

ABSTRACT

MCDADE, CAITLIN ELIZABETH. Leave No Trace at Frontcountry Recreation Sites: Understanding Visitor Behaviors and Social-Ecological Management Strategies. (Under the direction of Drs. Yu-Fai Leung and Lincoln Larson).

Visitors to parks and protected areas leave inevitable environmental and social impacts as they recreate including soil erosion, wildlife disturbance, habitat fragmentation through informal trail creation, and impacts on the recreation experiences of other users. Managers must engage in a challenging balancing act by prioritizing natural resource conservation while facilitating recreation opportunities, all in the face of limited resources. This thesis outlines two methods that may help managers achieve this balance: the use of educational messaging focused on Leave No Trace (LNT) principles (developed by the LNT non-profit focused on promoting responsible recreation) and strategic implementation and evaluation of indicators and methods associated with site degradation.

The first study focused on the ability of Leave No Trace (LNT) messaging to influence visitors' behavior and knowledge at frontcountry sites. Frontcountry sites, or popular sites that usually see many day-use visitors and have facilities on-site (e.g., bathrooms, parking lots), represent locations where the (im)balance between visitation and conservation objectives is more prominent. Situated in two popular parks in western, North Carolina, this research utilized 1,182 surveys and observations of visitor behavior to evaluate users' self-reported and assessed LNT knowledge and behaviors, and how they changed before and after an intervention (i.e., installation of LNT signage at the treatment site). Survey results revealed that seeing any LNT-related signs improved perceived knowledge and behaviors on site. Behavioral observations also showed a significant decrease in informal trail use at the treatment site. Effect sizes were small, though, and only

a small proportion of visitors (13.1%) stopped to read the LNT-intervention signs. Future research should explore how various messaging approaches can improve the efficacy of signage, potentially by targeting specific audiences as well as LNT behaviors that are most relevant to frontcountry settings.

The second study at the same site examined social-ecological indicators and methods that can be used to rapidly assess informal trails. Managers must often focus their limited resources, strategically choosing where to intervene to conserve the site and mitigate degradation. Rapid assessments are vital to providing managers quick ways to assess many site areas, making more informed management decisions regarding future actions. Many studies of informal trails have focused on either ecological or social indicators, but few have integrated both. Thus, we utilized the LNT-intervention described above to evaluate rapid assessment methods linked to ecological (e.g., informal trail frequency and condition, trail impacts) and social indicators (e.g., knowledge and behaviors, informal trail use). Our evaluation, backed by prior research and indicator-based frameworks (e.g., LAC, VUM, VERP), focused on the feasibility of each method (the cost of instruments needed, the ease of collecting data, and the time required for data analysis) and its practical utility (effectiveness of data visualization and indicator sensitivity) for managers. Our evaluation indicates that informal trail observations is one of the most feasible indicators, while trail camera observations may be more useful to managers. Ecological impacts overall are challenging to measure, though, as many methods are not sensitive to short timescales. This research underscores the need for managers to utilize both social and ecological indicators when assessing recreation impacts.

Collectively, our studies suggest that to ensure effective conservation interventions, managers should couple indirect management strategies such as LNT-focused educational signs promoting responsible recreation with rapid assessments to evaluate where and what type of intervention would be most effective, as informed by social and ecological indicators. Future research should continue to focus on assessments and interventions that are both feasible and practical for managers, while also investigating the efficacy of interventions, focusing on the best target audiences and messaging strategies.

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Leave No Trace at Frontcountry Recreation Sites: Understanding Visitor Behaviors and
Social-Ecological Management Strategies

by
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BIOGRAPHY

Caitlin McDade hails from Goose Creek, South Carolina. She spent her years in the Charleston area until she ventured to the South Carolina Governor's School for Science and Mathematics. While there, she developed an interest in conservation biology and environmental education following experiential learning opportunities abroad. She took these interests and pursued them when she returned to Charleston to attend the College of Charleston, double majoring in Biology and Secondary Education, B.S. and double minoring in Environmental Sustainability Studies and Spanish.

Her experience in college piqued her interest in becoming a professor and conducting research. After graduating from the Honors College Summa Cum Laude, Caitlin joined North Carolina State University's College of Natural Resources in the Parks, Recreation, and Tourism Management department. She gravitated towards this field of study due to her own affinity for our parks and protected areas paired with her interest in education. She used these interests throughout her master's research, presented here, to explore the question: how do we educate people in a way that motivates them to change their behavior for the conservation of our natural environment?

Having started her research journey with this thesis, Caitlin hopes to continue research focusing on environmental education and conservation. Looking forward, she hopes to complete her doctorate and then continue towards professorship, mentoring and inspiring others to pursue what they are passionate about, while researching her own.

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First, to my co-advisors, Drs. Yu-Fai Leung and Lincoln Larson, for their continued help – and I’m not just referring to certain ideas about deadlines (“Deadlines are meant to be broken!”), their late night reviews of my papers, or suggestions for presentations that are in...oh, 30 minutes. I am sincerely grateful to you, Yu-Fai, for taking me on, trusting that I would be able to learn from you and succeed in the world of academia and research. I am equally appreciative of you, Lincoln, who had no intentions of advising a ginger menace in the Fall of 2023, but nonetheless welcomed me, offering your own time and wisdom to help me succeed. I’d also like to thank Dr. Kathryn Stevenson for her immense support in both my research and pedagogical interests. You’re still who I want to be when I grow up.

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CHAPTER 1: INTRODUCTION

The duality of parks and protected areas lies in their concurrent function as sites of conservation and as spaces to accommodate visitors and outdoor recreation opportunities. Across the United States, state protected areas alone receive over 800 million visits a year (NASPD, 2024). Such high visitation rates highlight the importance of natural sites, and underscore the importance of conserving them into the future. These sites allow people to connect to the environment by facilitating recreational activities (e.g., hiking, biking, bird watching), which can in turn provide important health benefits to visitors (Kling et al., 2017, Maller et al., 2009). However, visitors inevitably leave impacts on these sites, hindering conservation efforts (Marion et al., 2016). Managers must negotiate these challenges to achieve balance between recreational use and environmental conservation, often striving to mitigate impacts by aiming to alter visitor behaviors and protect important ecological assets (Hughes et al., 2009).

Managers have various options for addressing recreation issues, often using interventions that are either direct or indirect (Schwartz et al., 2018; Bradford & McIntyre, 2007). Direct interventions may involve a staff member positioned at an informal trail telling visitors it is closed, physical barriers to prevent visitors from exploring a sensitive area, and/or stringent enforcement of usage restrictions and corresponding sanctions/fines (Schwartz et al., 2018). While effective, the amount of work staff can do – and the potential efficacy of direct interventions – is often stifled by limited resources, such as staffing, time, and money. Indirect interventions often aim for voluntary compliance via incentives or strategic communication. A key way managers can work to ease the stress on nature-based recreation destinations is by educating visitors about their impacts and

subsequently influencing their behavior (Ballantyne et al., 1998; Stern et al., 2010; Manning, 2003). For example, an indirect intervention may include posting a sign that asks visitors not to use an informal trail, hoping visitors will reduce their frequency of negative behaviors and increase their frequency of positive ones (Bradford & McIntyre, 2007; Rice et al., 2023). But the efficacy of education-based messaging strategies in outdoor settings is a subject of debate.

Public-private partnerships, working with NGOs, or partnering with nonprofits present ways in which sites can receive additional support to enhance communication efforts and further their conservation goals (Cordell & Super, 2000; Bremer & Graeff, 2006). Leave No Trace is one such organization that has promoted seven principles to hold backcountry visitors accountable for their actions in remote natural locations that are difficult to monitor; however, these actions would be just as applicable in less remote, more frequented natural locations (Cole, 2018). Although Leave No Trace has been studied in some popular frontcountry sites before (Leung & Attarian, 2003), gaps still remain. For instance, little research has simultaneously assessed self-reported and observed Leave No Trace-related actions (i.e., good and bad recreation behaviors).

Chapter Two of this thesis investigates some of these gaps, seeking to test the efficacy of a Leave No Trace messaging intervention (i.e., a trailside sign) at a popular frontcountry site in North Carolina, Hooker Falls. Our specific objectives were to understand frontcountry visitors' self-reported and assessed/observed Leave No Trace-related knowledge and behaviors, while also investigating the effectiveness of targeted Leave No Trace messaging on frontcountry visitors' self-reported and assessed/observed Leave No Trace-related knowledge and behaviors.

Chapter Three of this thesis focuses on refining monitoring and evaluation strategies in park settings. Assessing the efficacy of an intervention is vital to determining if behaviors are actually changing, but this too can be difficult with limited resources (Whiting et al., 2012). Most studies surrounding the impacts of recreation focus on ecological indicators (i.e., ecological signs of change, such as trail erosion), but understanding the social drivers of behavior may be equally important. Therefore, we explored a selection of social-ecological indicators that can be used to efficiently and effectively assess the extent and impacts of informal or “social” trail use. Our focus on informal trails stems from the conservation challenges presented by informal trail creation and proliferation, such as soil degradation and extensive habitat fragmentation (Primack & Terry, 2021). We concentrated on rapid assessment methods due to their ease of use to managers and their ability to provide an initial overview of various impacts, which can help managers make more informed decisions regarding prioritization of conservation efforts or investment in more in-depth monitoring efforts (del Campo & Clark, 2009; Larsen, 2016). Thus, the objective of Chapter Three was to evaluate methods for assessing both ecological indicators (frequency and condition of informal trails, trail impacts) and social indicators (visitor knowledge and behaviors, informal trail use), utilizing evaluation criteria focused on the feasibility of implementation and practical utility for managers.

Together, Chapters Two and Three highlight ways in which managers of parks and protected areas can further their conservation efforts: first by focusing on the efficacy of educating visitors through indirect messaging centered around principles of Leave No

Trace and second by evaluating rapid social and ecological indicators that can be used to assess and prioritize management interventions.

References

- Ballantyne, R., Connell, S., & Fien, J. (1998). Students as catalysts of environmental change: A framework for researching intergenerational influence through environmental education. *Environmental Education Research, 4*(3), 285–298.
- Bradford, L. E., & McIntyre, N. (2007). Off the beaten track: Messages as a means of reducing social trail use at St. Lawrence Islands National Park. *Journal of Park and Recreation Administration, 25*(1), 1–21.
- Bremer, S., & Graeff, P. (2006). Volunteer management in German national Parks—from random action toward a volunteer program. *Human Ecology, 35*(4), 489–496.
<https://doi.org/10.1007/s10745-006-9070-9>
- Cole, D. N. (2018). Leave No Trace: How it came to be. *International Journal of Wilderness, 24*(3), 54–65.
- Cordell, H. K., & Super, G. R. (2000). Trends in Americans' outdoor recreation. In *Trends in outdoor recreation, leisure and tourism* (pp. 133–144). CABI Publishing.
- Del Campo, A., & Clark, S. G. (2009). Rapid appraisals: An innovation in search of Sustainability. *Journal of Sustainable Forestry, 28*(6–7), 614–635.
<https://doi.org/10.1080/10549810902794618>
- Hughes, M., Ham, S. H., & Brown, T. (2009). Influencing park visitor behavior: A belief-based approach. *Journal of Park and Recreation Administration, 27*(4), 38–53.
- Kling, K. G., Fredman, P., & Wall-Reinius, S. (2017). Trails for tourism and outdoor recreation: A systematic literature review. *Tourism: An International Interdisciplinary Journal, 65*(4), 488–508.

- Larsen, T. H. (Ed.) (2016). *Core standardized methods for Rapid Biological Field Assessment*. Conservation International.
- Leung, Y.-F., & Attarian, A. (2003). Frontcountry visitor information/education programs: Are there lessons for wilderness? *International Journal of Wilderness*, 9(1), 32-33.
- Maller, C., Townsend, M., St Leger, L., Henderson-Wilson, C., Pryor, A., Prosser, L., & Moore, M. (2009). Healthy Parks, Healthy People: The health benefits of contact with nature in a park context. *The George Wright Forum*, 26(2), 51-83.
<http://www.jstor.org/stable/43598108>
- Manning, R. E. (2003). Emerging principles for using information/education in wilderness management. *International Journal of Wilderness*, 9(1), 20-27.
- Marion, J. L., Leung, Y.-F., Eagleston, H., & Burroughs, K. (2016). A review and synthesis of recreation ecology research findings on visitor impacts to wilderness and protected natural areas. *Journal of Forestry*, 114(3), 352-362. <https://doi.org/10.5849/jof.15-498>
- National Association of State Park Directors (NASPD). (2024). *Statistical report of state park operations in the U.S.: 2021-2022*. NASPD.
- Primack, R. B., & Terry, C. (2021). New social trails made during the pandemic increase fragmentation of an urban protected area. *Biological Conservation*, 255, 108993.
<https://doi.org/10.1016/j.biocon.2021.108993>

- Rice, W. L., Shellhorn, J., Bloomgren, V., Booth, L., Duncan, S., Elias, J., Flowers, K., Gambini, I., Gans, A., Medina, A., Obadare, D., O'Neill, C., Rooney, Q., Scherck, G., Schmidt, K., Thomas, C., Thomas, E., Walhus, G., Whitney, P., . . . Winckler, C. (2023). The impact of graphic design on attention capture and behavior among outdoor recreationists: Results from an exploratory persuasive signage experiment. *Journal of Outdoor Recreation and Tourism*, *42*, 100606. <https://doi.org/10.1016/j.jort.2023.100606>
- Schwartz, F., Taff, B. D., Lawhon, B., & VanderWoude, D. (2018). Mitigating undesignated trail use: The efficacy of messaging and direct site management actions in an urban proximate open space context. *Environmental Management*, *62*(3), 458–473. <https://doi.org/10.1007/s00267-018-1054-1>
- Stern, M. J., Powell, R. B., & Ardoin, N. M. (2010). Evaluating a constructivist and culturally responsive approach to environmental education for diverse audiences. *Journal of Environmental Education*, *42*(2), 109–122. <https://doi.org/10.1080/00958961003796849>
- Whiting, J. W., Lawson, L. R., & Green, G. T. (2012). Monitoring visitation in georgia state parks using the system for observing play and recreation in communities (SOPARC). *Journal of Park and Recreation Administration*, *30*(4), 21-37.

CHAPTER 2: LEAVE NO TRACE IN THE FRONTCOUNTRY: ASSESSING KNOWLEDGE AND BEHAVIORS BEFORE AND AFTER A TARGETED MESSAGING INTERVENTION

Abstract

Leave No Trace's efforts have historically focused on backcountry sites, but the (im)balance between visitation and conservation objectives is more prominent at frontcountry locations. Our research investigated the effectiveness of LNT signage at two frontcountry sites in western, North Carolina. Through 1,182 surveys and observations of visitor behavior, we evaluated users' self-reported and assessed LNT knowledge, behaviors, and how they changed before and after an intervention (i.e., installation of LNT-focused signage at the treatment site). Survey results revealed that seeing any LNT-related signs influenced visitor's perceived knowledge and behaviors on site. Behavior observations showed a significant decrease in informal trail use at the treatment site. Treatment effects were small, though, and only 13.1% of visitors stopped to read the new signs. Future research could explore how different messaging approaches could improve the efficacy of signage, helping to target specific LNT behaviors that are most relevant in frontcountry settings.

Introduction

Outdoor recreation is a significant part of American life. In 2023, over 175 million, or 57.3% of Americans, participated in some form of outdoor recreation, contributing to the population's health and well-being as well as the national economy (Outdoor Industry Association, 2024). This national trend is largely mirrored by growth in nature-based

tourism globally (Mandic & Walia, 2023). Many outdoor recreation activities take place in parks and protected areas, generating impacts that create challenges for managers.

Because many protected areas are also established for conservation of natural and/or cultural resources, the dual mandate of recreation (i.e., facilitating positive visitor experiences) and conservation (i.e., protecting important resources) often result in conflicts and perennial management challenges (Leung et al. 2018; Manning et al., 2017).

Recreation ecology research has documented a variety of environmental impacts associated with nature-based recreation (Marion et al., 2016). For example, visitors trample vegetation when traveling off-trail (Barros & Pickering, 2017; Huang et al., 2015), accelerate soil erosion on high-use trails (Leung & Marion, 1996; Meadema et al., 2020), and can introduce invasive species along their travel routes (Dolman & Marion, 2022; Senetra et al., 2020). Fecal matter left behind from activities like camping, dog-walking, and horseback riding contaminates water sources (Cooke & Xia, 2020). Furthermore, wildlife can become stressed (Taylor & Knight, 2003) or habituated (Gunter, 2015) near the presence of visitors or at popular recreation sites. These impacts have historically been studied in more remote or backcountry settings (D'Antonio et al., 2012), but there are growing concerns about how to manage the overwhelming number of visitors flocking to popular protected areas in the frontcountry, defined as day-use outdoor sites that are easily accessible (MacLeay, 2010).

The (im)balance between visitation and conservation objectives is especially prominent at frontcountry sites, such as those in state parks where easy access and amenities like restrooms, parking lots, and picnicking areas draw 750 million day-use visitors each year (National Association of State Park Directors, 2024). These features

appeal to novice recreationists and attract a more diverse set of visitors compared to backcountry sites (Cordell & Super, 2000). This presents an additional challenge to managers: how can they effectively reach the large, diverse populations at frontcountry sites and encourage behaviors that will mitigate visitors' impacts on the environment? This question is particularly relevant when many of these visitors might have limited previous experience in outdoor settings and minimal knowledge of environmental stewardship practices.

Managers' approaches to promoting visitors' pro-environmental behaviors on-site are often limited by resources – namely personnel and funding sources (Gilroy et al., 2013). Thus, parks frequently use messaging campaigns, often delivered via signage, to promote pro-environmental behaviors. Signs offer a consistent and relatively inexpensive option to inform visitors of proper actions, and research has examined their efficacy in reducing the use of informal trails (Bradford & McIntyre, 2007; Winter, 2006), discouraging behaviors that negatively impact wildlife (Freeman et al., 2023; Hughes et al., 2009; Marschall et al., 2017), and keeping dogs on-leash (Hughes et al., 2009; Rice et al., 2023). Although prior research suggests signage in parks has the potential to influence visitors' behaviors, more research is needed to understand the effects of signs in frontcountry locations with high visitor densities, especially given the more diverse visitors frontcountry sites can attract.

To assist managers, park management agencies often partner with nonprofit and volunteer organizations to maintain sites and encourage pro-environmental behaviors amongst visitors (for example, see Dresner et al., 2014). Perhaps the most prominent organization addressing these issues is the Leave No Trace Center for Outdoor Ethics (LNT), whose seven principles of responsible outdoor recreation have been communicated

for decades: (1) plan ahead and prepare, (2) travel and camp on durable surfaces, (3) dispose of waste properly, (4) leave what you find, (5) minimize campfire impacts, (6) respect wildlife, (7) be considerate of others (Marion, 2014; Cole, 2018; LNT, 2022).

A growing number of studies have evaluated the efficacy of LNT messaging at backcountry or overnight use sites (Backman et al., 2018). Several studies that integrated LNT messages and site management were conducted in backcountry settings within national parks to evaluate the additive effects of management actions (Park et al., 2008; Hockett et al., 2017, Park et al., 2023). A more sophisticated field experiment was conducted by Settina et al. (2020) to examine the effectiveness of LNT messaging delivered to overnight campers through multiple communication methods. Their results showed the effectiveness of non-personal communication methods (LNT brochure and poster display) in reducing tree damage but not litter and human waste, while personal communication (by a forest naturalist) was effective in reducing all three depreciative behaviors.

While LNT's messaging campaign has historically been tailored to backcountry sites and visitors, researches have explored its applicability to frontcountry sites as early as the 1990s (e.g., Leung & Attarian, 2003). More recently, LNT has focused on expanding their frontcountry presence; they partnered with Colorado Parks and Wildlife to spread their message across popular state parks and wildlife areas (CPW Partnership, 2023), and they also partnered with destination management organizations in NC to promote sustainable tourism more broadly (Hotchkiss & Savage, 2024). However, research has not yet thoroughly explored LNT's impact in frontcountry settings (Marion, 2014). Prior research has explored frontcountry visitors' attitudes and perceptions towards LNT in comparison to backcountry visitors. Blye & Halpenny (2020) found backcountry visitors' perceived LNT

knowledge was higher than frontcountry visitors', although frontcountry visitors expressed greater attitudinal support for LNT. Taff et al. (2014) assessed differences between frontcountry and backcountry users and found similar differences in perceived knowledge, but few practical differences in LNT-related attitudes. Other research has investigated if and how LNT messaging might be used across frontcountry sites with diverse visitors (Leung & Attarian, 2003), noting that walkers were more likely to stop to read LNT posters, especially if novel poster design and brochure distribution method was used in tandem. Lawhon et al. (2019) found that visitors were receptive to LNT and that a uniform approach may work across different types of frontcountry protected areas. Schwartz et al. (2018b) investigated how signage treatments in high-use areas, including combinations of signs and physical barriers, might influence social-trail use, and found that barriers with signs were the most effective treatment in mitigating social-trail use.

While these recent studies indicate an encouraging trend of attention devoted to LNT research in frontcountry destinations, many knowledge gaps remain, necessitating further studies that employ different research designs to evaluate the effectiveness of LNT messaging in various types of frontcountry sites. For instance, little research has analyzed how specific types of messages might influence frontcountry visitors' self-reported LNT knowledge in comparison to assessed knowledge, and few studies have explored how interventions might simultaneously impact self-reported and observed LNT-related actions (i.e., good and bad recreation behaviors). To address some of these knowledge gaps and test the efficacy of LNT messaging in the frontcountry, we conducted a mixed-methods, experimental design study at popular day use recreation areas in western NC. Our objectives were to:

- (1) understand frontcountry visitors' self-reported and assessed/observed LNT-related knowledge and behaviors, and,
- (2) investigate the effectiveness of targeted LNT messaging on frontcountry visitors' self-reported and assessed/observed LNT-related knowledge and behaviors.

Methods

Our study employed a combination of surveys and behavior observations at two popular outdoor recreation sites before and after installation of LNT-focused signage. Data collection at the beginning of summer 2024 provided a baseline understanding for frontcountry visitors' knowledge and behaviors at both sites. Data collection at the end of summer 2024 enabled us to compare changes in LNT-related knowledge and behavior at the treatment site (with LNT signage) and the control (without LNT signage).

Study Sites

We chose two highly visited frontcountry waterfall sites in western NC to conduct our research: Rainbow Falls and Hooker Falls (Figure 1). Rainbow Falls, our control site, is located in Pisgah National Forest and accessed from a trailhead originating in Gorges State Park. Hooker Falls, our treatment site, is located in DuPont State Recreational Forest. Both sites are frequented by day users, though Hooker Falls is a more popular destination. Based on trail counter data from 2024, the Hooker Falls trail received an average of 21,000 users per month during the summer season (May-August), while the Rainbow Falls trail received an average of 1,700 users per month over that same time span. These differences likely stem from the fact that Hooker Falls is closer to larger towns and more accessible (only a

0.5 mile hike from trailhead to waterfall) than Rainbow Falls (a 1.5 mile hike from trailhead to waterfall). Other than these differences in visitation and accessibility, the sites were relatively comparable in most other ways: large parking lots at the trailhead, bathrooms on-site, and easy-to-follow signs/maps for the day-use visitors who frequent each site. These pre-existing signs could not be removed by managers for our study, and some of them incorporated LNT themes — even at the control site. Pictures of what these look like can be seen in Supplemental Figure S1.

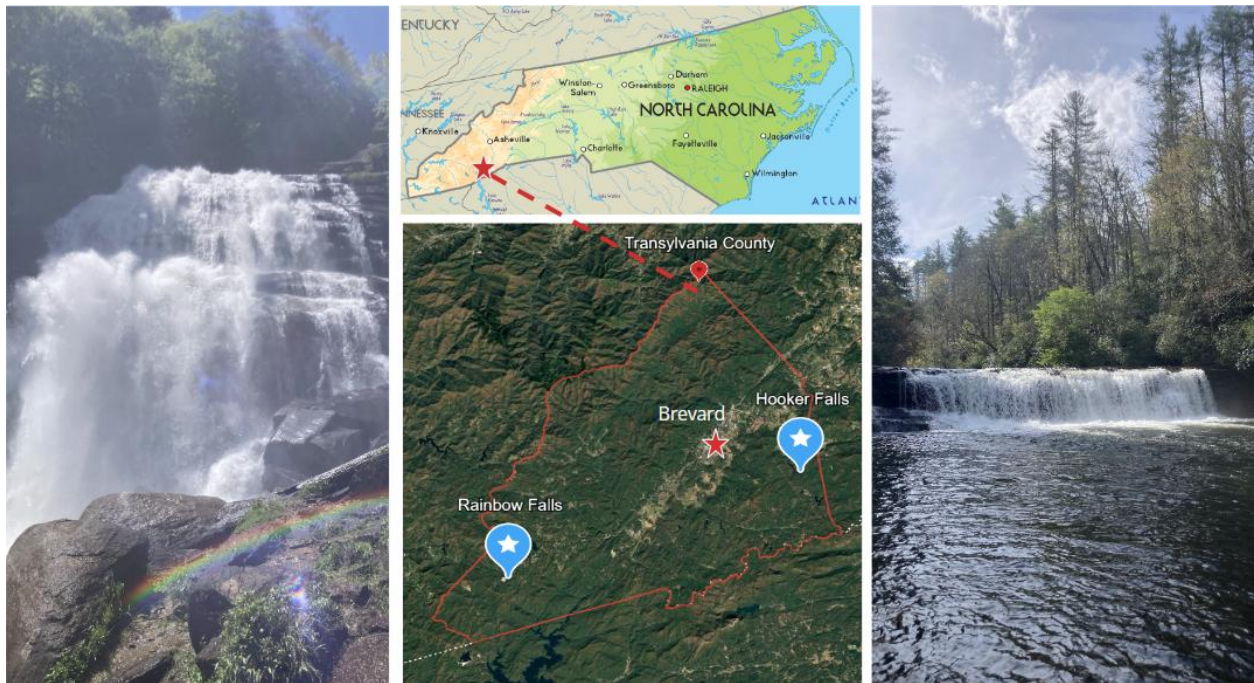


Figure 1. Left: Rainbow Falls. Right: Hooker Falls. Center: A map showing their locations in Transylvania County, NC.

Study Design

The treatment site (Hooker Falls) received an intervention in the summer of 2024. The intervention consisted of installing signage aligned with four specific LNT principles relevant to frontcountry site behaviors: staying on trail, packing out trash and dog poop, respecting wildlife (by keeping distance, being careful with food, and keeping dogs on-leash), and being courteous to other visitors. Discussions with site managers and LNT staff indicated these were the most relevant principles to these frontcountry sites. LNT staff helped us develop these signs in two languages (English and Spanish), which can be seen in Figure 2. We installed the intervention signs at Hooker Falls on June 23rd, choosing Hooker Falls for our intervention as opposed to Rainbow Falls (the control) due to its higher visitation rates. Two large (3'x4'), custom-printed metal signs were installed on wooden posts at the trailhead and base of the waterfall. About 15 smaller (9"x12") identical signs were laminated and put up in bathroom stalls and by water fountains. Supplemental Figure S2 shows the signs on location.



Figure 2. The LNT signs that were put up. Contents in English on the left and Spanish on the right.

Data Collection

Pre-intervention data was collected from both sites in May (10th-19th) prior to the signs going up in June. Post-intervention data was collected at the end of summer (August 30th-September 8th). Surveys were collected on weekends (Friday-Sunday and Labor Day Monday in the post-intervention), as these are busy days for sites frequented by day-use visitors. We only surveyed individuals aged 18+ and surveys were only available in English. Surveying occurred between 10:00 and 17:00 each day. Surveys were distributed on paper due to limited cell service and lack of charging capabilities on-site.

We approached potential respondents as they exited the trail and requested their consent to participate in our survey per the approved IRB protocol. We tried to approach every individual or group exiting the trail to get at least one survey per group. To document response rates, we tallied the number of non-responses we received from individuals and groups from which we could not get at least one respondent. During high visitation periods, if more individuals from a group were willing to take the survey than we had clipboards for, we would ask the person with the most recent birthday to take the survey.

During data collection, another researcher conducted direct observations on visitors' behaviors. They walked the trails and visited the waterfall locations once during the morning and afternoon (weather permitting). Along the trail, researchers noted how many visitors were on-trail and off-trail, while also tallying the number of dogs on-leash or off-leash. At the waterfalls, researchers noted the number of dogs on-leash vs off-leash and recorded if visitors were in a safe/allowed location or an unsafe/prohibited area. On the trail, the observer made tallies as they walked by visitors; at the waterfall, tallies were made immediately upon arriving at the view point. Due to the quick nature of the observation and tallies and the non-invasive approach of the researchers, it is unlikely that visitors would have changed their behavior due to being watched. Additionally, during the pre-intervention period, we placed a motion-activated Bushell trail camera (model: 2013 Trophy Cam) along a prominent informal trail near the waterfall at each site. Trail cameras can help to document visitors' unauthorized use of informal trails, a violation of LNT principles that generates significant environmental impacts (Campbell, 2006; Miller et al., 2017). These cameras were kept up through the post-intervention sampling period, with batteries and SD cards replaced as needed throughout the summer.

Survey and Measures

We administered the identical survey instruments (see Supplemental materials) before and after the intervention (i.e., at the beginning and end of the summer). Our surveys focused on four key dependent variables: self-reported LNT knowledge, assessed LNT knowledge, self-reported frequency of “good” LNT behaviors, and self-reported frequency of “bad,” non-LNT behaviors. Similar to previous research (Taff et al., 2014; Lawhon et al., 2017), self-reported LNT knowledge was obtained from a seven-point Likert-style question that asked visitors to gauge their LNT knowledge from one (none) to seven (expert). Following this, visitors were provided with a list of 15 common behaviors, including some good (e.g. staying on trail) and some bad (e.g., avoiding muddy puddles), and asked to mark if the behavior aligned with LNT principles. We then scored the responses based on accuracy, creating the assessed LNT knowledge variable ranging from 0-100% correct. This same list was used to gauge the frequency with which visitors claimed to participate in each behavior. This same list was used to gauge the frequency with which visitors claimed to participate in each behavior, by asking visitors how often they participated in each behavior on a scale of one (never) to five (always). We then calculated the average frequency of participation scores across the 3 good behaviors and the 12 bad behaviors. The chosen behaviors and scales were derived from prior research on LNT (Blye & Halpenny, 2020; Lawhon et al., 2017), in conjunction with the LNT Center for Outdoor Ethics.

We also collected descriptive data for visitors to see if there were any differences between groups. We asked if it was a respondent’s first time on site, if they thought visitors

had significant impacts on a site (using a Likert-style question ranging from one, no impact, to seven, high impact), if they recreated often, if they had kids or dogs with them, as well as other typical demographic data, such as: age, education-level, household income, racial/ethnic identity, and political affiliation.

To better understand visitor interactions with, and perceived impacts of, park signs we also surveyed visitors to ask if they saw LNT signs leading up to and during their trip to the waterfall that day, providing options such as: on a trail, at another location on site, social media, etc. Additionally, we asked where visitors thought messaging would be the most effective in encouraging LNT behaviors. Finally, we also asked visitors to indicate if they learned anything new and, if they saw messaging, if it changed the way they thought and/or acted during their trip to the waterfall. These self-reported responses were included to compare and potentially validate some of the observed differences from the experiment.

Lastly, to understand how many visitors actually read the LNT sign we put up at our treatment site, we calculated the proportion of visitors who stopped to read the sign during half-hour observation periods throughout our post-intervention data collection. Since the signs were located near the trailhead and in sight of our survey area, one researcher was able to discreetly watch as visitors passed the sign, using a clicker counter to tally the number of visitors who either walked by or stopped at the sign for at least 5 seconds. This allowed us to collect observations without influencing visitors' actions. Five seconds was used as a conservative estimate given prior research, which defined stopping to read a sign as an encounter that lasted more than 2 seconds (Hall et al., 2010). Given our sign focused on four LNT principles which were each accompanied by a pictogram representation, we

determined that 5 seconds is sufficient time for a visitor to scan the sign and all four principles.

Data Analyses

Data analyses were conducted using IBM SPSS Statistics (Version 27). After reviewing descriptive statistics, we created binary variables from demographic data to examine differences between groups of interest. The binary variables indicated if a visitor was white, male, held a graduate degree, identified as liberal, brought dogs, brought kids, was a first-time visitor, and participated in outdoor recreation often (multiple times per month). We applied linear regressions to evaluate the impact of these socio-demographic variables, site locations (Hooker Falls vs. Rainbow Falls), intervention (before vs. after the signs went up) and the interaction between site location and survey timing (effectively a measure of the treatment effect since only one site had a sign installed mid-summer, and the other did not) on each of the four dependent variables: self-reported LNT knowledge (index with means ranging from 1 to 7), assessed LNT knowledge (scale from 0 to 100%), and self-reported good and bad LNT behaviors (index with means ranging from 1 to 5). We ran a separate regression model (model 1) for each of these dependent variables.

Additionally, because the presence of a sign in a park did not necessarily mean that visitors saw it, we also ran a separate model (model 2) for each dependent variable where a “saw sign” variable (i.e., whether or not visitor reported seeing an LNT sign at the park) replaced the survey timing (i.e., treatment) variable, and the interaction between site location and saw sign enabled us to explore effects of LNT signage (whether or not it was part of our intervention). We examined overall model fit using adjusted R² and interpreted parameter

estimates to evaluate the significance of specific independent variables. In some cases, effective sample sizes for models are smaller than the full survey sample size due to missing data on certain variables.

To determine whether observed behaviors of on/off trail (for humans) and on/off leash (for dogs) use varied by site and intervention, we conducted independent sample t-tests. Images from the informal trail cameras were turned into tabular data to assess the number of visitors off-trail at each site throughout the summer. Trail cameras took a burst of three photos when detecting new motion for the first time within a 1-minute time frame. We later deleted all photos that were falsely triggered due to plant or animal movement (keeping photos of pets brought by visitors). We selected one photo from each burst that best showed the person(s) moving in front of the camera. We used the Timelapse software (Greenberg, 2024) to label and sort through these photos, allowing us to create a data table from our images. Lastly, we used this camera data to calculate the number of visitors off-trail, by week, prior to the date the signs went up (pre-intervention) and afterwards (post-intervention). We analyzed the photos for this research by individuals on the informal trail, as opposed to groups, because we were interested in the exact foot traffic on the trail, which directly impacts the natural resources along and around the trail (Primack & Terry, 2021). Additionally, running analyses by week, as opposed to individual days, increased statistical power (sample size was too small to analyze by days), increased our ability to assess temporal trends, and made the data more manageable and easier to work with.

Results

Profile of Frontcountry Visitors

Across both sites throughout the entire summer, we collected 1,182 surveys (700 at Hooker Falls, 482 at Rainbow Falls), with an 87.2% response rate. In May, we collected 438 surveys (261 at Hooker Falls, 177 at Rainbow Falls). In September, we collected 744 surveys (439 at Hooker Falls, 305 at Rainbow Falls). The average age of respondents across the entire summer was 43 (SD = 15.58), with ages ranging from 18 to 90 years old. The majority of respondents identified as female (59.7%), with 1.2% identifying as non-binary/other, and the other 39.1% identifying as male. Visitors were primarily White (83.5%), followed by Latinos (8.1%), Asians (4.5%), Native Americans/Pacific Islanders/Others (2.3%), and lastly Black visitors (1.5%).

34.3% of visitors came from North Carolina, 64.8% of visitors were from out-of-state, and 1.0% from outside of the U.S. The majority of visitors (60.2%) came from households that made more than \$100,000/year and held at least one college degree (52.6%). Visitors were split across the political spectrum with 33.1% identifying as liberal, 36.6% as moderates, and the remaining 30.3% as conservatives. Furthermore, 19.9% of visitors came with children and 18.0% came with dogs. For a full representation of these demographic descriptors, see Supplemental Table S1.

Seeing Signs

A majority of respondents (56.8%) surveyed across both sites and time periods reported seeing LNT-related signs. This number did not change much between the pre- and post-intervention data collection dates at the treatment site. At the control site, the

percentage of people seeing an LNT sign (i.e., a pre-existing one, because we did not install a new sign at Rainbow Falls) went from 50.3% in May to 52.5% in September. At the treatment site where we installed new LNT signs in June, this number grew from 57.5% in May to 62.0% in September, but this increase was not statistically significant. The frequent reports of seeing LNT-related signs at the control site and at the treatment pre-intervention may be attributed to pre-existing signs in the park, and visitors not distinguishing between these more generic signs and signs with specific LNT principles/messaging.

When visitors were asked where LNT messaging would be most effective, signs on the trail was by far the most popular response (84.6%), followed by signs elsewhere on site (31.1%) and conversations with staff on site (29.3%). Other approaches such as social media and on the site's website were rarely noted. Visitor preferences for messaging were similar across both sites.

Self-Reported Leave No Trace Knowledge

Across all surveys and sampling periods, 68.3% of visitors reported their level of LNT knowledge was above average, with a mean score of 4.91 (SD = 1.61) on a scale from 1 to 7. Linear regression models revealed several socio-demographic correlates of self-reported LNT knowledge (Table 1). Model 1 revealed scores were significantly higher for visitors who were white (B = 0.72, $p < 0.001$), older (B = 0.13, $p < 0.001$), liberal (B = 0.34, $p = 0.001$), had dogs with them (B = 0.26, $p = 0.039$), and participated in outdoor recreation often (B = 0.64, $p < 0.001$). Model 2 also revealed scores that were significantly higher for the same demographics (Table 1). Scores were similar across sites and interventions, but

we observed differences for the main effect of the seeing signs variable in model 2 ($B = 0.42$, $p = 0.004$; Table 1). The mean self-reported knowledge of visitors who saw signs was 4.92 ($SD = 2.48$) compared to a mean of 4.45 ($SD = 2.19$) by those who did not see signs, and these differences were consistent across sites.

Table 1. Linear regression modeling the effects of demographic variables and treatment groups by model 1 (intervention) and model 2 (saw signs) on self-reported LNT knowledge (n = 955). Significant variables are in bold to facilitate interpretation.

Effect	Model 1		Model 2	
	B (SE)	p-value	B (SE)	p-value
Intercept	3.13 (0.29)		2.86 (0.28)	
White	0.72 (0.14)	<0.001	0.72 (0.14)	<0.001
Male	0.17 (0.10)	0.085	0.15 (0.10)	0.137
Age	0.13 (0.00)	<0.001	0.01 (0.00)	<0.001
Graduate degree	0.13 (0.10)	0.207	0.17 (0.10)	0.100
Liberal	0.34 (0.11)	0.001	0.31 (0.10)	0.003
Dogs	0.26 (0.13)	0.039	0.26 (0.12)	0.034
Kids	-0.22 (0.13)	0.090	-0.21 (0.12)	0.095
First time visitor	-0.05 (0.10)	0.601	-0.05 (0.10)	0.618
Recreates often	0.64 (0.10)	<0.001	0.64 (0.10)	<0.001
Thinks visitors cause environmental impacts	0.10 (0.03)	0.757	0.01 (0.03)	0.782
Site	-0.02 (0.16)	0.917	-0.03 (0.15)	0.820
Intervention	-0.08 (0.15)	0.587		
Site * Intervention	0.16 (0.20)	0.434		
Saw signs			0.42 (0.15)	0.004
Site * Saw signs			0.10 (0.20)	0.601
Adj. Model R2	0.12		0.14	

Assessed Leave No Trace Knowledge

We found that the average respondent scored 81.9% (SD = 18.65) on the survey assessment of LNT behaviors, with 78.7% scoring 80% or above. Of the demographic variables in Model 1, those who were white ($B = 4.33$, $p = 0.036$), younger ($B = -0.16$, $p < 0.001$), and first time visitors ($B = 3.81$, $p = 0.008$) to the park scored significantly better than those who were not white, older, or had been to the park before (Table 2).

Demographic patterns were similar in Model 2. Assessed scores were also similar between sites and for both the interventions and saw signs variables (Table 2). Across our entire survey sample, we did not observe a significant correlation between self-reported and assessed LNT knowledge ($r = 0.05$, $p = 0.145$).

Table 2. Linear regression modeling the effects of demographic variables and treatment groups by model 1 (intervention) and model 2 (saw signs) on assessed LNT knowledge (n = 725). Significant variables are in bold to facilitate interpretation.

Effect	Model 1		Model 2	
	B (SE)	p-value	B (SE)	p-value
Intercept	80.74 (4.07)		81.58 (4.00)	
White	4.33 (2.07)	0.036	4.16 (2.08)	0.045
Male	-0.45 (1.37)	0.744	-0.39 (1.38)	0.778
Age	-0.16 (0.05)	<0.001	-0.15 (0.04)	<0.001
Graduate degree	2.18 (1.44)	0.130	2.20 (1.45)	0.128
Liberal	2.56 (1.44)	0.076	2.51 (1.44)	0.081
Dogs	0.47 (1.76)	0.790	0.43 (1.76)	0.808
Kids	-2.54 (1.77)	0.153	-2.88 (1.75)	0.100
First time visitor	3.81 (1.43)	0.008	3.70 (1.43)	0.010
Recreates often	1.66 (1.40)	0.237	1.75 (1.39)	0.210
Thinks visitors cause environmental impacts	-0.27 (0.46)	0.559	-0.24 (0.46)	0.600
Site	1.71 (2.13)	0.423	0.69 (2.11)	0.742
Intervention	2.54 (2.08)	0.222		
Site * Intervention	-3.41 (2.77)	0.219		
Saw signs			1.45 (2.00)	0.468
Site * Saw signs			-1.90 (2.75)	0.490
Adj. Model R2	0.02		0.02	

Visitors' Self-Reported Behaviors

Across all surveys, 73.6% of visitors self-reported that they engaged in LNT-aligned, good behaviors at the site “often” or “very often” ($M = 4.22$, $SD = 0.69$), and only 3.3% of visitors said they engaged in bad behaviors at the site “often” or “very often” ($M = 2.00$, $SD = 0.63$). The self-reported frequency of good behaviors correlated with only a few demographic variables in both models: race, gender, education, and age (Table 3). More frequent participation in good LNT behaviors was reported by visitors who were White ($B = 0.18$, $p = 0.005$) and by those who were older ($B = 0.01$, $p < 0.001$). Less frequent participation in good behaviors was reported by visitors who were male ($B = -0.13$, $p = 0.004$) and by those who held a graduate degree ($B = -0.11$, $p = 0.014$). Model 2 revealed similar findings. Only age was significantly correlated with the reported frequency of bad behaviors (Table 4), with younger visitors more likely to express these behaviors than older visitors ($B = -0.01$, $p < 0.001$).

In general, the frequency of both self-reported good and bad behaviors were similar across sites and intervention, with neither of these variables correlating to significant differences in the frequency of good behaviors (Table 3) or bad behaviors (Table 4). One exception, however, was the interaction between the site and the saw sign variable. Visitors who saw an LNT-related sign at Hooker Falls, the treatment site, were more likely to report good behaviors ($M = 4.19$, $SE = 0.05$) than visitors who saw an LNT related sign at Rainbow Falls ($M = 4.06$, $SE = 0.06$; $B = 0.17$, $p = 0.060$).

Table 3. Linear regression modeling the effects of demographic variables and treatment groups by model 1 (intervention) and model 2 (saw signs) on self-reported good behavior frequency (n = 945).

Effect	Model 1		Model 2	
	B (SE)	p-value	B (SE)	p-value
Intercept	3.58 (0.13)		3.50 (0.13)	
White	0.18 (0.03)	0.005	0.19 (0.06)	0.003
Male	-0.13 (0.04)	0.004	-0.14 (0.04)	0.002
Age	0.01 (0.00)	<0.001	0.01 (0.00)	<0.001
Graduate degree	-0.11 (0.05)	0.014	-0.10 (0.05)	0.026
Liberal	0.07 (0.05)	0.134	0.06 (0.05)	0.175
Dogs	-0.07 (0.06)	0.199	-0.07 (0.06)	0.180
Kids	-0.01 (0.06)	0.859	-0.01 (0.06)	0.860
First time visitor	0.08 (0.05)	0.074	0.08 (0.05)	0.061
Recreates often	-0.00 (0.05)	0.964	0.00 (0.04)	0.937
Thinks visitors cause environmental impacts	0.03 (0.01)	0.084	0.02 (0.01)	0.106
Site	0.03 (0.07)	0.700	-0.04 (0.07)	0.566
Intervention	-0.10 (0.07)	0.145		
Site * Intervention	0.06 (0.09)	0.487		
Saw signs			0.01 (0.07)	0.878
Site * Saw signs			0.17 (0.09)	0.060
Adj. Model R2	0.07		0.07	

Table 4. Linear regression modeling the effects of demographic variables and treatment groups by model 1 (intervention) and model 2 (saw signs) on self-reported bad LNT behavior frequency (n = 940).

Effect	Model 1		Model 2	
	B (SE)	p-value	B (SE)	p-value
Intercept	2.17 (0.12)		2.17 (0.12)	
White	-0.10 (0.06)	0.090	-0.10 (0.06)	0.088
Male	0.04 (0.04)	0.345	0.04 (0.04)	0.377
Age	-0.01 (0.00)	<0.001	-0.01 (0.00)	<0.001
Graduate degree	0.02 (0.04)	0.720	0.02 (0.04)	0.656
Liberal	-0.01 (0.04)	0.870	-0.01 (0.04)	0.825
Dogs	0.06 (0.05)	0.269	0.06 (0.05)	0.242
Kids	0.02 (0.05)	0.704	0.02 (0.05)	0.648
First time visitor	-0.02 (0.04)	0.594	-0.02 (0.04)	0.630
Recreates often	0.04 (0.04)	0.368	0.04 (0.04)	0.392
Thinks visitors cause environmental impacts	0.02 (0.01)	0.141	0.02 (0.01)	0.122
Site	-0.04 (0.06)	0.556	-0.05 (0.06)	0.387
Intervention	0.01 (0.06)	0.881		
Site * Intervention	0.03 (0.08)	0.706		
Saw signs			0.01 (0.06)	0.868
Site * Saw signs			0.05 (0.08)	0.538
Adj. Model R2	0.01		0.01	

An in-depth analysis of individual good behaviors found that staying on-trail was the most followed good behavior (93.9% of visitors did this often or very often, $M = 4.57$, $SD = 0.69$), while separating recyclables was the least followed good behavior (67.6% of visitors did this often or very often, $M = 3.82$, $SD = 1.28$; Supplemental Table S2). The most problematic bad behavior not aligned with LNT principles was avoiding muddy and wet spots on trails (53.8% of visitors did this often or very often, $M = 3.45$, $SD = 1.20$), and the least problematic behavior was carving into trees (2.4% of visitors, $M = 1.15$, $SD = 0.62$; Supplemental Table S2).

In general, visitors who said they saw a sign at either park were more likely to report changes in thinking and behavior. For example, at the treatment site, 19.2% of visitors who reported seeing an LNT sign ($n = 412$) said they learned something new during their visit, compared to just 11.8% who did not see a sign ($\chi^2[1] = 5.71$, $p = 0.017$, Cramer's $V = 0.09$). Additionally, 24.6% of visitors who saw a sign said they would think differently during their visit because of LNT messaging (compared to 17.7% who did not see a sign; $\chi^2[1]=4.20$, $p = 0.040$, Cramer's $V = 0.08$), and 15.1% said they would act differently during their visit (compared to 9.7% who did not see a sign; $\chi^2[1]=3.82$, $p = 0.051$, Cramer's $V = 0.08$). These percentages and patterns for visitors who saw LNT signs at the control site ($n = 244$) were nearly identical. Across both sites, 71.6% of visitors reported no change in thought or action in response to LNT messaging. For those who reported no change, reasons included: I already do that stuff anyway (63.2% of visitors), I didn't see any LNT messaging (30.2%), I saw messaging but didn't take time to read it (4.6%), and I don't want do that stuff (1.9%).

Visitors' Observed Behaviors

Our direct observations at the base of the waterfalls and along the trails at both the treatment and control sites did not reveal any statistically significant differences in the proportion of visitors engaged in bad behaviors at the beginning and end of the summer, though the rate of bad behaviors tended to increase later in the summer — even at the treatment site. For example, the proportion of hikers observed off trail at both sites ranged from an average of 7.2% per observation session in early summer ($n = 18$) to 9.7% in late summer ($n = 21$; $t(37) = -0.074$, $p = 0.466$), while the proportion of visitors exploring prohibited areas near the waterfalls ranged from an average of 10.2% per observation session in early summer ($n = 16$) to 17.4% in late summer ($n = 17$; $t(31) = -1.05$, $p = 0.302$). Across both sites, the proportion of off-leash dogs observed on the waterfalls and trails also increased from 6.7% per observation session in early summer ($n = 17$) to 17.1% in late summer ($n = 26$; $t(41) = -1.18$, $p = 0.246$).

However, the trail cameras capturing visitor use of prominent informal trails revealed potential treatment effects (Figure 3). At the Rainbow Falls control site, there was no change in observed off-trail visitors per week between the pre-intervention ($M = 12.35$, $SD = 2.73$) and post-intervention ($M = 11.69$, $SD = 2.34$; $t(df) = 15$, $p = 0.597$) time periods. But at the Hooker Falls treatment site, there was a significant decline in the number of visitors using the informal trail per week between pre-intervention ($M = 3.52$, $SD = 0.53$) and post-intervention ($M = 2.01$, $SD = 1.16$; $t(df) = 12$, $p < 0.009$). This shift came in spite of the fact that there were approximately 10% more day users visiting Hooker Falls in the post-intervention time period.

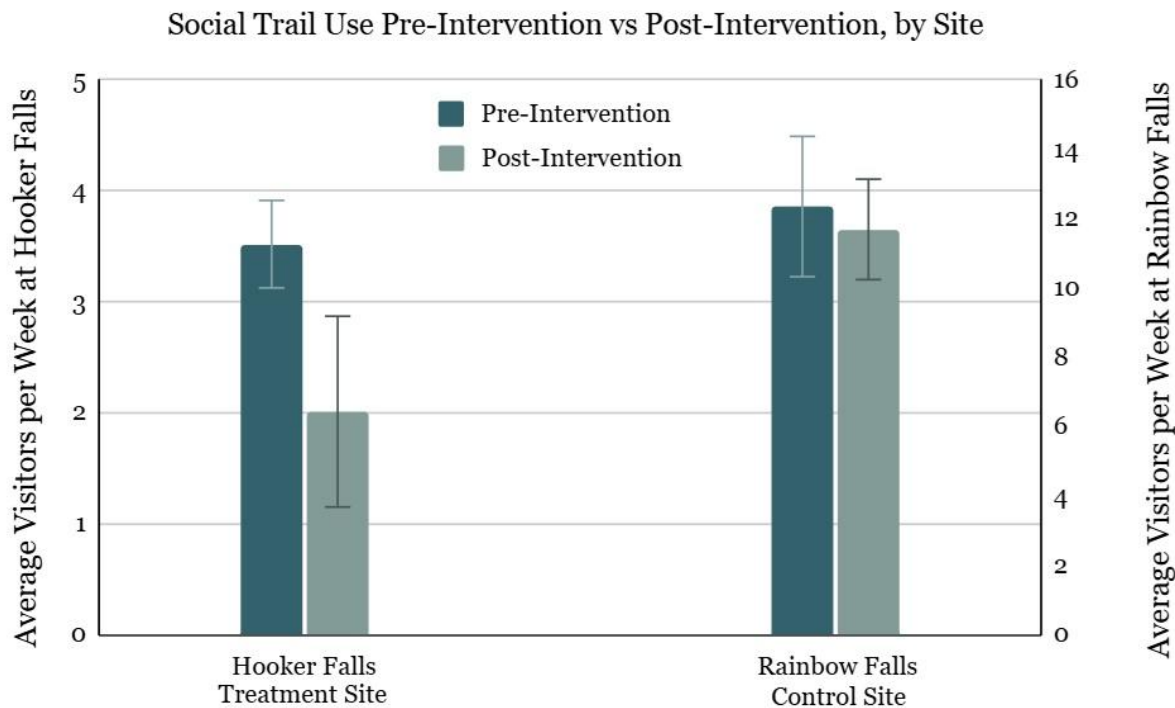


Figure 3. Average weekly visitor use of an illegal informal trail at Hooker Falls (treatment site) and Rainbow Falls (control site) from before our LNT signs went up (pre-intervention) and after (post-intervention), with 95% confidence intervals shown as error bars.

Lastly, our direct observations of visitors who stopped or walked by our newly installed trailhead LNT sign at Hooker Falls revealed that only 13.1% of visitors stopped to read it, yet 34.5% of the people who stopped were children. This small proportion of visitors that actually read the sign based on our observations suggests that other factors – beyond the sign alone – may have contributed to the reduced use of the informal trail and/or other “good” LNT behaviors at the treatment site.

Discussion

Our study revealed a variety of challenges and opportunities regarding LNT-related communication at frontcountry recreation sites, with impacts on both knowledge and behavior. Each of these outcome variables are discussed below, both in relation to demographic correlations and in terms of the potential for signage to impact them.

LNT Knowledge

Our investigation into frontcountry visitor's baseline knowledge revealed several socio-demographic groups (those who were white, liberal, had dogs with them, and recreated often) who rated their perceived LNT knowledge as significantly higher than their demographic counterparts. However, white visitors were the only one of these groups who also scored higher on assessed LNT knowledge. These results raise concerns about race-based inequities in LNT awareness and education, highlighting the importance of considering racial and cultural factors when communicating about LNT. For example, Stern et al. (2010) suggests that culturally responsive approaches to environmental education can better engage minority groups and lead to lasting impacts. These results also support findings from other studies suggesting that self-reported knowledge will often be higher than assessed knowledge, and the two may not be correlated (Kormos & Gifford, 2014; Snibsøer et al., 2018).

Curiously, those who were younger and first-time visitors scored higher on assessed LNT knowledge than their demographic counterparts. This suggests that younger visitors and those who are new to a protected area may be more likely to pay attention to signs, and that signs might need to be adjusted to capture the eye of older and more frequent site

visitors. As suggested by Maples et al. (2022), it is also likely that younger visitors who have a stronger environmental ethos are more aware that certain LNT behaviors, such as disposing of biodegradable waste, are now less acceptable than they used to be.

While our intervention did not influence visitors self-reported or assessed knowledge, seeing LNT-related signs—even if they were not the new ones we installed—did impact self-reported LNT knowledge scores. Visitors who recalled seeing any signs on site felt more confident in their knowledge, even if this was not reflected in assessed knowledge. While this is encouraging, it should be noted that many other factors beyond knowledge influence conservation behavior (Knapp et al., 2021; Steg & Vlek, 2009). For example, the increased rates of off-leash dogs and humans exploring prohibited areas that we observed post-intervention might be due to shifting social norms as the summer progresses (Heywood, 2002), which are typically more powerful drivers of behavior than any form of information. Thus, shifts in perceived knowledge alone are unlikely to result in tangible stewardship actions.

LNT Behavior

In our study, seeing signs at Hooker Falls (the treatment site) correlated with higher reports of participation in good behaviors. This is promising, as it suggests that LNT-aligned signs can impact visitors' behavior at a site. This change in good behavior was further supported by the increase in visitors who reported changing the way they thought and acted on site, based on if the visitor saw signs on site. Nevertheless, reported changes were minimal and effect sizes were small.

Some demographic groups, in particular, reported lower rates of good behaviors: males and those with graduate degrees. Thus, frontcountry messaging may need to better appeal to visitors who are confident and think they know a lot about environmental issues, such as those with graduate degrees and males (Casale, 2020; Clayton & Myers, 2015), reminding them to evaluate their actions and the impacts they can have on the environment. Additionally, younger visitors were more likely to report engaging in bad behaviors. Understanding why youth participate in the behaviors they choose, particularly bad and risky ones, can be vital to implementing change (France, 2000). Despite the challenge of connecting with young adult visitors, this demographic may still present an opportunity to promote positive behaviors because they tend to be more concerned about the environment (Gifford & Nilsson, 2014). If managers can better comprehend and respond to young people's values and motivations, they may be able to more successfully appeal to their concern for the environment and create lasting behavior changes.

Regardless of an absence of demographic correlations, further analyses of individual bad behaviors revealed specific areas of concern for managers. For example, many visitors said they were likely to avoid muddy or wet spots along the trail and hike side-by-side. The higher frequency of hiking side-by-side may be attributed to the fact that many frontcountry sites build wider trails, anticipating higher volumes of traffic (DuPont rangers, personal communication, 2024). Regardless, efforts to avoid muddy and wet spots along the trail are concerning given their correlation to increased erosion, trail widening, and vegetation degradation (Barros & Pickering, 2017; Huang et al., 2015; Leung & Marion, 1996; Meadema et al., 2020). Thus, rather than pushing all seven of LNT's principles,

communication efforts might focus on the behaviors of greatest concern and relevance in frontcountry contexts (e.g., staying on trail, littering, keeping dogs on leash).

The aforementioned behavior discussion revolves around self-reported behaviors, not direct observations of visitor behavior. This focus on self-reported data is a common limitation in many LNT studies (Lawhon et al., 2013; Vagias et al., 2014), and introduces potential reporting bias. It is therefore promising that, despite few significant correlations with self-reported good and bad behaviors, observations from our trail camera data revealed significant decreases in use of the prominent informal trail at Hooker Falls, our treatment site. These results highlight the potential for behavior change even if people are not aware of it, and they emphasize the importance of directly observing visitor behavior in addition to using self-reported data when assessing LNT outcomes (Kormos & Gifford, 2014).

Effective LNT Messaging

The apparent disconnect between self-reported and assessed knowledge in our study, coupled with the modest treatment effects we observed, could be largely explained by one fact: only 13.1% of visitors stopped to read the signs we installed. Signs might help educate visitors, but only if visitors engage with them; this can be difficult, as noted by other researchers (Hall et al., 2010; Park et al., 2008; Zhu et al., 2021). How, then, might managers increase the chances of visitors reading important LNT-related signs?

Research has shown that sign location matters, with trailheads being a good pick for signage (Bradford & McIntyre, 2007). Visitors in our survey also supported this, choosing signs on trail as the location they thought LNT messaging would be most effective.

However, with so few visitors stopping to see our signs, a change to the messaging approach itself might be needed (Weiler et al., 2015). Abrams et al. (2019) explored how a personal-benefit approach can appeal more to visitors, advocating for messaging that highlights how visitor experiences would also be improved via compliance or behavior change. Similarly, Rice et al. (2024) illustrated that positive, non-regulatory appeals (i.e. suggestions instead of rules) can be very effective at changing behavior, and this messaging is even more important when it incorporates emotional elements (i.e., images of distraught wildlife). Other research has focused on influencing and utilizing social norms to evoke desired behaviors, changing visitor perceptions about what is expected and commonly practiced at a site (Skibins et al., 2012).

Lastly, while our LNT-messaging was limited to signage, multimedia approaches such as using social media campaigns have the capabilities to reach more visitors and prompt more responsible recreation at popular sites (Gaffar et al., 2022; Li & Fang, 2022; Manning, 2003). This may be particularly effective at iconic and aesthetically appealing destinations such as the waterfalls we studied (though policies at our partner agencies prevented us from including social media messaging in this study). Similar approaches may be particularly useful for younger generations that have grown up surrounded by social media. Youth themselves represent another prime, and often overlooked, target for LNT messaging. Kids made up $\frac{1}{3}$ of the visitors that stopped at our sign, highlighting a greater potential for exposure and subsequent change that could “trickle up” to other family members. Intergenerational learning is increasingly recognized as an important tool in conservation (Peterson et al., 2019) and environmental education (Ballantyne et al., 1998;

Duvall & Zint, 2007), and it could be more effectively utilized in LNT communication as well.

Limitations and Future Research

Several limitations of this study could be addressed in future research. First, our study only focused on two frontcountry sites in western in NC; both featured popular day use waterfalls, but trail length/conditions and overall visitation varied across sites. Visitors to other frontcountry areas may differ from those found at our sites. Second, our surveys were only available on paper (due to limited cellular service and charging capabilities in the mountains of western NC) and in English (because most visitors spoke English). Future research could offer surveys or conduct focus groups in multiple languages, especially in frontcountry sites that attract more diverse users (Ryan et al., 2020). Third, our research primarily focused on adults, but children make up an important portion of frontcountry visitors (about 20% of groups surveyed in our study had children and over $\frac{1}{3}$ of those who stopped to read our LNT sign were children). Future work could explore the efficacy of LNT messaging with youth (Miller et al., 2014; Schwartz et al., 2018a). Although we were able to observe visitor behavior in multiple ways including trail cameras, the types of behaviors we could observe was limited. Some behaviors, such as avoiding muddy puddles can only be observed given the right weather and direct, in-person observations. Other instruments could also be used to assess the extension of pro-environmental and LNT-aligned behaviors away from the site (Mateer et al., 2022). Finally, because visitors seemed to be responding positively to all signs at the site (see Supplemental Figure S1), and not just the LNT-focused ones we developed, we were not able to definitively discern whether any changes in

knowledge or behaviors were due to our specific sign or other forms of messaging. Future research could integrate a greater variety of message framing and graphic design approaches to see which communication strategy works best through an interactive, experimental process to determine the most effective messaging for a site (He et al., 2023; Rice et al., 2024).

Implications for Practice

With outdoor recreation demand increasing and day-use visitation rising (National Association of State Park Directors, 2024; Papenfuse et al., 2000), it is necessary for park and protected area managers to find effective ways to mitigate the environmental impacts in frontcountry destinations. Our study suggests that targeted messaging via signs to promote Leave No Trace knowledge and behaviors could help address these concerns. For example, many visitors reported that seeing LNT signs changes the way they think and act at the site, and we found that visitors who saw LNT signs at either site reported higher levels of LNT knowledge and good behaviors. While many directly observed behaviors (e.g., off-leash dogs) did not change post-intervention, use of illegal informal trails appeared to decrease at the treatment site following sign installation. Visitors also indicated trailside signs were an effective and preferred means of communication. The signage communication strategy is also relatively inexpensive (collectively our signs and installation materials cost less than \$500) and efficient, as it frees up staff time to prioritize other activities.

However, there are drawbacks to signage that must be considered. Notably, as seen in our study, there is no guarantee that visitors will see or interact with signs. Although our

sign included common design elements (e.g., maps, American flag) that tend to attract attention (LNT staff, personal communication), only 13.1% of visitors on the trail stopped to look at the sign. This explains the small or minimal effect sizes seen in our experimental study. Our sign was purely informational, but previous research has found that different message frames and forms could be more successful. For example, signs that highlight the positive impacts changes in behavior can have on visitors themselves, in addition to the environment, might resonate more with day users (Abrams et al., 2019). Managers and researchers could team up to investigate how to craft LNT signs that are more attention-grabbing and effective at educating large, diverse groups of visitors at frontcountry sites. Because most frontcountry sites typically have more and different amenities and structures than backcountry sites (e.g., wider trails for anticipated crowds) the prioritization of certain LNT principles might need to shift as well. For example, instead of encouraging visitors to walk single file with their group, visitors may only need to do this when passing another group. Park managers might also want to directly target more frequent problematic behaviors, such as walking around muddy or wet areas on a trail, littering, and keeping dogs on leash, instead of emphasizing all 7 LNT principles. Promoting ecological stewardship among outdoor recreationists at high use sites might be difficult, but strategic partnerships with organizations such as LNT can help promote important pro-environmental behaviors and achieve collective conservation goals. Signs are only one of many tools that can advance LNT goals at frontcountry sites, and future testing and evaluation studies can help us better understand how different types of messaging and delivery methods can be combined to maximize reach and minimize recreation impacts in parks and protected areas.

References

- Abrams, K. M., Leong, K., Melena, S., & Teel, T. (2019). Encouraging safe wildlife viewing in national parks: Effects of a communication campaign on visitors' behavior. *Environmental Communication, 14*(2), 255–270.
<https://doi.org/10.1080/17524032.2019.1649291>
- Backman, C. L., Vaske, J. J., Lawhon, B., Vagias, W., Newman, P., Coulson, E., & Taff, B. D. (2018). Visitors' views of Leave No Trace Principles across a national park, a national forest, and three state parks. *Journal of Park and Recreation Administration, 36*(4), 41-54. <https://doi.org/10.18666/JPra-2018-V36-I4-8841>
- Ballantyne, R., Connell, S., & Fien, J. (1998). Students as catalysts of environmental change: A framework for researching intergenerational influence through environmental education. *Environmental education research, 4*(3), 285-298.
- Barros, A., & Pickering, C. M. (2017). How networks of informal trails cause landscape level damage to vegetation. *Environmental Management, 60*(1), 57–68.
<https://doi.org/10.1007/s00267-017-0865-9>
- Blye, C. J., & Halpenny, E. (2020). Do Canadians Leave No Trace? Understanding Leave No Trace attitudes of frontcountry and backcountry overnight visitors to Canadian provincial parks. *Journal of Outdoor Recreation and Tourism, 29*, 100258.
<https://doi.org/10.1016/j.jort.2019.100258>
- Bradford, L. E., & McIntyre, N. (2007). Off the beaten track: Messages as a means of reducing social trail use at St. Lawrence Islands National Park. *Journal of Park and Recreation Administration, 25*(1), 1–21.

- Campbell, M. J. (2006). Monitoring trail use with digital still cameras: Strengths, limitations and proposed resolutions. In D. Siegrist, C. Clivaz, M. Hunziker, & S. Iten (Eds.), *Exploring the Nature of Management: Proceedings of the 3rd International Conference on Monitoring and Management of Visitor Flows in Recreational and Protected Areas* (pp. 317-321). Rapperswil, Switzerland: University of Applied Sciences Rapperswil.
- Casale, S. (2020). Gender differences in self-esteem and self-confidence. In B. J. Carducci, & C. S. Nave (Eds.), *The Wiley Encyclopedia of Personality and Individual Differences: Personality Processes and Individual Differences* (pp. 185-189). New York: Wiley.
- Clayton, S., & Myers, G. (2015). *Conservation Psychology: Understanding and Promoting Human Care for Nature*. New York: John Wiley & Sons.
- Cole, D. N. (2018). Leave No Trace: how it came to be. *International Journal of Wilderness*, 24(3), 54-65.
- Cooke, M. T., & Xia, L. (2020). Impacts of land-based recreation on Water Quality. *Natural Areas Journal*, 40(2), 179. <https://doi.org/10.3375/043.040.0209>
- Cordell, H. K., & Super, G. R. (2000). Trends in Americans' outdoor recreation. In W. C. Gartner & D. W. Lime (Eds.), *Trends in Outdoor Recreation, Leisure, and Tourism* (pp. 133-144). Wallingford, UK: CABI.
- CPW (Colorado Parks and Wildlife) Partnership. Leave No Trace. (2023, November 17). <https://lnt.org/colorado-parks-and-wildlife-partnership/>

- D'Antonio, A., Monz, C., Newman, P., Lawson, S., & Taff, D. (2012). The effects of local ecological knowledge, minimum-impact knowledge, and prior experience on visitor perceptions of the ecological impacts of backcountry recreation. *Environmental Management, 50*, 542-554. <https://doi.org/10.1007/s00267-012-9910-x>
- Dolman, M. R., & Marion, J. L. (2022). Invasive plant hitchhikers: Appalachian Trail thru-hiker knowledge and attitudes of invasive plants and Leave No Trace practices. *Journal of Outdoor Recreation and Tourism, 40*, Art. 100581. <https://doi.org/10.1016/j.jort.2022.100581>
- Dresner, M., Handelman, C., Braun, S., & Rollwagen-Bollens, G. (2014). Environmental identity, pro-environmental behaviors, and civic engagement of volunteer stewards in Portland area parks. *Environmental Education Research, 21*(7), 991-1010. <https://doi.org/10.1080/13504622.2014.964188>
- Duvall, J., & Zint, M. (2007). A review of research on the effectiveness of environmental education in promoting intergenerational learning. *The Journal of Environmental Education, 38*(4), 14-24.
- France, A. (2000). Towards a sociological understanding of youth and their risk-taking. *Journal of Youth Studies, 3*(3), 317-331. <https://doi.org/10.1080/713684380>
- Freeman, S., Taff, B. D., Lawhon, B., Benfield, J. A., Kreye, M., Newton, J., Miller, L., & Newman, P. (2023). The impact of message framing on wildlife approach during ungulate viewing experiences in the Greater Yellowstone Ecosystem. *Journal of Interpretation Research, 28*(1), 7-24. <https://doi.org/10.1177/10925872231157596>

- Gaffar, V., Tjahjono, B., Abdullah, T., & Sukmayadi, V. (2022). Like, tag and share: bolstering social media marketing to improve intention to visit a nature-based tourism destination. *Tourism Review*, 77(2), 451-470.
- Gifford, R., & Nilsson, A. (2014). Personal and social factors that influence pro-environmental concern and behaviour: A review. *International Journal of Psychology*, 49(3), 141-157. <https://doi.org/10.1002/ijop.12034>
- Gilroy, L., Kenny, H., & Morris, J. (2013). Parks 2.0: Operating state parks through public-private partnerships. Washington DC: Conservation Leadership Council and Reason Foundation & Buckeye Institute.
- Greenberg, S. (2024, September 21). Timelapse. <https://timelapse.ucalgary.ca/>
- Gunther, K. A., Wilmot, K. R., Cain, S. L., Wyman, T., Reinertson, E. G., & Bramblett, A. M. (2015). Habituated grizzly bears: A natural response to increasing visitation in Yellowstone & Grand Teton National Parks. *Yellowstone Science*, 23(2), 32-40.
- Hall, T. E., Ham, S. H., & Lackey, B. K. (2010). Comparative evaluation of the attention capture and holding power of novel signs aimed at park visitors. *Journal of Interpretation Research*, 15(1), 15-36.
<https://doi.org/10.1177/109258721001500103>
- He, M., Blye, C. J., & Halpenny, E. (2023). Impacts of environmental communication on pro-environmental intentions and behaviours: a systematic review on nature-based tourism context. *Journal of Sustainable Tourism*, 31(8), 1921-1943.
- Heywood, J. L. (2002). The cognitive and emotional components of behavior norms in outdoor recreation. *Leisure Sciences*, 24(3-4), 271-281.
<https://doi.org/10.1080/01490400290050727>

- Hockett, K. S., Marion, J. L., & Leung, Y.-F. (2017). The efficacy of combined educational and site management actions in reducing off-trail hiking in an urban-proximate protected area. *Journal of Environmental Management*, *203*, 17–28.
<https://doi.org/10.1016/j.jenvman.2017.06.073>
- Hotchkiss, C., & Savage, A. (2024, August 5). Visit NC and Leave No Trace: Partnerships for improved outdoor rec. NC State Extension News.
<https://tourism.ces.ncsu.edu/2020/09/visit-nc-and-leave-no-trace-partnerships-for-improved-outdoor-rec/>
- Huang, X., Sheng, Z., Zhang, Y., Ding, J., & He, K. (2015). Impacts of trails on plants, soil and their interactions in the subalpine meadows of Mount Jade Dragon, Northwestern Yunnan of China. *Grassland Science*, *61*(4), 204–216.
<https://doi.org/10.1111/grs.12100>
- Hughes, M., Ham, S. H., & Brown, T. (2009). Influencing park visitor behavior: A belief-based approach. *Journal of Park and Recreation Administration*, *27*(4), 38–53.
- Knapp, J. L., Phillips, B. B., Clements, J., Shaw, R. F., & Osborne, J. L. (2021). Socio-psychological factors, beyond knowledge, predict people's engagement in pollinator conservation. *People and Nature*, *3*(1), 204–220.
<https://doi.org/10.1002/pan3.10168>
- Kormos, C., & Gifford, R. (2014). The validity of self-report measures of proenvironmental behavior: A meta-analytic review. *Journal of Environmental Psychology*, *40*, 359–371.
<https://doi.org/10.1016/j.jenvp.2014.09.003>

- Lawhon, B., Newman, P., Taff, D., Vaske, J., Vagias, W., Lawson, S., & Monz, C. (2013). Factors influencing behavioral intentions for Leave No Trace behavior in national parks. *Journal of Interpretation Research*, 18(1), 23-38.
<https://doi.org/10.1177/109258721301800103>
- Lawhon, B., Taff, B. D., Newman, P., Vagias, W. M., & Miller, Z. D. (2019). Understanding attitudes and support for Leave No Trace: Informing communication strategies with frontcountry state park visitors. *Journal of Outdoor Recreation, Education, and Leadership*, 11(1), 37-52. <https://doi.org/10.18666/jorel-2019-v11-i1-9290>
- Lawhon, B., Taff, B. D., Newman, P., Vagias, W. M., & Newton, J. (2017). Understanding and influencing state park visitors' Leave No Trace behavioral intent. *Journal of Interpretation Research*, 22(1), 53-71.
<https://doi.org/10.1177/109258721702200104>
- Leung, Y.-F., & Attarian, A. (2003). Frontcountry visitor information/education programs: Are there lessons for wilderness? *International Journal of Wilderness*, 9(1), 32-33.
- Leung, Y.-F., & Marion, J. L. (1996). Trail degradation as influenced by environmental factors: A state-of-the-knowledge review. *Journal of soil and water conservation*, 51(2), 130-136.
- Leung, Y.-F., Spenceley, A., Hvenegaard, G., & Buckley, R. (2018). Tourism and Visitor Management in Protected Areas: Guidelines for Sustainability. Best Practice Protected Area Guidelines Series No. 27. Gland, Switzerland: IUCN.
<https://doi.org/10.2305/IUCN.CH.2018.PAG.27.en>

- Li, C. Y., & Fang, Y. H. (2022). Go green, go social: Exploring the antecedents of pro-environmental behaviors in social networking sites beyond norm activation theory. *International Journal of Environmental Research and Public Health*, 19(21), 14265.
- LNT (Leave No Trace Center for Outdoor Ethics) (2022, February 16). History of LNT. <https://lnt.org/about/history/>
- MacLeay, A. (2010, July). *Backcountry vs. frontcountry: What's the difference? where's the line?* Trailspace. <https://www.trailspace.com/blog/2010/07/06/backcountry-versus-frontcountry.html>
- Mandic, A., & Walia, S. K. (Eds.) (2023). *Routledge Handbook of Nature Based Tourism Development*. New York: Routledge.
- Manning, R. E. (2003). Emerging principles for using information/education in wilderness management. *International Journal of Wilderness*, 9(1), 20-27.
- Manning, R. E., Anderson, L. E., & Pettengill, P. (2017). *Managing Outdoor Recreation: Case Studies in the National Parks* (2nd Ed.). Wallingford, UK: CABI.
- Maples, J. N., Bradley, M. J., Clark, B., Giles, S., & Leebrick, R. (2022). Leave no person behind: Exploring how demographic categories shape LNT principles among climbers in West Virginia's new river gorge. *Journal of Outdoor and Environmental Education*, 25(2), 219-245.
- Marion, J. L. (2014). *Leave No Trace in the Outdoors*. Mechanicsburg, PA: Stackpole Books.

- Marion, J. L., Leung, Y.-F., Eagleston, H., & Burroughs, K. (2016). A review and synthesis of recreation ecology research findings on visitor impacts to wilderness and protected natural areas. *Journal of Forestry*, *114*(3), 352–362. <https://doi.org/10.5849/jof.15-498>
- Marschall, S., Granquist, S. M., & Burns, G. L. (2017). Interpretation in wildlife tourism: Assessing the effectiveness of signage on visitor behaviour at a seal watching site in Iceland. *Journal of Outdoor Recreation and Tourism*, *17*, 11–19. <https://doi.org/10.1016/j.jort.2016.11.001>
- Mateer, T. J., Melton, T. N., Miller, Z. D., Lawhon, B., Agans, J. P., & Taff, B. D. (2022). A multi-dimensional measure of pro-environmental behavior for use across populations with varying levels of environmental involvement in the United States. *PLoS One*, *17*(10), e0274083. <https://doi.org/10.1371/journal.pone.0274083>
- Meadema, F., Marion, J. L., Arredondo, J., & Wimpey, J. (2020). The influence of layout on Appalachian Trail soil loss, widening, and muddiness: Implications for sustainable trail design and management. *Journal of Environmental Management*, *257*, 109986. <https://doi.org/10.1016/j.jenvman.2019.109986>
- Miller, A. B., Leung, Y. -F., & Kays, R. (2017). Coupling visitor and wildlife monitoring in protected areas using camera traps. *Journal of Outdoor Recreation and Tourism*, *17*, 44-53. <https://doi.org/10.1016/j.jort.2016.09.007>
- Miller, J., Hill, E., Shellman, A., Ramsing, R., & Lawhon, B. (2014). Measuring the effectiveness of the leave no trace PEAK program. *Journal of Youth Development*, *9*(2).

- NASPD (National Association of State Park Directors) (2024). Statistical Report of State Park Operations in the U.S.: 2021-2022. Raleigh, NC: NASPD.
- OIA (Outdoor Industry Association) (2024). 2024 Outdoor Participation Trends Report: Executive Summary. Boulder, CO: OIA.
- Papenfuse, M. K., Roggenbuck, J. W., & Hall, T. E. (2000). The rise of the day visitor in wilderness: Should managers be concerned? In D. N. Cole, S. F. McCool, W. T. Borrie, & J. O'Loughlin, (Comps.) *Wilderness Science in a Time of Change Conference — Volume 4: Wilderness Visitors, Experiences, and Visitor Management* (pp. 23-27). Proceedings RMRS-P-15-VOL-4. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station.
- Park, L. O., Manning, R. E., Marion, J. L., Lawson, S. R., & Jacobi, C. (2008). Managing visitor impacts in parks: A multi-method study of the effectiveness of alternative management practices. *Journal of Park and Recreation Administration*, 26(1), 97-121.
- Park, L. O., Marion, J. L., & Wimpey, J. (2023). Efficacy of combining education and site management in reducing off-trail travel in a fragile biotic community, Acadia National Park. *Journal of Interpretation Research*, 18(1), 25-49.
<https://doi.org/10.1177/10925872221133774>
- Peterson, M. N., Stevenson, K. T., & Lawson, D. F. (2019). Reviewing how intergenerational learning can help conservation biology face its greatest challenge. *Biological Conservation*, 235, 290-294.
- Primack, R. B., & Terry C. (2021). New social trails made during the pandemic increase fragmentation of an urban protected area. *Biological Conservation*, 255, 108993.
<https://doi.org/10.1016/j.biocon.2021.108993>

- Rice, W. L., Shellhorn, J., Bloomgren, V., Booth, L., Duncan, S., Elias, J., Flowers, K., Gambini, I., Gans, A., Medina, A., Obadare, D., O'Neill, C., Rooney, Q., Scherck, G., Schmidt, K., Thomas, C., Thomas, E., Walhus, G., Whitney, P., & Winckler, C. (2023). The impact of graphic design on attention capture and behavior among outdoor recreationists: Results from an exploratory persuasive signage experiment. *Journal of Outdoor Recreation and Tourism*, 42, 100606. <https://doi.org/10.1016/j.jort.2023.100606>
- Rice, W. L., Shellhorn, J., & Foster, M. (2024, October 6-9). *Improving bear safety signage in the greater Yellowstone ecosystem through transdisciplinary science* [Research symposium, Poster presentation]. Leave No Trace Global Summit: Powering the Next 30 Years, Boulder, CO, United States.
- Ryan, M. M., Lawson, S. R., Larkin, A. M., Roberts, S. J., & Pettebone, D. (2020). Engaging minority communities in local national park units through culturally competent focus groups. *Journal of Park & Recreation Administration*, 38(1), 67-87. <https://doi.org/10.18666/JPRA-2019-9747>
- Schwartz, F., Taff, B. D., Lawhon, B., Hodge, C., Newman, P., & Will, E. (2018a). Will they leave what they find? The efficacy of a Leave No Trace education program for youth. *Applied Environmental Education & Communication*, 17(4), 299-309. <https://doi.org/10.1080/1533015X.2017.1411217>
- Schwartz, F., Taff, B. D., Lawhon, B., & VanderWoude, D. (2018b). Mitigating undesignated trail use: The efficacy of messaging and direct site management actions in an urban-proximate open space context. *Environmental Management*, 62(3), 458-473. <https://doi.org/10.1007/s00267-018-1054-1>

- Senetra, A., Dynowski, P., Cieślak, I., & Źróbek-Sokolnik, A. (2020). An evaluation of the impact of hiking tourism on the ecological status of alpine lakes—a case study of the valley of Dolina Pięciu Stawów Polskich in the Tatra Mountains. *Sustainability, 12*(7), 2963. <https://doi.org/10.3390/su12072963>
- Settina, N., Marion, J. L., & Schwartz, F. (2020). Leave No Trace communication: Effectiveness based on assessments of resource conditions. *Journal of Interpretation Research, 25*(1), 5-25. <https://doi.org/10.1177/1092587220963523>
- Skibins, J. C., Powell, R. B., & Stern, M. J. (2012). Exploring empirical support for interpretation's best practices. *Journal of Interpretation Research, 17*(1), 25-44.
- Snibsøer, A. K., Ciliska, D., Yost, J., Graverholt, B., Nortvedt, M. W., Riise, T., & Espehaug, B. (2018). Self-reported and objectively assessed knowledge of evidence-based practice terminology among healthcare students: A cross-sectional study. *PLoS One, 13*(7), e0200313. <https://doi.org/10.1371/journal.pone.0200313>
- Steg, L., & Vlek, C. (2009). Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of Environmental Psychology, 29*(3), 309-317. <https://doi.org/10.1016/j.jenvp.2008.10.004>
- Stern, M. J., Powell, R. B., & Ardoin, N. M. (2010). Evaluating a constructivist and culturally responsive approach to environmental education for diverse audiences. *Journal of Environmental Education, 42*(2), 109-122. <https://doi.org/10.1080/00958961003796849>

Taff, B. D., Newman, P., Vagias, W. M., & Lawhon, B. (2014). Comparing day-users' and overnight visitors' attitudes concerning Leave No Trace. *Journal of Outdoor Recreation, Education, and Leadership*, 6(2), 133–146.

<https://doi.org/10.7768/1948-5123.1189>

Taylor, A. R., & Knight, R. L. (2003). Wildlife responses to recreation and associated visitor perceptions. *Ecological Applications*, 13(4), 951–963.

[https://doi.org/10.1890/1051-0761\(2003\)13\[951:wrtraa\]2.0.co;2](https://doi.org/10.1890/1051-0761(2003)13[951:wrtraa]2.0.co;2)

Vagias, W. M., Powell, R. B., Moore, D. D., & Wright, B. A. (2014). Predicting behavioral intentions to comply with recommended Leave No Trace practices. *Leisure Sciences*,

36(5), 439-457. <https://doi.org/10.1080/01490400.2014.912168>

Weiler, B., Zeppel, H., Saunders, R., & Scherrer, P. (2015). A review of safety signage for Queensland Parks and Wildlife Service Report.

Winter, P. L. (2006). The impact of normative message types on off-trail hiking. *Journal of Interpretation Research*, 11(1), 35–52.

<https://doi.org/10.1177/109258720601100103>

Zhu, L., Davis, L. S., & Carr, A. (2021). A picture is not always worth a thousand words: The visual quality of photographs affects the effectiveness of interpretive signage for science communication. *Public Understanding of Science*, 30(3), 258-273.

<https://doi.org/10.1177/0963662520982535>

CHAPTER 3: RAPID ASSESSMENT OF INFORMAL TRAILS IN PROTECTED AREAS: AN EVALUATION OF SOCIAL-ECOLOGICAL INDICATORS AND METHODS

Abstract

Visitors to parks and protected areas leave impacts that managers must try to mitigate, often working with limited resources. Rapid assessments are cost-effective, essential ways for managers to quickly assess many site areas, allowing for more informed management decisions regarding future conservation decisions (e.g., where to implement interventions). Rapid assessments often focus on ecological indicators, despite the inextricable link between social drivers and ecological impacts. Thus, this research sought to demonstrate how rapid assessment methods can be used to measure both ecological and social indicators of informal trail use (over the course of an intervention) and to evaluate the advantages and disadvantages of each method. We used prior research and indicator-based frameworks (e.g., LAC, VUM, VERP) to guide our selection of indicators and methods for evaluation. Our evaluation focused on the feasibility of implementing methods associated with each indicator and practical utility for managers. Feasibility was evaluated by considering the cost of instruments needed, the ease of collecting data, and the time required for data analysis while practical utility was evaluated by considering the effectiveness of data visualization and indicator sensitivity to change. Our study revealed a variety of methods that managers can use to assess both ecological (e.g., informal trail frequency and condition, trail impacts) and social indicators (e.g., knowledge and behaviors, informal trail use) when faced with limited resources such as personnel, time, and money. We call for managers to utilize both social and ecological indicators,

considering key tradeoffs in feasibility and practicality, as they continue to collect data to inform recreation and conservation-related decision making at their sites.

Introduction

Parks and protected areas enable people to access and interact with the natural environment by facilitating recreation activities like hiking, birdwatching, and biking (Kling et al., 2017; Vas, 2013). However, visitors often harm the environment in different ways during recreation. Hikers erode trails and degrade vegetation as they walk (Leung & Marion, 1996; Barros & Pickering, 2017), noise from recreationists alters animal patterns and behaviors (Zeller et al., 2024), human waste can contaminate water sources and habituate animals (Cooke & Xia, 2020; Knight, 2009; Taylor & Knight, 2003), and as visitors travel between sites they may introduce invasive species that can proliferate and upset fragile ecosystems (Dolman & Marion, 2022; Senetra et al., 2020). While providing recreational access and opportunities, park managers must control these environmental impacts so that other important management objectives are not unduly compromised. Furthermore, they must do so in a complex environment where numerous constraints such as lack of funding, lack of staffing, and other challenges impede progress (Pitas et al., 2017; Digun-Aweto et al., 2018).

Visitor impacts often concentrate around trails, which facilitate visitor exploration and recreation (Lucas, 2020). However, trails themselves can fragment habitats (Primack & Terry, 2021), and trail use can generate an array of unintended consequences, such as erosion (Marion & Leung, 2001). Managers plan for these costs through trail design, maintenance, and by choosing which activities to permit. However, when visitors travel off-

trail, creating informal trails, managers are faced with additional, unanticipated costs that require further consideration.

Informal trails, also known as social trails, are user-created trails prevalent in many parks (Havlick et al., 2016; Interagency Visitor Use Management Council, 2025). Visitors create and use informal trails for various reasons – for example, to avoid poorly maintained (i.e., muddy, wet, and/or otherwise damaged or obstructed) formal trails, to seek shorter routes, or to follow their friends (Goh, 2020). Past research has documented the popularity of informal trails and the variety of ways they increase anthropogenic effects in protected areas (Ballantyne & Pickering, 2015). For example, Kolasinska et al. (2015) found that over a quarter of visitors (29.4%) to the Pieniny Mountains National Park travelled off-trail. Primack and Terry (2021) studied the development and impacts of informal trail creation in Webster Woods, Massachusetts, and found 4.9 km of informal trails formed throughout the first few months of COVID – a 36% increase in trail-system length, which corresponded to a decrease from 3.2 to 2.1 hectares of interior habitat, illustrating the link between trails and habitat fragmentation.

Consequently, research around visitor impacts usually focuses on actions managers can take to mitigate informal trail use and the extent of damage associated with use. These actions, or interventions, can be direct or indirect (Schwartz et al., 2018). Direct methods usually involve stronger deterrents like the presence of staff enforcement or fines; indirect methods are more passive (e.g., using signs to discourage the use of a certain trail). While both interventions require time, personnel, and funding, direct interventions that require personnel can be more costly and challenging for managers to implement. But indirect interventions also come with a cost, and may be less likely to generate short-term behavior

change (Schwartz et al., 2018). Although managers have limited resources, proactive monitoring or conservation efforts can reduce future expenses and are necessary to continue promoting sustainable parks (Manning et al., 2011; Walls, 2018). Thus, various visitor management frameworks, such as the Limits of Acceptable Change (LAC) model, the Visitor Experience and Resource Protection (VERP) framework, and Visitor Use Management (VUM) framework recommend monitoring indicators that reflect a variety of visitor impacts – both to the natural environment and to the visitor experience at the site (Interagency Visitor Use Management Council, 2025; Belnap, 1998; Watson & Cole, 1992).

Building on these past efforts, we developed a conceptual framework specific to informal trails, highlighting key antecedents, problems, and consequences associated with the creation and continued use of informal trails (Figure 1). This framework guided our selection of indicators specific to informal trails. Jackson et al. (2000) define indicators as signs or signals that relay complex messages about the state or dynamics of a system. In the context of parks and protected areas, many researchers focus on ecological indicators (for examples, see Tomczyk et al., 2017; Belnap, 1998; and Marion & Leung, 2001). Ecological indicators help evaluate the condition of an environment. They can be used to detect or diagnose changes in the environment that could be an early warning sign of significant environmental problems (Dale & Beyeler, 2001). Thus, ecological indicators relate to *what* is happening to the environment. These indicators usually measure the extent of biophysical damage to a site (e.g., vegetation degradation, soil erosion, water quality). Given that sites usually have multiple informal trails, managers may need to prioritize applying interventions to informal trails experiencing heavy ecological impacts. However, social indicators can also be vital, informing managers *why* visitors behave the way they do,

providing insights to the nature of tourists and recreational use (Moscardo & Ormsby, 2004). For example, if an informal trail is popular because it provides access to a resource visitors can't reach by established trails, managers may want to consider developing a formal trail that allows access or working to help visitors understand how their actions are impacting the environment and why that resource should not be accessed. Overall, research suggests that effective integration of a multi-indicator monitoring framework is key to achieving sustainable recreation and conservation goals (Morse, 2020; Miller et al., 2022). Yet, despite the inextricable link between ecological and social indicators, research and management actions typically focus on a single domain (ecological versus social) and this integration has been difficult to achieve.

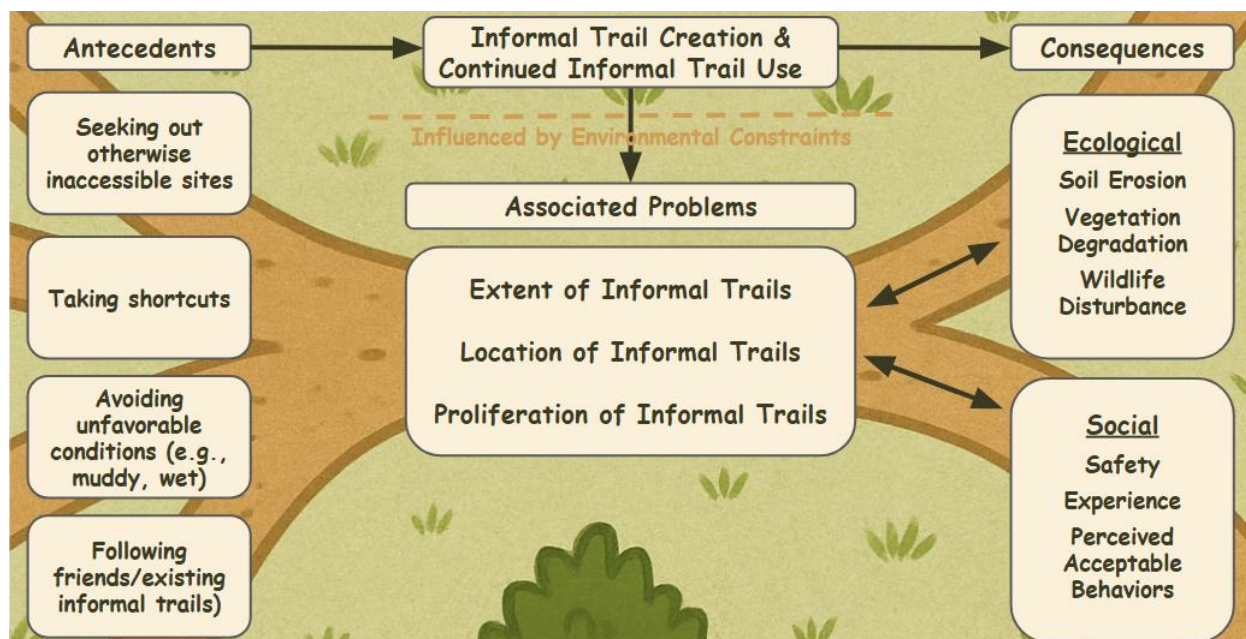


Figure 1. Framework modeling antecedents and consequences surrounding informal trail use.

Note. Background trail image generated using ChatGPT (<https://chat.openai.com/>).

To monitor indicators effectively under resource constraints, managers can turn to rapid assessment methods. Rapid assessment methods are cost-effective ways to evaluate plans and decisions, providing quick data that can be used to address a myriad of recreation and conservation needs by providing baseline measurements (Larsen, 2011). While timely, these rapid assessments often provide less precise measurements; however, they allow managers to preliminarily assess an issue, shaping specific responsive actions and justifying more in-depth or prolonged monitoring efforts. These assessments should be viewed as the first step in a multi-step conservation program. These measurements can also be conducted longitudinally, providing information on change over time, or in collaboration with the public, engaging visitors to help collect data through various forms of citizen science (Korpilo et al., 2017). For example, Cheung et al. (2025) compared volunteers' abilities to collect ecological measurements, such as trail width and multiple trail treads, to manager's, finding volunteer data was comparable to manager data for some but not all variables. Regardless of who is conducting rapid assessments, it is important to understand the advantages and disadvantages of various methods for measuring key ecological and social indicators to help inform management priorities (del Campo & Clark, 2009; Manning, 2011).

In this research, we sought to demonstrate how rapid assessment methods can be used to measure relevant social and ecological indicators of informal trail use based on our framework (Figure 1). We tested and evaluated each method at a popular outdoor recreation destination in western NC, USA, focusing on the feasibility of implementation and practical utility for managers, with the goal of highlighting tradeoffs among the various

methods and indicators to guide decision making and balance recreation and conservation goals.

Methods

Selection of Indicators and Methods

Before selecting rapid assessment methods for evaluation, we first strategically selected ecological and social indicators associated with informal trail use. The framework we created (Figure 1) illustrates how ecological indicators are typically tied to problems and consequences associated with informal trail use (e.g., soil erosion or wildlife disturbance), while social indicators are typically tied to antecedents of informal trail use (seeking out otherwise inaccessible sites or taking shortcuts). For ecological indicators, we focused on the frequency and condition of informal trails, along with trail impacts. These indicators have been well-studied and used in many rapid assessments, often to gauge the extent of erosion (Marion & Leung, 2011). We relied on human observations and trail measurements to address these indicators, seeking rapid assessment tools that might be feasible for managers. For social indicators, we focused on visitor knowledge and behaviors as well as overall informal trail use. Understanding visitor behaviors and knowledge can be important in designing messaging and interventions (Reigner, 2008). The methods we chose to gauge these indicators included surveys and trail camera observations.

Study Design

We took advantage of an ongoing research project investigating the efficacy of Leave No Trace messaging at Hooker Falls, a popular frontcountry waterfall site in DuPont State

Recreational Forest, North Carolina, USA, to carry out our evaluation of the rapid methods (human observations, trail measurements, surveys, and trail camera observations) we chose to measure selected indicators (frequency and condition of informal trails, trail impacts, visitor knowledge and behaviors, and informal trail use). This site has numerous informal trails that present an excellent opportunity to evaluate rapid ecological and social methods, both independently and concurrently. Ecological data was collected before and after peak visitation season (i.e., summer) on less busy weekdays in May and September, 2024. Social data was then collected on busier days (Friday-Sunday + Labor Day) and throughout summer.

Informal Trail Observations

We recorded the frequency of informal trails with a Garmin GPSmap 62s (95% probability of being within 10m horizontally). We chose to focus on the number of informal trail branch points off of the main trail, as mapping the entire network of informal trails would be more time-consuming and poorly aligned with our rapid assessment approach. As we passed an informal trail, defined as a discernible path over trodden vegetation and/or exposed soil that differed from the formal trail, we plotted a point in the GPS. We then recorded this point on a data sheet which also noted if the informal trail branched off to the left or right of the main trail (going from the trailhead to the waterfall). While noting the proliferation of informal trails via GPS, we also observed the condition of each informal trail at the intersection of the formal trail. We classified trail conditions into 5 categories, following guidelines by Marion & Leung (2011): (1) trail distinguishable; slight loss of vegetation cover and/or minimal disturbance of organic litter; (2) trail obvious; vegetation

cover lost and/or organic litter pulverized in primary use areas; (3) vegetation cover lost and/or organic litter pulverized within the center of the tread, some bare soil exposed; (4) nearly complete or total loss of vegetation cover and organic litter within the tread, bare soil widespread; (5) soil erosion obvious, as indicated by exposed roots and rocks and/or gullying (Figure 2).



Figure 2. Class 2 informal trail (left) and class 4 informal trail (right).

Informal Trail Measurements

We measured informal trails by recording the trail's width, incision, and composition. These measurements collectively demonstrate the extent of trail erosion (Marion & Leung, 2001). To measure trail width, we first identified the boundary of the trail by where the trail composition changed, distinguishing where the majority of visitors walk (Figure 3). Once we established the boundary, we placed one stake on each side of the trail so that a line between the two stakes would be perpendicular to the trail, hammering

each stake to the same depth. We marked depth by using stakes that have alternating red and white bands of the same length (Figure 4). Then, we tied a taut string between the top of the two stakes and measured the length of the trail (Figure 5). Following this, a plumb bob was used to measure the incision, or depth, of a trail. The plumb bob was placed so the tip just hit the surface of the trail, dragging it across the length of the trail, following the taut string (Figure 5). We then recorded the maximum deviation of the trail from its average slope. We also measured the grade of the trail. Lastly, we determined trail composition by utilizing the same stake set up, with a tape measure pulled out to 20 cm placed in the middle of the trail, perpendicular to the width of the trail, directly below the taut string. This subdivided the trail into four quadrants to better determine the trail composition (Figure 6). Composition categories included natural boulders, gravel by management, plant litter, bedrock, soil, live vegetation, boulders by management, natural gravel, and wooden materials.



Figure 3. The stake in the photo marks the border of the trail for measurement purposes, as determined by the change in gravel distribution, indicating more consistent travel to the left of the stake.



Figure 4. The stakes used during data collection; alternating red and white bands, alongside the addition of tape, ensures they are both inserted to the same depth.



Figure 5. Setup for measuring the width of informal trails; also pictured, in the center of the trail, is the plumb bob used to measure incision.



Figure 6. Pictured are two hiking treks used to help visualize the four quadrants; the quadrants can be helpful in determining the trail composition.

Visitor Surveys

We used intercept surveys to gauge visitors' perceptions of their recreation impacts and behaviors regarding off-trail use and impacts. We asked visitors to participate in the survey after they exited the trail, with the goal of getting at least one respondent per group. We collected surveys on paper due to a lack of reception and limited charging capabilities on site. Surveys were only provided in English as managers said this was the primary language of visitors, and the research team only spoke English. Specifically we asked visitors to check all of the activities they participated in (e.g., hiking, fishing, viewing wildlife or scenery) at the site and their motivations for visiting the site. We also asked them to indicate: what they thought of the environmental quality of the forest (from 1=extremely low quality to 7=extremely high quality); the extent they thought visitors caused environmental impacts at the forest (from 1=no impact to 7=high impact); how often they stay on designated/established trails (1=never to 5=always); and how often they travel off trail to experience the natural environment (1=never to 5=always).

Visitor Observations via Trail Cameras

We measured overall trail use with a motion activated Bushell trail camera (model: 2013 Trophy Cam) that was discretely mounted on a tree along one of the most popular informal trails that carried visitors between the base of the falls and the top of the waterfall. The camera took a burst of three photos when motion was detected for the first time within a one-minute period. We utilized a trail camera as opposed to a trail counter due to the additional information images could provide. Not only were we able to record the number of visitors passing on this informal trail, but the images also revealed information about who was exploring the informal trail (e.g., child vs. adult), and provided insight as to why (e.g., if someone is passing by with a fishing rod, it is likely they are seeking out a fishing spot via the informal trail). Unlike our other assessment methods, these data were recorded throughout the summer. Every two to four weeks, a member from our team would switch out the SD card and batteries. We only retained images with visitors, discarding any images triggered by wildlife or moving plants. We also ordered a trail counter to calculate the percentage of overall park visitors who used the informal trail.

Criteria for Evaluating Methods

Methods that are scientifically defensible, but also feasible and useful to managers, are vital for reliable, effective monitoring of sites (Buckley, 2003). However, managers also rely on assessments that are cost-effective and quick (Larsen, 2011). Monitoring strategies that require little change from daily work routines of on-site personnel can be particularly advantageous, as few tradeoffs and negotiations will be required by management to

facilitate assessments. Thus, we evaluated our rapid assessment methods by focusing on two criteria supported by previous research and indicator based frameworks (Kurtz et al., 2001; Interagency Visitor Use Management Council, 2025; Belnap, 1998; Watson & Cole, 1992; Jackson et al., 2002): feasibility of implementation and practical utility for managers. Specifically, we evaluated the cost of instruments needed, the ease of collecting data, and the time required for data analysis to form our feasibility criterion. We evaluated the effectiveness of data visualization and sensitivity (to detecting change) to form our practical utility criteria. Our results and discussion section below presents our findings from each method in the context of a Leave No Trace message-testing intervention at the site. The section is designed to illustrate how managers might utilize the data, as well as our evaluation of each method based on the feasibility and practical utility criteria for managers.

Results and Discussion

Informal Trail Observations

We compiled our data of informal trail frequency and conditions into maps, thereby helping to visualize changes in trail proliferation and degradation over the summer (Figure 7). The number of informal trails didn't change substantially across our timeframe (10 to 13 informal trails). The change in condition of informal trails varied: three worsened and two improved; however, one of the informal trails that saw improvement also saw the creation of an additional informal trail near it. While there is not a clear spatial pattern to the changes we saw over our study, there is a clear area of persistent degradation prevalent near the waterfall. These results can help managers quickly identify areas of

concern and inform management decisions. For example, if informal trails are forming in unsafe locations, such as dangerous spots near the top of a waterfall, managers may want to intervene with a physical block to prevent use of these trails.

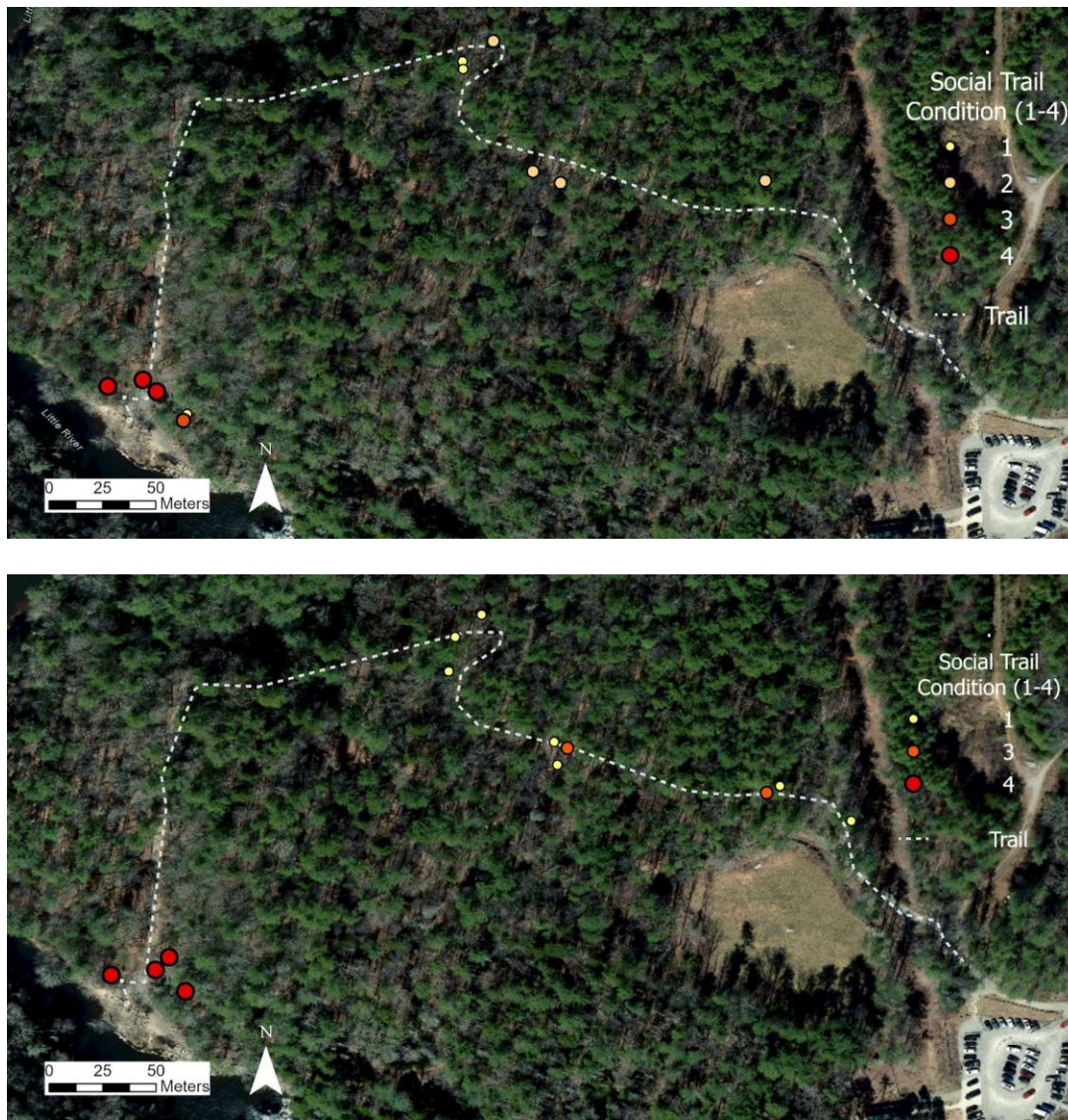


Figure 7. Maps of Hooker Falls, NC, indicating proliferation and condition of informal trails across the Leave No Trace messaging intervention period; pre-intervention from May 2024 (top) and post-intervention from September 2024 (bottom).

Implementation of informal trail monitoring via human observations also provided insights in terms of feasibility and utility for managers. With respect to feasibility, the instruments required to measure informal trail frequency and assess informal trail conditions are relatively cheap compared to other materials, with the biggest cost coming from GPS, the price of which varies with the level of precision offered. If sites have many informal trails clustered together, managers may want to use a GPS that can locate to a precision of <5 meters.

The time required to mark the number of informal trails and observe their conditions added minimal time to a hike. However, managers should be careful in how trails are classified (see methods). Training might be needed to ensure proper classification of trails over time and standardization of trail classifications between different observers. New observers should practice trail condition classification with standard reference images from each category to ensure classifications are repeatable and reproducible. Lastly, analysis can also be time consuming and requires familiarity with mapping software (e.g., ArcGIS or Google Earth Maps).

Assuming familiarity with mapping software though, this method can be very practical for managers regarding data visualization. The GPS points marking the number of informal trails can be combined with trail conditions to create maps that depict the proliferation of informal trails and extent of degradation of each trail (Figure 7). This can point managers to areas that are seeing the most deterioration. It should also be noted that trail conditions may show seasonal variation. Growth in the spring and summer may make a trail appear as if it has more vegetation and is less trampled. Conversely, in the fall and

winter, lack of vegetation may make a trail appear more degraded even if foot traffic has declined. This can present a challenge when trying to collect data over short periods of time. Thus, trail conditions may not be well suited for capturing quick changes, such as changes following an intervention, as managers should aim to conduct assessments at similar times of year. However, proliferation of informal trails is a fairly objective indicator, making it more sensitive to change over variable time scales (i.e., it is easy to determine if more informal trails have appeared no matter the timescale).

Informal Trail Measurements

The three aspects of informal trails that we measured – width, incision, and composition – each revealed unique considerations. Over the study period, average trail width increased from 61.75 cm to 76.60 cm (Table 1); comparing the width of 4 individual trails, one trail (trail 2; Table 2) was significantly wider and likely used more than the others (79 cm versus 47-51 cm). Incision results were surprising in that negative results were obtained (Tables 1 and 2), implying that incision depth decreased over time. Although results appear to be significant ($p = 0.008$, Table 1), variations may exist due to measurement error or inconsistencies. This specific measurement may need further refinement and testing before it can be reliably used. Lastly, composition changes were observed, but none were significant. This may be due to the short timescale over which data were collected. Managers can use these trail measurements to identify the most physically damaged trails. If the goal is to prevent degradation past a certain point, rapid monitoring allows managers to determine which trails can wait for further action and which trails need immediate action. Potential responses include brushing, or covering a

trail with natural materials such as leaves and trees, to make a trail inaccessible and allow time for the environment to recover.

Table 1. Results from trail measurements across the Leave No Trace messaging intervention period at Hooker Falls, NC (May to September, 2024).

Measurement	Pre-Intervention		Post-Intervention		Change p-value
	Mean	Range	Mean	Range	
Width (cm)	61.75	51.00 to 79.00	76.60	62.00 to 105.00	0.095
Incision (cm)	-0.75	-2.50 to 0.50	0.50	-2.00 to 2.00	0.008*
Composition (percent) – MGravel	16.25	0.00 to 50.00	2.50	0.00 to 10.00	0.170
Composition (percent) – NGravel	-	-	12.50	0.00 to 30.00	0.097
Composition (percent) – PLitter	60.00	10.00 to 100.00	53.75	20.00 to 95.00	0.258
Composition (percent) – Bedrock	2.50	0.00 to 10.00	1.25	0.00 to 5.00	0.196
Composition (percent) – Soil	16.25	0.00 to 40.00	22.50	0.00 to 45.00	0.139
Composition (percent) – Vegetation	5.00	0.00 to 20.00	7.50	0.00 to 20.00	0.091

Note. MGravel stands for gravel placed by management; NGravel stands for natural gravel;

PLitter stands for plant litter; LiveVeg stands for live vegetation.

**Indicates a significant difference between pre- and post-intervention averages based on paired t-tests.*

Table 2. Comparing trail measurements of four informal trails at Hooker Falls, NC; data from May 2024 only.

Informal Trail Number	Width (cm)	Incision Depth (cm)	Percent Comp.: MGravel	Percent Comp.: PLitter	Percent Comp.: Bedrock	Percent Comp.: Soil	Percent Comp.: LiveVeg
1	47	-0.5*	0	100	0	0	0
2	79	-2.5*	0	80	0	0	20
3	50	0.5	50	10	0	40	0
4	51	-0.5*	15	50	10	25	0

Note. Comp. stands for composition of trail; MGravel stands for gravel placed by management; PLitter stands for plant litter; LiveVeg stands for live vegetation.

**The incision measured was subtracted from the depth of the stake; occasionally this resulted in negative values indicating no incision.*

Regarding feasibility, trail measurements may be one of the most cost-effective indicators. Although it does not take long to collect data from an individual informal trail (about 10 minutes), the total time depends on the number of informal trails present. Ease of data collection can also vary depending on the substrate, as stakes need to be inserted deep enough to remain steady when the string is pulled taut between them. Bedrock under a shallow trail surface or very compacted soil (e.g., clay) can make this difficult.

Additionally, determining the trail boundary is another area in which managers should be wary of potential measurement error; training can ensure consistency and reproducibility between observers documenting trail width. Lastly, incision depth may not be the most reliable measure, contributing to difficulty collecting useful data. While these challenges are present in collecting the data, trail measurement data are quantitative, enabling quick

and easy data interpretation, tracking over time, and comparison between informal trails to determine which trails are most used or degraded (i.e., trails that have greater widths/incisions or less plant litter).

However, ecological impact data might not show much change over short periods of time, making them less sensitive to interventions. Thus, managers may not reap many benefits from collecting this data unless they (a) do so for multiple years, or (b) compare degradation between informal trails to find the most impacted trail (Table 2). Lastly, although storing and analyzing ecological data over time does not require sophisticated software, careful attention should still be paid to when data is collected. Observed changes between the end of summer and the end of winter may be due more to seasonal changes than actual usage of informal trails and can affect this method's sensitivity to change specific to informal trail use alone.

Visitor Surveys

Survey data, summarized in Table 3, revealed visitors' perception of environmental quality decreased significantly, falling from 6.33 to 6.15 (on a scale of 1-7, $p = 0.002$), while perceptions regarding the extent to which they cause environmental impacts increased slightly ($p = 0.066$). Despite an increase in awareness of impacts, self-reported frequencies of staying on-trail decreased significantly (73.44 to 64.22, $p = 0.006$) and traveling off-trail showed no notable change (7.42 to 7.58, $p = 0.469$). These results can help managers understand visitors' knowledge and behavioral patterns related to informal trail use. A decline in perceived environmental quality, paired with an increase in the extent to which visitors think they impact the environment, points to an increase in awareness of problems

and possibly heightened knowledge of LNT. However, this did not seem to be translated into appropriate behavior of staying on trail. Indeed, a concurrent decrease in reported on-trail behavior points to a need for more effective interventions that target overt behavior change in addition to knowledge gains. Managers should continue to seek out this information from social indicators when implementing new interventions.

Table 3. Results from intercept surveys regarding visitor knowledge and behavior across the Leave No Trace messaging intervention period (May to September 2024) at Hooker Falls, NC.

Measurement	Pre-Intervention		Post-Intervention		Change p-value
	Mean	Range	Mean	Range	
Perceived Environmental Quality (1-7)	6.33	3 to 7	6.15	1 to 7	0.002*
Extent Visitors Cause Impacts (1-7)	5.08	1 to 7	5.26	1 to 7	0.066
Frequency of Staying on Establish Trails (percent)	73.44	-	64.22	-	0.006*
Frequency of Traveling Off-Trail (percent)	7.42	-	7.58	-	0.469

**Indicates a significant difference between pre- and post-intervention averages based on independent samples t-test.*

Feasibility is the biggest challenge to implementing visitor surveys. While surveys require little equipment, the time and effort required to collect data can be costly. Intercept surveys represent a particularly time consuming process as personnel must ask visitors to take a survey, ideally collecting data over multiple days. If obtained via an online survey these data can be fairly quick to analyze; however, if collecting surveys on paper, as we had

to due to our site location and facilities and network availability, data entry and analysis can take much longer.

Unlike the previous ecological indicators, surveys provide a unique perspective into visitor behaviors, patterns, and thought processes. The information gathered can help explain what visitors are hoping to do at a site, their knowledge of visitor impacts, how often visitors stay on established trails, and how often visitors go off-trail (Table 3). This information can also help managers gauge not only how many of their visitors are traveling on informal trails, but also identify the reasons why this behavior is happening and perceptions of impacts. Understanding motivations is crucial to targeting interventions (e.g., signage or messaging campaigns) aimed at changing behaviors (McDade et al., 2025). This also speaks to the high sensitivity of self-reported and observed knowledge and behaviors, as changes following interventions are easy to assess as long as pre- and post-data are collected. It is important to remember that surveys rely on self-reported information, and results can be confounded by discrepancies between visitors' actual and self-perceived behaviors. Visitors may downplay the frequency they use informal trails or omit certain activities they know are not allowed. These limitations are difficult to navigate with surveys alone as an indicator.

Visitor Observations via Trail Cameras

Despite the self-reported increase in frequency of off-trail behaviors, trail camera observations along a major informal trail throughout the summer revealed a statistically significant, but not necessarily practical, decrease in use: declining from an average of 3.58 visitors per week to 2.46 ($p = 0.008$, Table 4). Additionally, we found that nearly one in five

informal trail users (18.14%) were anglers (who visibly had fishing gear with them on the informal trail). Although the decrease in visitors with fishing gear on informal trails between the pre- and post-intervention was not statistically significant, this comparison was likely limited due to the small sample size. These data illustrate the importance of collecting social indicators such as informal trail use. While extent of informal trail use via degradation may help managers see where an intervention is needed, understanding the visitors who comprise a large proportion of those users can be just as important in terms of designing an effective intervention. Furthermore, managers may assess whether a formal trail is needed to provide access to popular resources visitors are seeking out via informal trails (e.g., fishing spots).

Table 4. Results from trail camera observations across the Leave No Trace messaging intervention period (May to September 2024) at Hooker Falls, NC.

Measurement	Pre-Intervention		Post-Intervention		Change p-value
	Mean	Range	Mean	Range	
Number of Visitors/week	3.58	3.00 to 4.29	2.46	1.50 to 3.86	0.008*
Number of Visitors with Fishing Gear/week	0.33	0 to 1	0	0 to 0	0.087

**Indicates a significant difference between pre- and post-intervention averages based on independent samples t-test.*

When it comes to feasibility, trail cameras may represent a costly and risky tool: even when locked and placed discretely around a tree, visitors can tamper with or steal the cameras (we lost one camera during our study). However, if the trail camera can be hidden

reasonably well, data collection requires minimal time investment. The camera settings can be set and the camera can be mounted within five minutes. Collecting the data then simply requires exchanging the SD card (if remote storage and downloading of photos is not available due to internet constraints) and checking batteries every 2-4 weeks. Although collecting data requires minimal work by staff, sorting through images requires much more time. We collected 1,413 photos from our informal trail camera, 1,127 of which contained people. Programs such as Timelapse (Greenberg, 2024) can facilitate the sorting of photos. In addition to providing information on the number of visitors on the informal trails, camera data may also reveal if visitors are using the informal trail for a particular purpose (e.g., 18.14% of visitors to our informal trail were anglers). This may help inform managers' messaging to dissuade certain subgroups of visitors (e.g, anglers) from using the trail.

Furthermore, cameras create the possibility of continuous data recordings that enable managers to observe if an intervention is working to deter informal trail use over time (McDade et al., 2025). Because informal trail use may directly relate to overall trail use, managers might use a trail counter on the established trail to compare the proportion of visitors (not the actual number) traveling on informal trails over different time periods. However, trail counters also come with limitations. It can be difficult to detect visitors walking side-by-side or in large groups. Managers using a trail counter should therefore "calibrate" it first; this entails doing hand counts during busy and slow times to determine how accurate the counter is and if a multiplier is necessary. For example, our trail counter only captured 60% of visitors during busy hours. Thus, we multiplied our data during peak visitation by a factor of 1.67 to compensate. To demonstrate how this can be utilized: our

trail camera images from the last week of August showed 13 visitors on the informal trail. Our trail counter, once adjusted, counted 2,775 visitors the same week. Thus, we estimated that, for every 1,000 park visitors, 4.68 visitors traveled on this informal trail during that week. (We should note that we were not able to install our trail counter until June; hence, we could not include calibrated pre-post differences in this analysis.)

Combining Ecological and Social Indicators





















The indicators and methods we have highlighted represent a variable selection of tools managers can use to evaluate the impacts associated with informal trails, considering both feasibility of implementation and practical utility to managers. Our evaluation of these indicators and methods is summarized in Table 5. Ideally, to shape interventions and maximize effectiveness, managers would utilize at least one ecological and one social indicator to inform not only the extent of recreation and impacts, but also why degradation is happening and why informal trails are being used (and by whom). Our framework in Figure 1 highlights the importance of both ecological and social indicators surrounding informal trail use, while also illustrating how antecedents and consequences can inform indicator selection. Initial use and creation of informal trails may lead to the normative use of these informal trails by other visitors, exacerbating problems. This cyclical pattern involving both social drivers of informal trail use and ecological consequences demands the use of integrated indicators to inform management decisions.

Social indicators can tell managers why visitors are using informal trails and ecological indicators can highlight the damage associated with use. Social indicators may be important for informing an intervention and ecological indicators can then illustrate how

long it will take a trail to recover. A potential integrated approach to impact management is to utilize linked data from ecological indicators within interventions. That is to say, management may show eroded trail images on signs to help visitors visualize the consequences of their behaviors.

Lastly, when deciding which indicators and methods to use, managers should consider their available resources, current staff routines, and flexibility. Managers with time and personnel constraints may decide to focus on rapid assessment measures such as trail observations to identify informal trail proliferation and conditions or visitor observations with trail cameras to track usage patterns. If park personnel already walk the trails frequently, they can mark and classify informal trails en route and put up a camera or switch out SD cards. Mapping may then indicate which trails most need an intervention from an ecological standpoint, and the cameras may reveal the culprits (i.e., visitors using informal trails). This information, combined with social indicators such as intercept surveys, can help managers develop a more comprehensive understanding of informal trail use and impacts to develop appropriate responses to address the problem.

Table 5. Evaluation of methods used to measure different ecological and social indicators of informal trails, rated based on feasibility of implementation and practical utility for managers.

Rapid Method		Feasibility			Utility for Managers	
		Cost of Instruments	Ease of Collecting Data	Time Required for Data Analysis	Effectiveness of Data Visualization	Indicator Sensitivity
Ecological	Informal Trail Observations					
	Measurements of Informal Trails					
Social	Visitor Surveys					
	Visitor Observations					

Future Research

Our research highlights the potential value of an integrated social and ecological approach to information trail management, but several limitations and corresponding research opportunities should be noted. First, our study occurred over a relatively short time frame, making it difficult to detect any treatment effects that might exist (especially for ecological impacts). Nevertheless, many intervention studies naturally occur over short time frames, and many managers hope their communication and messaging generates immediate impacts. Research should evaluate the sensitivity of indicators and methods over smaller timescales to help managers determine whether an intervention is working or not. Second, we only focused on one season at one park. Indicators should be continuously assessed over time and across different situations to make sure they are context-appropriate. Informal trails across geographical contexts may have different concerns that should be considered and studied. For example, waterfall sites may want to factor in safety considerations, while alpine sites with fragile ecosystems may care more about monitoring the spread of invasive species (Senetra et al., 2020). Third, emerging technologies could be used to expedite the assessment process. For instance, sorting and cataloguing photos from trail cameras may be streamlined with assistance from AI (artificial intelligence; Staab et al., 2021) using approaches similar to the Wildlife Insights platform for camera trapping wildlife (Ahumada et al., 2020). Lastly, future research should continue to investigate how to effectively couple social and ecological indicators in a management context.

This work highlights opportunities for improving the efficacy of interventions designed to reduce informal trail use, but expansion of this approach could also enhance monitoring and management of larger social-ecological systems with an outdoor recreation

component. Frameworks such as those developed by Miller et al. (2021) and Morse (2020) emphasize the importance of looking past ecological impacts and more traditional measures in recreation ecology to understand social motivations and consequences associated with outdoor recreation. Given the dual challenge managers face balancing both visitor experiences and conservation efforts, we urge researchers to continue these investigations and encourage managers to utilize these frameworks and strategies in their planning and decision making processes.

References

- Ahumada, J. A., Fegraus, E., Birch, T., Flores, N., Kays, R., O'Brien, T. G., ... & Dancer, A. (2020). Wildlife insights: A platform to maximize the potential of camera trap and other passive sensor wildlife data for the planet. *Environmental Conservation*, 47(1), 1-6.
- Ballantyne, M., & Pickering, C. M. (2015). Differences in the impacts of formal and informal recreational trails on urban forest loss and tree structure. *Journal of Environmental Management*, 159, 94–105. <https://doi.org/10.1016/j.jenvman.2015.05.007>
- Belnap, J. (1998). Environmental auditing: Choosing indicators of natural resource condition: A case study in Arches National Park, Utah, USA. *Environmental Management*, 22(4), 635–642. <https://doi.org/10.1007/s002679900135>
- Buckley, R. (2003). Ecological indicators of tourist impacts in Parks. *Journal of Ecotourism*, 2(1), 54–66. <https://doi.org/10.1080/14724040308668133>
- Cheung, S.-Y., Leung, Y.-F., & Larson, L. (2025). Can citizen scientists contribute to Trail Assessment and monitoring programs? an empirical evaluation of data congruence and overall efficacy. *Environmental Management*, 75(4), 778–792. <https://doi.org/10.1007/s00267-025-02111-7>
- Dale, V. H., & Beyeler, S. C. (2001). Challenges in the development and use of ecological indicators. *Ecological Indicators*, 1(1), 3–10. [https://doi.org/10.1016/s1470-160x\(01\)00003-6](https://doi.org/10.1016/s1470-160x(01)00003-6)
- Del Campo, A., & Clark, S. G. (2009). Rapid appraisals: An innovation in search of Sustainability. *Journal of Sustainable Forestry*, 28(6–7), 614–635. <https://doi.org/10.1080/10549810902794618>

- Digun-Aweto, O., Fawole, O. P., & Saayman, M. (2018). Constraints to conservation at Okomu National Park: A Ranger's perspective. *International Journal of Comparative and Applied Criminal Justice*, 43(2), 173–187.
<https://doi.org/10.1080/01924036.2018.1509012>
- Goh, E. (2020). Walking off-trail in national parks: Monkey see monkey do. *Leisure Sciences*, 45(1), 1–23. <https://doi.org/10.1080/01490400.2020.1755750>
- Greenberg, S. (2024, September 21). Timelapse. <https://timelapse.ucalgary.ca/>
- Havlick, D. G., Billmeyer, E., Huber, T., Vogt, B., & Rodman, K. (2016). Informal trail creation: Hiking, trail running, and mountain bicycling in Shortgrass Prairie. *Journal of Sustainable Tourism*, 24(7), 1041–1058.
<https://doi.org/10.1080/09669582.2015.1101127>
- Jackson, L., Fisher, W., & Kurtz, J. (2002). U.S. EPA Office of Research and Development Guidelines for technical evaluation of ecological indicators. *Managing for Healthy Ecosystems*. <https://doi.org/10.1201/9781420032130.ch31>
- Kling, K. G., Fredman, P., & Wall-Reinius, S. (2017). Trails for tourism and outdoor recreation: A systematic literature review. *Tourism: An International Interdisciplinary Journal*, 65(4), 488–508.
- Knight, J. (2009). Making wildlife viewable: Habituation and attraction. *Society and Animals*, 17(2), 167–184. <https://doi.org/10.1163/156853009x418091>

- Kolasinska, A., Witkowski, Z., Adamski, P., Ciapała, S., & Svajda, J. (2015). Trail management, off-trail walking and visitor impact in the Pieniny Mts National Park (Polish carpathians). *Eco.Mont (Journal on Protected Mountain Areas Research)*, 7(1), 26–36. <https://doi.org/10.1553/eco.mont-7-1s26>
- Korpilo, S., Virtanen, T., Saukkonen, T., & Lehvävirta, S. (2018). More than A to B: Understanding and managing visitor spatial behaviour in urban forests using public participation GIS. *Journal of Environmental Management*, 207, 124–133. <https://doi.org/10.1016/j.jenvman.2017.11.020>
- Kurtz, J. C., Jackson, L. E., & Fisher, W. S. (2001). Strategies for evaluating indicators based on guidelines from the Environmental Protection Agency's Office of Research and Development. *Ecological Indicators*, 1(1), 49–60. [https://doi.org/10.1016/s1470-160x\(01\)00004-8](https://doi.org/10.1016/s1470-160x(01)00004-8)
- Larsen, Trond Halvor. (2016). *Core standardized methods for Rapid Biological Field Assessment*. Conservation International.
- Lucas, E. (2020). A review of trail-related fragmentation, unauthorized trails, and other aspects of recreation ecology in protected areas. *California Fish and Wildlife Journal*, (Recreation Special Issue), 95–125. <https://doi.org/10.51492/cfwj.recreationsi.6>
- Manning, R. E. (2011). Defining and Managing Visitor Capacity in National Parks: A Program of Research in the U.S. National Park System. *Journal of Tourism and Leisure Studies*, 17(2), 183–214.

- Manning, R., Valliere, W., Anderson, L., McCrown, R., Pettengill, P., Reigner, N., Lawson, S., Newman, P., Budruk, M., Laven, D., Hallo, J., Park, L., Bacon, J., Abbe, D., van Riper, C., & Goonan, K. (2011). Defining, Measuring, Monitoring, and Managing the Sustainability of Parks for Outdoor Recreation. *Journal of Park and Recreation Administration*, 29(3), 24–37.
- Marion, J. L., & Leung, Y.-F. (2001). Trail Resource Impacts and An Examination of Alternative Assessment Techniques. *Journal of Park and Recreation Administration*, 19(3), 17–37.
- Marion, J. L., & Leung, Y.-F. (2011). Indicators and Protocols for Monitoring Impacts of Formal and Informal Trails in Protected Areas. *Journal of Tourism and Leisure Studies*, 17(2), 215–236.
- McDade, C., Fatone, A., Larson, L. R., Leung, Y.-F., Tanner, J. D., & Taff, D. (2025). Leave no trace in the frontcountry: Assessing knowledge and behaviors before and after a targeted messaging intervention. *Journal of Interpretation Research*.
<https://doi.org/10.1177/10925872251327416>
- Miller, A. B., Blahna, D. J., Morse, W. C., Leung, Y.-F., & Rowland, M. M. (2022). From recreation ecology to a recreation ecosystem: A Framework Accounting for Social-Ecological Systems. *Journal of Outdoor Recreation and Tourism*, 38, 100455.
<https://doi.org/10.1016/j.jort.2021.100455>
- Moscardo, G., & Ormsby, J. (2004). A social indicators monitoring system for tourist and recreational use of the Great Barrier Reef.
- Morse, W. C. (2020). Recreation as a social-ecological complex adaptive system. *Sustainability*, 12(3), 753. <https://doi.org/10.3390/su12030753>

- Pitas, N. A., Barrett, A. G., & Mowen, A. J. (2017). Trends in local park and Recreation Department finances and staffing in the early twenty-first century. *Journal of Park and Recreation Administration*, 35(3), 20–34. <https://doi.org/10.18666/jpra-2017-v35-i3-7712>
- Primack, R. B., & Terry, C. (2021). New social trails made during the pandemic increase fragmentation of an urban protected area. *Biological Conservation*, 255, 108993. <https://doi.org/10.1016/j.biocon.2021.108993>
- Reigner, N. (2008). *Exploring visitors: Using the theory of planned behavior to understand visitor behavior and improve the efficacy of visitor information in Haleakalā National Park* (thesis). Virginia Tech.
- Schwartz, F., Taff, B. D., Lawhon, B., & VanderWoude, D. (2018). Mitigating undesignated trail use: The efficacy of messaging and direct site management actions in an urban-proximate open space context. *Environmental Management*, 62(3), 458–473. <https://doi.org/10.1007/s00267-018-1054-1>
- Senetra, A., Dynowski, P., Cieślak, I., & Żróbek-Sokolnik, A. (2020). An evaluation of the impact of hiking tourism on the ecological status of alpine lakes—a case study of the valley of Dolina Pięciu Stawów Polskich in the Tatra Mountains. *Sustainability*, 12(7), 2963. <https://doi.org/10.3390/su12072963>
- Staab, J., Udas, E., Mayer, M., Taubenböck, H., & Job, H. (2021). Comparing established visitor monitoring approaches with triggered trail camera images and machine learning based Computer Vision. *Journal of Outdoor Recreation and Tourism*, 35, 100387. <https://doi.org/10.1016/j.jort.2021.100387>

- Taylor, A. R., & Knight, R. L. (2003). Wildlife responses to recreation and Associated Visitor Perceptions. *Ecological Applications*, 13(4), 951–963.
[https://doi.org/10.1890/1051-0761\(2003\)13\[951:wrtraa\]2.0.co;2](https://doi.org/10.1890/1051-0761(2003)13[951:wrtraa]2.0.co;2)
- Tomczyk, A. M., Ewertowski, M. W., White, P. C. L., & Kasprzak, L. (2017). A new framework for prioritising decisions on Recreational Trail Management. *Landscape and Urban Planning*, 167, 1–13. <https://doi.org/10.1016/j.landurbplan.2017.05.009>
- U.S. Department of the Interior. (2025, April 14). *IVUMC-Vum Framework*. National Parks Service. <https://visitorusemanagement.nps.gov/VUM/Framework>
- Vas, K. (2013). Birding Trails as Sustainable Tourism Development. *OIDA International Journal of Sustainable Development*, 6(3), 23–34.
- Walls, S. C. (2018). Coping with constraints: Achieving effective conservation with limited resources. *Frontiers in Ecology and Evolution*, 6.
<https://doi.org/10.3389/fevo.2018.00024>
- Watson, Alan E.; Cole, David N. 1992. LAC indicators: An evaluation of progress and list of proposed indicators. In: Merigliano, L., ed. *Ideas for the Limits of Acceptable Change: Planning Process, Book Two*. Washington, D.C.: U.S. Department of Agriculture, Forest Service, Recreation Staff. p. 65-84.
- Zeller, K. A., Ditmer, M. A., Squires, J. R., Rice, W. L., Wilder, J., DeLong, D., Egan, A., Pennington, N., Wang, C. A., Plucinski, J., & Barber, J. R. (2024). Experimental recreationist noise alters behavior and space use of Wildlife. *Current Biology*, 34(13), 2997–3004. <https://doi.org/10.1016/j.cub.2024.05.030>

CHAPTER 4: CONCLUSION

Parks and protected areas are likely to continue seeing high visitation over the next few decades, following recent trends in increased attendance to parks and protected areas (Smith et al., 2019). Therefore, managers will need to continue working to mitigate recreation impacts by encouraging pro-environmental behaviors on site and by monitoring and minimizing the range of impacts visitors generate. This thesis explored two strategies to support conservation in heavily visited frontcountry parks: educational messaging and rapid assessment of informal trail indicators.

The first study, examining the effectiveness of Leave No Trace (LNT) signage in influencing visitor behaviors and knowledge, revealed that signs in parks were associated with small pro-environmental behavior changes, but effect size was minimal and the catalyst of change (new LNT-specific signs vs. older park signs regarding visitor impacts) was unclear. Signs and messaging may need to be more engaging to capture the attention of more visitors. Iterative research with sign design may help formulate key components of messaging that can more effectively capture visitor's attention and result in changed behaviors, such as integrating social norms with graphical designs that appeal to visitors or using positive, non-regulatory messaging (Rice et al., 2024). Knowing who to target with messaging is also important. Children stopped to look at our LNT signs at a much higher rate than adult visitors, suggesting that appeals to youth in frontcountry areas may be especially important, and could be a way to connect with other visitors too (e.g., their guardians, family, friends; Miller et al., 2014; Schwartz et al., 2018) via intergenerational learning (Peterson et al., 2019). Additionally, while all recreators leave impacts on the environment, certain groups may think they know more than they actually do, such as

those who recreate more often and are older, highlighting the need for more research about communication strategies that appeal to these groups.

The second study, evaluating social-ecological indicators and methods related to informal trails, emphasized rapid assessments that can be used which are both feasible and practically useful for resource-limited managers. We highlight the value of holistic understanding that concurrent utilization of both social and ecological indicators can provide, calling for managers to try to integrate social and ecological assessments to better inform their conservation management decisions. For example, ecological indicators may point to where interventions are most needed (e.g., informal trails that are most heavily used and in the worst condition), while social indicators may help managers understand who they should be targeting so that an intervention is most effective (e.g., anglers at Hooker Falls made up a disproportionately large portion of informal trail users). Specifically, information from rapid indicator assessments revealed anglers may be a great target audience to mitigate informal trail use at Hooker Falls. Our evaluation of methodologies suggests informal trail observations may be one of the most feasible indicators, while the most practically useful for managers may be visitor observations via trail cameras. Ecological assessments of trail impacts can be valuable, but they are not sensitive to change and typically work best over long timeframes.

Results of our studies can help managers hoping to mitigate recreation impacts at popular parks and protected areas determine what to focus on (e.g., informal trails), who to target (e.g., anglers), how to reach them (e.g., strategic signage, possible with LNT themes), and what further support to request (e.g., resources for in-depth impact assessments or monitoring management effectiveness). Our studies also faced many limitations which may

help guide future research. Our messaging intervention only entailed the use of informative signs on site. Future research may want to look into the effect of social media campaigns and signage using various messaging, such as positive, non-regulatory messaging or signs that visually display ecological changes due to visitor impacts to make visitors more aware of the consequences of their actions. Additionally, our research selected a few key indicators based on informal trails at our chosen site location and only evaluated methods for measuring these indicators over the course of one summer. Research should continue to develop and evaluate indicators and methods, studying their use across different contexts and over longer timeframes. Lastly, given the importance of effective interventions, especially under resource constraints, we encourage researchers to continue investigating how to couple and integrate social-ecological indicators for resource-limited managers. Together, these studies contribute to a broader understanding of how strategic interventions targeting visitor behavior and rapid, integrative assessments of recreation impacts can inform management and conservation efforts at high-use frontcountry sites.

References

- Cordell, H. K., & Super, G. R. (2000). Trends in Americans' outdoor recreation. In *Trends in outdoor recreation, leisure and tourism* (pp. 133–144). CABI Publishing.
- Miller, J., Hill, E., Shellman, A., Ramsing, R., & Lawhon, B. (2014). Measuring the effectiveness of the Leave No Trace PEAK program. *Journal of Youth Development*, 9(2), 52–64.
- Peterson, M. N., Stevenson, K. T., & Lawson, D. F. (2019). Reviewing how intergenerational learning can help conservation biology face its greatest challenge. *Biological Conservation*, 235, 290-294.
- Rice, W. L., Shellhorn, J., & Foster, M. (2024, October 6-9). *Improving bear safety signage in the greater Yellowstone ecosystem through transdisciplinary science* [Research symposium, Poster presentation]. Leave No Trace Global Summit: Powering the Next 30 Years, Boulder, CO, USA.
- Schwartz, F., Taff, B. D., Lawhon, B., Hodge, C., Newman, P., & Will, E. (2018). Will they leave what they find? The efficacy of a Leave No Trace education program for youth. *Applied Environmental Education and Communication*, 17(4), 299–309.
<https://doi.org/10.1080/1533015X.2017.1411217>
- Smith, J. W., Wilkins, E. J., & Leung, Y. F. (2019). Attendance trends threaten future operations of America's State Park Systems. *Proceedings of the National Academy of Sciences*, 116(26), 12775–12780. <https://doi.org/10.1073/pnas.1902314116>

APPENDICES

Appendix A: Supplementary Figures for Chapter Two



Figure S1. Examples of other LNT-related signs that were installed at (a) the Gorges State Park control site and (b) the DuPont State Recreational Forest treatment site prior to our study.



(b)



Figure S2. Location of LNT signs at DuPont State Recreational Forest (a) near the waterfall, with a junior member of the research team pictured, and (b) at the bathrooms.

Appendix B: Supplementary Tables for Chapter Two

Table S1. The percentage of visitors who belong to each demographic category, by site.

Demographic	Rainbow Falls	Hooker Falls	Total for Both Sites
Brought dog(s)	16.0	19.1	18.0
Brought kid(s)	17.4	21.4	19.9
Age 18-34	30.0	39.9	36.2
Age 35-64	55.6	52.1	53.4
Age 65+	14.4	8.0	10.4
Female	60.3	59.4	59.7
Male	38.5	39.5	39.1
Nonbinary/Other	1.2	1.1	1.2
High School Diploma or Less	14.5	19.2	17.4
Undergraduate Degree	52.6	47.7	49.6
Graduate Degree	32.9	33.1	33.0
Household Income < \$50,000	11.2	16.1	14.3
Household Income < \$100,000	24.8	26.0	25.5
Household Income ≥ \$100,000	64.1	58.0	60.2
White	87.6	81.1	83.5
Black	1.7	1.5	1.5
Latino	6.2	9.2	8.1
Asian	2.4	5.9	4.5
Native American, Pacific Islander, or Other	2.2	2.3	2.3
Liberal	34.1	32.5	33.1

Table S1 (continued).

Demographic	Rainbow Falls	Hooker Falls	Total for Both Sites
Moderate	38.5	35.5	36.6
Conservative	27.4	32.0	30.3
From NC	36.0	33.2	34.3
From out-of-state	62.7	66.0	64.8
International	1.3	0.8	1.0

Table S2. Self-reported frequency of participation in good and bad behaviors.

Good (LNT-aligned) Behaviors	Mean	SD
(LNT) Stay on designated or established trails	4.57	0.68
(LNT) Yield right-of-way to visitors who are hiking uphill	4.23	0.94
(LNT) Separate recyclable items from trash in park	3.82	1.28
Bad (not LNT-aligned) Behaviors	Mean	SD
Walk around muddy or wet spots on the trail	3.45	1.20
Hike side-by-side with friends on existing trails	3.43	1.10
Take breaks off the trail and away from other visitors	2.21	1.12
Travel off trail to experience the natural environment	1.97	1.05
Talk in loud voices or make loud noises	1.93	0.93
Hike with large groups (8 or more people)	1.86	1.00
Discard biodegradable waste (such as apple cores in the forest)	1.86	1.15
Take something small from the forest as a souvenir (like a rock, plant, feather, stick, etc.)	1.65	0.92
Allow dogs to run off leash to explore the forest	1.36	0.87
Approach or follow wildlife	1.34	0.77
Leave behind food scraps for wildlife	1.15	0.59
Carve artwork or names into tree bark	1.15	0.62

Good behaviors are listed first, followed by bad behaviors. Each then sorted by descending mean frequencies.

Appendix C: Survey Instrument



DuPont State Recreational Forest Visitor Survey

Thank you for agreeing to participate in our survey. The focus of this study is to better understand people's experience when traveling to DuPont State Recreational Forest. Please read and respond to each question carefully. Participation is voluntary and your responses are confidential. Thanks for your input!

1. Is this your first time visiting DuPont State Recreational Forest?

- Yes
 No ➔ How many other trips have you made to this forest in the last 5 years? _____

2. What types of activities did you participate in (or do you plan to participate in) TODAY in DuPont State Recreational Forest? Check ALL that apply.

- | | | |
|--------------------------------------|--|--|
| <input type="checkbox"/> Backpacking | <input type="checkbox"/> Photography | <input type="checkbox"/> Viewing wildlife or scenery |
| <input type="checkbox"/> Fishing | <input type="checkbox"/> Picnicking | <input type="checkbox"/> Other (please specify): _____ |
| <input type="checkbox"/> Hiking | <input type="checkbox"/> Swimming | |
| | <input type="checkbox"/> Taking a scenic drive | |

3. How important to you are each of these reasons for visiting DuPont State Recreational Forest? Circle ONE number per item.

	Not important	Slightly important	Moderately important	Important	Very important
To get exercise	1	2	3	4	5
To improve my mental health	1	2	3	4	5
To relax/get away from the daily routine	1	2	3	4	5
To be with friends and/or family	1	2	3	4	5
To learn about plants and animals	1	2	3	4	5
To view scenery	1	2	3	4	5
To view wildlife	1	2	3	4	5
To experience adventure	1	2	3	4	5
To experience solitude	1	2	3	4	5
To have experiences to talk about later	1	2	3	4	5
To take pictures of my trip to share online	1	2	3	4	5

4. How would you rate the environmental quality of the forest you experienced TODAY?

Circle ONE number.

Extremely low quality			Extremely high quality			
1	2	3	4	5	6	7

5. To what extent do you think visitors cause environmental impacts at DuPont State Recreational Forest? (for example, impacts to soil, scenery, and wildlife?) Circle ONE number.

No impact			High impact			
1	2	3	4	5	6	7

6. In the past 12 months, about how often have you participated in ANY type of nature-based recreation and leisure activities? [i.e., any type of activity occurring in a natural environment such as visiting parks, hiking/walking on trails, swimming in a lake/ocean, or gardening] *Check 1 response.*

Never	Rarely (a few times in the past twelve months)	Occasionally (about every month or so)	Often (several times each month)	Very often (pretty much every week)
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Next, we would like to know a little more about your experience with "Leave No Trace" (LNT) messaging, both in general and at the site today...

7. How would you describe your current level of knowledge of "Leave No Trace" (LNT) practices? *Circle ONE number.*

None	Very limited	Limited	Average	Above average	Extensive	Expert
1	2	3	4	5	6	7

8. Below are actions that people who visit this site might engage in...

a) FIRST, in column A, indicate which of these actions you think follow Leave No Trace (LNT) principles. *Check ALL that apply in column A.*

b) NEXT, in column B, indicate how often YOU engage in these actions during nature-based recreation trips such as your visit to the forest today. *Circle ONE number per item in column B.*

Recreation Behaviors	(8a) LNT Behavior?	(8b) How often do YOU do this?				
		Never	Rarely	Some-times	Often	Always
Stay on designated or established trails	<input type="checkbox"/>	1	2	3	4	5
Hike with large groups (8 or more people)	<input type="checkbox"/>	1	2	3	4	5
Hike side-by-side with friends on existing trails	<input type="checkbox"/>	1	2	3	4	5
Take breaks off the trail and away from other visitors	<input type="checkbox"/>	1	2	3	4	5
Walk around muddy or wet spots on the trail	<input type="checkbox"/>	1	2	3	4	5
Travel off trail to experience the natural environment	<input type="checkbox"/>	1	2	3	4	5
Allow dogs to run off leash to explore the forest	<input type="checkbox"/>	1	2	3	4	5
Approach or follow wildlife	<input type="checkbox"/>	1	2	3	4	5
Yield right-of-way to visitors who are hiking uphill	<input type="checkbox"/>	1	2	3	4	5
Talk in loud voices or make loud noises	<input type="checkbox"/>	1	2	3	4	5
Leave behind food scraps for wildlife	<input type="checkbox"/>	1	2	3	4	5
Discard biodegradable waste (such as apple cores) in the forest	<input type="checkbox"/>	1	2	3	4	5
Separate recyclable items from trash in the park	<input type="checkbox"/>	1	2	3	4	5
Carve artwork or names into tree bark	<input type="checkbox"/>	1	2	3	4	5
Take something small from the forest as a souvenir (like a rock, plant, feather, stick, etc.)	<input type="checkbox"/>	1	2	3	4	5

9. Leading up to and during your visit to DuPont State Recreational Forest (DSRF) TODAY, did you see Leave No Trace (LNT)-related messaging in ANY of the following places?

Check ALL that apply. If you did not see any, leave responses blank.

- Signs on a trail DSRF social media Other (please specify):
 Signs at other locations on site DSRF website
 Conversations with staff/volunteers Other social media/websites _____

10. Which ONE of the messaging strategies listed here do you think is (or would be) MOST effective in encouraging LNT behaviors? *Check 1 response, even if you did not see any messaging today.*

- Signs on a trail DSRF social media Other (please specify):
 Signs at other locations on site DSRF website
 Conversations with staff/volunteers Other social media/websites _____

11. To what extent do you agree with the following statements? *Circle ONE number per item.*

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
I feel welcome at DuPont State Forest	1	2	3	4	5
DuPont State Forest is for people like me	1	2	3	4	5
Leave No Trace (LNT) messages at the forest are relevant to me	1	2	3	4	5
Leave No Trace (LNT) messages at the forest are for people like me	1	2	3	4	5

12. Did you learn something new from any of the Leave No Trace (LNT) messaging you saw at DuPont State Recreational Forest TODAY?

- Yes ➔ What did you learn? _____
 No

13. Did the way you think or act during your trip to DuPont State Recreational Forest TODAY change because of Leave No Trace (LNT) messaging? *Check ALL that apply.*

- Yes, it made me *think* differently about the impacts I create
 Yes, it made me *act* differently to minimize my impacts
 No, it didn't change the way I thought or acted during my trip today (*proceed to Q13a*)



13a. If Leave No Trace (LNT) messaging did NOT affect the way you thought or acted during your trip TODAY, why not? *Check ONE response.*

- No effect because I didn't see any LNT messaging
 No effect because even though I saw LNT messaging, I didn't take time to read it
 No effect because even though I saw LNT messaging, I don't want to do that stuff
 No effect because even though I saw LNT messaging, I already do that stuff anyway

Finally, we would like to know a little more about you...

14. Do you have any of the following in your group today? Check ALL that apply.

- Dog(s) Children under age 18

15. What year were you born? Year: _____

16. Which of the following best describes your gender identity? Check ONE response.

- Female/woman Non-binary
 Male/man I identify the following way: _____

17. What is the highest level of education that you have completed? Check ONE response.

- Some primary/secondary school Associate's or Bachelor's degree (BA, BS, etc.)
 High school diploma or GED Graduate or professional degree
(MS, MBA, MD, PhD, etc.)

18. What was your approximate household income before taxes in 2023? Check ONE response.

- Less than \$24,999 \$50,000 - \$74,999 \$100,000 - \$124,999 \$150,000 or more
 \$25,000 - \$49,999 \$75,000 - \$99,999 \$125,000 - \$149,999

19. Which of the following best describes your racial/ethnic identity? Check ONE response.

- White Asian Native Hawaiian or Pacific Islander
 Black American Indian/
 Hispanic/Latino Alaska Native _____

20. What is the ZIP Code of your primary residence? ZIP: _____

21. How do you identify politically? Check ONE response.

Very liberal	Liberal	Moderate	Conservative	Very conservative
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

22. Please share any additional thoughts you have about Leave No Trace (LNT) messaging at DuPont State Recreational Forest, including how it might be communicated more effectively.

Thanks again for your input!