An assessment of ecological values and conservation gaps in protection beyond the corridor of the Appalachian Trail

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Abstract
The Appalachian Trail (AT) traverses the Appalachian Mountains across 11 degrees of latitude from Springer Mountain in Georgia to Maine’s Mt. Katahdin. The 3,524 km (2,190-mile) long trail is buffered within a conserved corridor that is at least ~ 305 m wide and covers approximately 101,000 hectares (250,000 acres) overseen by the National Park Service (NPS), making it one of the largest NPS units in the East. Although a continuous marked trail has been established since 1937, protection of the corridor was not complete until the last couple of decades. Additional conservation designations exist adjacent to much of the trail corridor, but significant gaps in protection remain. A variety of land trusts and other non-profit conservation organizations, federal and state land management agencies, and regional trail clubs overseen by the Appalachian Trail Conservancy (ATC) actively seek to add to the local, regional, and national conservation significance of this landscape or to improve the management of lands already protected. Here, we assess biodiversity and ecological integrity along the entire AT among 2,123 trail sampling segments and four planning regions. We evaluated gradients of biodiversity and ecological integrity in relation to the existing management status of trail sampling segments to identify gaps in protection of high value areas. The AT possesses high species diversity at the southern end, where much of it exists in federal multiple-use management, and high ecological integrity in the north on private timberlands. Inadequately protected areas of such high biological diversity and ecological integrity occur throughout the trail. Our data are analyzed at the scale of the entire AT with summaries and comparisons among broad sections, regions, states, and some specific locations. We include our spatial data so that it may be used for analyses and prioritization at multiple scales from the local maintenance club to the ATC.

KEYWORDS
Appalachian Mountains, Appalachian Trail, biodiversity, climate change, conservation, wilderness

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INTRODUCTION

The Appalachian Trail (AT) protects 101,000 ha (250,000 acres) in a 305-m (1000-ft) corridor from Georgia to Maine (Figure 1), making it one of the largest National Park Service (NPS) units in the eastern United States, enjoyed by 2–3 million people each year (Appalachian Trail Conservancy, 2015). It has also facilitated the protection of much larger contiguous blocks along its extent in national forests, national parks, state lands, and private land protection projects. Although the AT was not established explicitly to protect such values as ecological integrity and species diversity, its wilderness environment has facilitated protection of these qualities for their own sake and the sake of the human experience. Attainment of the full conservation potential of the AT now requires assessment of the distribution of ecological values with respect to the protective status of adjacent land along the length of the AT to provide guidance on where more work may be done to protect these values from mismanagement or loss through land use conversion.

In this paper, we focus on ecological integrity and species richness as indicators of conservation value. Ecological integrity reflects the degree to which land remains free of the degrading human effects on ecosystems (Theobald, 2013). Areas of high ecological integrity may be considered conservation priorities as they represent relatively permeable lands likely conducive to species movements (sensu Theobald, Reed, Fields, & Soulé, 2012, Krosby et al., 2015, Belote et al., 2016), as well as ecosystems with intact structure and function. In contrast, data representing geographic gradients in species richness have been used to identify hotspots of biological diversity and conservation priorities associated with species protection (Jenkins, Van Houtan, Pimm, & Sexton, 2015). While richness patterns alone fail to account for patterns of complementarity among species distributions (Brown et al., 2015), hotspots of species can be used as a coarse-scale assessment to evaluate areas rich in species but lacking conservation protection (sensu Albuquerque & Beier, 2015). Although high species richness is not necessarily associated with rarity and threat to a species at smaller scales (Lennon, Koleff, Greenwood, & Gaston, 2004; Lombard, 1995; Pearman & Weber, 2007), richness is positively associated with high endemism (Ceballos, Rodrigues, & Medellin, 1998, Xu et al., 2008) and rarity and threat at larger scales (Berg & Tjernberg, 1996; Cofre & Marquet, 1999; Curnutt, Lockwood, Luh, Nott, & Russell, 1994; Tardif & DesGranges, 1998). Species richness at larger scales is, therefore, a potentially useful indicator for spatial prioritization of conservation areas.

Although significant conservation work has already been accomplished along the Appalachian Trail, additional protections are needed to fulfill its conservation potential. The biological diversity and ecological integrity of the corridor and its greater landscape are under increasing stress, including habitat loss and fragmentation, air and water pollution, regional development and land use, soil compaction, trampling, invasive species, and illegal collection of rare plants (NPCA, 2010). Compounding the impacts of these threats to biological diversity is a changing climate. The Appalachian region is projected to experience increased temperature and moisture deficit (Wang, Hamann, Spittlehouse, & Carroll, 2016), resulting in geographic shifts in species distributions as they track climate change (Lawler, Ruesch, Olden, & McRae, 2013). Halpin (1997) suggested the Appalachian mountain range may facilitate adaptive movements of species in response to climate change, and Hunter Jr., Jacobson Jr., and Webb III. (1988) specifically suggested that the

FIGURE 1 The route of the Appalachian Trail in relation to the Appalachian Mountain range topography. The trail variously follows the heights of the mountain range and the lower elevations and valleys at the eastern edge of the range. Thirteen areas are identified for reference: 1, Springer Mountain, Georgia; 2, Great Smoky Mountains National Park; 3, Roan Mountain, Tennessee; 4, Mount Rogers, Virginia; 5, Shenandoah, National Park; 6, Harpers Ferry, West Virginia; 7, Susquehanna River, Pennsylvania; 8, Delaware Gap, New Jersey; 9, Hudson River, New York; 10, Green Mountains, Vermont; 11, White Mountains, New Hampshire; 12, Maine’s 100-mile wilderness; 13, Mount Katahdin, Maine
Appalachian Trail corridor itself may serve that role. Carroll, Parks, Dobrowski, and Roberts (2018) recently mapped future paths organisms may need to traverse to track changes in climate, showing the Appalachian chain with its north–south orientation to be a critical area for connectivity under a changing climate. Unfortunately, much of the landscape outside of the trail corridor is privately owned and remains vulnerable to development, especially in the mid-Atlantic and northern regions of the trail (Mittlefehldt, 2013; Potere, Woodcock, Schneider, Ozdogan, & Baccini, 2007). Privately owned commercial forests in the north have been harvested heavily through short rotations over the last 200 years resulting in ecological degradation and fragmentation. Even more concerning, the timber industry is in the process of divesting of its ownership in northern New England, putting all forests at risk of eventual permanent conversion to residential, commercial, and energy generation and transmission development. Across Virginia and the Southern region of the trail, multiple-use national forest lands are subject to timber harvest, road building, and development of energy infrastructure (e.g., pipelines), resulting in habitat loss and fragmentation. In this paper, we briefly review the conservation history of the AT, examine where biological diversity and ecological integrity remain high, and consider where additional conservation action may help protect the AT’s values in the face of these threats.

2 | HISTORICAL BACKGROUND

Nearly a century ago, forester and regional planner Benton MacKaye (1921) first proposed the idea of an Appalachian Trail footpath in an article entitled “An Appalachian Trail: A Project in Regional Planning.” Four years later, MacKaye founded the Appalachian Trail Conference (ATC) to engage volunteers in the trail effort and served as its first president. MacKaye’s proposal for a 3,219 km (2000 mile) footpath along the spine of the Appalachian Mountains was intended to provide half the United States’ population the opportunity to escape “the scramble of every-day worldly commercial life.” (MacKaye, 1921). He also envisioned the trail as a “physical and symbolic wilderness bulwark against the inroads of modern industrialism, urbanism, and commercialism.” (Anderson, 2002). In his 1928 book “The New Exploration,” MacKaye (1990) described the AT as “the backbone of Appalachian America...the barrier of barriers within the world-empire of industrial and metropolitan upheaval.”

MacKaye also saw the trail effort as much more than a narrow backbone, stating in his January 1923 address to the New England Trail Conference: “This is not to cut a path and then say – ‘Ain't it beautiful!’ Our job is to open up a realm. This realm is something more than a geographical location—it is an environment. It is the environment, not of road and hotel, but of trail and camp. It is human access to the sources of life.” (Anderson, 2002). MacKaye prepared remarks delivered by ATC Vice President Harvey Broome to the 1931 meeting in Gatlinburg, Tennessee that elaborated on the concept of the “realm,” stating, “A realm and not a trail marks the full aim of our effort,” (Anderson, 2002) and explained that “[o]ur realm must be broad as well as long.” (Anderson, 2002). This realm was to simultaneously conserve wilderness and humanity, and it required sufficient physical space to achieve this goal. Under the leadership of Myron Avery, third president of the ATC, this “backbone of Appalachian America” was completed as a continuous marked trail in 1937. Avery worked tirelessly to secure permission and build trails across public and private lands (Anderson, 2002; Ryan, 2017). Even if the AT did not always track the wildest lands or public lands, completion of a continuous marked trail was instrumental to the passage of the National Scenic Trails Act of 1968 designating the Appalachian Trail a National Scenic Trail along with the Pacific Crest Trail. This designation has ultimately provided funding and legal mechanisms used to secure permanent protection of the roughly 305-m (1,000 ft) trail corridor, completed in the last decade.

While not its original intent, expectations of the trail as part of a biodiversity conservation strategy grew in the latter part of the 20th century as more land for the treadway itself came under permanent protection. Charles H.W. Foster, former chairman of the National Scenic Trail Advisory Council, suggested that the AT could contribute to a bioregional conservation program (Foster, 1987). The ATC launched the MeGa Transect Program in 2000 to initiate long-term ecological studies including the effects of climate change (Dufour & Crisfield, 2008; Mittlefehldt, 2013). This program was conceived as a partnership engaging citizen scientists, state and federal agencies, and non-governmental research and conservation organizations. In 2005, the ATC changed its name to the Appalachian Trail Conservancy to reflect a focus on conserving the surrounding landscape, sustainable management of the corridor itself, and community development around the trail.

The Appalachian Trail Conservancy, the NPS, land trusts, and conservation advocacy organizations started convening annually as the Appalachian Trail Landscape Partnership in the fall of 2015. This partnership seeks to accelerate the pace and increase the scale and ecological relevance of efforts to conserve lands outside of the protected trail corridor to address global stressors on biological diversity (Shaffer, 2016). As this century-long progression of mission and expectations from wilderness-way for human well-being and recreation to large scale biological conservation draws
to an end, it is time to systematically assess ecological values and the conservation status of the AT.

3 METHODS

Following methods developed by Belote, Cooper, and Daniels (2017), we obtained the spatial data representing the current roadway location of the Appalachian Trail from the Appalachian Trail Conservancy and imported the file into a geographic information system using ArcGIS v. 10.5 (Environmental Systems Research Institute, Redlands, CA). We split the AT into 1.6-km (1-mile) segments and numbered them from 1 to 2,124 from the southern to the northern terminus, a length that contrasts with the 2,190 miles cited by the ATC, due to differences in the methods used to assess trail length. We spatially joined these segments to data on species richness, ecological integrity, and protection status along the trail (see Table 1 for the data sources used in this analysis). Species richness data were calculated by Jenkins et al. (2015) by overlapping range maps for 6 different taxonomic groups (mammals, birds, amphibians, reptiles, freshwater fish, and trees). (We also include biodiversity priority [Jenkins et al., 2015] and rarity weighted richness [NatureReserve, 2013] for comparison to species richness to help interpret the significance of this parameter as a determinant of conservation priority in Appendix 1) We quantified ecological integrity for each segment by extracting human modification data (Theobald, 2013) and plotting a rescaled version of its complement ([1-HM] × 100) along the full AT. We transformed the data in this way so that higher values represented greater ecological integrity and multiplied the complement by 100 to convert the values to integers to more efficiently combine data in our GIS. A loess smoothing line (a technique similar to a moving average) using 0.1 sampling proportion from SigmaPlot v 11.0 (Systat Software, San Jose, CA) is shown to highlight general trends along the trail. To provide broad multi-state context of the ecological integrity and species richness along the trail, we compared the species richness and ecological integrity values for AT segments to the median value and the 75, 80, 85, 90, 95, and 99th percentiles across the 14 states traversed by the AT.

We assessed the conservation status of lands along the AT corridor using the protected areas database (PAD), developed by the Conservation Biology Institute (CBI, 2015), combined with data on U.S. Forest Service Inventoried Roadless Areas (USDA Forest Service, 2001) and the National Conservation Easement Database (NCED, 2011). IRAs are afforded some protection from multiple use management but are vulnerable to administrative decisions and reversal of this status; therefore, this designation is a unique level of protection. The conservation easement database does not consistently distinguish among easement requirements. So-called “working forest” easements, which allow harvest but forbid land use conversion, are pooled with easements that require wilderness management. Large-scale working forest easements in Maine, for example, are generally considered a GAP 3 management regime. Unfortunately, the GAP 3 designation in the PAD does not identify these working forest easements as GAP 3.

We buffered our segmented AT spatial data by 1-km on either side of the trail to evaluate the conservation status of lands beyond the narrow AT corridor protected by the NPS. Potere et al. (2007) showed that the level of protection generally declines with distance from the AT (out to 16 km). Our 1-km buffer represents the distance beyond which development likely would not produce direct edge effects on the trail corridor, though this buffer size may be insufficient for achieving all conservation objectives. Abiotic edge effects have been demonstrated to extend to hundreds of meters into the forest (reviewed by Saunders, Hobbs, & Margules, 1991), and biotic edge effects have been demonstrated to occur hundreds of meters into forest interior (Andren & Angelstam, 1988; Batary & Baldi, 2004; Haddad, 2015; Haddad, Holt, Fletcher Jr, Loreau, & Clobert, 2017; Laurance et al., 2017; Paton, 1994; Wilcove, McLellen, & Dobson, 1986). We selected the 1 km buffer to exceed the maximum edge effect distance demonstrated in most of these studies (Beier, 2018). Beier (2018) recently published a rule of thumb for minimum corridor width based on the need, he argued, to provide overlapping home ranges for long term transitory residents. His rule of thumb posits that a 2-km total width will accommodate 96% of corridor dwelling mammal species (Beier, 2018). We rasterized this buffered sampling area using a 270-m resolution grid, which

| Data                      | Source                        | Resolution | Sampling area within each AT segment           |
|---------------------------|-------------------------------|------------|-----------------------------------------------|
| Ecological integrity      | Theobald, 2013                | 270 m      | 270 m grid cells along the AT                 |
| Species richness          | Jenkins et al., 2015          | 10 km to 270 m | 270 m grid cells along the AT                  |
| Protected areas           | Conservation Biology Institute | 270 m (from polygons) | 270 m grid cells within 1-km buffer on either side of AT |

Abbreviation: AT, Appalachian Trail.
resulted in 562,227 ha of total area (77,123 grid locations) along the buffered AT.

We then combined data from the PAD, IRAs, and NCED with our buffered segmented AT layer allowing us to evaluate the composition of conservation lands for each segment of the AT. In cases where the conservation status of lands overlapped (e.g., IRAs are located on GAP 3 status lands), we classified lands using the highest level of protection (GAP 1 and 2 lands were assigned before IRAs, then GAP 3, then NCED lands, then GAP 4, unknown or other). We then plotted GAP status classification, roadless status, and easement status for each segment of the AT. GAP status is a classification of conservation protection based on the management and protection of lands (USGS GAP, 2011). Please refer to Table 2 for definitions of these protection categories. The NCED category is considered a lower level of protection than GAP 3 for its inclusion of large scale working forest easements that typically do not provide biodiversity protections as robust as the GAP 3 multiple-use management of national forest lands.

To assess future conservation opportunities, we identified all segments that had at least 20% of their area belonging to one or more of the following categories: IRA, GAP 3, NCED, and GAP 4 and that also possessed areas of ecological integrity above the median value (high integrity) or species richness above the median value (high richness). We used these criteria to select high-value, under-protected segments of the AT. We selected a 20% threshold to identify segments that had a potentially ecologically meaningful start on conservation of the segment (IRA, GAP 3, conservation easement) but that could still benefit from adding area to the segment's protected lands in that category or elevating the existing lands to a higher order GAP status. We also selected a 20% threshold to identify segments that had a potentially ecologically meaningful area lacking any protection at all (GAP 4) that would benefit from elevation of GAP 4 to a status that would, at the very least, preclude land cover conversion.
RESULTS

Figure 1 shows the AT in relation to Appalachian Mountain topography, as the trail's origin, scenic appeal, enduring wildness, ecological value, and conservation value owe much to this terrain. The Appalachian Trail begins in the Appalachian Mountains of Georgia and climbs to its high point of 2025 m (6,643 ft.) at Clingman's Dome in Great Smoky Mountains National Park. Through the South, it generally remains above 1,000 meters before descending to the Potomac River at Harpers Ferry, West Virginia. For approximately the next 500 miles the AT stays below 500 meters crossing the Hudson River before ascending the mountainous topography of New England to Maine's Mt. Katahdin. Figure 1 identifies 13 geographic points throughout the trail to assist interpretation and discussion of the results in several of the subsequent figures.

Based on predicted occurrence from range maps, peak species richness occurs near the Georgia-South Carolina border with 582 combined species of mammals, birds, reptiles, amphibians, fish, and trees (Figure 2). Species richness reaches its lowest value of 281 species of combined taxa in northern Maine. All taxa exhibit this broad pattern except birds, which peak at 249 species in the lowlands between the Delaware and Hudson Rivers (Figure 2). Fish diversity is particularly high in the watersheds of the first 600 miles of trail in the Southern Appalachians, with over 200 species of freshwater fish. Tree species richness varies between 75 and 100 species throughout most of the trail before dropping to about 50 in New England. Mammal, amphibian, and reptile richness all show a less dramatic but consistent decline in richness from south to north. We have provided a comparison among species richness of major taxa (birds, fish, mammals, trees, amphibians, reptiles) combined, biodiversity priority index value (Jenkins et al., 2015) based on biodiversity representation among protected lands, and rarity weighted richness (Natureserve, 2013) in Appendix S1 to demonstrate how these three parameters signal diversity and conservation priority at different scales.

The plot of species richness contrasts with ecological integrity, which fluctuates as the trail crosses tracts of forest far from roads (high integrity) and developed areas or roads (low integrity) (Figure 3). Ecological integrity drops to zero where trail segments cross roads in every state except New Hampshire and Maine. The loess smoothing line plotted for ecological integrity drops from the southern region to its lowest values in the middle Atlantic near Harper's Ferry, West Virginia and the Hudson River Valley. The value then climbs consistently from the Green Mountains of Vermont to its highest point in the 100-mile Wilderness and Baxter State Park (Figure 3).

Within the entire buffered sampling area along the AT, 33% is in GAP 1 or 2 status lands, 4% is in inventoried roadless areas, 27% is in GAP 3 (as defined by PAD and,
therefore, excluding GAP 3 working forest easements), 3% is within conservation easements, and the remaining 32% of land is classified as GAP 4 or otherwise has an unknown conservation status (Table 3). If there were overlapping polygons of protection category, we only counted the highest level of protection for that point in space.

Roadless areas and GAP 3 as defined by the PAD are more common in the South and Virginia, where national forests predominate (Figure 4). Easements are more common in New England but achieve their highest level on the stretch of the Trail cared for by the Old Dominion ATC in Virginia (Table 3). New England and Virginia also have a substantial proportion of land in GAP 4 or without known conservation protections, whereas only 12% of the South is in GAP 4 or without known protections. Gap 1 and 2 protection is more common in the Mid-Atlantic and New England, but all regions exhibit stretches with high proportions in GAP 1 and 2. Maine's 38.8% in GAP 1 and 2 is achieved via Baxter State Park, White Mountain National Forest, and state ecological reserves. While the state writ large has substantial GAP 3 forests in conservation easement, little of that GAP 3 is adjacent to the AT and by and large the PAD fails to identify it as GAP 3.

Eighty two percent of the trail scores above the 50th percentile for ecological integrity for all 14 states traversed by the AT (Table 4). Areas of high ecological integrity on IRAs are concentrated, predictably, where national forests intersect the AT in the southern Blue Ridge, Virginia, Vermont, and New Hampshire (Figure 5a). Areas of high integrity on GAP 3 and GAP 4 are found over most of the trail (Figure 5b,d), including much of Maine's privately owned industrial forestlands surrounding the trail corridor. High-integrity lands on conservation easements are concentrated in New England (Figure 5c).

More than one third of the trail (38%) scores above the 50th percentile for species richness for all 14 states traversed by the AT (Table 4). Areas of high species richness on IRAs are found where national forests of the southern Blue Ridge and Virginia intersect the AT (Figure 5e). Areas of high species richness in GAP 3 and GAP 4 occur throughout the southern Blue Ridge, Virginia, and northeastern Pennsylvania (Figure 5f,h), with high species richness occurring in GAP 4 in the Hudson River Valley of New York (Figure 5h). Conservation easements with high species richness occur in the Hudson River Valley, and in central and southern Virginia (Figure 5g).

5 | DISCUSSION

Since its establishment, the AT has served as a footpath corridor spanning the Appalachian Mountains, a globally significant hotspot of biodiversity possessing relatively large contiguous forest blocks. In recent decades the trail has inspired conservation protections around the footpath. Until now, we have lacked a systematic and spatially explicit assessment of the AT. Our assessment illustrates geographic gradients in ecological integrity and richness. Ecological integrity is generally higher along the trail landscape than surrounding lands and is highest in northern New England and the southern Appalachians (Table 4). Higher integrity areas are often higher elevation areas that have experienced less human intervention. Species diversity is generally higher in the southern Appalachians than the northern Appalachians but lower along the trail landscape compared to the states traversed (Table 4), possibly due to the trail's location at the highest end of the elevation gradient (Whittaker, 1956; see review in Kozak and Wiens, 2010). Our analysis helps identify where to focus conservation efforts to increase protection of the most ecologically intact and species rich areas within a 2-km buffer which may be the minimum corridor.
| ATC region | Club | GAP 1 or 2<sup>a</sup> (%) | IRAs<sup>b</sup> (%) | GAP 3<sup>c</sup> (%) | NCED<sup>d</sup> (%) | GAP 4 or Unknown<sup>e</sup> (%) |
|------------|------|-----------------------------|---------------------|----------------------|----------------------|-------------------------------|
| South      | Carolina Mountain Club | 0.6 | 9.9 | 70.0 | 0.0 | 19.6 |
|            | Georgia Appalachian Trail Club | 43.5 | 8.4 | 45.2 | 0.1 | 3.0 |
|            | Nantahala Hiking Club | 22.6 | 9.1 | 62.4 | 0.2 | 5.8 |
|            | Smoky Mountain Hiking Club | 71.9 | 5.8 | 14.8 | 0.4 | 7.1 |
|            | Tennessee Eastman Hiking and Canoeing Club | 10.5 | 13.7 | 58.0 | 0.1 | 17.8 |
| Total      | | 29.1 | 9.7 | 49.4 | 0.1 | 11.8 |
| Virginia   | Mt. Rogers Appalachian Trail Club | 34.6 | 3.6 | 52.0 | 0.0 | 9.9 |
|            | Natural Bridge Appalachian Trail Club | 28.8 | 10.5 | 49.1 | 0.3 | 11.3 |
|            | Old Dominion Appalachian Trail Club | 46.3 | 0.0 | 7.7 | 9.1 | 37.3 |
|            | Outdoor Club at Virginia Tech | 16.6 | 18.6 | 24.6 | 0.8 | 39.6 |
|            | Piedmont Appalachian Trail Hikers | 15.9 | 16.3 | 41.9 | 1.6 | 24.3 |
|            | Roanoke Appalachian Trail Club | 17.2 | 1.9 | 38.8 | 7.7 | 34.5 |
|            | Tidewater Appalachian Trail Club | 74.2 | 0.0 | 3.8 | 0.3 | 22.0 |
| Total      | | 25.0 | 7.6 | 40.1 | 3.2 | 24.1 |
| Mid-Atlantic | Allentown Hiking Club | 0.0 | 0.0 | 54.1 | 0.0 | 45.9 |
|            | AMC—Delaware Valley Chapter | 9.7 | 0.0 | 35.1 | 0.4 | 55.0 |
|            | Batona Hiking Club | 25.3 | 0.0 | 0.0 | 4.8 | 70.0 |
|            | Blue Mountain Eagle Climbing Club | 13.9 | 0.0 | 53.5 | 0.1 | 32.5 |
|            | Cumberland Valley A.T. Club | 0.0 | 0.0 | 5.9 | 2.1 | 92.1 |
|            | Mountain Club of Maryland | 2.3 | 0.0 | 39.6 | 1.9 | 56.2 |
|            | New York—New Jersey Trail Conference | 44.0 | 0.0 | 8.9 | 1.8 | 45.4 |
|            | Philadelphia Trail Club | 2.8 | 0.0 | 37.0 | 0.0 | 60.5 |
|            | Potomac Appalachian Trail Club | 53.0 | 0.0 | 13.5 | 3.3 | 30.1 |
|            | Susquehanna Appalachian Trail Club | 2.0 | 0.0 | 62.2 | 1.5 | 34.3 |
|            | Wilmington Trail Club | 62.7 | 0.0 | 0.0 | 0.3 | 37.2 |
|            | York Hiking Club | 0.0 | 0.0 | 3.0 | 0.0 | 97.0 |
| Total      | | 36.4 | 0.0 | 21.1 | 2.1 | 40.4 |
| New England | AMC—Berkshire Chapter | 30.6 | 0.0 | 22.2 | 6.1 | 41.2 |
|            | AMC—Connecticut Chapter | 15.4 | 0.0 | 12.6 | 4.0 | 68.1 |
|            | Appalachian Mountain Club | 70.3 | 11.9 | 4.8 | 0.1 | 13.0 |
|            | Dartmouth Outing Club | 31.9 | 0.6 | 3.2 | 5.4 | 58.9 |
|            | Green Mountain Club | 26.2 | 5.7 | 38.8 | 3.1 | 26.2 |
|            | Maine Appalachian Trail Club | 38.8 | 0.0 | 0.2 | 9.0 | 52.1 |
| Total      | | 38.3 | 3.0 | 11.6 | 5.4 | 41.8 |
| Grand total mean | | 33.4 | 4.4 | 27.4 | 3.0 | 31.8 |

Abbreviations: AMC, Appalachian Mountain Club; AT, Appalachian Trail; ATC, Appalachian Trail conservancy; IRA, inventoried roadless area; NCED, National Conservation Easement Database.

<sup>a</sup>Managed for biodiversity.
<sup>b</sup>Managed as roadless area.
<sup>c</sup>Managed for multiple use.
<sup>d</sup>Conservation easement wilderness or multiple use.
<sup>e</sup>Privately held no protection status.
needed to facilitate movement of organisms (Beier, 2018). The need for establishing connected landscapes across latitudes in response to changing climate is increasingly clear (Lawler et al. 2013, Carroll et al. 2018).

The high-integrity lands of northern New England are primarily GAP 4 in Maine's private industrial forest lands (Figure 5d) and represent an opportunity to first ensure protection of these lands from permanent conversion by minimally elevating their status to GAP 3. This single incremental improvement in management is a significant step and maintains options for even better management or higher levels of protection at some future date. After two centuries of using Maine's forests to supply lumber and paper mills, the forest products industry in Maine has sold off much of its holdings. These lands are typically sold to real estate investment trusts and timber investment management organizations, who prioritize short-term yields over long-term stewardship. Private lands possessing high species richness in smaller parcels occur throughout the Mid-Atlantic and northern Virginia regions and southern New England (Figure 5h). These private lands surround the AT in places where only the 1,000-ft corridor ensures permanent protection. Elevation to GAP 3 would benefit these areas by minimally ensuring the land remains in native land cover instead of being converted.

In addition, there is a significant conservation opportunity in the Southern and southern Virginia regions on federal lands in GAP 3 management. Those GAP 3 lands scoring high on ecological integrity (Figure 5b) and species richness (Figure 5f) are good candidates for improved conservation management by elevation to GAP 1 or 2, prioritizing protection of ecological integrity and biological diversity over resource extraction. High ecological integrity areas in IRA (Figure 5a) and high species richness areas in IRA (Figure 5e) are similarly good candidates for elevation to GAP 1 and 2 protection.

This opportunity also applies to some of the high integrity and species rich lands protected by conservation easements (Figure 5c and Figure 5g). The conservation easement database does not distinguish working forest easements of northern New England, which are likely GAP 3, from easements managed as wilderness. Working forest easements are typically considered to be under GAP 3 management and are not identified within the PAD as GAP 3. In general, though, large scale conservation easements in Maine are managed as GAP 3 according to the easement terms. These conservation easement lands, though protected from permanent land use conversion, would benefit from elevation to GAP 1 or 2.

Potere et al. (2007) examined the short term loss of forest cover primarily from timber harvest within 4 km of the Trail and found that 75,000 acres of forest cover was lost between 1990 and 2000, including approximately 4% of multiple use

**TABLE 4** Number and percent of AT trail segments with average ecological integrity and species richness values greater than select percentile values of pixels for the 14 states through which the AT passes.

| Select percentile breaks | Ecological integrity | Species richness |
|--------------------------|----------------------|------------------|
|                          | Number of AT corridor segments greater than select percentile | Percent of AT corridor segments greater than select percentile | Number of AT corridor segments greater than select percentile | Percent of AT corridor segments greater than select percentile |
| 50th                     | 1,751                | 82 | 809 | 38 |
| 75th                     | 1,098                | 52 | 549 | 26 |
| 80th                     | 833                  | 39 | 541 | 25 |
| 85th                     | 618                  | 29 | 466 | 22 |
| 90th                     | 411                  | 19 | 193 | 9 |
| 95th                     | 201                  | 9  | 50  | 2 |
| 99th                     | 9                    | <1 | 3   | <1 |

Abbreviation: AT, Appalachian Trail.
GAP 3 national forest lands between Georgia and Southern Virginia and approximately 2% of GAP 4 private industrial lands, mostly in Maine. Even worse than short rotation harvests and targeting late seral stages for harvest in National Forest is the permanent loss of forest cover when land is converted to another use. The Vital Signs study of the entire Appalachian Trail (Shriver, 2005) examined a number of indicators of concern relevant to current and future trail condition, including land use change in the Northeast and concluded, “In the Northeast, most ecosystems have
experienced loss and fragmentation of habitat, and these changes are a principal threat to native biodiversity.” We agree with the Vital Signs report with the clarification that it is permanent conversion of private land to non-forest that leads to the permanent loss of habitat, while timber harvest leads to creation of different habitat.

Halpin (1997) suggests that establishment of continental-scale “connective corridor systems” as a climate adaptation strategy in North America would have to be centered along the three major mountain ranges including the Appalachians. He cites the concentration of native vegetation and public lands along these mountain ranges, as our best opportunity to capitalize on existing ecological values and conservation already in place. Numerous authors have also noted the potential adaptation value and resilience of complex mountain landforms and terrain (Anderson & Ferree, 2010; Beier & Brost, 2010; Hunter Jr. et al., 1988). More recently, Carroll et al. (2018) modeled future climate movement for North America and identified a potential corridor along the extent of the Appalachian Mountains.

Our work is intended to identify priority areas for expansion and better management of this potential “connective corridor system.” If the AT is to serve this function, multiple strategies must be employed along the trail. Strategies include better management of GAP 3 national forest lands and permanent protection of IRA lands with high species richness or high integrity. Other strategies will require outright purchase of GAP 4 private lands in small non-industrial parcels along the trail corridor in places such as the Mid-Atlantic region and purchase of large-scale GAP 4 private industrial forestlands in northern New England or at the least purchase of large scale working forest easements. Existing GAP 3 working forest easements of Northern New England with high ecological integrity relative to the entire trail might benefit from elevation to GAP 1 or 2. Such trail-wide evaluation can be used to steer and motivate conservation at the national level among partners such as the Large Landscape Partnership convened by NPS and ATC. It is our hope that individual conservation entities operating at smaller scales will use our analyses directly or as a guide to their own analyses using our data rescaled for their own landscape extents and relative comparisons.

Our publicly available data (Appendix S2) may be applied to make relative comparisons within smaller landscape extents at the state or ATC club or local land trust level. As an example of this scalable application of our work, The Wilderness Society (TWS) has worked with the Maine Appalachian Trail Land Trust (MATLT) who use Land and Water Conservation Fund awards with state matching funds and other funding sources to protect industrial forest lands with working forest easements and ecological reserves. TWS also works at regional and local scales in the Southern Appalachians in the national forest planning process. GAP 3 national forest lands scoring highly in ecological integrity and species richness are good candidates for elevation to GAP 1 or 2 levels of protection. Conservation planners interested in making relative comparisons of values, threats, and conservation opportunities along trail segments (at any scale) should refer to Appendix S2 for access to all spatial data used in these analyses.

In conclusion, neither MacKaye nor Avery could have foreseen the present day need or expectation that the AT corridor serve a role in large-scale biological conservation. Nonetheless there is substantial overlap in the value sets that interested them in their day and the ecological values we seek today for regional conservation planning. For its first 70 years, the Appalachian Trail Conference (now known as the Appalachian Trail Conservancy) was dedicated primarily to mapping, blazing, building, and conserving the narrow footpath itself. MacKaye’s vision and Avery’s perseverance enabled the trail’s completion but much opportunity remains to protect MacKaye’s broader “Realm”.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

AUTHORS CONTRIBUTIONS

All authors contributed equally to conception and development of the paper. R.T.B. performed the majority of the GIS analyses and P.M. was responsible for overseeing assembly for publication.

DATA ACCESSIBILITY

The data included in this work is open access, including Supporting Information Appendix S2.

ETHICS STATEMENT

The authors declare that this manuscript is not published elsewhere.

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SUPPORTING INFORMATION
Additional supporting information may be found online in the Supporting Information section at the end of this article.

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