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PAPER

Building an inclusive conservation vision founded upon ecological values and social opportunities

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Abstract

We developed a spatially explicit model for the eastern United States to help identify where we work to conserve a network of ecologically important lands with the input of communities often excluded from conservation planning. We built multiple individual and composite maps from ecological data selected from four broad themes: ecological integrity, connectivity, biodiversity, and ecosystem services. Datasets selected from these themes identify lands important for a conservation network resilient to global change stressors that provide important functions upon which people depend. We also built multiple individual and composite maps using spatial data from existing efforts to measure social conditions constructed around three broad themes: frontline communities, historically marginalized populations, and people who experience the impacts of climate change most accurately. We view these areas as having high social opportunity through improvement of the environmental conditions experienced by these communities. We also hope to engage a greater representation of values, experience, and knowledge held by communities not typically part of conservation planning. We assert that these aims can only be achieved by amplifying excluded community voice and leadership when developing approaches to conservation. This spatially explicit social-ecological model is comparable to models we have built to facilitate development of various collaboratives and initiatives in our place-based work. This is a type of decision support tool, not a decision maker. We present a broad spatial summary of three conditions: 1) co-occurring high social opportunity and nationally significant ecological value, 2) areas of high social opportunity, and 3) areas of high ecological value. These analyses are presented as a foundation for large scale and collaborative conservation planning that seeks to conserve key ecological areas while addressing the needs of a broader spectrum of people. We envision regional conservation efforts that support collective ecological and social well-being. Our framework and data can also be rescaled to smaller extents to identify projects where social and ecological well-being might intersect in local areas. While our combined spatial data synthesizes myriad information, our collection of the individual criteria can serve as a geospatial library of resources available to regional and local conservation efforts. While we intend for this work to guide conservation strategies including land protection, land management, and land stewardship initiatives in conjunction with social initiatives, this work is a tool and not itself a method or blueprint for the challenging work ahead.

1. Introduction

The Eastern Program of The Wilderness Society works throughout the eastern region on a variety of land protection, management, and stewardship projects with NGO, land trust, outdoor recreation club, university, general public, state, federal and tribal partners. We seek to build and implement an inclusive national vision for a connected network of lands and waters that will sustain biological diversity and human communities under increasing global change stressors not unlike the efforts undertaken by Appalachian Trail Landscape Partnership (ATLP) (Hegedus 2021, Appalachian Landscape Climate Advisory Group 2022). Advancement of conservation goals comes in many forms and uses different tools including participation in administrative planning processes with federal and state agencies, collaborating with land trusts on conservation purchases, outdoor recreation access, and establishment of community forests. These initiatives may include state, federal, and private funding authorization, state and federal policy setting, and legal efforts all concerned with improved management of existing conserved lands, the establishment of new conservation lands and ensuring equitable public access to lands. We seek to people who have historically been ignored by conservation organizations. More direct work with tribal and Black, Indigenous, or People of Color (BIPOC) partners to represent their needs in various conservation initiatives is ongoing.

The Eastern United States (hereafter the 'Eastern Region') is a globally significant region for conserving biological diversity, ecosystem carbon absorption and storage, and drinking water for human communities (Jung *et al* 2021). The Eastern region is also a place of complex colonial beginnings of the United States spanning from the 1500s to the early 1900s (Beckles 1997). This history includes the lasting scars of indigenous removal, the seat of slavery and rapid exploitative economic growth in early America. This foundational history is embedded in the land, policies and social dynamics of the United States. Subsequently it is also embedded in approaches to conservation efforts which, like society at large, often fail to acknowledge this present-day legacy of human history and experience. Acknowledging and addressing these past and ongoing injustices is overdue and has the potential to build a stronger mutually beneficial environmental and social movement. We set out to understand where the interests of nature and people of the eastern region of the United States potentially overlap and could contribute to a connected network of native landscape cover and connected, interdependent human communities across the Eastern Region.

Multiple recent assessments have identified Eastern North America as a region critical for maintaining biodiversity at a continental scale especially as the climate changes. Lawler *et al* (2013) modeled routes of nearly 3,000 species of mammals, birds, and amphibians across the western hemisphere and identified Eastern North America as a critical region for species (see figure 1). This analysis was used as the basis for the widely shared 'Migrations in Motion' animated map. Carroll *et al* (2017) and Parks *et al* (2020) examined the geographic displacement that multivariate climate analogs may experience and identified pathways organisms may need to take to track shifts in climate. Similar to Lawler *et al* (2013), Carroll *et al* (2017) and Parks *et al* (2020) also found that Eastern North America, specifically the Appalachian Mountains, constitutes a critical region for maintaining continental connectivity in the face of climate change. Other connectivity maps from Barnett and Belote(2021), Belote *et al* (2022), Anderson *et al* (2023) have all identified Eastern North America as a critical region for connecting natural or protected areas (see figure 1). Similarly, McKinley *et al* (2019) identified the nationally significant biodiversity of the eastern forest landscape of the National Scenic Appalachian Trail. McKinley *et al* (2017) placed their analyses of conservation priorities in the context of the vision that the Appalachian Trail founder, Benton MacKaye, had for a conserved natural landscape for all people's benefit spanning the entire eastern forest (MacKaye 1921).

Conserving and restoring ecological connectivity may benefit from such a large landscape and aspirational vision that inspires and motivates affiliated human communities (Hebblewhite *et al* 2022). For instance, in the 1.3 million km^2 region between Yellowstone National Park and the Yukon Territory, the Yellowstone-to-Yukon (Y2Y) initiative and regional vision has led to significantly more conservation funding and actions. Holterman *et al* (2023) present an updated agenda for the Y2Y initiative in their call for incorporation of social science and human value-based discussions alongside models of ecological priorities. Given the growing studies that have identified Eastern North America as critical for ecological connectivity, we recommend the region be considered as another continental region for conservation, like Y2Y.

Our Eastern Program works within local, regional, and national collaborative efforts from the Carolinas to Maine including the ATLP. The ATLP seeks to unite the conservation and land stewardship practices of Land Trusts, conservation and research NGO's, Federal and State agencies, tribal partners, BIPOC communities, and local municipalities under a vision for an intact eastern forest landscape (Appalachian Landscape Climate Advisory Group 2022). For its national level spatial prioritization, the ATLP has adopted a decision support tool founded upon ecological and social values modeled after one we developed in conjunction with the Maine Appalachian Trail Land Trust to inform and promote conservation efforts across Maine's northern forest landscape (McKinley and Rucker 2020). Our work also includes several efforts that

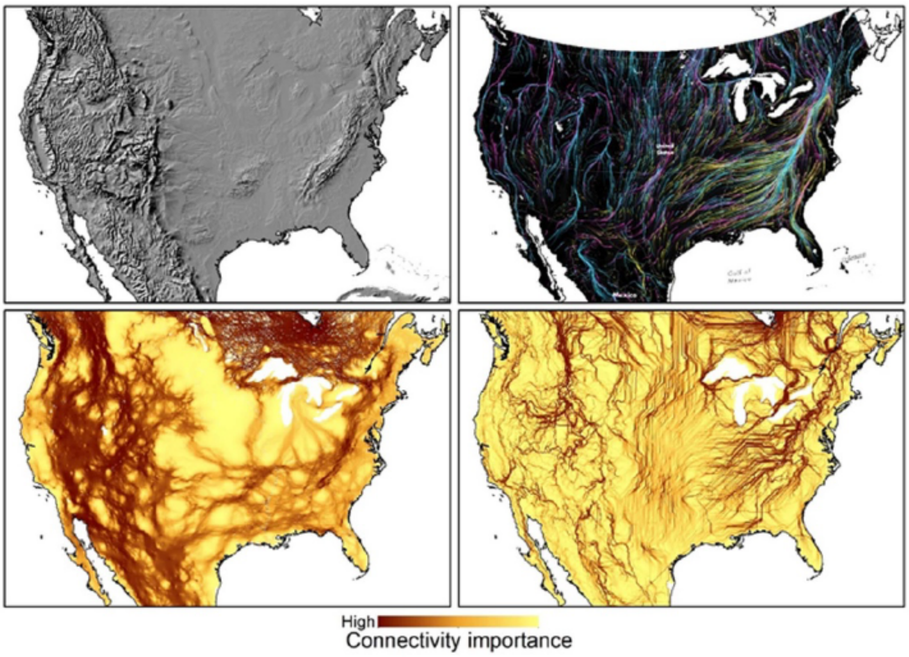

Figure 1. Multiple maps of continental connectivity point to Eastern North America and other mountainous regions as areas of high importance. The upper-left panel shows a shaded relief map from Natural Earth to highlight topography. The upper-right panel shows a georeferenced screenshot from the animated 'Migrations in Motion' map produced by The Nature Conservancy based on predicted movements of nearly 3000 species of birds, mammals, and amphibians based on Lawler *et al* (2013) (concentrated lines indicated areas important for connectivity to sustain species under a changing climate). The lower-left panel shows a composited model of connectivity between large and highly-protected conservation areas based on Barnett and Belote(2021). The lower-right panel shows concentrations of potential pathways of 'climate analogs' from Carroll *et al* (2018).

span the US—Canadian border into Quebec and the Maritime Provinces including the Staying Connected Initiative and previous work with two countries one forest. In this paper we chose to take advantage of the ecological and social datasets readily available for the U.S. though our northeastern regional work includes transborder connectivity modeling ecological data.

Such large landscape conservation requires coordinated action, rigorous science, and—perhaps most importantly—a commitment to including diverse people in the planning and implementation of conservation actions (Belote *et al* 2021a). Conservation-planning efforts are typically conducted without consideration for environmental justice (Ban *et al* 2013, Lechner *et al* 2014, Stephanson and Mascia 2014). However, datasets on social conditions that can help build comprehensive spatial decision support tools are available and conservation organizations increasingly aspire to bring these data and excluded communities to conservation planning.

In addition to benefitting from a large landscape aspirational vision, conservation efforts can benefit from perspectives of the communities who were not included in early conservation ideology, thus advancing conservation through a deepening connection with social justice. If we acknowledge that colonialism has impacted and continues to impact both people and environment, then working with the communities most impacted by colonialism will support understanding of how to repair the harm it has caused. Communities of color including those in urban areas can have a strong cultural tradition of close ties to nature (Pinckney 2024) and might prioritize conservation in ways that traditional conservation approaches typically overlook, including ensuring that conservation approaches will limit harm to surrounding and related communities. These community led efforts could include conservation solutions complementary to traditional strategies of establishing protected areas such as policies and initiatives that improve community agency over the lands and resources they live alongside. These community centered approaches have been implemented in other regions around the planet (Fariss *et al* 2023) and are recognized in targets 3 and 22 of the Global Biodiversity Framework (Armitage 2020). Targets, intentions, and pleas to address the biodiversity extinction crisis have not been sufficient to stop the crisis and we do not anticipate that social injustice will be any easier to fix. Perhaps though, the starting point for working on both is to work on them simultaneously in community led initiatives that have ecological and social environmental values delineated up front.

Examples of conservation solutions led by communities that our group of conservation practitioners have intersected with include the creation of community managed protected areas (Cherokee One Feather 2024) and joint advocacy to eliminate point sources of environmental damage which may also overlap with negative community health impacts (Tran *et al* 2023). Approaches uplifted by communities might also include traditional practices that help to strengthen a sense of connection among and between community and the natural world (Henion 2019) or policy implementation that advances community views and authority (Native News Online 2024). Communities highlighted in our model often experience greater magnitudes of environmental injustice and climate impacts more frequently (Taylor 2016) and therefore are uniquely equipped to identify stewardship and management needs based on personal experience. As we reference community led conservation solutions throughout this paper, it is with the understanding that these solutions may not take the shape that the conservation movement is most familiar with, and these new ways of approaching environmental conservation is something to welcome as we engage with historically excluded and frontline communities.

Centering the perspective and approaches of those who have been excluded from the conversations that formed the early conservation movement, as well as those who are most significantly impacted by environmental decline will positively inform approaches. One example includes the conservation community's recent recognition that indigenous land management practices and traditions support biodiversity (IPBES 2019). This has led to greater emphasis of indigenous led conservation and support for Tribal land rematriation (Artelle *et al* 2019). Application of strategies which champion indigenous knowledge and land management can benefit the conservation community's progress towards addressing the biodiversity crisis and can contribute to the aspirational vision of a large, connected landscape.

We set out to identify the ecological features and processes necessary for an eastern network of conservation lands and the social conditions of people who have not typically had a voice in land conservation and management. Such communities stand to benefit from greater representation in large scale conservation management and planning exercises such as the protection and stewardship of an eastern-wide conservation network. These communities might therefore be strong natural allies for the realization of this vision. To identify critical elements of biodiversity and ecological processes upon which people depend, we selected datasets to represent the following four themes: 1) ecological integrity, 2) connectivity across a network of sites, 3) representation of various levels of biodiversity (ecosystems and species), and 4) critical ecosystem services. To ensure that efforts are conducted in communities that have been overlooked or otherwise experience environmental injustices, we selected datasets that report on the following 3 themes: 1) aspects of frontline communities, 2) aspects of communities that have been historically marginalized, and 3) the communities that may be most vulnerable to a changing climate. We analyzed these data as follows,(1) conducted a multi-criteria spatial assessment focused on ecological principles and datasets, (2) similarly evaluated social conditions, and (3) overlaid our ecological and social assessments to identify places where (1) high ecological value that contributes to a large-scale conservation network co-occurs with high opportunity to address environmental injustices and (2) where areas of high ecological value and high social importance occur independently. We do not intend our findings to be prescriptive as they are not a complete decision analysis but rather to serve as a decision support tool (Hemming *et al* 2022). We hope this work can serve as a resource to ensure conservation is planned in the most important places for sustaining nature in a way that additionally centers people historically excluded from conservation plans.

2. Methods

2.1. Delineating the region and selection of the measures

We identified and delineated the eastern region as an organizational planning boundary that captures the breadth of ecological and social conditions of the eastern landscape. At its core, the region includes the Appalachian Mountains and extends across the piedmont and coastal plains along the Atlantic Ocean, south to the Everglades and Florida Bay, and back up along the Gulf of Mexico west to the Mississippi and Ohio Rivers. Its extent was intended to capture biological, physical, and social conditions present in the eastern United States with an arbitrary Midwestern cut-off that follows a combination of major waterways, watersheds, and level IV U.S. E.P.A. ecoregional boundaries (Omernik 1987). Our intention was to delineate a tractable unit with some semblance of biological, physical and social identity.

2.2. Ecological assessment

We used 16 spatial datasets drawn from four ecological themes: ecological integrity, ecological connectivity, biodiversity, and ecosystem services (see table 1). We organized them by theme to help us identify and include the broad classes of elements needed for a well-connected, ecologically representative, and ecologically functional conservation network. Our work is designed to inform not dictate the work at hand and we encourage simultaneous inspection of the small multiple maps alongside the composites to understand the roles of scale and regional dynamics.

Table 1. Ecological condition datasets by theme.

Theme	Indicator data set	Original resolution	Citation
Ecological integrity	Permeability	270 m	Unpublished
	Carnivore community intactness	100 km	Belote *et al* 2020
	Naturalness (inverse of human footprint)	1 km	Theobald (2013)
Ecological connectivity	Backward climate velocity	1 km	Carroll *et al* (2015)
	Forward climate velocity	1 km	Carroll *et al* (2015)
	Corridors among protected areas	1 km	Belote *et al* (2016)
	Omniscape connectivity	1 km	Belote *et al* (2022)
	TNC regional connectivity	90 m	Anderson *et al* (2023)
Biodiversity	Biodiversity priority Clinton index	1 km	Jenkins *et al* (2015)
	Biodiversity importance NatureServe	290 m	Hamilton *et al* (2022)
	Biodiversity complementarity	5 km	Belote *et al* (2021b)
	Ecosystem representation	30 m	Belote *et al* (2017)
	Species of conservation concern (richness)	1 km	Dietz *et al* (2020)
Ecosystem Services	Drinking water Forests to Faucets	1 km	Mack *et al* (2022)
	Carbon sequestration	1 km	Liu *et al* (2020)
	Carbon stored	1 km	Liu *et al* (2020)

Conservation scientists and planners have recommended that sustaining biodiversity, ecological processes, and ecosystem services requires conserving lands, waters, and biota of high ecological integrity, within networks of structurally and ecologically connected protected areas and distributed in a way that represents biological diversity across varying gradients of physical and ecological gradients (Belote *et al* 2017). We selected datasets representative of these conceptual requirements but that produced alternative scenarios based on a particular model's assumptions.

2.3. Ecological integrity

Our assessment of ecological integrity included three datasets. We included the additive inverse of Theobald's map of human modification (Theobald 2013) as a composite of various datasets representing stressors to ecosystem structure, composition, and function such that its inverse is commonly used as an indicator of naturalness (Woolmer *et al* 2008, Theobald 2013, Belote *et al* 2017). This dataset includes roads, land cover, human population density, and other indicators of alterations to ecological integrity.

The ecological integrity theme included a dataset on mammal community intactness to highlight regions where few local extirpations have occurred in the last 500 years (Belote *et al* 2020). Our assessment of ecological integrity also includes a dataset representing landscape permeability based on an unpublished dataset produced using 100 iterations of cost-weighted distance calculations from 5000 random points in the contiguous US where human modification represented landscape resistance. The resultant map of landscape permeability identifies relatively unfragmented lands of low human modification.

2.4. Ecological connectivity

Our assessment of connectivity included five datasets representing several assessments with various premises and assumptions concerning ecological connectivity. We used two datasets developed to identify regions important for potential migrations forced by climate change, namely the backward and forward climate velocity output of Carroll *et al* (2018). Carroll *et al* (2018) evaluated the projected spatial displacement of multivariate climate analogs from current conditions to future conditions (predicted conditions centered on the year 2085). Forward climate velocity pathways track where climate analogs (and by implication affiliated animal and plant species) are going, while backward climate velocity pathways track from where climate analogs are coming.

We also used a map of predicted ecological corridors between protected areas produced by Belote *et al* (2016). This analysis used several maps of human modification to identify the most natural linkages between large and highly protected (GAP 1 and GAP 2) conservation areas. The GAP system from the national Protected Areas Database identifies degree of protection, with designations 1 and 2 being strictly for conservation of biological diversity with no commercial resource extraction allowed.

Finally, we used two coreless connectivity maps to incorporate potential movements of species irrespective of fixed starting and ending points. Specifically, we used an omnidirectional Circuitscape connectivity model from Belote *et al* (2022), and the wall-to-wall Circuitscape model of Anderson *et al* (2023). The former is designed to model connectivity among pixels in all directions and performs this operation locally and iteratively as a moving window across the landscape extent in all directions. It typically identifies areas of concentrated flow through predicted corridors. The latter predicts flow from edge to edge of a study extent and typically measures more diffuse alternate pathways.

2.5. Biodiversity importance

Our assessment of biodiversity included five datasets representing different approaches to identifying geographies important for conserving biodiversity. We used four datasets that relied on species distributions using different pools of species, different taxonomic groups, and different methods and one dataset that focused on ecosystem types and their representation in existing protected areas. Specifically, we used biodiversity maps of Jenkins *et al* (2015), Dietz *et al* (2020), Belote *et al* (2021b), and Hamilton *et al* (2022) and an ecosystem representation priority originally produced by Aycrigg *et al* (2013) and updated and recalculated by Belote *et al* (2017).

Jenkins *et al* (2015) used distributions of mammals, birds, amphibians, reptiles, freshwater fish, and trees to calculate and map an index of biodiversity priority that included the range sizes and the proportion of ranges in existing protected areas. Hamilton *et al* (2022) used a similar method to Jenkins *et al* (2015) but focused on species of conservation concern and included some invertebrates (butterflies and bees) and some smaller statured vascular plants. Dietz *et al* (2020) calculated and mapped richness of species of conservation concern focusing on mammals, birds, amphibians, and reptiles. Belote *et al* (2021b) conducted a complementarity-based analysis of biodiversity priorities using all species of mammals, birds, amphibians, and reptiles. Finally, Aycrigg *et al* (2013) and Belote *et al* (2017) calculated the proportion of all natural ecosystem types that occurred in highly protected areas (i.e. lands with GAP status 1 or 2) and mapped ecosystem-representation priority assuming ecosystems with that lower proportions of protection are higher conservation priorities.

2.6. Ecosystem services

We included three datasets to highlight the critical role ecosystems play in delivering drinking water to people and for capturing and storing carbon. Clean water is a requirement of all biological diversity including, of course, human beings. We used the forest-to-faucets dataset which models how important a spatial unit is to providing drinking water to people. Importance is a function of the volume of water a spatial unit produces and the demand placed upon this volume by human populations. Areas scoring high on this index are meeting the demands of high densities of people and high per capita consumption (Mack *et al* 2022).

Carbon and carbon storage are relevant to mitigating atmospheric carbon emissions by human industrial activity. Mitigation has direct benefits on the severity of climate change and thus positive impacts on physical and biological systems required by all biodiversity including humans. High volumes of carbon sequestration and carbon storage are also positively associated with forest condition and biological diversity, and other ecosystem services including natural systems' capacity to regulate water flow, store water, and reduce flood risk. We modeled (1) carbon using the data of Liu *et al* (2020) which estimates the average annual carbon balance (carbon flux) for the years 1971–2015 and (2) total carbon storage for the year 2015.

2.7. Composite map of ecological importance

We wished to visualize all the ecological data summed in one place not as a definitive proclamation about where to work but rather to understand where ecological value and similarly summarized social importance might broadly align. We resampled all datasets to 270 m resolution using bilinear interpolation and combined the 16 datasets into a composite map of ecological value. We first normalized each dataset into integers representing deciles (i.e. 1 through 10) using the *ntiles.wtd* function in the *dineq* package in R (Schulenberg 2022) and then summed the normalized data resulting in a composite map of ecological value that ranged (hypothetically) from 16 to 160. We normalized data into deciles instead of using other methods, because data from criteria with highly skewed distributions tend to not influence the final solution using other normalization methods (e.g. $(x_i - x_{\min})/(x_{\max} - x_{\min})$; Belote *et al* 2017).

We summed the deciles as a straightforward and easily understood method for multi-criteria spatial assessments. However, we also used Zonation v.4 to combine our 16 ecological criteria into a composite map using the additive benefit function (ABF, Moilanen 2007) and compared our summed results to these outputs. Composite maps based on summing deciles were very similar to composite maps based on the ABF approach ($r = 0.95$, $p < 0.0001$), so we decided to use the summed composite, as this method is more easily communicated.

To better describe and summarize the geographic patterns, we created kernel density plots (smoothed histograms) of the composite ecological value for level 3 ecoregions using the *ggridges* package in R (Wilke 2024). These plots provide a tool to interpret the patterns we observe among the ecological indicators in terms beyond the geopolitical lines of the maps, such as states boundaries which we do use in the course of presenting and discussing our results. The kernel density plots identify the actual ecosystems associated with the ecological and social data.

3. Social assessment

We sought to identify three broad social themes: frontline communities, communities who have historically been excluded from natural resource planning and management decisions, and communities most vulnerable to the impacts of climate change across the Eastern region. We organized them by theme to help us understand and discuss potential broad patterns in the types of conditions experienced by people in place. We selected 13 spatially explicit social datasets to measure conditions affiliated with the three broad themes. These datasets were obtained from several peer reviewed and expert vetted sources including the EPA's Environmental Justice Screening tool (EPA 2022), the White House Council on Environmental Quality's Climate and Economic Justice Screening Tool, (CEJST 2022) and FEMA's National Risk Index for Environmental Hazards (FEMA 2023).

Social Vulnerability indices have been commonly used as an indicator of a community or individuals' sensitivity to certain hazards, their ability to avoid these hazards, or their ability to adapt to hazards (Tuccillo and Spielman 2022). It is important to acknowledge that the term 'vulnerable' is one that communities are calling to retire due to its suggestion that the problem, such as some implied weakness or deficiency, lies with the community rather than the institutional factors impacting a community (Katz *et al* 2020). We maintain that these measures of 'social vulnerability' can alternatively be viewed as an implicit measure of communities' capacity to adapt and persist in addition to identifying communities that have been treated inequitably, as such we refer to areas identified by our social composite as areas of high social importance. This reframing allows us to understand that communities on the frontlines have strengths and experiences that can benefit the conservation movement when properly incorporated, rather than viewing communities as victims in need of saving. We see such communities not only as places where resources may be dedicated to the improvement of the community and conservation, but also as places that have much to teach us. Prioritizing conservation engagement in these communities creates opportunities to help improve peoples' lives, opportunities to learn firsthand about human ingenuity and opportunities to learn from yet unengaged allies in large scale landscape protection and stewardship.

3.1. Frontline communities

Frontline communities have been defined as groups of people who experience disproportionate lack of access to resources and power (Sanders 2021). Consequently, they experience the first and the worst of the economic, health and social impacts of environmental degradation. We included eight indicators reflective of conditions or attributes of frontline communities which have been identified through the research conducted by the EPA in their EJ Screen development process as key indicators of environmental justice and exposure. These include the percent of the population under 5 years of age and over 64 (EJScreen 2022), proximity to superfund sites determined by the number of sites within 5 km of the geometric centroid of a census tract (EJScreen 2022), proximity to hazardous waste sites determined by the number of sites within 5 km of the geometric centroid of a census tract (EJScreen 2022), a measure of unemployment defined as the percent of the population without any work (CEJST 2022), housing burden defined by percentage of households spending more than 30% of their income on housing (CEJST 2022), low income defined as percent of the population earning less than or equal to half the poverty level for that census tract, (EJScreen 2022), education level defined as percent of the population possessing less than a high school education (EJScreen 2022)

3.2. Historically excluded

The first of two indicators of historical exclusion from conservation was demographic data identifying percent of BIPOC in a census tract (EPA 2022). BIPOC communities have historically been excluded from political decision-making processes as well as the decision making processes about the shape and direction of the conservation movement (Taylor 2016). BIPOC communities are often the least able to access processes that allow them to voice and control the impacts on their communities. BIPOC communities are, for example, often the most targeted for large-scale development projects which may have serious environmental and health repercussions, such as pipeline development or manufacturing plants (Hendricks and Van Zandt 2021). Empowering these communities to protect themselves and their resources lays the groundwork for opposition to environmentally harmful extractive industries even before they are sited.

Our second indicator of historical exclusion from conservation was a model of proximity to a natural area (Belote, unpublished data). The actual parameter was distance from any point to the nearest publicly accessible conserved natural area defined as lands conserved in GAP 3 or better (PADUS 2020) with at least

50% native vegetation cover. The GAP database is a national inventory of land tenure status ranging from 1 to 4, with 1 establishing the protected area as what is often called wilderness, or areas where human intervention or manipulation even for conservation purposes is not permitted. GAP 2 only allows human intervention or management for the sake of conserving a particular species or aspect of biodiversity. GAP 3 establishes the main use of the land will include its existence in natural vegetation but some resource extraction is allowed such as sustainable timber harvest. GAP 4 is private land not subject to any particular conservation covenant other than the applicable laws and regulations governing all lands in a jurisdiction.

This measure of proximity to a natural area by no means captures the nuances of accessibility such as access to transportation, available free time, nor resources such as outdoor equipment. This measure also fails to account for barriers resulting from perception of safety in place (Ribot and Peluso 2003). There may also be negative outcomes from proximity to protected areas that can lessen the benefits this area provides neighboring communities, for example when established, many protected areas resulted in the loss of individual or community control over land and resources (Dominguez and Luoma 2020). The potential impact of this history is another area where this data set is likely limited. Protected areas do, however, generally see success in conserving healthy ecosystems, which are beneficial in providing services that support the health and wellbeing of the communities connected to them (Leverington *et al* 2010), such as access to outdoor recreation (MacKinnon *et al* 2019), nature and biodiversity (Fuller *et al* 2018) and provision of clean water (Open Space Institute 2024). We acknowledge the shortcomings in this dataset but nonetheless find this parameter useful in approximating a measure of the relationship that communities have with conserved lands.

3.3. Vulnerability to climate change

We used three datasets to assess communities' vulnerability to climate change including the FEMA National Risk Index (FEMA 2023), FEMA's map of flooding risk (FEMA 2023) separately, and climate dissimilarity (Belote *et al* 2018). The FEMA National Risk Index calculates risk using three themes, Expected Annual Loss (natural hazard exposure), Social Vulnerability, and Community Resilience. These three themes use data for 18 different natural hazards including but not limited to variables such as risk of wildfire, drought, hurricanes, and other disasters, as well as a community's ability withstand these natural climate-driven events. We chose to separately include flood risk from FEMA to demonstrate its novel and relevant geographic pattern compared with the general risk FEMA composite. First, the patterns of flood risk were very different from those of the composite. Secondly, recent flooding in the Southern Appalachian Mountains has showcased the need to assess flood risk in the face of climate change (Bartels 2024).

Climate dissimilarity is a measure of multivariate change in climate using 11 different variables (mean annual precipitation and temperature, season precipitation and temperature, and moisture deficit). We used the median estimate of climate dissimilarity for data centered around the year 2055 that combines 9 different global climate model outputs from two different relative concentration pathway scenarios (RCP 4.5 and 8.5).

3.4. Composite map of social importance

As with our ecological composite maps, we wished to visualize all the social data summed in one place not as a definitive proclamation about where to work but rather to understand where ecological values and social importance might broadly cluster. Like our treatment of the ecological data, we resampled each raster to 270 m using bilinear interpolation and combined the 13 social datasets into a composite score of social importance by normalizing the data and binning each criterion into deciles using the *ntiles.wtd* function in R. We are aware that the flood dataset is counted twice in this summation and, therefore, we ran the composite without the separate flood dataset and found no discernible difference in the maps for our purposes. We then summed the normalized values to map social importance. To investigate an alternative method for producing a composite map, we also subjected these 14 normalized datasets to the ABF algorithm in Zonation V4 and found that the summed composite was highly correlated with the composite produced using ABF ($r = 0.92$, $p < 0.0001$). As with the ecological composite, we chose to focus on the summed composite as the method is more easily understood.

Similar to the ecological composite and to better describe and summarize the geographic patterns in the social data, we created kernel density plots (smoothed histograms) of the composite social importance value for level 3 ecoregions using the ggridges package in R (Wilke 2024). These plots provide a tool to interpret the patterns we observe among the social indicators in terms beyond the geopolitical lines of the maps. They identify the actual ecosystems that are the homes to the people and the ecological patterns and process that.

3.5. Bivariate ecological and social map

Finally we wished to visualize all the ecological and social composite data summed in one place. We combined the composite maps of ecological value and social importance into one bivariate map. To speed processing time, we resampled the 270 m composites to 1 km resolution using bilinear interpolation. We then classified each composite into three equally sized bins (terciles), combined, and mapped them into 9 bivariate classes (i.e. low ecological value and low social opportunity, low ecological value and moderate social opportunity, low ecological value and high social opportunity, etc.).

3.6. Sensitivity analyses

For both ecological and social datasets, we evaluated whether fewer variables could be used to create composite maps by evaluating correlations among variables (supplemental figures 1 and 2) and conducting a Monte Carlo sensitivity analysis (supplemental figures 3 and 4). Following the correlation and sensitivity analyses, we chose to keep 16 variables for the ecological assessment and 14 variables for the social assessment (see supplemental figures 1–4 for more details).

Because we categorized each variable into themes (i.e. ecological integrity, connectivity, biodiversity, and ecosystem service for the assessment of ecological value and frontline communities, historically marginalized, and vulnerable to climate change for the assessment of social importance), we evaluated whether compositing data within themes before creating the full composites affected the final maps of ecological value and social importance. To do this, we summed the datasets within each theme (i.e. creating 4 thematic composites for ecological value and 3 thematic composites for social importance), normalized the thematic composites, and then summed those to produce the final maps of ecological value and social importance. However, these maps produced using thematic composites were highly correlated with the simpler version produced from summing 16 (for ecological, $r = 0.98$) or 14 (for social, $r = 0.92$) normalized inputs (figure S4). Again, we chose to interpret outputs using the more straightforward approach but report the results of this analysis here as evidence that our results are robust to alternative methods.

4. Results

4.1. Ecological criteria

Figures 2 and 3 present the maps for the 16 ecological datasets across 4 themes summarized in table 1. Figure 2 groups the models associated with the integrity and connectivity themes while figure 3 presents models associated with the biodiversity and ecosystem services themes.

4.2. Ecological criteria: integrity theme

The three models of Ecological Integrity (figures 2(a)–(c)) agree on areas of high integrity throughout the northeast including the New England states and Adirondacks of New York, western Pennsylvania and the Florida Everglades. Figures 2(a) and (b) model the relative freedom from the impacts of human disturbance to natural landscapes. The permeability model of figure 2(a) is more specifically designed to capture the existence of landscape tracts that have low predicted internal resistance to ecological movement whereas the naturalness model of figure 2(c) is not designed to identify nodes or concentrated pathways but rather present a continuous model of landscape modification or lack of modification. The model of historic carnivore community intactness (figure 2(b)) contrasts with the other two models of ecological integrity in that areas west, south, and east of the southern Appalachians score low with the notable exception of a narrow band between north Florida through Georgia and western North Carolina and eastern Tennessee. An area scoring well on this measure of community intactness is one whose carnivore species composition remains relatively unchanged over the last several hundred years. It provides insight into ecological processes including the structure and function across lower trophic levels not available with measures of naturalness (Belote *et al* 2020). Measures of naturalness are more directly reflective of landscape condition which is primarily defined by the intactness of natural landcover.

4.3. Ecological criteria: connectivity theme

Figures 2(d) and (e) depict models of backward and forward climate velocity demonstrating a general pattern of low elevation and lower latitude sources of biodiversity shifting upslope and to higher latitudes in the modeled future. These data are concerned with predicted animal and plant movements in response to climate change. The map of forward velocity shows areas receiving relative input while the map of backward velocity models areas of high relative output, or movement away.

The remaining maps of connectivity, figures 2(f), (g) and (h), model relative strengths of potential daily, seasonal, annual, and dispersal movements of animal and plant species. Figure 2(f) is a model of connectivity among protected areas that prioritizes connectivity within networks of reserves protected with at least GAP 2 protection in the PADUS North American database. The notable discontinuity between West Virginia and western Pennsylvania is a function of this particular model's use of GAP 1 and GAP 2 lands while discounting large areas of natural cover and potential connectivity provided by multiple-use GAP 3 and

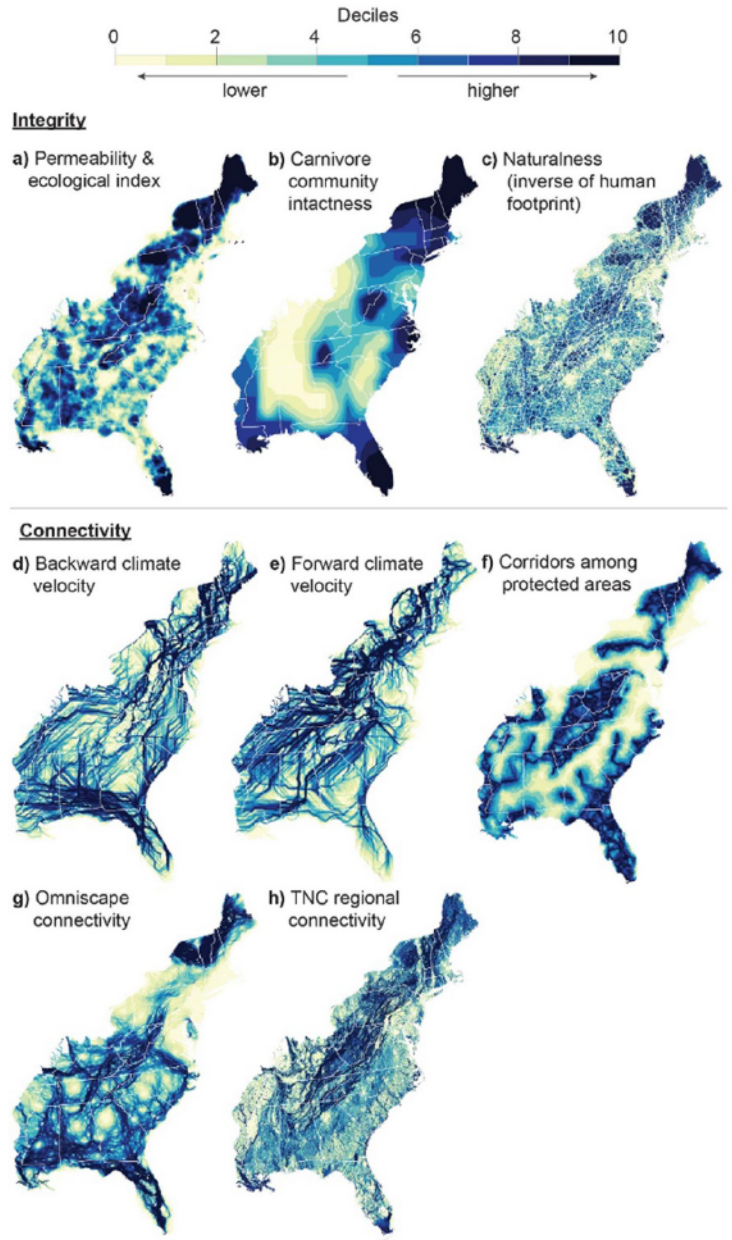

Figure 2. Ecological integrity and connectivity themes. Please refer to methods, results, and table 1 for detailed description of these indicators.

private lands. Here is a good example of the value in having several models for the same concept. The models of figures 2(g) and (h) in fact do demonstrate connectivity through this discontinuity as these models' assumptions permit flow through private natural landcover and GAP 3 conserved natural landcover.

Figure 2(h) demonstrates high modeled ecological flow along the entirety of the Appalachian Mountain corridor. Notably it identifies an important area of flow in western Pennsylvania through an area identified in figure 2(f) as a discontinuity. While the Omniscape model depicted in figure 2(g) and the connectivity model of 2 h are both coreless models, the former is designed to identify corridors of high potential flow more so than the model of 2 h which identifies areas of diffuse potential ecological connectivity.

4.4. Ecological criteria: biodiversity theme

Figure 3(a) through 3(e) are models of biodiversity importance based variously on species richness, species richness in association with conservation status, species richness in association with complementarity and representation, and ecosystem representation. As with the other measures, each data set contributes new information as was demonstrated by our analyses of correlation and sensitivity (figures S1–S3 for both the ecological data and the social data). Figures 3(a), (b) and (e) are based on species richness and predictably

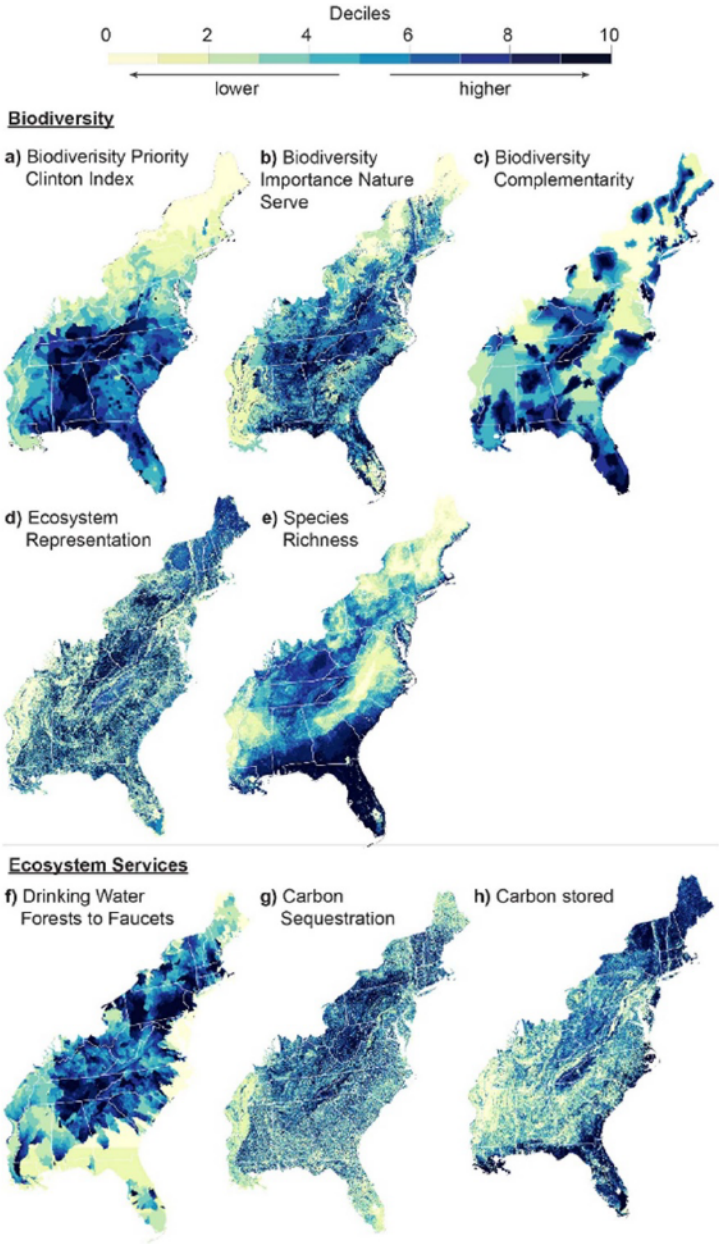

Figure 3. Biodiversity and ecosystem services themes. Please refer to methods, results and table 1 for more detailed description of these indicators.

identify the importance of lower latitudes and the southern Appalachians as hotspots of biological diversity with low richness in the northern Appalachians. Measures of richness are based on local maximal counts versus representation or complementarity. The approach of the models of figures 3(a) and (b) are broadly similar but differ in that the model of 3(b) incorporates conservation concern and includes invertebrates (bees and butterflies), and small statured vascular plants in addition to birds, mammals, reptiles, amphibians, and fish modeled in 3(e). The models of figures 3(e) and (b) mapped richness of species of conservation concern. The model of 3(b) identified notable differences including high values along coastal New England from Cape Cod Bay to the Gulf of Maine and inland from the coast as well. Models 3(a) and 3(b) identified high values in the central to southern Piedmont not identified by model 3(e). Finally, model 3(e) stands out for its identification high richness for most of the Florida peninsula.

The complementarity approach of map 3(c) and (d) identify areas in the northern Appalachians not identified by the three richness models (3(a)–(e)). Model 3(c) identifies high value along the New England coast from Cape Cod Bay through the Gulf of Maine and in the western mountains of Maine and the Adirondacks. As 3(c) portrays a complementarity model based on species versus ecosystems, its identification of high value areas occurs in more granular and defined patches associated with species' populations. Model 3d, which is based on complementarity of ecosystem representation, shows more diffuse and coarser grained high value areas associated with ecosystems relative to species populations. Taken together, these models depict high value up and down the entirety of the Appalachian Mountains extending to the Atlantic and Gulf of Mexico coasts and west to the boundary of our defined eastern region.

4.5. Ecological criteria: ecosystem services theme

Figures 3(f), (g) and (h) depict areas important to the production of drinking water for large human populations and the annual capture for ecosystem carbon and current stores of ecosystem carbon respectively. Carbon storage and sequestration were selected for the role of carbon in global climate change and by extension the many challenges such as severe flooding exacerbated by global climate change. Carbon also reflects forest cover and forest cover is important to the regulation of water flow and mitigation of flood impacts. Carbon volume is also a useful indicator of forest cover maturity and many associated biodiversity parameters. There are many ecosystem services measures embedded in other ecological themes including the potential flood control inherent in the measures of ecosystem integrity for example. The ecosystem services parameters called out explicitly by our methods were selected as these are uniquely important and not as likely to be represented implicitly in our other ecological or social themes. These are presented as but three of many potential ecosystem services that a The model of drinking water does not depict an area's absolute potential for producing drinking water as exhibited by the relatively low importance of perhaps one of the highest capacity regions in the United States, the state of Maine. Though amply supplied with water, not many people depend upon it in Maine for example, in contrast to the populations of the middle Atlantic and southeast and west of the southern Appalachians who are drawing water from adjacent forested areas. Figures 3(g) and (h) depict annual carbon uptake and current carbon storage respectively and predictably show an inverse pattern of high values. While carbon uptake is low in the northeast and Florida, these two areas demonstrate high current carbon storage relative to areas of high uptake but lower current storage west of the Appalachians. These patterns reflect current existing relatively high forest cover in those areas exhibiting low uptake but high current storage as opposed to areas undergoing forest regrowth but low current storage.

4.6. Social criteria

Figures 4 and 5 present the results for the 13 social datasets across 3 themes summarized in table 2. Figure 4 presents the results associated with frontline communities while figure 5 presents the maps associated with historically excluded communities and communities vulnerable to climate change.

4.7. Social criteria: frontline communities theme

Figure 4(a) demonstrates a higher proportion of families with children under age 5 along the coasts and piedmonts of the southeast while an older population seen in figure 4(b) occurs along the Appalachians from Tennessee through West Virginia and into western New England, New York state, and northern New England.

Figures 4(e), (g) and (h) show comparable patterns of high unemployment, low income, and lower education levels across the southerneastern U.S. continuing along the Gulf States into the southwestern part of the eastern region and another concentration in West Virginia and eastern Kentucky. Higher densities of households burdened by expensive housing (figure 4(f)) occur along the Gulf states, through Georgia and north Florida up along the southeastern Atlantic to Chesapeake Bay. The housing burden problem extends north from Maryland throughout western through central New Jersey and Pennsylvania and western New York and western New England.

Figures 4(c) and (d) depict relatively high proportions of Households near Superfund Sites and Hazardous Wastes sites along coastal mid-Atlantic and coastal southeast including the low country and piedmont. High proportions of households near Hazardous Waste is generally more widely dispersed and occurs across the extent of the eastern region with slightly lower densities further west of the southern Appalachians. The same pattern holds for Superfund sites but at a different spatial granularity with populations impacted being more densely clustered than with the more diffuse hazardous waste exposure.

4.8. Social criteria: historically excluded theme

Figures 5(a) and (b) depict communities historically excluded from conservation decisions, benefits, and access to designated conservation. A rather striking pattern of high densities of BIPOC populations is evident in figure 5(a) from southern New England, New York south along the coast and piedmont of New Jersey, Maryland, Washington D.C., Virginia, and the Carolinas, Georgia, and Florida. This high density of BIPOC populations continues west across Louisiana, Alabama, and Mississippi, to the far west of the mapped eastern region. Figure 5(b) portrays the distribution of populations located more distantly from conserved natural areas. Higher densities of these populations are evident along the coastal Carolinas, west through the Gulf states and Arkansas back through, western Kentucky, Tennessee, eastern Ohio and western Pennsylvania.

Figure 4. Frontline community theme. Please refer to methods, results, and table 2 for detailed description of these indicators.

4.9. Social criteria: vulnerable to climate change theme

Figures 5(c)–(e) depict populations vulnerable to various aspects of climate change and associated physical events such as drought, fire, flooding, and extreme heat. While figure 5(c) incorporates flood risk data, we chose to draw attention to it separately as well (figure 5(e)). We ran this composite using both the separate flood risk dataset and without the separate flood risk dataset (as it is embedded in the FEMA composite) and found no discernible difference for our purposes. Figure 5(c) shows high risk of climate change hazards (this is the FEMA composite model) along the mid-Atlantic coast, Virginia, Carolinas, Georgia and coastal Florida around the southern tip and up the Gulf coast of Florida and coastal Gulf States with a relatively low predicted risk in the Appalachians. In contrast, the stand-alone flood model of figure 5(e) predicts a high risk of flooding along the extent of the Appalachian Range and near coastal areas along the Atlantic and Gulf Coasts. Our third indicator within the climate vulnerability theme is Climate Dissimilarity depicted in figure 5(d). There is a notable trend from south to north of increasing dissimilarity, meaning the climates of New England for example will experience the greatest predicted change. The climates of the southern U.S., Gulf coast, southeast coast and Florida are predicted to change the least.

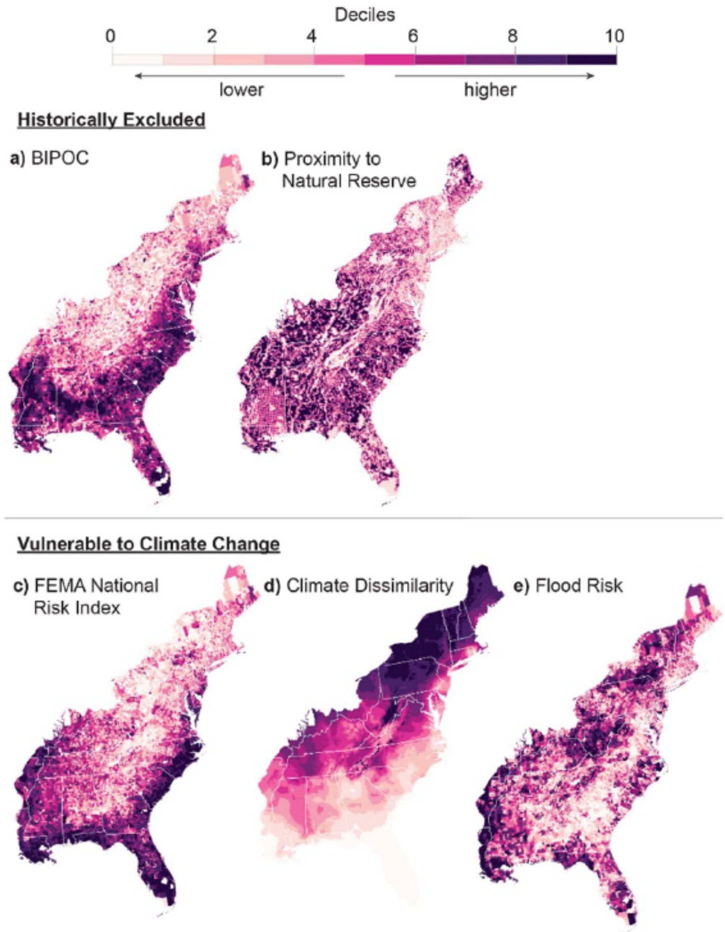

Figure 5. Historically excluded and vulnerability to climate change themes. Please refer to methods, results, and table 2 for detailed description of these indicators.

5. Ecological and social composites

The ecological composite of figure 6 shows high combined value from the southern Appalachian Mountains west into interior United States and north through western Pennsylvania, Adirondacks, western Massachusetts, into Vermont, New Hampshire and Maine. High value occurs along the Gulf coast states, much of Florida and the coastal portions of the southeast with fingers of moderately high value lands connecting coastal Carolinas and Virginia with the Appalachians similar to areas of moderately high value connecting Maine's coast to its high value interior western mountains and north woods. The individual datasets as already reviewed help to uncover different combinations of attributes driving these patterns in the various places of high composite value.

The social composite map of figure 6 demonstrates a pattern of high values associated with social importance in a 'u' shaped pattern that starts in the vicinity of Washington D.C. and extends down the southeast coast through the Carolinas and Georgia into Florida and across the Gulf States and up into the western extent of the mapped eastern region in the vicinity of Arkansas. Generally, the area within the center of this 'u' shaped region of social importance scores higher than the central and northern U.S. Another cluster of high scoring social importance occurs in the vicinity of eastern Kentucky and western West Virginia. As with the ecological maps it is helpful to continue to think in terms of the individual models that form these composites to understand which themes are driving high scoring areas, or which individual datasets are driving a high scoring area within a theme.

We found it helpful to relate natural ecosystems to the ecological and social patterns observed as they can exert considerable mutual influence and feedback. We built kernel density plots for composite ecological and composite social importance scores that are associated with Level 3 Ecoregions (figure 7). The four top scoring ecoregions on the composite ecological value are: Appalachian-Blue Ridge forests, Appalachian mixed mesophytic forests, New England-Acadian forests, and Everglades flooded grasslands; three in the mountains and one in the wetlands of south Florida. The four top scoring ecoregions on the composite social

Table 2. Social condition datasets by theme.

Theme	Indicator data set	Original resolution	Citation
Frontline communities	Age: proportion of population in census tract ⩽5 years of age	Census tract	EJScreen (2022)
	Age: proportion of population in census tract ⩾ 64 years of age	Census tract	EJScreen (2022)
	Superfund: number of superfund sites within 5 km of census tract	Census tract	EJScreen (2022)
	Hazardous waste: number of hazardous waste sites within 5 km of census tract	Census tract	EJScreen (2022)
	Unemployment: proportion of population in census tract without any work	Census tract	CEJST (2022)
	Housing burden: proportion of households in census tract spending more than 30% of their income on housing	Census tract	CEJST (2022)
	Low income: proportion of the population earning ⩽ half the poverty level for that census tract	Census tract	EJScreen (2022)
	Education: proportion of the population in census tract with less than high school education	Census tract	EJScreen (2022)
Historically Excluded	BIPOC: proportion of population in census tract identifying as Black, Indigenous or of color	Census tract	EPA (2022)
	Proximity to a natural area: Euclidean distance of point in space from any boundary of nearest natural area defined as PADUS GAP 1, 2, or 3 with at ⩾ 50% of area in natural vegetation cover	270 m	Unpublished data
Vulnerable to climate change	FEMA Natural Hazard Risk: National Risk Index percentile ranking	Census tract	FEMA (2023)
	Climate Dissimilarity Index percentile ranking	1 km	Belote *et al* (2018)
	Flood Risk Index percentile ranking	Census tract	FEMA (2023)

index are: Mississippi lowland forests, Mid-Atlantic US coastal savannas, Southeast US conifer savannas, and Central US forest-grassland transition; all low lying and at one time highly productive areas now heavily altered by settlement, agriculture, forestry, or industry and often times all of these stressors.

6. Bivariate ecological and social assessment

The upper right corner of the bivariate plot of figure 8 corresponds to areas on the map where there is high ecological value located in the same place as areas of high social importance. These places occur in a reverse L-shape pattern along the Atlantic and Gulf coasts including southern Georgia and northern Florida into central Florida. The co-occurrence of high ecological value and high social importance also occurs near eastern Kentucky and other parts of central interior Appalachia.

The upper left and lower right of the bivariate plot correspond to areas scoring high on the composite measures ecological value and social importance respectively and independently. A U-shaped area of high social importance with lower ecological value shows up in the piedmonts of Virginia, the Carolinas, and Georgia along the Atlantic and Gulf coasts and wrapping into a wide band occupying the western extent of our mapped eastern region through Arkansas, western Tennessee, and the lower Midwest. Notably a finger of high ecological value with lower social importance extends from the southern Appalachians to the northern

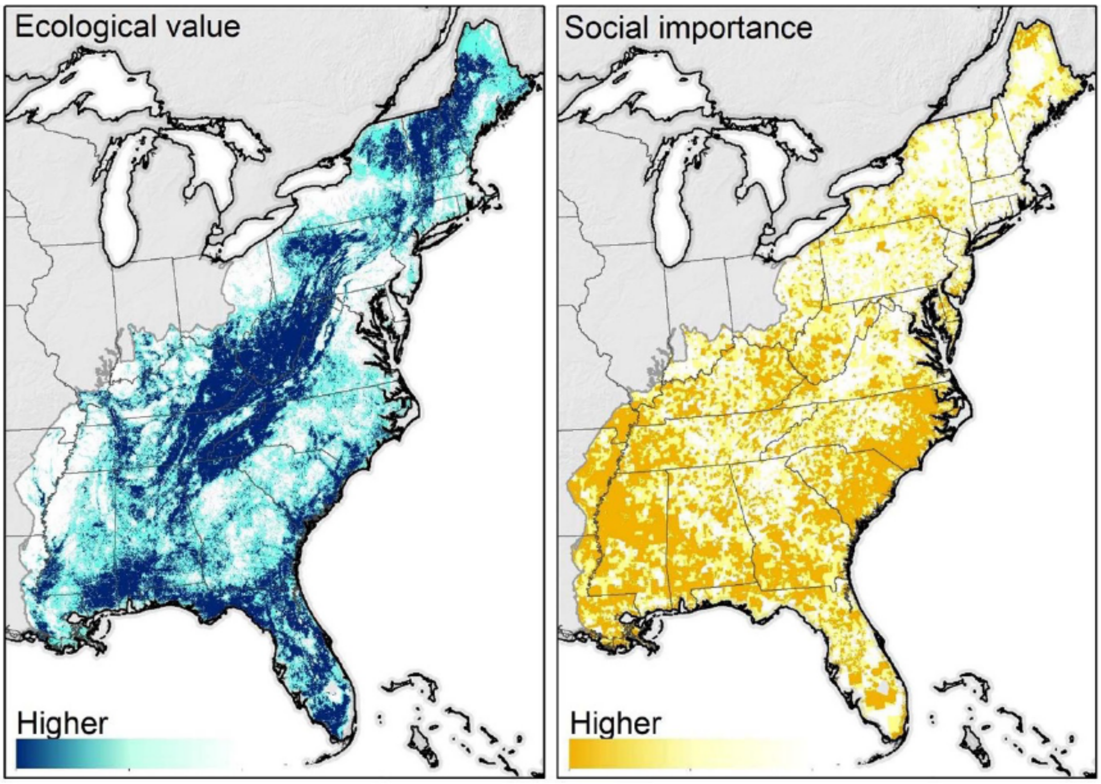

Figure 6. Composites of all ecological data sets across themes (left) and all social data sets across themes (right). Index values reported in deciles.

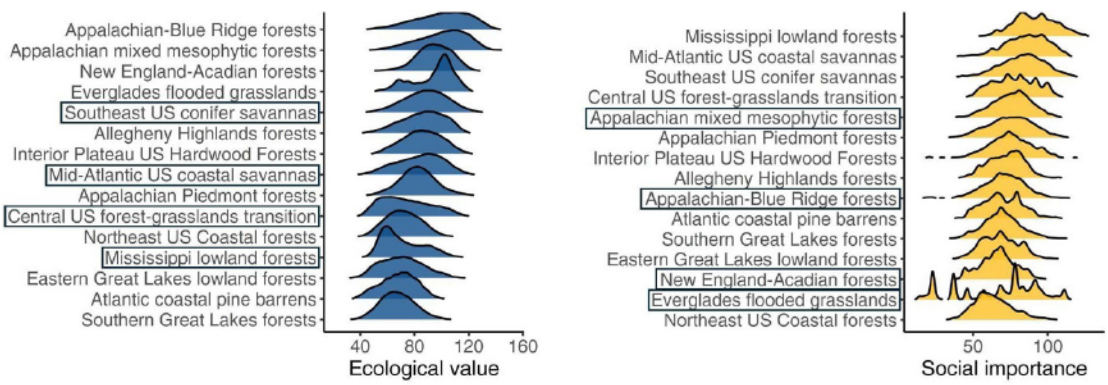

Figure 7. Kernel density plots for the composite ecological value (left) and social importance (right) by Level 3 ecoregion. Ecoregions are rank ordered by the mean composite value for each plot. Each plot has the four highest scoring ecoregions from the other plot signified by a box.

Appalachians. High composite ecological value is also found along the Gulf coast and throughout the Florida peninsula.

7. Discussion

Our results identified places in the Eastern United States where the potential exists to simultaneously include marginalized voices as we undertake stewardship and other conservation projects in the interest of an intact and resilient eastern forest landscape. We take as our inspiration the scale and continental vision of the Y2Y initiative and further look to the inclusion of the social dimension as is called for by Holterman *et al* (2023) in their application of social considerations to the Y2Y initiative. This work and our results are already informing our collaborative work with the ATLP, a large-scale effort to conserve and steward the eastern forest's ecosystems well beyond the trail into, as phrased by Benton MacKaye, the Realm of the trail (MacKaye 1921). The Eastern U.S. is a globally significant region with respect to biodiversity

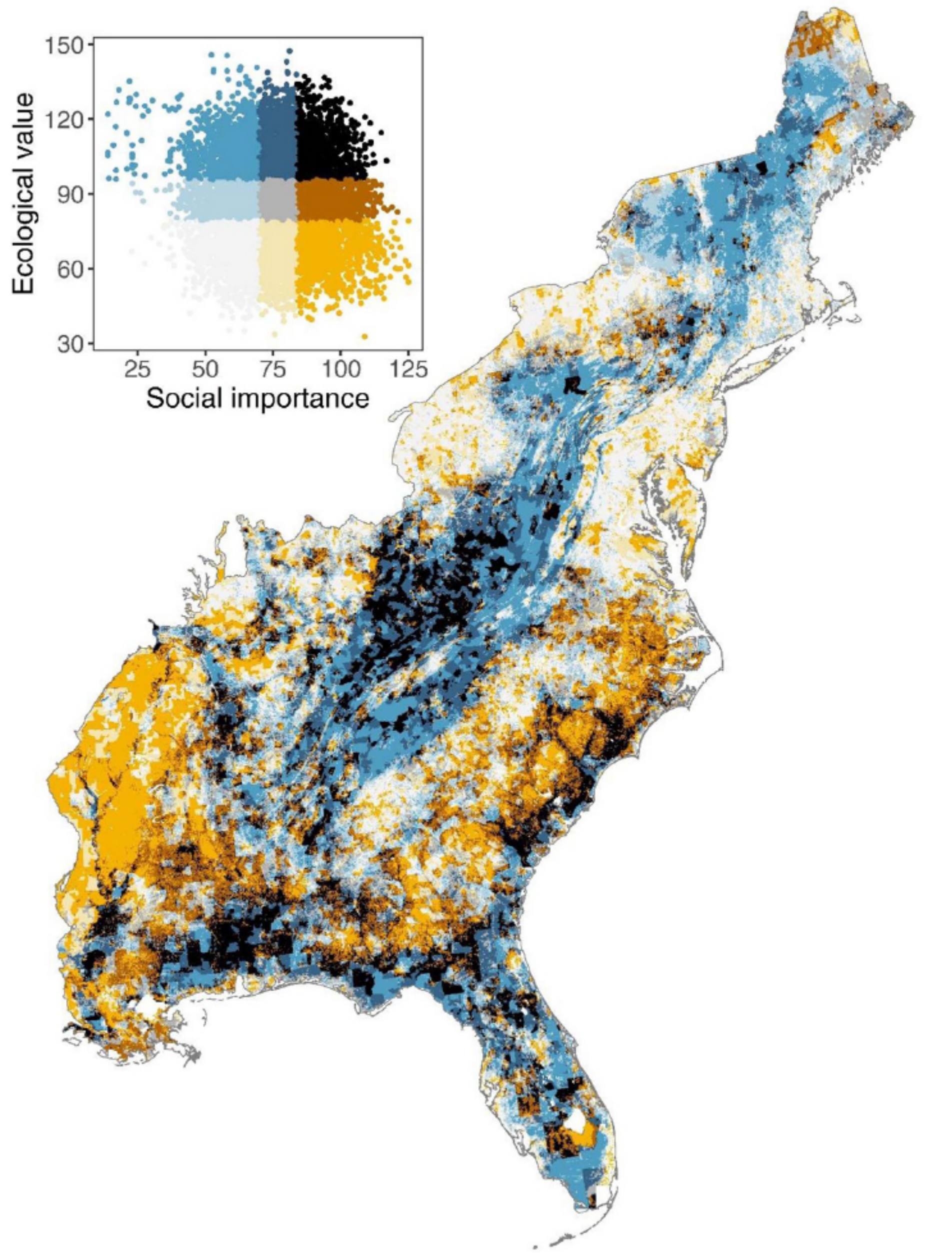

Figure 8. Bivariate maps of ecological and social composites. Black areas represent the intersection of the top third areas of both ecological value and social importance. Conservation planners can use assessments like this at multiple scales. For instance, zooming into blue areas in the lower third for ecological value and higher third of social importance will include areas of *relatively* high ecological value. Likewise, zooming into yellow areas in the highest third ecological value and lowest third social importance will include communities with relatively high importance.

(Jung *et al* 2021), carbon capture and storage (Jung *et al* 2021, Jiang *et al* 2022), and continental connectivity (Carroll *et al* 2018, Barnet and Belote 2021). The region is also home to substantial populations of people whose views and conservation ethic have not been adequately included in the conservation conversation and who stand to benefit from conservation approaches that center their lived experiences.

Our identification of so-called high ecological value—high social importance, low ecological value—high social importance, and high ecological value—low social importance areas is comparable to the analyses of Whitehead *et al* (2014) as we seek a simple way to broadly identify geographies and people for our work. Similarly we found that easily communicated general summations are helpful to the development of collaborative efforts when done early on in conservation and social planning efforts. Similar to Thiault *et al* (2017) we present our results in social and ecological composite maps as an operational tool to support mutual understanding among project partners. Hemming *et al* (2022) present an overview of decision science and decision analysis wherein they discuss the role of decision support tools that help collaborators to identify, communicate and understand values. This is our current and intended use of this work rather than as a prescriptive and conclusive decision maker. Our model is merely one part of a much bigger process that has to include solicitation of collaborators' values and working at smaller scales relevant to the convened partners. Our model and data are scalable and often times at smaller scales in particular geographies it is important to determine which individual models are relevant and what might be missing and possibly added to the model.

A conservation network requires ecological representation in adequately sized areas that are well connected. We mapped the values derived from several spatially explicit ecological models for each of four ecological themes; integrity, connectivity, biodiversity, and ecosystem services, to broadly identify areas of high value to ecological representation and connectivity. Our work identified areas of high ecological value throughout the eastern region. Land use histories and early conservation efforts have maintained a pattern of high ecological connectivity stretching the length and breadth of the Appalachian Mountains. Although tapped for timber production, they have remained in native forest cover in large landscape tracts. The distribution of ecoregional types reflects this pattern with the three highest scoring ecoregional types occurring in mountain ecosystems. Our results show that throughout the eastern region, the Appalachian Mountain range possesses areas rich in endemic species, host carbon-storing and capturing forests, and serve as critical ecological linkages identified through the various data we used.

In contrast with the higher elevation Appalachians the four ecoregions scoring highest on measures of social importance are unsurprisingly lower elevation and long settled areas currently with some combination of high urban density and industrialization, forestry, or agriculture along coastal savannas, central grasslands or lowland coastal forest. While these low elevation and long developed areas typically score low on measures of ecological integrity and ecological connectivity, they do often score high on measure of species richness and complementarity. This underscores the need to spend time with the small multiple models after looking for broad patterns in the composite models. It is usually at this scale and level that communities identify with an area and rally in support of collaborative conservation and community betterment.

Our assessment highlighted other areas of high ecological value including the southern coastal plains that, like the Appalachian Mountains, are subject to relatively less intense industrialization, settlement, resource extraction, and infrastructure development. This is an area recognized as a global hotspot of biodiversity (Noss *et al* 2015). Our spatial analyses of high social opportunities also identified the southern coastal plain and parts of the Appalachian Mountains, mostly in the Cumberland Plateau region. Both areas were characterized by lower income levels with different risks associated with climate vulnerability. While the southern plains are characterized by BIPOC communities with high exposure to climate change impacts, mountainous communities have lower proportions of BIPOC communities and higher flood risks. Our composite social map represents divergent communities of people facing comparable challenges ranging from climate change to finding employment.

The western central Appalachians include rural, low income, largely white populations with lower levels of education. Another factor contributing to social importance appears to be the high risk of climate change impacts through flooding. From an ecological perspective this area scores well on various models of connectivity, biodiversity importance, ecological integrity, and provision of ecosystem services. Notably, this area is a vital linkage in the Appalachian and eastern region-wide connected network of conservation lands we envision. Conservation actions and community engagement might be attempted simultaneously in partnership with local communities who are involved in priority setting and implementation. The Southern Coastal Plain also has co-occurring high ecological and high social importance along the Atlantic and Gulf coasts through southern Georgia and northern Florida. This region represents another space where conservation of biodiversity might be approached in collaboration with local communities simultaneously in place, remembering that conservation actions are by no means defined by land protections. In a recent series of community engagement meetings from western North Carolina through the Piedmont we unrolled these maps as a first step in engagement around river and community health.

The southern and northern extents of the eastern forest do not stand out as areas with clear social and ecological overlap in the composite maps. In contrast, however, the small multiples portraying the results of individual models within the social and ecological themes in figure 4 through 6 do typically identify areas of co-occurrence for some permutation of ecological and social importance not evident in the composite bivariate model. Therefore, we encourage looking at individual model output within the ecological themes and social themes to find potential spatial overlap of ecological and social importance in the same place.

We also suggest looking for potential relationships between a physically disjunct human population and an ecological value. The provision of recreational access or drinking water to neighboring urban centers are examples of a mutually beneficial relationship between people and conservation that does not depend on direct spatial overlap. For example, the areas of high ecological integrity of the central and northern Appalachians are also significant destinations for outdoor recreation and drinking water for people of U.S.

cities from the mid-Atlantic to Boston. These cities are notable for scoring high on multiple individual social measures of importance.

Our results show the Chattahoochee Forest to be an area of high ecological significance that lies along the Southern Appalachians. South of here we see areas of high social importance which center around the city of Atlanta, one of the most diverse and climate impacted cities in the US. The Chattahoochee River provides two-thirds of the drinking water to Atlanta (Basmajian 2011). Atlanta communities are, therefore, key stakeholders in the ecological health of the Chattahoochee Forest as it serves as the headwaters of the Chattahoochee River. Many regional organizations such as the Trust for Public lands, Chattahoochee Riverkeeper and the Chattahoochee River Conservancy recognize the importance of the river for the city of Atlanta and are working jointly to improve protections and water quality (Trust for public lands 2025) and pass legislation to preserve and protect the Chattahoochee River (Ossoff 2022) Application of this model by the organizations working to conserve the Chattahoochee River could bolster support by helping to identify and convene those communities most reliant on the river's health in the stakeholder decision making process.

Using the model presented in this paper in conjunction with research and conversations with communities are only the initial steps for engaging in conservation efforts that support communities on the frontlines of this river's conservation and status. It is important to acknowledge that the spatial analysis being presented in this paper was not conducted in a way that directly incorporates the voices of the communities we hope to include, namely the communities where social opportunities exist according to our analysis. Doing this direct engagement and listening will be an important next step for entities hoping to use analyses such these. We intend for this work to first and foremost inspire conversations among communities and conservation organizations and agencies. These community-led efforts could include conservation solutions complementary to traditional strategies of establishing protected areas. Policies and initiatives that improve community agency over the lands and resources with which they live have been implemented in other regions around the planet (Fariss *et al* 2023) are recognized in targets 3 and 22 of the Global Biodiversity Framework (Armitage 2020). We recognize that community-led conservation is challenging and that we all must do better at following through with the hard work required.

8. Conclusions

We have demonstrated how spatial data can be used to map potential overlap of ecological and social importance. We demonstrated (1) where high composite ecological value co-occurs with high composite social importance and, therefore, where conservation and community betterment might physically coincide in some places, (2) areas with high composite ecological value not co-occurring with high composite social importance, and (3) areas with high composite social importance not co-occurring with high composite ecological value. Though in the latter two cases physical overlap of ecological and social value is missing, there may nonetheless be a relationship between a natural area or water source and a population of people whom it might benefit.

We also have discussed the continued importance of looking at the individual models of ecological and social importance as their utility is not just as a component of the composite models. On the contrary, the ecological and social importance are best understood at smaller scales where different patterns and processes emerge and where partners' priorities generally emerge. Actions that address both nature conservation and human well-being should be implemented in a way that does not further harm local people and moreover is a desired outcome for local people. Better engagement of local people is, therefore, one of the chief goals of our work here. We present these analyses as a tool to start and inform conversations that turn into learning from historically marginalized communities as we attempt to advance equitable conservation.

Data availability statement

No new data were created or analysed in this study.

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