state regions such as Appalachia.

The PPGIS approach refines the location of cultural values that people hold to specific places. Through the mapping process particular values can be identified with distinct locations in the landscape, though the question of whose values they are might remain. PPGIS provides a means of spatially identifying cultural information and adding this into the planning process.

Strengths

- Allows stakeholders to participate in value assignments
- Can capture specific values at specific places
- Enriches planning through additional information provided by the public and the inclusion of local knowledge

Weaknesses

- Scale is an issue. Theory of spatial discounting - people will associate greater value closer to where they live
- Difficult to assign multiple values to same place
- Values are defined in survey and may not capture unique cultural perspectives
- Values may not be as specific as a single data point, intention of respondent may be unclear

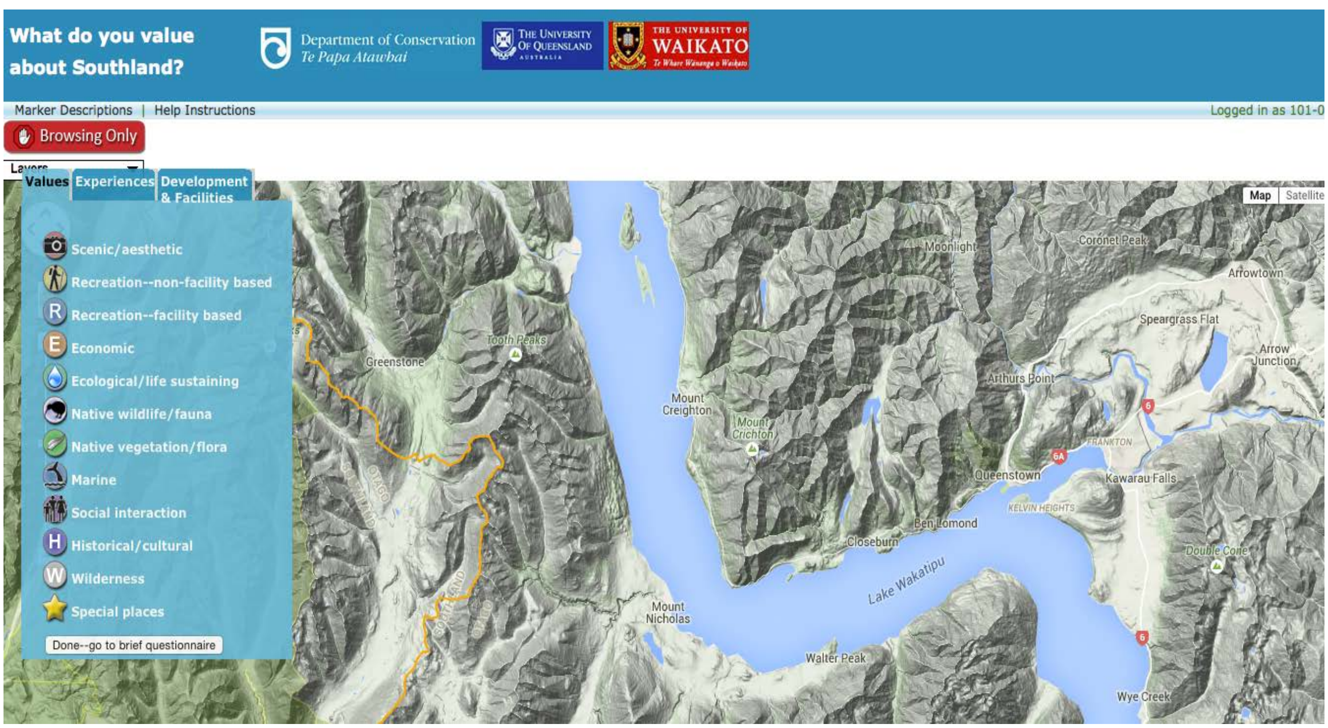


Figure D2 - Internet based mapping interface

Economic Valuation Mapping

Efforts at mapping the benefits of cultural resources have also used methods based on assigning monetary value to places. Economic value is seen as a substitute for the non-market or intangible values people hold for their environment. Work at placing economic value on cultural resources has typically focused on those aspects that can be assessed through traditional measures of economic impact, such as tourism and recreation. This can be done through techniques such as contingent valuation and travel cost.

Contingent valuation (CV) is a method that attempts to assign monetary value to the environment amenities. The premise is to determine the benefits and costs associated with certain actions based on the preferences of the individual. This method directly asks what a person would be willing to pay for an environmental good or service based on a given scenario. Willingness to pay asks respondents what would be an acceptable amount to pay to protect certain resources. This type of surveying seeks to identify preferences that people hold for certain places or resources (Arrow et al., 1993; de Groot, Wilson, & Bouman, 2002).

Contingent valuation has been used in a number of surveys and legal proceedings but is heavily criticized (Chee, 2004). There are issues of bias based on how the survey is constructed, whether values are open-ended, and how people react to hypothetical scenarios (Hanemann, 1994). Despite its shortcoming, the CV method has been employed in assessing the value of environmental features and determining damages from environmental accidents.

Travel cost is a method for determining value of recreation and tourism sites based on the cost associated with visiting those sites. In a recreation example this method would account for costs such as travel, equipment, licenses, etc. Travel costs are subject to the judgment of those doing the analysis as some boundary must be set for what to include.

Using travel cost can distort the value of places as sites close to population centers will be visited more, increasing the total monetary value. The method is less suited to sites that are less frequently visited, like wilderness, or less tangible characteristics of the landscape, such a scenic or livelihood values (Chee, 2004).

With contingent value and travel cost an economic number can be assigned to sites of environmental or cultural value. These monetary amounts can be mapped to sites, summarized and even transferred to other, similar locations to assess value where data is limited (Troy and Wilson, 2006).

Economic valuation can provide a measurable assessment to places that cannot easily be valued by typical policy tools. While the amounts determined are considered to be objective, the idea of placing a price on history or culture is controversial, especially when the resource is not replaceable. This method is also more applicable to smaller scale studies where respondents have knowledge to be able to make specific value judgments.

Strengths

- Can assign economic value to places of environmental or cultural importance
- Fits into traditional economic thinking and planning practices

Weaknesses

- Results can be varied depending on method and quality of surveying
- Assigning a monetary number to intangible attributes is controversial

Social Indicators

Local culture can also be viewed through the social condition of a place. Cultural resources, like other ecosystem benefits, can contribute to the well-being of residents in an area. A method of measuring and mapping well-being is through the use of social indicators. Demographic, health, cultural, or political data can be determined for populations and mapped, providing information for conservation planning efforts (Stephanson & Mascia, 2014). More recently a number of indexes have been developed that include cultural measures such as number of protected sites, number of cultural organizations, or creative businesses (i.e. WNC Vitality Index). While these include cultural aspects in the overall evaluation of a region, the items measured typically are indicative of cultural offerings or events and less associated with the traditional definition of cultural resources.

In measuring the human side of ecosystems social indicators can describe the contemporary state, accounting for aspects of society that interact with and impact natural systems. This is one part of how people relate to their environment, but does not provide a measure of the values people hold about place. In attempting to include cultural resources in conservation planning, and be of interest to a broad audience, both present and past values need to be incorporated.

Strengths

• Includes the social condition in conservation planning

• Captures current state of the human component of ecosystems

Weaknesses

• Focused more on outcomes of economic, education, or health policy

• Doesn't capture intangible values that might lie outside of already designated cultural sites

By trying to represent the views people hold about places, these approaches to mapping cultural resources and values illustrate the difficulty of including values in planning. Some methods try to capture an objective measure of values, while others lean more on public participation to describe the amount significance held for the landscape. Components of these techniques can be applied to specific sites or to more general areas, resulting in varying amounts of each characteristic (i.e. high utilitarian value and low aesthetic). Each method has its strengths and weaknesses that can help inform an approach that could be effectively applied on a regional scale.

Case Study Example

To illustrate how this framework might be implemented, a cultural resource layer was created for the area around Chattanooga, TN. This city lies within the Tennessee River Basin and has a number of significant historical and cultural sites (Map 1).

Sources		**Data**
Tennessee GIS Data Server	tngis.org	Background data for state
University of Tennessee at Chattanooga	geoportal.utc.edu	Infrastructure, Recreation, Open Space
The Commission for Environmental Cooperation	www.cec.org	Terrestrial Protected Lands
ESRI		Cultural data
The Nature Conservancy	www.tnclands.tnc.org	Conserved lands
Land Trust for Tennessee	landtrusttn.org	Land Trust properties
National Conservation Easement Database	conservationeasement.us	Conservation Easements
National Park Service	irma.nps.gov	National Register, National Parks
USGS	gapanalysis.usgs.gov/padus/	PAD-US

Table D3 - Data Sources

Process

The process for compiling this dataset included:

- Search for data (Table D3)

- Check quality
- Clean and organize
- Classify
- Combine
- Produce outputs

In this case all data was found in available and accessible datasets. Across the LCC there may be more searching or creation of datasets required to reach consistency of data at each classification level.

In this example all lands that serve cultural resource functions are identified in the Chattanooga area (Map 3). These are classified according to the framework outlined above. To translate the amount of cultural resources across the area, sites are aggregated to a 5km hexagon grid through an additive procedure. Some alternative methods are presented that can represent the data:

- Raw number - additive, sum up number of sites
- Absence/Presence - 0,1
- Weighted sum based on classification (Map 4)
  - Inverse weighting - 1 – 0.2
- Cultural Resource Diversity Index - based on Simpson’s Index of Diversity

Issues

The accuracy of datasets varied with some containing more detail than others. Additionally, there were features repeated between some datasets. These required cleaning to avoid double counting features in the aggregation. Coverage of sites that serve cultural functions was adequate across the study area. The community level (5) was the least represented in the data. In future use this level may require more investigation to identify additional features.

Data Gaps

This example showed that there are gaps at the county level, particularly with historical sites. This data may be found with State level historical sites if they are obtained in the future. Additional data may be found through listings, such as spiritual retreats, music festivals, or farmers markets. This case illustrates that even state level data may include gaps. For example, there were many broken links for data from the TN Department of Environment. While this data was found elsewhere, this may not always be the case. Necessary datasets most likely exist within organizations but would require inquiry to obtain. Across the LCC states it is possible that there will be inconsistent availability of data that will require communication with the appropriate agencies.

Possible Input Dataset Sources

NPS

National Register of Historic Sites (Needs attention)

USGS, USFS, FWS

Landscape data, Protected areas

States

State departments of natural resources, environment, etc.

State Offices of Historic Preservation (data not easily available)

State Historical Sites

Counties

Parks, historical sites

(Many counties have GIS data, not always freely available)

NGO/Nonprofit

National Conservation Easement Database

Trust for Public Land

The Nature Conservancy

Land Trusts

National Trust for Historic Preservation

(Determining which lands are protected for cultural, rather than solely ecological, reasons may be fuzzy)

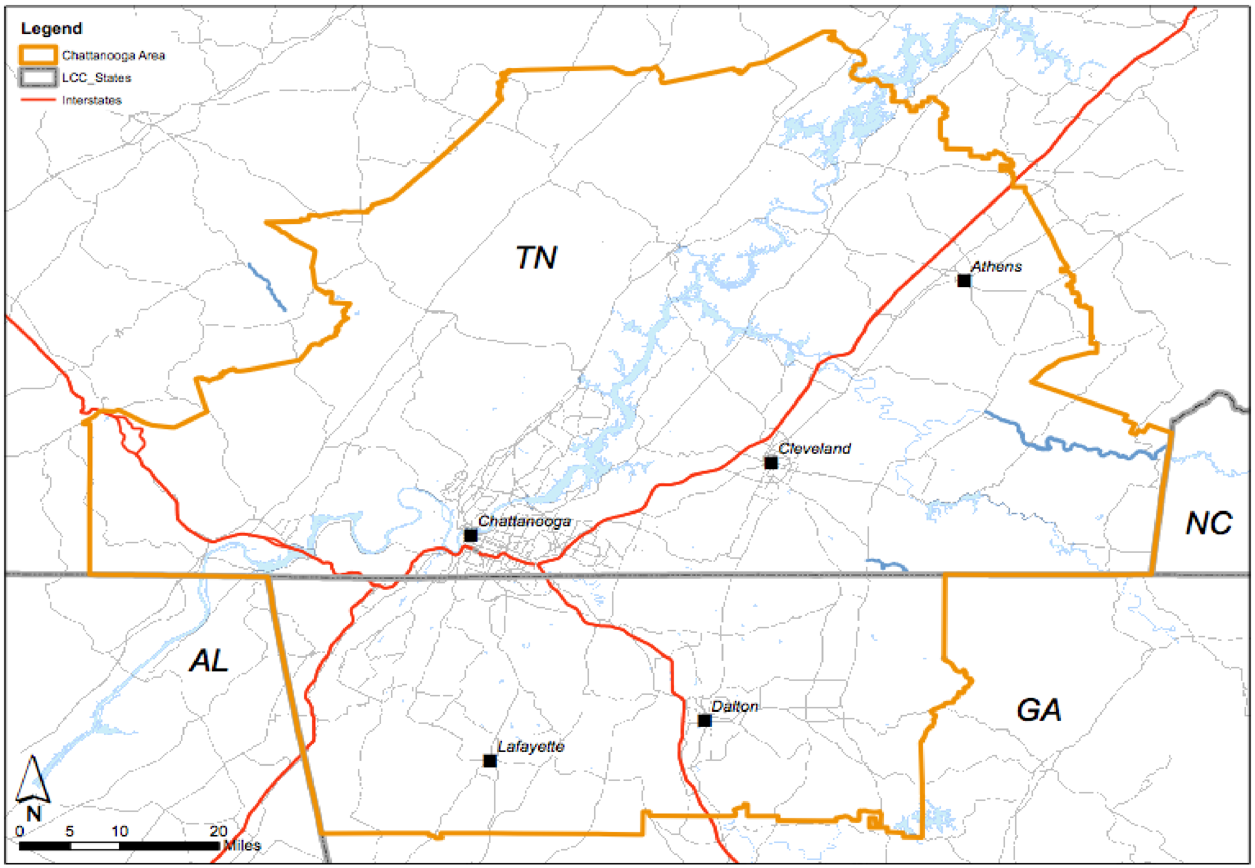
ESRI

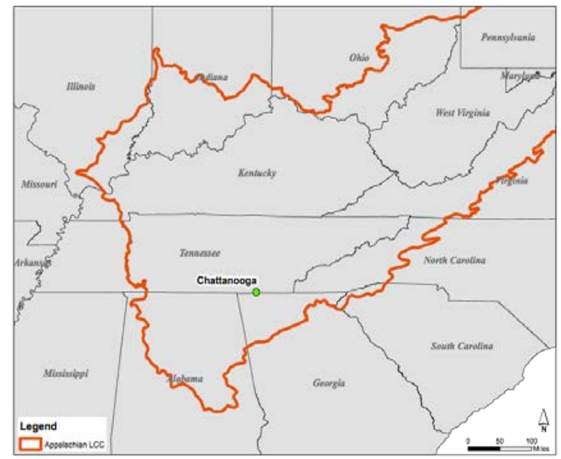
Parks and cultural sites (recreation, cemeteries, etc.) are available for US

(Licensing issues for use in planning? This would need verification)

Map 1.

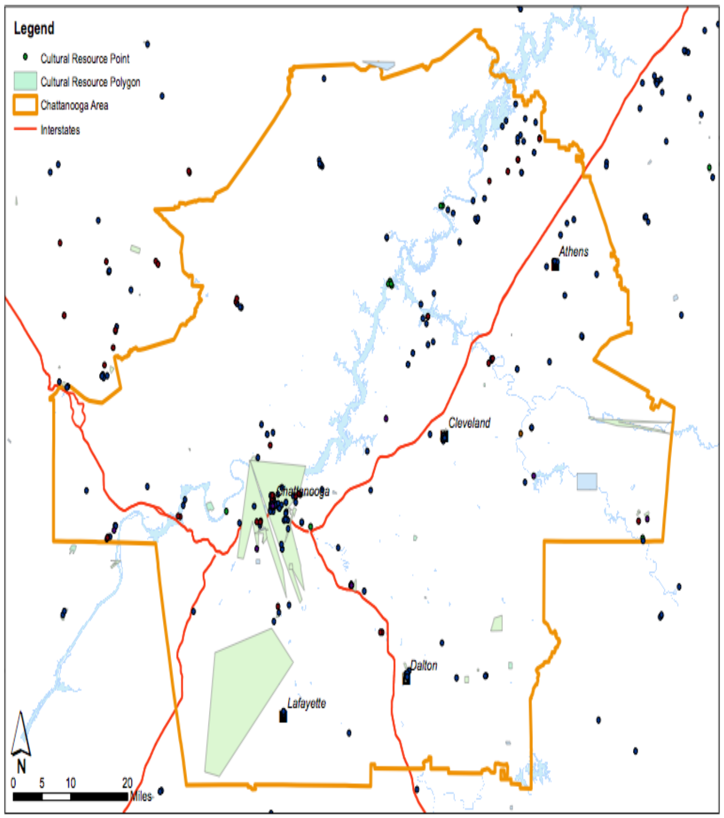
Chattanooga Area – locator

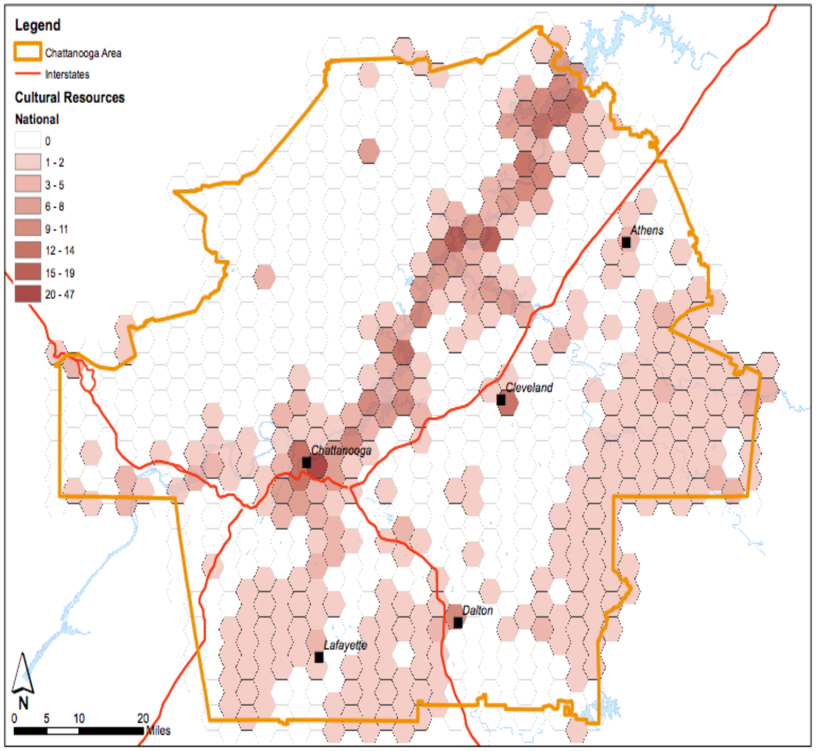




Map 2. Data from National Register of Historic Sites

Only National category data aggregated to hexagonal grid (5km)





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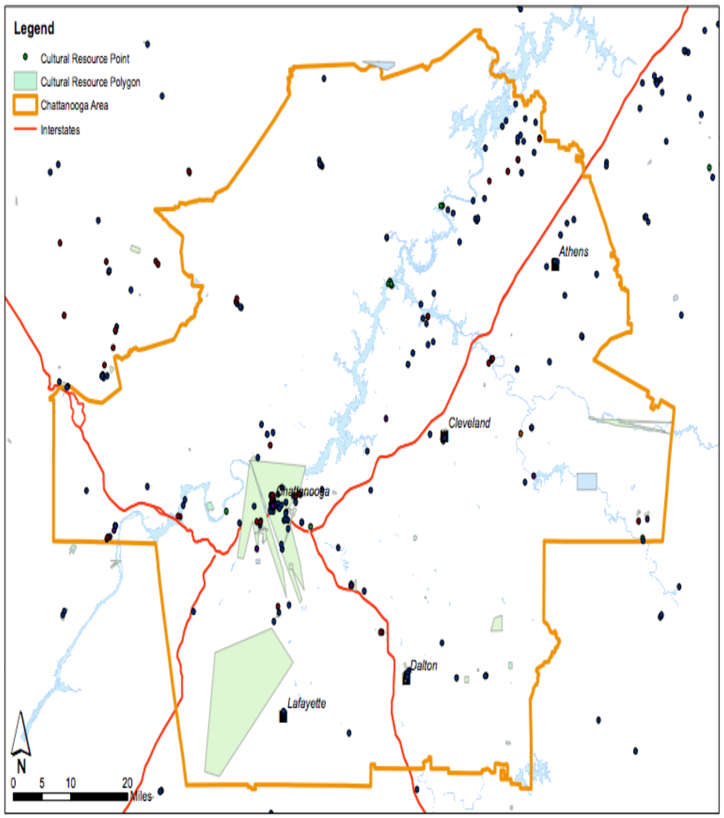
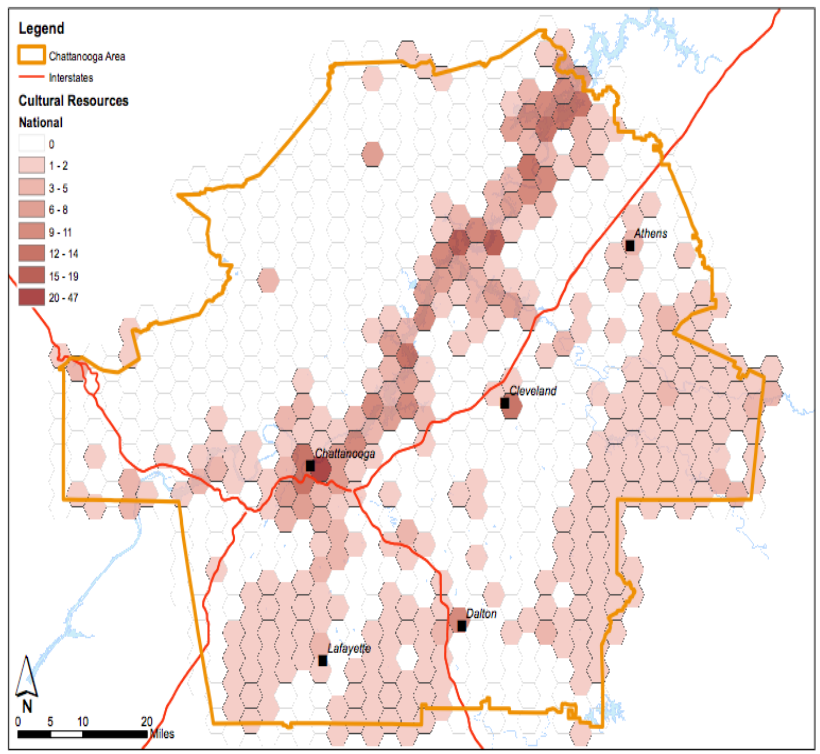
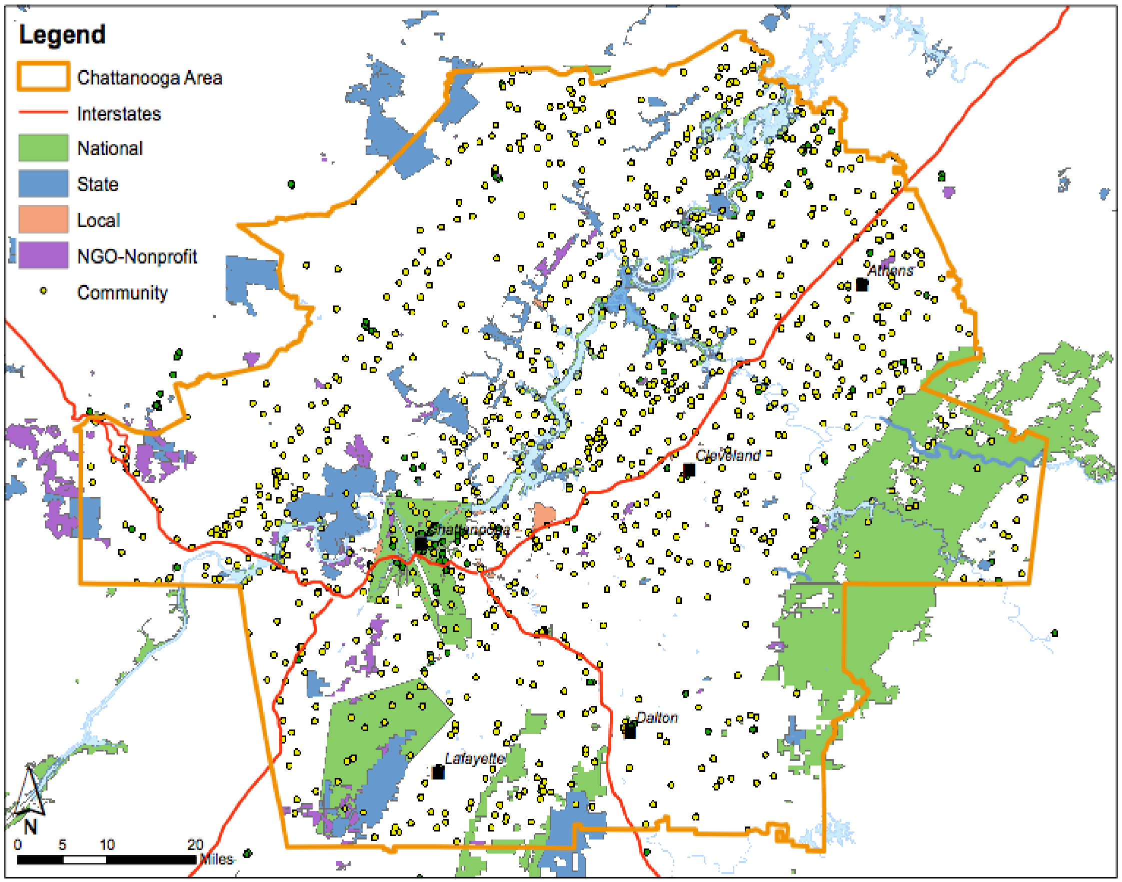
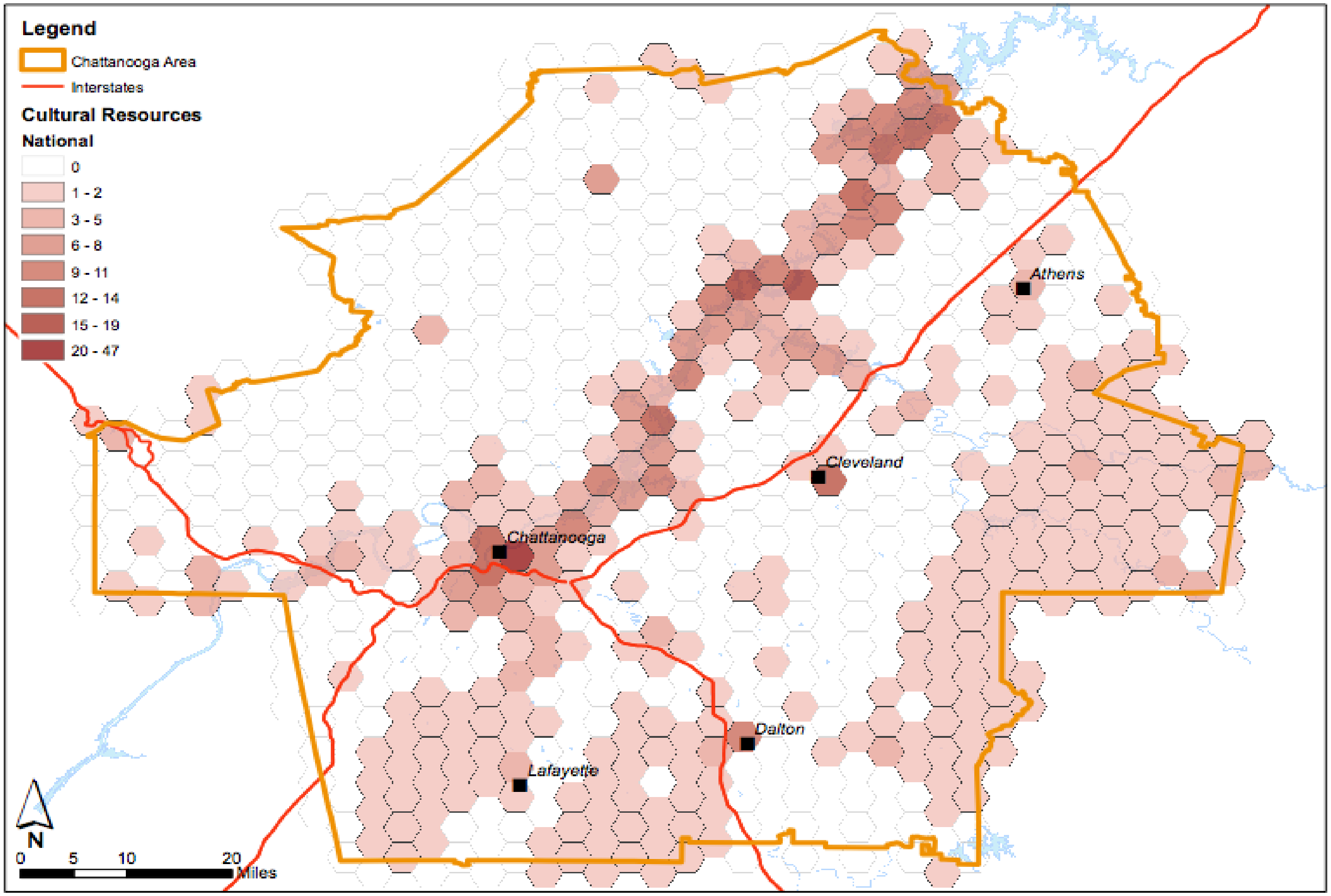




Map 3. All cultural sites identified for area of interested. Classified according to proposed framework.



Map 4. Cultural resources aggregated to a hexagonal grid based on weighted sum. Cultural resources aggregated to hexagonal grid (5km). Cultural resource features per cell are a weighted sum based on: ∑ *(1/Class x number of features)*. A higher value would indicate a greater amount of cultural resources.



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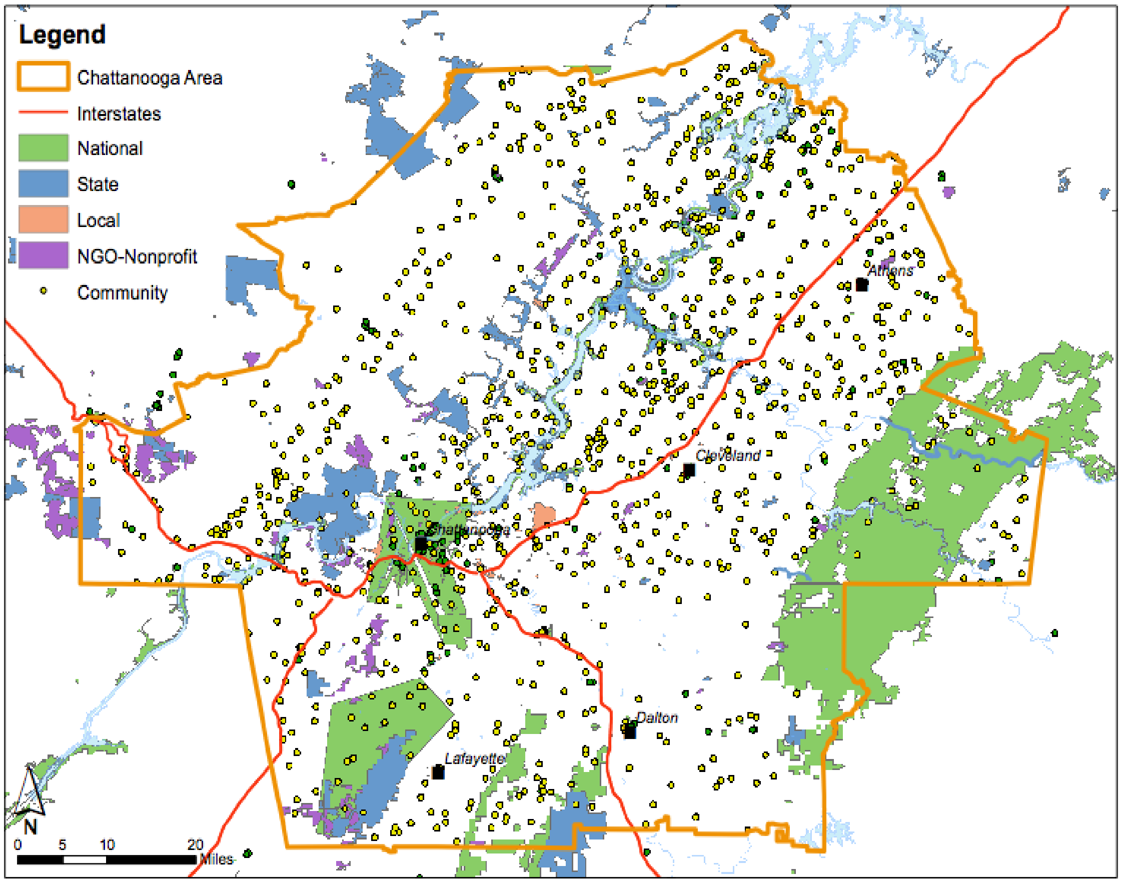

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