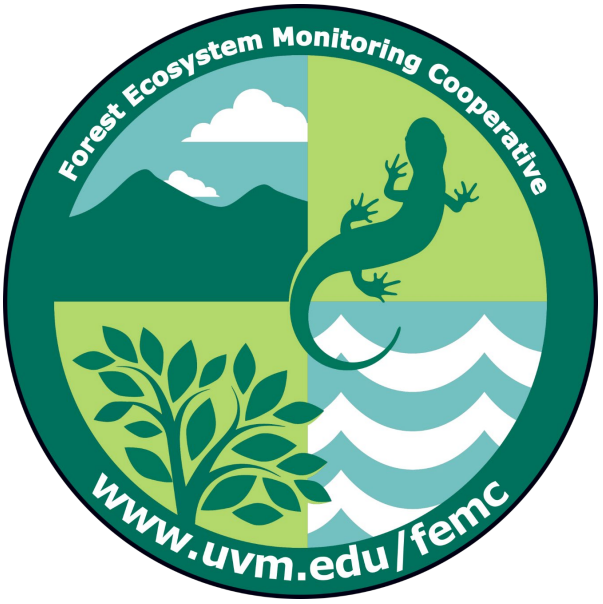

MONITORING THE CONNECTION BETWEEN FOREST HEALTH AND OUTDOOR RECREATION

Monitoring the Connection Between Forest Health and Outdoor Recreation

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Contents

Executive Summary

An exploratory literature review was conducted to assess the state of available monitoring of the impact of outdoor recreation on forest health in the Northeast. Given the increasing use of forests for recreation, this search supported the need to identify options for monitoring aspects of forest health that interact with recreational uses. Academic databases were initially searched for articles assessing the effects of specific recreation types (i.e., hiking, mountain biking, camping) and outdoor recreation in general.

Availability of long-term data in this region is limited. There are some datasets that can be useful, but do not directly monitor changes in forest health as a result of recreational use. The majority of recreation impact monitoring is based in the western United States. Existing studies in the Northeast are generally site-specific and limited to one dimension of forest health at one point in time. Protected areas are popular study locations, such as Acadia National Park, White Mountain National Forest, and the Appalachian Trail.

Within existing research, the most common results involve impacts on soils and vegetation, due to historical research trends and observable, easily measured changes in these resources. Impacts on wildlife and the dispersal of invasive plant species are of increasing interest, but minimal research makes a direct connection to recreational uses. Some experimental studies do investigate and measure the spread of seeds via mountain bike tires and hiking boots (Hardiman, Dietz, Bride, & Passfield, 2017).

“Recreation ecology” is the area of study documenting the effects of outdoor recreation on natural systems. Some studies specific to the Northeast are available, but most are based in the western United States, Europe, or Australia. Overall, more data collection and monitoring efforts are needed in this region. Future regional monitoring efforts should replicate existing research to document and assess trends in northeastern forest health. Graduate students, recreation ecologists, and trained citizen scientists could be well-suited to implement monitoring protocols and collect data.

Literature Review

INTRODUCTION

Outdoor recreation in natural areas is an attractive outlet for individual well-being. Spending time in nature has positive effects on human physical and mental health (Russell, et al., 2013). Forest-based recreation in particular contributes to human wellness and has seen increasing participation since COVID-19 (Forestry, 2022). Hiking, camping, and mountain biking are popular activities enjoyed in forests. While outdoor recreation has its benefits, these uses impact the natural resources being explored and enjoyed.

Recreation ecology is the primary area of study dedicated to measuring and monitoring this impact (Monz, Cole, Leung, & Marion, 2010). Financial support for recreation ecology studies originated in the National Park Service (Cole, Reflections on the early history of recreation ecology, 2021). Subsequently, the majority of areas studied were on public lands in states like Montana, Colorado, and Utah. In addition, a focus within federal agencies resulted in a focus on backcountry areas and less adherence to academic discipline (Cole, Reflections on the early history of recreation ecology, 2021).

Studies documenting the effects of recreation in Northeastern forests are limited. While popular protected areas like Acadia National Park have been examined within the past few decades (Marion, Leung, Eagleston, & Burroughs, 2016; Monz, et al., 2010), other forested areas are not being systematically monitored in relation to outdoor recreation. Furthermore, most research occurs at a specific site, at one point in time. Gaps remain to monitor regional forests in long-term studies. While there are some sources available, more systematic investigations over time are needed to document and assess trends in impacts visitors have on regional forest resources. Additional visitor impact monitoring will help current and future land managers care for our forests more effectively (Monz, Cole, Leung, & Marion, 2010). For more information on sources, please see the Annotated Bibliography.

METHODS

This literature review documents research capturing impacts from outdoor recreation in forests of the northeastern United States. Academic research databases were the starting point for this search, slowly expanding to websites of regional government agencies and programs like Mountain Birdwatch.

Based on results from preliminary interviews with regional land managers, primary categories explored were the influence of outdoor recreation on the dispersal of invasive species, soil quality (i.e., erosion, compaction, and sedimentation in water bodies), and wildlife biology. Common recreational uses searched for included hiking, camping, mountain biking, and backcountry skiing. Keywords were used to search for sources based on these areas of interest. Popular keywords that yielded results or were included in the source are listed in Table 1.

Sources meeting research criteria were logged in a separate spreadsheet to use for future reference, documenting elements such as: forest health categories, metrics and monitoring protocols, location of study, and citations. Relevant sources identified in this literature review are also documented in the following sections, explaining types of recreational uses and ecological impacts.

TABLE 1. KEYWORDS USED IN SEARCHES THAT YIELDED DESIRED RESULTS ACROSS DATABASES.

Activity	"backcountry" or "trails"
	"hiking" or "camping"
	"recreation"
Forest Health Category	"soil"
	"invasive species"
	"wildlife"
Forest Health subcategory	"disturbance"
	"abundance"
Other	"impacts" or "effects" or "consequences"
	"monitoring"
	"northeast" or "eastern"
Exclusions	"western"
	"australia"
	"Europe"

RESULTS: RECREATIONAL USES

Non-Mechanized Activities

Popular recreational activities in northeastern forests include hiking, running, birdwatching, and horseback riding (Northeastern Forests, n.d.). Although horseback riding is present in regional forests, its primarily researched in the western United States. Hiking is a popular activity to research in the East, specifically impacts of trampling on soils and vegetation (Thurston & Reader, 2001; Ednie & Daigle, 2007; Monz, et al., 2010; Wilkerson & Whitman, 2010; Eagleston & Marion, 2020). Regional hiking trails have also been studied for impacts on wildlife (Deluca & King, 2014; Erb, McShea, & Guralnick, 2012; Garber & Joanna, 1995).

Camping is another regional forest-based activity monitored by researchers and land managers. Camping activities can induce substantial and localized resource impacts on soil, vegetation, and water (Newman, Monz, Leung, & Theobald, 2006). In the Northeast, impacts from camping have been explored in the context of spreading invasive species via firewood (Snell, et al., 2014), erosion, and trampling (Arredondo, Marion, Meadema, & Wimpey, 2021). While some sociological data exists on camper preferences for firewood and regional travel patterns (Koch, Yemshanov, Magarey, & Smith, 2012), additional long-term ecological data is needed to determine trends in impacts from this activity.

Mechanized Activities

Northeastern forests are also popular destinations for activities like hunting, snowmobiling, skiing, and mountain biking (Northeastern Forests, n.d.). Impacts associated with motorized and non-motorized travel differ greatly from those associated with equestrian and foot traffic (Monz, Cole, Leung, & Marion, 2010). Impacts of motorized activities in this region have been explored in the context of soils (Wilkerson & Whitman, 2010),

vegetation (Thurston & Reader, 2001), and wildlife (Hagen, 1999; Richens & Lavigne). However, multiple-use areas can complicate the ability to link impacts to one activity in particular.

Mountain biking, rock climbing, ATV riding, geocaching, and other mechanized recreational uses are increasing rapidly in participation, with minimal visitor impact monitoring. A recent literature review and roundtable session conducted by a graduate student at the University of Maine revealed a growing interest in mountain biking unmatched by research on its social, economic, and environmental impacts (Kuklinski, 2022). Limited research exists on the matter. One experiment in an Eastern deciduous forest concluded that biking and hiking can have similar physical impacts on vegetation and soil (Thurston & Reader, 2001). Another experiment quantified and compared the tendency for seeds to attach to hiking boots versus bike tires, but concluded that results are site-specific and cannot be generalized (Hardiman, Dietz, Bride, & Passfield, 2017). Additional descriptive research is needed on the ecological impacts of mountain biking and other mechanized activities (Monz, Cole, Leung, & Marion, 2010).

RESULTS: ECOLOGICAL IMPACTS

Changes in Soil Quality and Vegetation

Impacts of recreation on soils and vegetation dominate recreation ecology literature (Monz, Cole, Leung, & Marion, 2010). Pioneer studies date back to the 1970s, although long-term measurements are rare (Salesa & Cerda, 2020). Erosion and compaction have been experimentally researched and measured on trails (Marion, Leung, Eagleston, & Burroughs, 2016). Trampling and other visible impacts on vegetation tend to accompany soil impact monitoring, with an equally long history of study (Monz, Cole, Leung, & Marion, 2010). Recently, northeastern forests are also being monitored for the presence of the invasive "jumping worm," noteworthy for its negative impacts on forest health by altering soil horizons and the ability for forests to regenerate (Chang, et al., 2021). Citizen science data is being collected to monitor the presence of this species.

Data is more commonly available for hiking trails and campsites in forested areas formally managed for recreation, like wilderness areas and national parks (Cole & Wright, 2004). Acadia National Park is a common site for recreation ecology research in the Northeast (Ednie & Daigle, 2007; Monz, et al., 2010). Natural environments with higher levels of protection tend to receive greater attention from tourists and have an increased presence of trail networks (Salesa & Cerda, 2020). The gap in available research and data on this topic provides important opportunities for long-term monitoring. Opportunities remain to monitor forested areas that do not have a formal designation, such as privately-owned forests. According to Salesa and Cerda (2020), future research on mountain trail erosion should establish a common way to measure, monitor, and report findings. This will make regional scale comparisons and monitoring more feasible.

Nonindigenous Plant Species

"Nonindigenous," "alien," or "invasive" plant species impact forest productivity and quality of habitat for wildlife (Kurtz, 2010). However, the spread and impact of invasive species are difficult to link to a single variable like recreational use. Historical land uses tend to play an important role in the spread of invasive species and should be considered in conjunction with recreation (Mosher, Silander, & Latimer, 2009). Research indicates that invasions originate and spread most often from roadsides and trails (Mortensen, 2009; Allen, 2013). Forest roads in areas designated for recreation and hunting often spread invasive species, sometimes with localized invasions (Mortensen, Rauschert, Nord, & Jones, 2009). The distribution and abundance of invasive species can

be strongly influenced by habitat suitability in roadside environments, featuring disturbed soils and ample sunlight. Focusing studies on recreational roads and trails will be a practical approach for future monitoring efforts.

Seed dispersal by tourists has been explored in other parts of the world (Pickering & Mount, 2010). The Northeast is the most densely populated region in the U.S., with many opportunities for human-mediated introductions of pests and high recreation use in forests (Poland, et al., 2021). Furthermore, most forests in the East are privately owned and proximate to urban areas (Nelson, Liknes, & Butler, 2010). Efforts in this region could focus on outreach in urban areas and monitoring popular destinations. Management of invasive species requires work across institutional and ownership boundaries (Poland, et al., 2021). Sharing data and collaborating with private landowners will be a necessary strategy to properly prevent, identify, and monitor infestations.

Monitoring and management should also focus on habitat edges, where disturbance and potential for human-mediated seed dispersal are high. Some biotic resistance may help stop the spread of invasive species in the forest interior, but prevention is the best method to slow their spread. The phenology of species will need to be taken into consideration. More experimental studies are needed to address specific environmental drivers that affect groups of species in a similar way, enabling generalization beyond sites and individual species (Meyer, 2021).

Wildlife Biology

Forests provide food and shelter for hundreds of animal species, including mammals, birds, and amphibians (Northeastern Forests, n.d.). Effects of recreation on animals include behavior responses such as increased flight and vigilance, changes in spatial habitat use, physiological stress, reduced reproductive success, and altered species richness and composition (Larson, Reed, Merenlender, & Crooks, 2016). One long-term study monitored the decline of a wood turtle in a Connecticut forest before and after it was opened to hiking and fishing (Garber & Burger, 1995). Recreational uses were the direct cause of the extinction of the wood turtle in this forest. Other studies have monitored impacts of recreation on wildlife, but only in the short-term (Boyle & Samson, 1985; Deluca & King, 2014, 1999; Erb, McShea, & Guralnick, 2012).

Monitoring impacts of recreation on wildlife has lagged in comparison to vegetation and soil. Generalizing about wildlife responses is challenging given the variable responses of different animals to different situations (Cole, Reflections on the early history of recreation ecology, 2021). In addition, effects may manifest beyond where the data is captured. Regardless, more long-term monitoring is needed, as well as studies exploring management actions and the trends in impacts that follow.

Water Quality

Nobody has systematically studied water the way recreation ecologists have studied vegetation, soil, and wildlife (Cole, Reflections on the early history of recreation ecology, 2021). However, motorized, non-motorized, and non-mechanized trails all degrade stream quality (Wilkerson & Whitman, 2010). The impact of sedimentation on water quality in mountainous and forested environments needs more research (Salesa & Cerda, 2020).

CONCLUSION

In the final analysis, it is apparent that regional monitoring efforts documenting impacts of recreation on forest health is limited. Availability of regional data is minimal in the areas of interest, including dispersal of invasive species and impacts on wildlife. Multi-scale research designs and measures at multiple scales are needed to address large-scale issues over time (Monz, Cole, Leung, & Marion, 2010).

Although there is not data specifically gathered to monitor the connection between recreation and forest health, there are sources that could provide useful starting points. Mountain Birdwatch datasets could be leveraged in future analyses. Citizen science is a promising avenue for data collection. This method is also being leveraged to collect distribution data on invasive species (University of Georgia, 2022).

There are numerous articles published on the impacts of hiking and other uses on forest trails. Most of this research is based in the western United States, though there are some examples in the Northeast. As remote sensing technology becomes more accessible, other indicators to forest health have been increasingly monitored by interested parties, including impacts on wildlife and invasion of nonindigenous plant species. Impacts on wildlife have been monitored more frequently in recent years, but few studies explore the same species, ecosystem, or use the same methodology (Marion, Leung, Eagleston, & Burroughs, 2016). Addressing and reducing impacts of the spread of invasive species is an important goal (Forestry, 2022). However, this cannot be properly managed without adequate monitoring in regional forests. Opportunities remain to collect data on the impacts of outdoor recreation on wildlife biology, invasive species, and water quality (Marion, Leung, Eagleston, & Burroughs, 2016). Data specific to these connections will help guide proactive management of forest health in the face of rapidly increasing outdoor recreation.

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Invasive Species Dispersal

Hardiman, N., Dietz, K. C., Bride, I., & Passfield, L. (2017). Pilot Testing of a Sampling Methodology for Assessing Seed Attachment Propensity and Transport Rate in a Soil Matrix Carried on Boot Soles and Bike Tires. *Environmental Management*, 68-76. https://doi.org/10.1007/s00267-016-0773-4

This experimental study gave the first published quantification of the propensity for attachment of seeds on bike tires, in comparison to the soles of hiking boots. The experiment was a 2x2x2 factorial design conducted on a sampling track at a university, with commercially purchased topsoil and colored beads simulating seeds. Factors were the "vector" (boots versus bikes), soil condition (moist versus wet), and traversal distance (short versus long). Results indicated that, generally, more beads attached to boots than bike tires in the same conditions, wet soils, and over long traversal distances. However, results varied, and are difficult to compare with the limited number of previous experiments given different sampling protocols and site conditions. Although this is a cost-effective method for testing influencing factors on seed attachment and dispersal, the results are case-specific and cannot be generalized more widely.

Koch, F. H., Yemshanov, D., Magarey, R. D., & Smith, W. D. (2012). Dispersal of Invasive Forest Insects via Recreational Firewood: A Quantitative Analysis. *Journal of Economic Entomology*, 438-450. http://dx.doi.org/10.1603/EC11270

This study analyzed the risk of forest insect spread with firewood and dispersal parameters based on data from the U.S. National Recreation Reservation Service database. Authors analyzed subregions of the U.S. including the northeastern region. Based on kernel density estimation, theoretical distribution fitting, and mixture distributions, the authors are able to draw some generalizations, one being the majority of campground visits involve relatively short travel distances. According to the authors, this is relevant since short-distance trips have the potential to transport pests beyond their natural dispersal ranges. This also suggests that outreach efforts should primarily target campers in the region. However, subpopulations of campers with distinctive travel patterns may have other implications for developing awareness campaigns. The authors identify future research needs on the acquisition of firewood, given many homeowners obtain firewood from private and public lands for recreation and to heat their homes.

Koch, F.H., Yemshanov, D., Haack, R. A., & Magarey, R.D. (2014). "Using a Network model to Assess Risk of Forest Pest Spread via Recreational Travel." *PLoS ONE*, 1-10. https://doi.org/10.1371/journal.pone.0102105

Based on data processed from the U.S. National Recreation Reservation Service database, authors created a bi-directional model to generate summary maps and support broad-scale decision making. The maps generated two basic spatial patterns for out-of-state origin risk. In the eastern United States, the riskiest out-of-state origin locations are in localized regions, usually restricted to portions of adjacent states. When compared to kernel-based spread models discussed in the previous citation, this model can identify possible "secondary origin points" that invasive species dispersed from. This model also has significant potential to aid decision makers in making pathway-based security strategies to identify geographic locations responsible for spreading invasive species.

Snell, M., Straub, D. C., Leahy, D. J., de Urioste, D. S., Daigle, D. J., & Bird, N. (2014). *Campers and Invasive Forest Pests in Northern New England.* University of Maine.

This study surveyed campers at public and private campgrounds in Northern New England about Emerald ash borer (EAB) and Asian Longhorned Beetle (ALB). Surveys were conducted in 2013 exploring camper's knowledge, attitudes, and behaviors around movement of firewood. The primary reason campers chose to bring their own wood to campgrounds was cost, followed by quality and convenience. Most were aware of EAB and ALB because of outreach from state agencies and "other" sources like the television. The most compelling argument to not transport firewood appeared to be visually showing the effect invasive forest pests have on the natural world. The authors conclude that outreach is an important tool to help prevent the spread of invasive forest pests.

Wildlife

Banschback, V. S., Yeamans, R., Brunelle, A., Gulka, A., & Holmes, M. (2012). "Edge Effects on Community and Social Structure of Northern Temperate Deciduous Forest Ants." *Psyche,* 1-7. https://doi.org/10.1155/2012/548260

The authors of this study explored the impacts of habitat edge on ant communities in a forest to determine if ants can be used as a bioindicator taxon. They worked in the deciduous hardwood forest at a park in Jericho, VT, a multiple-use conservation area with heavily used trails for hiking, mountain biking, and horseback riding. They collected a census of ants using pitfall sampling and litter plot sampling to determine abundance and diversity at the edge of the trail and interior of the forest. Significantly more individual ants were found in edge pitfall traps than interior, and more nests were found at the edge than interior.

The dominant species at their study site is *Aphaenogaster rudis*. This species had lower abundance in the trail edge than the forest interior, but individuals were collected most frequently in the edge habitat. An important kind of food for this species is the seeds of perennial herbs, found along the edges of trails.[1] [2] Since *A. rudis* plays an important role in as a disperser of perennial herb seeds,[3] this edge effect has ramifications for forest plant community and the forest ecosystem overall. Ant communities may be worth pursuing in future forest health monitoring efforts.

Boyle, S. A., & Samson, F. B. (1985). Effects of Noncosumptive Recreation on Wildlife: A Review. *Wildlife Society Bulletin (1973-2006)*, 110-116.

The authors of this article review human-wildlife interactions during outdoor recreation documented across North America. Studies reviewed had an emphasis on birds, mammals, or herpetofauna. Negative effects were reported for most activities, impacting birds, mammals, and herpetofauna (Table 1). The authors describe some representative examples from the literature. For example, hiking and camping may affect wildlife through trampling of habitat and discarded food. In addition, snowmobile use can result in mortality, habitat loss, and harassment of wildlife. Compacted snow can also increase winter mortality of subnivean wildlife. Although the articles reviewed did not deal exclusively with forests in the northeast, some articles did study this region. The

[1] Morales, M.A. and Heithaus, E. R. "Food from seed-dispersal mutualism shifts sex ratios in colonies of the ant *Aphaenogaster rudis*." *Ecology,* vol. 79, no. 2, 1998, pp. 734-739.
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[3] Ness, J. H., Morin, D. F., and Gialdi, I. "Uncommon specialization in a mutualism between a temperate herbaceous plant guild and an ant: are *Aphaenogaster* ants keystone mutualists?" *Oikos,* vol. 118, no. 12, 2009, pp. 1793-1804.

authors conclude with research suggestions and management implications that could help with the future direction of this project.

Deluca, W., & King, D. I. (2014). Influence of Hiking Trails on Montane Birds. *Journal of Wildlife Management*, 494-502. https://doi.org/10.1002/jwmg.675

In 2006 and 2007, this study examined the effects of hiking trails on the abundance, seasonal movements, and detection probabilities of montane birds in the White Mountains, New Hampshire. Point count surveys by trained observers were conducted both years, three times at each location, during the height of the breeding season. Daily use was measured at each trail using an active infrared trail counter. Based on their data, the authors found no evidence that recreational hiking trails have adverse effects on the abundance, detection probabilities, abundance stability, or recruitment of the five bird species considered in this study. They also found no evidence that recreational hiking trails influence the daily nest survival of montane forest indicator bird species.

The authors conclude that trail-based surveys may represent a valid methodology for sampling birds in the region. Given their results, they suggest management resources for bird species may be more effective in efforts other than altering or reducing hiking activity. These results do not speak to potential impacts on other species in the forest.

Erb, P. L., McShea, W. J., & Guralnick, R. P. (2012). Anthropogenic Influence on Macro-Level Mammal Occupancy in the Appalachian Trail Corridor. *Ecological Applications*, 1-10. https://doi.org/10.1371/journal.pone.0042574

This article assessed impacts of multiple disturbance factors on wildlife along the Appalachian Trail. Three years of data were collected from Pennsylvania to North Carolina with infra-red, remote trip cameras by trained volunteers. The forests consisted primarily of Northeastern Interior, Southern and Central Appalachian Oak Forests. A logistic regression framework “PRESENCE” was used to estimate occupancy and detection probabilities for each species of interest. Deciduous forest data was extracted from the 2006 National Land Cover Data, GIS road data was acquired from Census 2007 TIGER/Line county data sets, and a landowner survey helped determine the percent of adjacent private lands that were hunted.

Nineteen meso and large animal species were detected, along with five small mammal taxa. Eight species were most commonly detected (Table 2). Predictors of occupancy as a result of human influences on these eight common species were modeled (Table 3 and Table 4). Forest cover was a significantly important feature for bobcats, black bears, and white-tailed deer. The presence of hunting on adjoining lands was the second most common factor selected by the models, particularly for black bears and bobcats. Hunting is a popular form of recreation through the Appalachian region, particularly on adjacent lands. The third strongest predictor for mammal occupancy was the amount of recreational trail use surrounding each sample point.

According to the authors, these findings ultimately show localized, compounding human activities strongly affect mammal occupancy across broad landscapes. They recommend citizen science-based camera trapping protocols for generating other macro-level environmental data.

Garber, S. J., & Burger, J. (1995). A 20-yr Documenting the Relationship Between Turtle Decline and Human Recreation. *Ecological Applications*, 1151-1162.

The authors of this study document the decline of the North American wood turtle in a forested area of Connecticut over a twenty-year period. Populations of this species became reproductively isolated from one another after the installment of a human-made pond. From 1974 to 1982, the entire watershed was closed to recreation. In 1983, the watershed was open to permitted recreation (hiking and fishing), which continued through the completion of this study. Authors monitored the number, age, and sex of all the turtles in each population (Table 1, Figure 1). They also monitored human populations of the surrounding towns and human-related usage patterns of the forests to determine a significant correlation with turtle populations (Table 2). Through other monitoring efforts with the South-Central Connecticut Regional Water Authority, weather and water quality were not considered to be relevant factors in population demographics.

From 1974 to 1982, both wood turtle populations remained stable. When the forest was opened to human recreation, the populations began to rapidly decline. A parking lot built near an important hibernaculum for one of the populations may have accounted for their decline. Other possibilities included increased predation from people taking turtles home, or from crows and raccoons attracted by garbage and dead fish left behind by recreationalists. Regardless, this study demonstrates the negative effect human recreation has on an amphibian species reliant on a forested environment for its survival.

Gutzwiller, Kevin J., D'Antonio, Ashley L., and Monz, Christoper A. (2017). "Wildland recreation disturbance: broad-scale spatial analysis and management." *Frontiers in Ecology and the Environment,* 517-524. https://doi.org/10.1002/fee.1631

The authors of this article identify gaps in research knowledge about impacts to recreation on wildlands, including forests. They support landscape-scale studies, since broader scale approaches to monitoring disturbances to wildlife will help inform decisions about both wildlife management and recreation use. They provide methodology for monitoring the spatial pattern of recreational visitors on wildlands (not just observable effects), apply landscape ecology metrics to build predictive wildlife response models, and demonstrate how landscape ecology software can be applied to calculate broad-scale metrics of recreation disturbance. Authors also discuss interaction effects and the importance of considering other dimensions (i.e., forest connectivity) when determining the magnitude of an impact.

Although one regionally relevant area was discussed in this article, its primary purpose was to provide useful information that recreation ecologists and land managers can use to advance understandings of recreation disturbance on wildlife. This approach will be valuable for building future data sets in this region.

Larson, C., Reed, S. E., Merenlender, A. M., & Crooks, K. R. (2016). Effects of Recreation on Animals Revealed as Widespread through a Global Systematic Review. *PLos ONE*, 1-21. https://doi.org/10.1371/journal.pone.0167259

This literature review explored publications documenting the effects of outdoor recreation on wildlife on a global scale. Most articles focused on mammals or birds in North America, most frequently in forests. The results of their search indicate that non-motorized activities have more evidence of negative impacts that motorized recreation. Winter terrestrial activities (alpine skiing, Nordic ski or snowshoeing, and motorized snow sports) have greater evidence of effects on animals than summer activities, though the number of articles was small. In addition to the need for increased monitoring on the effects of recreation on wildlife, the authors identify a strong need for empirical tests of the efficacy of management actions that are taken in response to existing research.

Hill, J. M. and Campbell, J. (27 November 2019). “Continued Exploration of the Relationship between Downhill Ski Area Edges and Bicknell's Thrush in the Northeastern U.S. Using Mountain Birdwatch Data (2016-2019).” Vermont Center for Ecostudies.

This study analyzed patterns of Bicknell's Thrush abundance at downhill ski areas in the region. Authors used citizen science point count data from Mountain Birdwatch and National Land Cover Data. Although the data shows a higher abundance of this species adjacent to sites of ski area disturbance, this does not necessarily indicate high-quality habitat. The authors conclude with recommendations for future studies to determine fitness benefits more accurately as they relate to natural and anthropogenic edges.

Richens, V. B., & Lavigne, G. R. (1978). Response of White-tailed Deer to Snowmobiles and Snowmobile Trails in Maine. *Canadian Field-Naturalist, 92*(4), pp. 334-344.

This study monitored White-tailed deer use of a snowmobile trail system in Somerset County, Maine from 1972 to 1975. It was located on the eastern edge of the White Mountain Plateau, with mixes of hardwood and softwood stands as a result of logging. In line with conclusions from other studies determining the energy expended by deer walking in snow, the authors of this study conclude that the presence of a strategically placed snowmobile trail system in a deer wintering area could improve over-winter deer survival. This was in part due to the reduction of energy expended when traveling on the packed snowy surface. They also found that deer generally used snowmobile trails near bedding areas daily, all winter, and as a regular travel route to feeding sites.

As for snowmobile activity, abrupt changes in deer activity did not appear to be related to snowmobile disturbances. Deer consistently bedded near trails and fresh tracks were repeatedly observed on trails after machines had passed by. They also tended to become more habituated to snowmobiles as the season progressed. Furthermore, deer tended to flee less frequently in later winter, or when they were spotted within softwood stands. However, snowmobiling at high speeds frightened deer more easily than at low speeds, and humans stopping to view deer invariably resulted in their flight. Overall, this study concludes that snowmobiles can be used to benefit deer by making it easier for them to travel through the snow and find sources of food in the winter.

Soil Quality

Eagleston, H., & Marion, J. L. (2020). Application of airborne LiDAR and GIS in modeling trail erosion along the Appalachian Trail in New Hampshire, USA. *Landscape and Urban Planning*, 1-9. https://doi.org/10.1016/j.landurbplan.2020.103765.

This study advanced the application of remote sensing technology in recreational ecology research. LiDAR and GIS were used in the White Mountains National Forest along highly used and impacted segments of the Appalachian Trail. Soil loss was modeled based on many terrain characteristics at different scales. According to the authors, the regression modeling used in this study provided more accurate and significant predictions of soil loss on unsurfaced trails in comparison with earlier studies. Future studies could continue to develop and refine these models to help understand the sustainability of trails and inform trail management in the future.

Salesa, D., & Cerda, A. (2020). Soil erosion on mountain trails as a consequence of recreational activities. A comprehensive review of scientific literature. *Journal of Environmental Management*, 1-13.

Authors reviewed literature on soil erosion related to recreational impacts on mountain trails. They discussed social and economic dimensions in historic research trends, identifying common themes and gaps in the research to be explored moving forward. Erosion in protected natural environments are highly explored for their social, environmental, and economic values, particularly in wealthy countries like the United States. They identify a variety of methodology to measure, assess, and report impacts, uneven results, and the challenges these differences create when trying to compare data sets. Furthermore, they identify a lack of long-term monitoring efforts, a gap that should be filled in order to advance scientific knowledge in this area of recreation ecology. Although this review does not deal directly with the northeast region of the United States, it provides useful feedback on the state of knowledge and research related to recreation and forest health.

Change in Vegetation

Ednie, A. J., & Daigle, J. J. (2007). Detecting Vegetation Change Using Multi-temporal Aerial Photographs at Cadillac Mountain in Acadia National Park, Maine. *Proceedings of the 2006 Northeastern Recreation Research Symposium* (pp. 300-306). Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station.

The authors of this study measured vegetation changes at the summit of Cadillac Mountain in Acadia National Park, Maine. During summer months, this fragile area receives a high amount of visitor traffic. Three aerial photographs (with smaller pixels than Landsat TM) were scanned and georeferenced in 1991, 1996, and 2004. Overall, vegetation regrowth in a highly trafficked area was greater than reduction. Authors cannot say with high confidence it is because of management actions. Physical barriers and signage did appear to be effective.

Images were processed to measure the effects of management actions originating from the mid 1990s. Although the imagery used in this study was less coarse than a popular alternative (Landsat TM), more detailed changes can be detected with fine grain imagery. Researchers concluded that this data will be useful for long-term monitoring of Cadillac Mountain in the future. Authors also recommend the use of multi-spectral imagery to identify change over time.

Kim, M. and Daigle, J. J. (2011). "Detecting vegetation cover change on the summit of Cadillac Mountain using multi-temporal remote sensing datasets: 1979, 2001, and 2007." *Environmental Monitoring and Assessment*, 63-75.

Vegetation change was assessed at the summit of Cadillac Mountain based on datasets captured with remote sensing technology in 1979, 2001, and 2007 in Acadia National Park. Actions were taken to curtail visitor uses and changes in vegetation were assessed between managed and unmanaged sites. Applied change detection analysis was used to measure the change in vegetation cover. Sites under management experienced significant changes in rates of recovery compared to unmanaged sites. Visitor management practices were validated by this monitoring effort in an alpine area with sensitive vegetation. Expanding management beyond the summit loop could prevent unintended and additional vegetation impact.

Wang, Y., Mitchell, B.R., Nugranad-Marzilli, J., Bonynge, G., Zhou, Y., & Shriver, G. (2009). "Remote sensing of land-cover change and landscape context of the National Parks: A case study of the Northeast Temperate Network." *Remote Sensing of Environment,* 1453-1461.

Changes in forest land cover were measured as a result of urbanization, recreational use, and other anthropogenic influences using remote sensing technology. In general, urban areas are increasing, and forested areas are decreasing in the region. However, this varied between states and national park units. For example, forest cover remained relatively stable in parks in Vermont and Pennsylvania, but New Jersey saw changes in forest cover as a result of urban and recreational development. Monitoring these landscape dynamics are important because development within and adjacent to parks can alter water quality, increase the likelihood of invasive plant expansions, and reduce contiguous forests, among other impacts from urban and recreational uses. Land-cover change analysis can be a useful tool to determine landscape-scale impacts to park units and other forested areas.

Multiple Indicators

Arredondo, J. R., Marion, J. L., Meadema, F. P., & Wimpey, J. F. (2021). Modeling areal measures of campsite impacts on the Appalachian National Scenic Trial to enhance ecological sustainability. *Journal of Environmental Management*, 1-14.

The authors of this study used combinations of ground-based sampling and publicly available aerial imagery to model and measure vegetation loss near campsites along segments of the Appalachian Trail. Generalized Random Tessellation Stratified sample design was used to select segments, GPS were used to collect data in the field, and LiDAR-derived DEM data was accessed for coverage of 42 out of 63 sampled segments.[4] Site characteristics recorded in the field included campsite type, tree canopy cover, offsite woody vegetation density, offsite topographic roughness, and site expansion potential.

This study finds that campsite impacts can be minimized by strategic locations on steep slopes with low expansion potential ("side hill campsites"). Side hill campsites can also limit other forms of impact, such as fire sites, damaged trees, and soil loss. Authors highlight advantages to camping structures and their ability to concentrate activity in one area. The authors also found a positive and significant relationship between canopy cover and vegetation loss. Plants that survive in meadows or open forests (grasses/sedges) are more resistant to trampling. Herbs and forbs are less resilient in trampling and are found under more canopy coverage, hence more vegetation loss. The data collected for this study measured impacts from recreation on indicators of forest health but did not monitor long-term trends.

Behrend, D. F. and Lubeck, R. A. (1986). "Summer Flight Behavior of White-Tailed Deer in Two Adirondack Forests." *The Journal of Wildlife Management*, 615-618.

Authors studied the flight behavior of White-tailed deer in hunted and un-hunted areas in the Adirondacks. Researchers approached by vehicle, making roadside observations of antlerless, spikehorns, other antlered, and unidentified categories of deer. Deer with antlers (exclusive of spikehorns) had a much longer mean flight distance in hunted areas than other types of deer in both areas. The results of this study indicate a greater sensitivity to disturbance in hunted areas for big game animals. However, authors mention that results of flight distance may vary, and identification may be easier when observers approach by foot. The methods in this study limited results.

[4] Marion, Jeffrey L. et al. "Improving the Sustainability of the Appalachian Trail: Trail and Recreation Site Conditions and Management." Final Report to the DOI, National Park Service, Appalachian Trail Park Office and the Appalachian Trail Conservancy, Harpers Ferry, WV. 2020. Publicly available LiDAR data for the Northeast can be found in Appendix 1.

Chang, C.-H., Bartz, M. L., Brown, G., Callaham, M. A., Cameron, E. K., Davalos, A., . . . McHugh, D. (2021). The second wave of earthworm invasions in North America: Biology, environmental impacts, management and control of invasive jumping worm. *Biological Invasions*, 379-400. https://doi.org/10.1007/s10530-021-02598-1

This article details the impact and implications of invasive jumping worms, Pheretimoids in the family Megascolecidae. Their invasion in ecosystems throughout the eastern USA has raised concerns, leading to their identification as a species of concern in New York and Wisconsin. Invasive earthworms reduce the organic leaf litter layer and alter soil pH. The spread of exotic earthworms into northern forests can have substantial effects due to the changes in carbon storage in the forest floors, bioaccumulation of toxic metals, and habitat loss for a variety of plant and animal species. Their dispersal is aided by human activities, primarily the exchange of plants and soil material in the horticultural industry. Other recreational activities responsible for their spread are fishing, and shoes, tires, and vehicles that carry soil containing their cocoons. Gardens adjacent to forest environments infested with jumping worms may pose a serious threat to forest health. Prevention is currently the only reliable method to avoid their invasion. Monitoring the spread of this species may be warranted given their significant impacts to forest health.

Cole, D. N., & Wright, V. (2004). Information about Wilderness and Recreation Impacts: Is It Adequate? . *International Journal of Wilderness*, 27-31.

This chapter discusses the impacts of hiking and camping on soils and vegetation, and the state of research in this field. Cole discusses the historical context for research, as well as research designs, results, and future directions. He identifies spatial and temporal dimensions to this type of recreation ecology research, including the lack of long-term research and focus on scales relevant to humans. He recommends research move beyond the easily observed and measured metrics for the effects of recreation, towards relationships between the physical, chemical, and biological effects of recreation on soil and subsequent impacts on flora and fauna. This review may be helpful in guiding the development of future monitoring projects in northeastern forests.

Hagen, K. (1999). *The Effects of Ski Area Development on Populations of Stream Salamanders in Central Vermont.* Antioch University.

A graduate student conducted a study at fourteen streams in central Vermont, comparing pristine and developed conditions on three species of salamander. All streams were located near major commercial ski areas, and each stream cascaded through hardwood forests. Searches were conducted twice in nearly all streams, and salamanders were captured, identified, measured, and released. Results indicated that Northern Dusky Salamanders and Spring Salamanders were significantly less common in ski area streams, and Two-lined Salamanders were not significantly different in abundance between both stream types.

Results indicated that Spring and Northern Dusky salamanders may be negatively impacted by activities associated with ski area development. Because salamanders are important food sources for other forest-dwelling species, and are negatively impacted by poor water quality, monitoring spring salamander populations may offer effective means of assessing impacts of recreation on forest health.

Monz, C. A., Marion, J. L., Goonan, K. A., Manning, R. E., Wimpey, J., & Carr, C. (2010). Assessment and Monitoring of Recreation Impacts and Resource Conditions on Mountain Summits: Examples from the Northern Forest, USA. *Mountain Research and Development*, 332-343. http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00078.1

Based on summit studies at Cascade Mountain (Adirondacks), Camel's Hump (Green Mountains) and Cadillac Mountain (Acadia National Park), formal and informal trails were mapped using a variety of methods. Informal trail conditions were generally poor, with substantial vegetative cover and soil exposure and erosion. Managers will need to determine how to balance recreation use with resource management in sensitive areas. Methods used in this study could be replicated in other places.

Thurston, E., & Reader, R. J. (2001). Impacts of Experimentally Applied Mountain Biking and Hiking on Vegetation and Soil of a Deciduous Forest. *Environmental Management*, 397-409.

This experimental study compared the effects of mountain biking and hiking on the soil and understory vegetation of an undisturbed deciduous forest in Ontario, Canada. The forest had a forb-dominated understory with a canopy dominated by sugar maples. The experiment had two treatment types: activity type and pass intensity. Treatments were applied by four participants between June and August, and measurements were taken pretreatment, one week, two weeks, and one year after application. The authors concluded that impacts on vegetation and soil increased with both biking and hiking activity, without significant differences between both activity types. In addition, loss of vegetation, species, and soil all increased with pass intensity. They suggest conducting additional studies to confirm the generality of their findings, which may lead to other reasons for the belief that mountain biking may contribute more to trail degradation problems.

Wilkerson, E., & Whitman, A. (2010). Recreation Trails in Maine and New Hampshire: A Comparison of Motorized, Non-Motorized, and Non-Mechanized Trails. *Proceedings of the 2009 Northeastern Recreation Research Symposium* (pp. 214-222). Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station.

This study provides baseline information about trail conditions in northern New England. Authors assessed the environmental impact of motorized and non-motorized recreation trails by sampling trail segments in Maine and New Hampshire. Motorized trails were primarily used by all-terrain vehicles or snowmobiles. Non-motorized trails permitted both mountain biking and hiking, while non-mechanized trails only permitted hiking. Researchers collected data measuring tread width, maximum tread depth, and cross-sectional area (CSA), to assess soil and water quality. Motorized trails are significantly wider to accommodate vehicles, a feature which can also improve safety and reduce conflict on non-motorized trails. In addition to high frequency of trash visible from the trail, motorized trails also had significantly greater CSA and maximum tread depth, common indicators of soil loss.

Although motorized trails had greater soil disturbance and more frequent ruts and erosion than the other types of trails, the authors conclude that all types of trails degrade stream quality. They recommend installing, maintaining, and repairing stream crossings to prevent degradation of water quality.