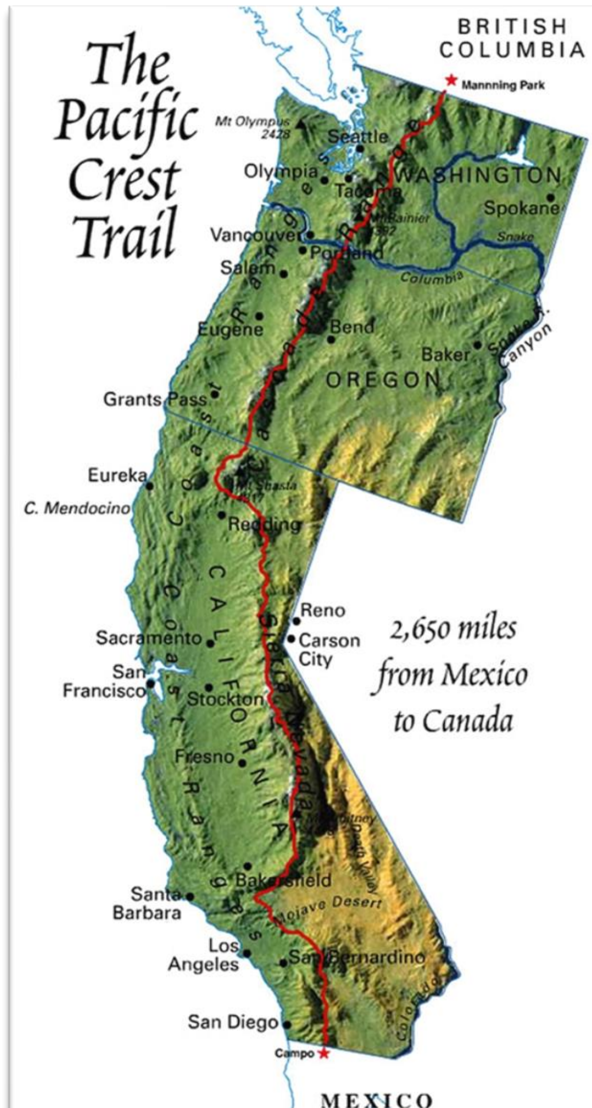
U.S. Geological Survey, Virginia Tech Field Unit

DRAFT RESEARCH REPORT

Improving the Sustainability of Camping Management on the Pacific Crest National Scenic Trail

Draft Final Report, February 2022



Virginia Tech, College of Natural Resources & Environment

Department of Forest Resources & Environmental Conservation

Improving the Sustainability of Camping Management on the Pacific Crest National Scenic Trail

Draft Research Report, February 2022

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EXECUTIVE SUMMARY

The Pacific Crest National Scenic Trail (PCT) is a national scenic trail extending from the U.S.-Mexican border 2,650 miles to the U.S.-Canadian border through California, Oregon, and Washington. The trail is restricted to foot and equestrian traffic and traverses through remote backcountry and wilderness lands that are predominantly in federal and state ownership. PCT managers are charged with protecting the trail corridor's natural conditions and processes while accommodating more than a million visitors annually. This recreation ecology research project was supported by the U.S. Forest Service, National Park Service, Bureau of Land Management, and the Pacific Crest Trail Association to investigate camping impacts and the development of strategies and practices for enhancing the sustainability of camping management throughout the PCT corridor. The information provided in this report supports science-based carrying capacity and Visitor Use Management (VUM) planning, decision-making, and adaptive management actions to support greater overnight visitation while minimizing any associated degradation of resource and social conditions.

Report findings document baseline campsite conditions assessed between 2017-21 in nine separate study areas that mostly receive moderate to high camping visitation. These data were collected to characterize the various types of camping impacts to vegetation and soils and their potential effects on water quality, wildlife, and the experiences of PCT visitors. Protected area managers generally seek to limit these impacts by constraining the aggregate areal extent of camping impact by minimizing both campsite sizes and numbers. This report therefore focused on identifying and describing Best Management Practices (BMPs) that aid managers in selecting and promoting the use of small sustainable campsites that will remain in good condition despite high use, while constraining the proliferation and use of non-sustainable campsites. A comprehensive "toolbox" of sustainable camping site management, educational, and regulatory strategies and practices are described in an extensive literature review section that includes legislative, agency, carrying capacity, and VUM guidance, along with recreation ecology research findings describing influential factors and relationships.

This multi-year study was successful in identifying numerous factors that managers and stewards can apply to select more sustainable campsites and to apply site management, regulatory, or educational practices that effectively constrain the twin problems of campsite expansion and proliferation. Our research indicates that aggregate impact and campsite sizes can be permanently constrained by shifting camping from flat and smooth terrain to existing or new campsites that are surrounded by sloping or rocky/uneven terrain. Incorporating visitor campsite preferences for necessity, experience, and amenity attributes into the selection of campsites ensures inclusion of sites that will be sought out and used by visitors. Many PCT managers have already developed active programs that shift use to "preferred" campsites more than 100-200 ft from water, formal trails, and other campsites. This new BMP guidance could be incorporated into those efforts through a more focused Established site camping policy that encourages the use of both preferred *and* desirable/sustainable campsites. This general policy can be effectively augmented by requiring Designated site camping in particularly high use areas like popular lake basins and advocating improved Dispersed Pristine site camping practices that seek to preclude lasting impact within lower use areas. A more holistic approach employing these three options can more effectively limit the spatial extent of camping impact, improve social and experiential qualities, and provide an array of camping experiences that satisfy visitor needs while protecting wilderness character.

Secondary BMPs include the promotion of educational practices and regulations (e.g., Leave No Trace camping practices and food storage requirements), "push-pull" site management prescriptions (e.g., improving, or ruining tenting sites, installing rock/log borders and anchored fire sites or stove rocks), and use of phone apps to communicate camping policies, low impact practices, and efficiently guide visitors to Established or Designated campsites. By increasing the use of a broader array of toolbox BMPs, PCT stewards can achieve their objectives and reduce their historic core reliance on use limitation (e.g., permit and trailhead quotas). The sigmoidal use-impact relationship described in this report greatly reduces the efficacy of use limitation for lessening impacts on moderate to high use campsites. Use limitation can reduce aggregate impact by reducing campsite numbers, but *only* when effective camping containment and dispersal strategies (e.g., Established, Designated, and Dispersed Pristine site camping) are also employed. We note that the Appalachian Trail community has steadily broadened its visitor impact management strategies and practices to avoid employing use limitation, considered by many to be a less desirable tool of last resort. This approach, successful in many but not all areas, illustrates the advantages of more diverse policies that seek to accommodate increasing visitation with less regulation.

ACKNOWLEDGEMENTS

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INTRODUCTION

The Pacific Crest National Scenic Trail (PCT) was designated as a national scenic trail by the 1968 National Trails System Act (P.L. 90-543, as amended by P.L. 111-11). Administrative responsibility was assigned to the USDA Forest Service (FS) as the lead managing agency, to coordinate management and operations with the Bureau of Land Management (BLM), the National Park Service (NPS), California State Parks and the Pacific Crest Trail Association (PCTA). In particular, the Act directs the FS to collaborate with volunteer and non-profit organizations in all planning and management efforts and highlights their contributions:

> "Congress recognizes the valuable contributions that volunteers and private, nonprofit trail groups have made to the development and maintenance of the Nation's trails. In recognition of these contributions, it is further the purpose of this Act to encourage and assist volunteer citizen involvement in the planning, development, maintenance, and management, where appropriate, of trails."

The Act promotes a system of national trails to "provide for the ever-increasing outdoor recreation needs of an expanding population and in order to promote the preservation of, public access to, travel within, and enjoyment and appreciation of the open-air, outdoor areas and historic resources of the Nation."

The PCT extends 2,650 miles from the U.S.-Mexican border in Soledad Canyon of Southern California, through Oregon and Washington to the U.S.-Canadian border in the Pasayten Wilderness. The PCT passes through 48 wilderness areas (45% or the trail), 25 National Forests, 7 BLM units, 6 National Parks, 5 National Monuments, and 5 State Parks. It also passes through nine of North America's ecoregions, including high and low deserts, old-growth forests, and many high alpine zones (PCTA website, 2021). Though designated in 1968 the PCT was not formally completed until 1993 and still retains several roaded sections. The trail is restricted to foot and equestrian travel, with bicycle and motorized vehicles prohibited. Overnight use permits are required when hiking in FS Wilderness, National Parks, California State Parks, and some other areas. Trailheads in the most popular PCT areas, like the High Sierras and Central Cascades, commonly have quotas that limit the number of people/day. Visitors traveling more than 500 miles require a restricted long-distance permit, provided to individuals and limited to 50/day for northbound hikers, 15/day for south-bounders, 1400 permits for section hikers on the John Muir Trail overlap, and 600 permits for trips starting in the Southern Sierras (PCTA website, 2021).

Trail managers estimate that more than a million people use the PCT on an annual basis, and in 2019, 7,888 hikers from 50 states and 47 countries received permits to hike more than 500 miles (PCTA website, 2021). PCT thru-hiking has steadily increased over the years and nearly 1200 reported completing the trail in 2018. An increasing number of protected area (PA) visitors inevitably contribute negative effects to fragile natural and cultural resources. Such visitation-related resource impacts can degrade natural conditions and processes and the quality of recreation experiences. Core impact problems highlighted on the PCTA website include campsite proliferation, improper food, trash, and human waste disposal, crowded camping areas, and trampled vegetation near water sources. These visitor impact problems run counter to the stated *"Trail Experience"* that the PCT community has adopted to guide both land and visitor management:

> "The PCT experience should favor panoramic views of undisturbed landscapes in an uncrowded, non-mechanized, tranquil, and predominantly natural environment. It should feature diverse, untrammeled ecosystems and historic high-country landmarks while avoiding, as much as possible, road crossings, private operations and other signs of modern development. Trail facilities such as campsites, water sources and other amenities for hiker and pack-and-saddle use should be simple." (Excerpt from the PCTA Board of Director's *Statement of the Trail Experience*, 2015).

The PCTA and its management community has adopted the new National Interagency Visitor Use Management Council's Visitor Use Management (VUM) framework for addressing land, recreation infrastructure, and visitor use management (IVUMC, 2021). Highlighted management strategies include:

1) Focus on influencing trail user behavior by encouraging Leave No Trace (LNT) practices. PCTA staff and volunteers have been substantially increasing the quantity and quality of LNT-related information and have launched a Crest Runner program to enhance education and stewardship work.

2) Focus on making the trail more resilient. New efforts to evaluate the appropriateness and legality of informal (visitor-created) campsites and to work with map and phone app makers to evaluate and improve the information they provide visitors. Other work focuses on improving the active management of campsites, including closure and restoration of poorly located sites and improving, developing, and/or designating campsites in more durable, sustainable locations.

3) Permitting systems are used to limit the number of visitors in popular/overcrowded areas to protect the trail, its natural resources, and the desired PCT trail experience. (PCTA 2021).

Responding to these concerns, the PCT federal land management agencies funded this five-year program of research investigating the resource impacts associated with camping on the PCT and focused on improving the sustainability of camping management practices. The information provided by this research is vital for science-based Visitor Use Management planning and decision-making to accommodate increasing visitation while protecting unimpaired the vast natural resources of the PCT. More specifically, agency staff and the PCTA stewardship community require information to improve the overall sustainability of the trail's camping infrastructure and address topics that include carrying capacity and the quality of visitor's experiences. This research will enhance managers abilities to protect the PCT's natural resources by investigating factors that influence the nature and severity of visitor impacts and the sustainability of its campsites. Principal products include a quantitative characterization and documentation of baseline conditions in a diverse array of mostly high use camping areas, identification of factors that influence campsite sustainability, and development of Best Management Practices, including improved capabilities for assessing, selecting, and managing sustainable campsites.

This research is necessary due to the high and increasing PCT visitation, but also to provide essential information as the PCT community begins implementation of the new Visitor Use Management (VUM) framework, especially regarding carrying capacity decision-making. It will also aid managers in responding to an increasing number of special uses, including group use, commercial use, special events, and other uses that require information to adequately address resource protection decisions.

Finally, this research is advancing basic knowledge in the recreation ecology field of study that will benefit PAs worldwide. The PCT dataset includes research-level measures of a diverse array of campsite indicators and dozens of potentially influential factors. We reviewed and refined indicator protocols from prior studies, developed new indicators and protocols related to the assessment of campsite sustainability, and added new indicators through extensive Geographic Information System (GIS) analyses, including some derived from newly available LiDAR topography datasets. The dataset is derived from a diverse array of environmental conditions, latitudes, elevational gradients, geologic, soil, and plant community types, as affected by a variety of camping activities. These data support relational analyses that model the role and influence of factors affecting camping impacts, knowledge that will enhance corrective management actions.

Project Objectives

This five-year program of research on camping impacts and sustainable camping management Best Management Practices evolved over time and in phases as new study components and field research locations were added. Core study objectives included:

1. Conduct fieldwork in a diverse array of locations from southern California to northern Washington to provide quantitative data documenting the range of camping impacts to characterize the type, areal extent, and severity of visitation-related resource impacts to vegetation and soils,

2. Summarize and analyze data to evaluate campsite location, design, and biophysical attributes to improve understanding of the use-related, environmental, and managerial factors that affect the severity and areal extent of camping resource impacts,

3. Develop sustainable campsite location, design, and management practices and formulate science-based Best Management Practices describing alternative actions (educational/interpretive, regulatory, and site/infrastructure management) that avoid or minimize camping-associated resource and experiential impacts,

4. Develop and publish a final report that describes and communicates the core research findings and present them in agency meetings and workshops with agency managers, PCTA staff, and PCT volunteers, and

5. Consult with agency managers and PCTA staff in deliberations and applications of Best Management Practices (BMPs).

LITERATURE REVIEW

This section begins with a review of the resource impacts associated with visitor use, which can expand or degrade existing campsites and lead to the creation of new campsites. Next, we include a review of federal agency management guidance related to visitor use, followed by a review of the literature on agency management frameworks that may be applied to assist managers in evaluating and managing the impacts of visitation, highlighting the new Interagency Visitor Use Management Council (IVUMC) framework (IVUMC 2019b). We also include a review of the literature on methods for monitoring visitor use impacts to campsites, and some guidance for selecting preferable indicators to monitor relative to management thresholds (standards).

Visitation-Related Resource Impacts

Visitors participating in various types of recreational activities, including day-hiking, camping, and backpacking, contribute to a diverse array of direct and indirect impacts on PA resources, including vegetation, soils, water, and wildlife (Table 1). The term *impact* is commonly used to denote any undesirable visitor-related change in these resources. Marion et al. (2016) provide a comprehensive review of these trampling-related impacts, which are summarized here. Even light recreational traffic can reduce ground vegetation height, cover, and biomass (Cole 1995a,b, Cole 2004, Leung & Marion 1996). Trampling disturbance can alter the appearance and composition of vegetation by reducing plant height and favoring trampling resistant species. Plant resistance is the intrinsic capacity of vegetation to withstand the direct effect of trampling by feet, hooves, and tires (Liddle 1997).

Under light recreational traffic, most plants respond with a reduction in plant height. Even light trampling will break rigid stems, which can halt flower and seed development and reduce plant vigor (Barros & Pickering 2015, Cole 1987). Plant morphological characteristics influence the response of vegetation to trampling disturbance. The taller rigid stems of many forest broad-leafed forbs (herbs) are highly susceptible to trampling damage, with stem breakage eliminating the growing tips, flowers, and seed production (Cole & Monz 2002). In contrast, grasses and sedges have flexible stems and leaves that are considerably more resistant to traffic, and research has also shown them to be significantly more resilient, i.e., they recover relatively quickly. Studies reveal that these differences in morphology and trampling resistance and resilience (ability to recover) are positively correlated with the amount of sunlight that reaches ground vegetation (Cole & Monz 2003, Liddle 1997), i.e., shade-tolerant forest plants lack the resistance and resilience of shade-intolerant (sun-loving) plants.

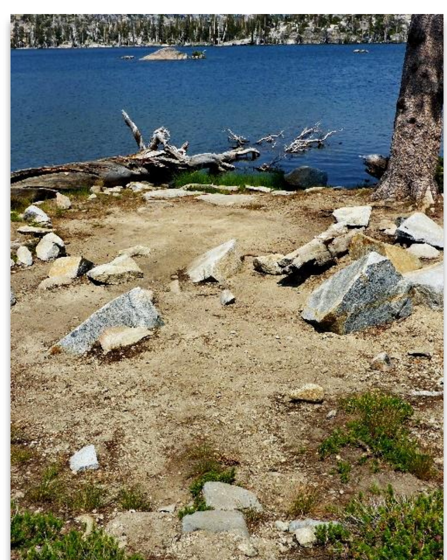


Table 1. Direct and indirect effects of recreational trampling and camping on soils and vegetation.

Effects	Vegetation	Soil
Direct	Reduced height/vigor, and seed production	Loss of organic litter
	Loss of ground vegetation, shrubs and trees	Soil exposure and compaction
	Introduction of non-native vegetation	Soil erosion
Indirect	Altered composition – shift to trampling resistant native or non-native species	Reduced soil pore space and moisture, increased soil temperature
	Altered microclimate	Increased water runoff
		Reduced soil fauna

Higher levels of trampling cause more complete ground vegetation loss and compositional change (Cole 1995b; Marion & Cole 1996). Concentrated traffic also pulverizes soil leaf litter and humus layers, which are either lost through erosional processes or intermixed with underlying mineral soils (Marion et al. 2016). These soils then become exposed and vulnerable to displacement, wind or water erosion, and compaction (Monti & Mackintosh 1979). The compaction of soils decreases soil pore space and water infiltration, which in turn increases water runoff, muddiness, and soil erosion (Liddle 1997).

Severe trampling impacts, such as erosion and muddiness, often cause additional avoidable impact to water resources or to vegetation and soils in the form of campsite expansion or trail widening and formation of parallel secondary trails. Campsite expansion and proliferation of informal (visitor-created) campsites and trails can substantially expand the cumulative spatial extent of disturbance (Leung & Marion 1996, Marion et al. 2018a). Trails and campsites can also alter natural patterns of water runoff (Sutherland et al. 2001), resulting in irreversible soil erosion and subsequent turbidity and deposition in streams and other water bodies (Fritz 1993, Leung & Marion 2000, Marion et al. 2018b). Finally, research demonstrates that the quality of a visitor's experience is likely to decrease when substantial resource degradation is present (Lynn & Brown 2003).

Recreational activities can also directly degrade and fragment wildlife habitats, and the presence of visitors may disrupt essential wildlife activities such as feeding, reproduction and the raising of young (Knight & Cole 1995, Marion et al. 2016, Marion 2019). For example, Miller and others (1998) found decreased presence of nesting birds near trails in grassland ecosystems. Trails and campsites can fragment the landscape with barriers to flora and some fauna (Leung *et al.* 2002, 2011, Leung & Louie 2008). Finally, visitors and recreational stock can also introduce and transport non-native plant species along trails and between campsites, some of which may out-compete undisturbed native vegetation and migrate into adjacent undisturbed areas (Adkison & Jackson 1996, Benninger-Truax *et al.* 1992, Bhuju & Ohsawa 1998, Eagleston & Marion 2018, Hill & Pickering 2006, Potito & Beatty 2005).

Camping Impacts

Most campsites, even sites designated by land managers, were originally selected and created by visitors. As with trails, many campsites are poorly (non-sustainably) located with respect to resource protection considerations and are thus susceptible to environmental impacts from camping activities (Table 1). Most campsite impacts are caused by trampling and are similar to those occurring on trails. Non-trampling campsite impacts include damage and felling of trees, several types of campfire-related impacts, improperly disposed human waste, dishwashing greywater, and trash that's not packed out. The nature and severity of these impacts are substantially related to visitor behaviors and can therefore be minimized by effective low impact visitor education programs and messaging (Bromley et al. 2013, Marion & Reid 2007, Settina et al. 2020).

The traditional "twin problems" of camping impact management are *site expansion* and *proliferation*, these are generally the most significant resource impacts of concern to land managers, whose primary objective is to limit the "footprint" of visitor impact – its aggregate areal extent across a protected landscape (Arredondo et al. 2021, Eagleston & Marion 2017). By accomplishing this objective, managers coincidentally avoid and/or limit the extent and severity of numerous other impacts, such as the area over which vegetation is lost, soil is exposed, compacted, and eroded, trees are damaged or felled, and impacts to water quality and wildlife (Marion 2016, Marion et al. 2016).

Campsite *expansion* can occur when large groups use smaller sites, when campsite demand in an area exceeds supply, and even when soil loss on a campsite exposes rocks and roots to a degree that visitors seek tenting spots in adjacent smoother offsite areas (Eagleston & Marion 2017). Campsites can range in size from several hundred to more than 8,000 ft^2 (Marion & Cole 1996), generally more than half of which is non-vegetated and more than one-quarter has also lost most organic litter. While these larger expanses of exposed soil are generally in flatter terrain, sheet erosion can still remove large amounts of soil over time (Eagleston & Marion 2017). Soil erosion is a more ecologically significant problem when campsites are located along shorelines, where eroded soil from the site and steeper shoreline access trails can drain runoff with soil directly into waterways (Marion et al. 2018b). Other concerns related to their large size are the loss of woody vegetation and its slow regeneration over time. Gaps in forest canopies caused by trampling and tree cutting can alter microclimates and create sunny disturbed locations that promote the dispersal and establishment of invasive vegetation (Eagleston & Marion 2018).

Campsite *proliferation* is a frequent occurrence in areas where managers permit ***Unconfined*** (unregulated, at-large) camping, where visitors have substantial freedom to select or create campsites in locations of their choosing. This is sometimes referred to as "dispersed camping" and often combined with recommended or required camping "setbacks" from water, formal trails, or other campsites. Unfortunately, compliance is often poor, and visitors frequently seek out scenic flat areas near water sources, trails, and other visitors, locations that are both environmentally and socially less desirable and unsustainable (Marion et al. 2018a). Campsite surveys consistently document that unconfined camping in popular areas creates substantial numbers of duplicative and unnecessary campsites, generally in high-density clusters that expand in number and size and merge, forming dense mega-clusters with substantially degraded ecological and social/experiential conditions (Cole 2013a, Cole & Parsons 2013). For example, surveys of the Sunshine-Obsidian Falls area of the Three Sister's Wilderness (Figure 1) found 269 campsites with use data (639 groups and 1.9 nights/yr) indicating each site was used only an average of 4.5 nights/yr (Cole et al. 1997).

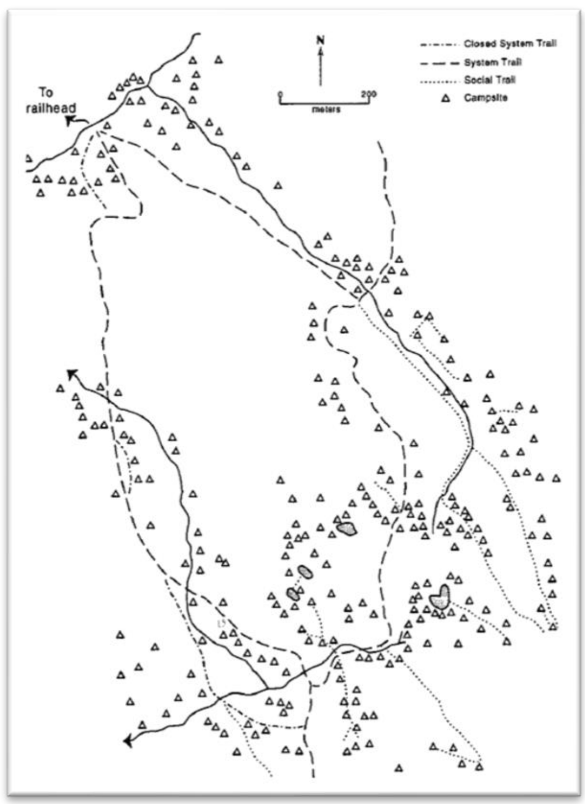


Figure 1. A 1991/92 campsite survey of the Sunshine-Obsidian Falls area of the Three Sister's Wilderness found 269 campsites, with an aggregate area of impact of 220,057 ft^2 (818 ft^2/site) (Cole et al. 1997).

Under a "*containment*" strategy (described further in a following section), managers might select and require visitors to use the 50 most sustainable and socially distant ***Designated*** campsites, which would receive 24 nights/yr and allow the recovery of 219 campsites and 179,142 ft^2, an 81% reduction in impacted area. Alternately, under an ***Established*** site camping policy, managers might select and encourage visitors to use the 100 best campsites, which would receive 12 nights/yr and allow the recovery of 169 campsites and 138,242 ft^2, a 62% reduction in impacted area.

The scientific literature and management experience reveal an extensive list of resource impacts attributed to campfires. Campfires are an especially challenging issue for public land managers because wildfire impacts from escaped campfires have subsequently burned exceptionally large areas. Yet campfires remain an important element of a high-quality camping experience for many visitors, particularly youth, despite the near-universal use of backpacking stoves (Christensen & Cole 2000, Reid & Marion 2005). However, campfires continue to contribute many aesthetic and ecological impacts to protected natural areas. Fenn and others (1976) measured the effects of campfires on soil regimes, finding that intense campfires reduce organic matter content to a depth of more than four inches and cause substantial alterations to soil chemistry. These changes diminish soil fertility and water holding capacity, making the soil prone to erosion and compaction (Fenn & others 1976). Fire sites also attract litter and garbage when visitors attempt to dispose of wastes through burning (Reid & Marion 2005). The burning of these wastes retains odors that promote wildlife attraction behaviors and contribute long-lasting chemical contaminants to campfire ashes. Davies (2004) analyzed gas emissions and ash content from 27 products commonly burned in campfires and found greatly increased levels of a variety of toxic materials.

Although the most obvious impacts tend to be focused at and around campfire sites, wood collection contributes to ecological impacts associated with extensive offsite trampling and the loss of both live and dead woody vegetation. Firewood collection in pristine off-site areas promotes the proliferation of informal (visitor-created) trails (ITs) and tramples native flora and could introduce and disperse non-native plants (Leung et al. 2002, Wimpey & Marion 2011). Tree damage, including broken or cut limbs, hatchet wounds and girdling, is an aesthetic impact associated with campfires, but such wounds make trees more susceptible to insect and fungal attacks that can lead to tree mortality (Cole & Dalle-Molle 1982, Reid & Marion 2005). Felled dead trees from wood gathering reduces habitat for cavity-nesting fauna and removes large populations of insects that require dead wood (Cole & Dalle-Molle 1982). Hall and Farrell (2001) assessed the extent of woody material depletion in the Cascade Mountains of Oregon and found a significant reduction in woody materials adjacent to campsites when compared to controls; Bratton and others (1982) concluded that the collection of campfire wood likely affects nutrient cycling over a 50–70-year time frame. A 32-yr study of camping impacts to designated sites in the Boundary Waters Canoe Area Wilderness found forested campsites increasingly devoid of trees, with an average of 18 felled trees/site, equating to an estimated loss of 36,000 trees for the entire Wilderness (Eagleston & Marion 2017).

Leave No Trace wood gathering practices promote collecting small-diameter materials that can be broken by hand and easily burned to ash, and leaving woods tools (axes, hatchets, saws) at home (Marion 2014). Tree damage and the felling of live or dead trees by woods tools are a *completely avoidable* form of visitor impact, and scientists have suggested that prohibiting woods tools are a more effective and less onerous regulation for protecting woody vegetation than prohibiting campfires (Eagleston & Marion 2017; Reid & Marion 2005).

Resource degradation on visitor-created campsites is often severe due to their lack of professional design, siting/layout, construction, and maintenance. Such unplanned recreation infrastructure development has created many thousands of campsites that receive no environmental review, yet they frequently accommodate considerable use over long periods of time (Cole 2013a, Cole & Parsons 2013, Marion et al. 2018a). Furthermore, many land managers have later formalized and designated poorly located visitor-created campsites (Leung & Marion 2004). Resource impacts to these informal facilities are often linked to their unsustainable flat locations that permit site expansion and proliferation, proximity to fragile vegetation, soils, water resources, or sensitive wildlife habitats, or their disturbance to rare flora, fauna, or archaeological sites (Cole et al. 1997, Marion et al. 2018a). These attributes make them substantially more susceptible to resource impact and increase the difficulty of their ongoing management.

In summary, many camping impacts are limited to campsites, with managers focused on campsite numbers and sizes and reflected by the aggregate areal extent of camping impact. However, impacts like off-site trampling and the creation of trails, wildlife disturbance, introduction and dispersal of non-native plants, and escaped campfires can extend considerably further into natural landscapes (Kasworm & Monley 1990, Tyser & Worley 1992). However, even localized disturbance can harm rare or endangered species or damage sensitive plant communities, particularly in environments with slow recovery rates.

Visitation-Related Experiential Impacts

As with environmental impacts, managers are also mandated to provide and protect high quality visitor experiences. Visitors may experience unacceptable levels of crowding, conflict, or degraded resource conditions, and managers need to understand the potential for each, how visitors cope, and what this means for recreation and visitor management decision-making.

Social scientists study crowding in natural areas as it relates to the social interface and stimulus overload theories (Manning 2011, Schmidt & Keating 1979). The social interface theory says that visitors feel crowded when the number of people in an area interferes with their goals and objectives. Stimulus overload theory says someone experiences crowding when the presence of others overwhelms them (Manning 2011). Several psychological studies indicate that the feeling of being crowded relies on the setting and the activities taking place. As concluded by Robert Manning in his book "Studies in Outdoor Recreation" (2011), a variety of factors influence a visitor's perception of what is normal, and thus influence if they feel crowded. Crowding is a normative concept: "The normative approach to crowding suggest that use level is not interpreted negatively as crowding until it is perceived to interfere with or disrupt one's objectives or values." Through a synthesis of social science literature centered on outdoor recreation, he groups these differences or factors into three categories: 1) personal characteristics of visitors, 2) characteristics of others encountered, and 3) situational variables.

The **personal characteristics** that affect visitor's perceptions of crowding are motivations for outdoor recreation, preferences and expectations for contacts, experience level, and attitudes toward management:

- If one is *motivated* to get outside for the opportunity for solitude or quietude there is a higher likelihood of experiencing crowding.
- If one *prefers* to have interactions with other people in nature (share the experience) there is a higher threshold of people encountered without feeling crowded.
- If one *expects* to see a lot of people (you know this is a popular spot) there is less likelihood of feeling crowded.
- As you gain more *experience* in an activity or area you may refine your preferences for level of crowding.
- The extent to which *attitudes* conform to how a place is managed (i.e., in accordance with the Wilderness Act) may affect someone's definition of crowding (Manning, 2011).

Factors that affect crowding in relation to **characteristics of other users** can be categorized as one of three types: group type and size, behavior, and degree to which other groups are perceived to be alike (Manning 2011).

Several studies support the view that the type and size of groups that are encountered affects tolerance for meeting another group. Most often groups are characterized by type of activity (Manning 2011). Some of the conclusions drawn from a variety of studies are:

- Users have the highest tolerance for meeting other groups of the same type of activity (Manning 2011).
- Party size may affect the crowding norms (Monz et al. 2000).

A few studies have shown that behavior also affects crowding norms. West (1982) found that 31% of hikers to a Michigan National Forest were disturbed by other users and 57% of those were most disturbed by the *behavior* of other users, particularly: noise, yelling, littering, polluting lakes, and noncompliance with rules (Manning 2011).

Lastly, there are some **situational variables** that can affect perceptions of feeling crowded. These include: the type of area and the location within an area.

- Type of area refers to backcountry (remote areas with mostly overnight visitation) versus frontcountry (accessible areas with mostly day use visitation). For example, a wilderness or backcountry hiker may feel crowded with relatively few interactions with others but not feel crowded with even more interactions in a frontcountry setting at a popular vista.
- The location within an area refers to intrasite interactions. A visitor may have a higher tolerance of seeing others on a formal trail, in comparison to seeing them in an off-trail area.

Coping

There are three coping options that visitors use in responding to crowding: displacement, rationalization, and product shift. First suggested by Clark, Hendee, and Campbell (1971) as "invasion and succession," displacement theory is the idea that "as use levels increase, some recreationists become dissatisfied and alter their patterns of recreation activity to avoid crowding, perhaps ultimately moving on to less used areas, and are displaced by users more tolerant of higher use levels" (Manning 2011). There can be intersite, intrasite, or temporal displacement. Users will either shift use to less-visited PAs (intersite), shift use within a PA to a lower use area (intrasite), or shift their visit to a less busy season or time (temporal). Managers can proactively improve social conditions and promote high quality camping experiences by physically separating campsites from each other by establishing minimum distances or visibility guidance, by asking or requiring visitors to shift away from peak use periods, and by encouraging a shift of visitation to less-visited areas (which often shift resource and social impacts to these areas unless preceded by proactive sustainable use management practices).

Several studies have found spatial or temporal displacement to have occurred and provide useful insights. Hammitt and Patterson (1991) asked campers in Great Smoky Mountains National Park how often they employed either intrasite or temporal displacement. Between 14-44 percent of those asked reported using these behaviors "usually" or "always" and those who value solitude reported more displacement behaviors. Another study found that visitors who were least sensitive to crowding altered their visit temporally, visitors with moderate sensitivity to crowding altered their route, and those most sensitive terminated their visit (Fleishman et al. 2007). Rationalization and product shift coping mechanisms involve changes in the way visitors think. Rationalization involves visitors 'rationalizing' their experience and reporting high levels of satisfaction despite poor conditions. How much investment (time, money and effort) into planning the experience seems to play a role in when visitors experience this (Manning 2011), with higher investment making it more likely to occur. Product shift occurs when visitors who experience a higher level of use than expected or preferred will alter their view of that area to one that fits with what was experienced.

Managers can prevent these negative coping behaviors and low quality social and experiential conditions by proactively managing their camping infrastructure through the location of campsites with sufficient spacing to prevent crowding and conflicts and promote natural quiet. Resolving such problems through infrastructure management is a less direct non-regulatory practice, in comparison to trailhead quotas and permit rationing, which compels visitation shifts from preferred places and times and frequently relocates resource and social impacts to new areas. For example, many western land managers witnessed the folly of past regulatory actions to reduce use at popular alpine lake basins, only to discover a decade later that resource and social conditions improved little while those same problems rapidly appeared and worsened at other nearby lake basins. As a result, more areas are implementing sustainable infrastructure management through the designation of campsites located to promote the protection of resource *and* social conditions. As described in the following section, recreation ecology studies reveal that a visitor *containment* strategy is optimal when seeking to minimize visitor impacts in areas that receive moderate to high visitation.

Finally, visitors do perceive recreation-associated resource impacts and their experiences are negatively affected by them, both in terms of the degraded utility of the recreation infrastructure and the aesthetics of spending time on heavily impacted sites (Farrell, Hall, & White 2001, Leung & Marion 2000, Moore et al. 2012). Visitors spend considerable time on campsites and their perceptions of backcountry and wilderness environments are shaped by the resource conditions that most commonly surround them.

Management Guidance

Legislative Mandates

As previously noted, the Pacific Crest National Scenic Trail (PCT) was designated as a national scenic trail by the 1968 National Trails System Act (P.L. 90-543, as amended by P.L. 111-11). Administrative responsibility was assigned to the USDA Forest Service (FS) as the lead managing agency, to coordinate management and operations with the Bureau of Land Management (BLM), the National Park Service (NPS), California State Parks, the Pacific Crest Trail Association (PCTA) and with volunteer and non-profit organizations. The National Trails Act provides little guidance for managing overnight visitation along these trails, with a single reference that authorizes: "campsites, shelters, and related public-use facilities."

The PCT passes through 47 federally designated Wilderness areas for a total of 1183 miles, 44.7% of its length. The Wilderness Act of 1964 (P.L. 88-577) is therefore applicable to federal areas through which the PCT passes. These acts overlay the land management designations of the USFS, NPS, and BLM and are intended by Congress to provide a higher degree of protection for selected areas singled out for exceptional ecological or social value. Wilderness areas are managed under the Wilderness Act to protect their natural resources and processes and to provide visitors with high quality wilderness experiences.

Wilderness is defined by Congress as:

- *an area where the earth and its community of life are untrammeled by man -- where man himself is a visitor who does not remain;*
- *undeveloped federal land retaining its primeval character and influence, without permanent improvements or human habitation;*
- *which is protected and managed so as to preserve its natural conditions;*
- *which generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable;*
- *which has outstanding opportunities for solitude or a primitive and unconfined type of recreation*.

The Wilderness Act establishes strong objectives for the provision of recreational use and the protection and preservation of wilderness resources. Wilderness areas:

> "*shall be administered for the use and enjoyment of the American people in such manner as will leave them unimpaired for future use and enjoyment as wilderness and so as to provide for the protection of these areas, the preservation of their wilderness character, and for the gathering and dissemination of information regarding their use and enjoyment as wilderness...*"

Agency Guidance

Authority to implement congressional legislation is delegated to federal agencies, who identify and interpret all relevant laws and formulate management policies to guide implementation. For the USFS, guidance is provided in their manual #2300-90-2, Recreation, Wilderness, and Related Resource Management (Forest Service 1990). Recreation use should be consistent with management of the area as wilderness through experiences that depend on a wilderness setting (section 2323.11). Managers are to maximize visitor freedom and minimize direct controls and restrictions within the wilderness. Information and education should be the primary visitor management tools, with more restrictive measures applied only when essential for protecting wilderness resources (section 2323.12).

No new camping shelters may be constructed, though those that existed at the time of wilderness designation may be maintained if allowed by specific legislation, or until they require extensive maintenance (sections 2323.13 & 2323.13b). Generally, facilities are installed only as a last resort and only for protection of the wilderness resource. Managers are directed to relocate or remove unnecessary campsites to allow maximum opportunity for solitude and to minimize the evidence of human use. However, designation of campsites is considered a "last resort" action (section 2323.13a).

The "cat hole" method of human waste disposal is recommended, though pit or vault toilets may be used if necessary. Sign use should be minimal; justified for either the routing or location of the traveler or the protection of the wilderness resource.

For the NPS, resource and recreation policies are set forth in Management Policies 2006 (NPS 2006) and other guidelines and manuals.

Congressional legislation directs the NPS to manage visitation contingent upon preserving park environments in an "unimpaired" condition. However, research demonstrates that resources are inevitably changed by recreational activities, even with infrequent recreation by conscientious visitors (Cole 1982 1985, Marion et al. 2016). What constitutes an impaired resource is ultimately a management decision, a judgment. According to the NPS Management Policies:

> "*The impairment that is prohibited by the Organic Act and the General Authorities Act is an impact that, in the professional judgement of the responsible NPS managers, would harm the integrity of park resources or values, including the opportunities that otherwise would be present for the enjoyment of those resources or values. Whether an impact meets this definition depends on the particular resources and values that would be affected; the severity, duration, and timing of the impact; the direct and indirect effects of the impact; and the cumulative effects of the impact in question and other impacts (section 1.4.5).*"

If interpreted strictly, the legal mandate of unimpaired preservation may not be achievable, yet it serves as a useful goal for managers striving to balance recreation provision and resource protection objectives. Consistent with park purposes, managers are directed to avoid those impacts that can be avoided, and to minimize those that cannot:

> "*NPS managers must always seek ways to avoid, or to minimize to the greatest degree practicable, adverse impacts on park resources and values (section 1.4.3).*"

In backcountry settings, NPS managers are directed to: "identify acceptable limits of impacts, monitor backcountry use levels and resource conditions, and take prompt corrective action when unacceptable impacts occur (section 8.2.2.4)." The number and types of facilities: "will be limited to the minimum necessary to achieve a park's backcountry management objectives and to provide for the health and safety of park visitors."

More specific guidance for wilderness management is contained within federal agency manuals. Information from these sources most relevant to camping management policies are reviewed in this section.

For the NPS, guidance is provided in Director's Order # 41, Wilderness Preservation and Management (NPS 1999). Recreational uses of wilderness should be those traditionally associated with wilderness and that will leave the area unimpaired. Management should provide for outstanding opportunities for solitude or primitive and unconfined types of recreation (section 6.4.3). The construction of new shelters for public use is not generally allowed, though existing shelters may be maintained or reconstructed if the facility is determined to be necessary to achieve wilderness management objectives identified in the park's management plans (section 6.3.10.3).

Campsite facilities may include a site marker, fire rings, tent sites, food storage devices, and toilets if these are determined to be necessary for the health and safety of visitors or the preservation of wilderness resources and values. Toilets can be used only where their presence will resolve health and sanitation problems or prevent serious resource impacts (section 6.3.10.3). Only signs needed for visitor safety or to protect wilderness resources are permitted (section 6.3.10.4).

Guidance may also be found in the various management plans of federal and state agencies that manage lands bisected by the PCT corridor. For example, camping guidance, including regulations and low impact practices, may be specified for backpackers or stock users and these can vary by management zone or unit. State and local guidance must also be investigated and followed. For example, the trail infrastructure and recreation management must comply with local building codes, sanitation regulations, and fire laws.

Pacific Crest Trail Association Guidance

PCTA guidance is included in the 2018-21 Strategic Plan and various internal documents. The Strategic Plan defines the PCTA mission, vision, values, goals and objectives. Relative to camping, the plan calls for the PCTA to collaborate with the land management agencies to develop a Visitor Use Management program to address the physical and social impacts associated with campsites along the PCT corridor. This would include "planning efforts that address acceptable levels of use and impacts within the PCT corridor."

Carrying Capacity Decision-Making

As reviewed in Marion (2016), the traditional body of knowledge developed by managers and scientists to address the negative impacts of visitation to resource and social conditions was termed "carrying capacity." While the early management activity and literature focused on defining a numeric limit on visitor numbers below which resource and social conditions would be protected, several decades of management and research experience have documented a curvilinear or asymptotic use-impact relationship, demonstrating that amount of use is strongly correlated with the magnitude of resource impact only at low levels of use (Marion 2016). Thus, limiting use is often an ineffective means for achieving resource protection objectives on moderate to high use trails and recreation sites, prompting the need to consider a diverse array of alternative considerations and actions (Leung & Marion 2000, Manning 2007, 2011, Wagar 1964). This is widely accepted in the context of minimizing resource impacts, though court challenges based on dated laws specifying the role that numerical limits should play in carrying capacity planning continue to focus management attention on visitor numbers (Capacity Work Group 2010, Graefe et al. 2011, Whittaker et al. 2011).

NPS *Management Policies* (2006) defines carrying capacity as, "the type and level of visitor use that can be accommodated while sustaining the desired resource and visitor experience conditions in the park. By identifying and staying within carrying capacities, superintendents can prevent park uses that may unacceptably impact the resources and values for which the parks were established." These policies additionally state that:

"When making decisions about carrying capacity, superintendents must utilize the best available natural and social science and other information, and maintain a comprehensive administrative record relating to their decisions. The decision-making process should be based on desired resource conditions and visitor experiences for the area; quality indicators and standards that define the desired resource conditions and visitor experiences; and other factors that will lead to logical conclusions and the protection of park resources and values.

The general management planning process will determine the desired resource and visitor experience conditions that are the foundation for carrying capacity analysis and decision-making. If a general management plan is not current or complete, or if more detailed decision-making is required, a carrying capacity planning process … should be applied in an implementation plan or an amendment to an existing plan.

As use changes over time, superintendents must continue to decide if management actions are needed to keep use at acceptable and sustainable levels. If indicators and standards have been prescribed for an impact, the acceptable level is the prescribed standard. If indicators and standards do not exist, the superintendent must determine how much impact can be tolerated before management intervention is required. (Section 8.2.1)."

Many managers will already have considered or made carrying capacity decisions in a general management plan. The 1978 National Parks and Recreation Act (P.L. 95-625) requires the NPS to determine carrying capacities for each park as part of the process of developing management plans. Specifically, amendments to Public Law 91-383 (84 Stat. 824, 1970) require relevant NPS management plans to include "identification of and implementation commitments for visitor carrying capacities for all areas of the unit" and determination of whether park visitation patterns are consistent with social and ecological carrying capacities.

Carrying capacity has long provided the predominant framework for planning and management decision-making that addresses the protection of natural resource and social conditions (Manning 2011). Over time, managers have shifted from a narrow focus on numeric carrying capacity to a broader decision-making framework that incorporates a more comprehensive array of management strategies and actions (Graefe et al. 2011). As directed by the NPS *Management Policies*, carrying capacity determination and management should be developed through an adaptive management process. In its simplest form adaptive management means learning by doing, and adapting based on what's learned (Williams and Brown 2012). A more formal definition is "… flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process" (National Research Council 2004).

Instead of an emphasis on amount of use, research increasingly points to the strong influence of a diverse array of use-related, managerial, and environmental factors affecting resource and social/experiential impacts (Marion & Leung 2004, Marion 2016, Marion et al. 2016):

- Use-related factors include attributes like the number visitors, the types of activities they are engaged in, the locations where activities occur, and the extent to which visitors know and apply low impact behaviors.
- Managerial factors include the presence and physical size/capacities of facilities (e.g., campsites, shelters, formal trails), the types of facilities and level of containment (e.g., trails and recreation sites in flat vs. sloping terrain, presence of containment borders like logs or scree walls), durability of substrates (e.g., vegetation, soil, wood, gravel, rock), regulations and enforcement, existence/efficacy of low impact education efforts.
- Environmental factors include the resistance and resiliency (ability to recover) of soils and vegetation, weather (vegetation and soil impacts increase with increasing soil moisture), topography, and the presence of water resources and wildlife, and their sensitivity to human impact.

Particularly influential factors that minimize resource impacts demonstrated in scientific studies include:

1) sustainable siting and designs for recreation sites and trails relative to topography and soil/vegetation type,
2) actions that spatially concentrate activity to a limited "footprint" of disturbance, and
3) regulations and persuasive communication that promote low impact behaviors and reduce the number of People At One Time (PAOT) within single locations or small areas (Cole 1989b, Hammitt et al. 2015, Leung and Marion 2000, Marion 2014).

Similar findings have been identified for social impacts like crowding and conflict, such as the significant influence of visitor motives, use type, user behavior, and the density of use and location or timing of encounters (Manning 2007, 2011).

Visitor Use Management

Recently, six U.S. federal agencies – the Bureau of Land Management, Forest Service, National Oceanic and Atmospheric Administration, NPS, U.S. Army Corps of Engineers, and U.S. Fish and Wildlife Service – formed an Interagency Visitor Use Management Council (IVUMC; http://visitorusemanagement.nps.gov/) to "increase awareness of and commitment to proactive, professional, and science-based visitor use management on federally-managed lands and waters." They have developed a new Visitor Use Management (VUM) framework focused on managing visitor use to protect resources and provide high quality experiences, with numeric carrying capacity determinations included as an option when needed or required by law. Its attributes include prescriptive management objectives that define desired resource and social conditions, selection of indicators and thresholds (standards) specifying the limits of acceptable change, monitoring to compare current conditions to standards, and implementation and evaluation of corrective management actions.

Comprehensive guidance for implementing VUM is available at the IVUMC website, including several publications (IVUMC 2019,a,b). They define VUM as the "proactive and adaptive process for managing characteristics of visitor use and the natural and managerial setting using a variety of strategies and tools to achieve and maintain desired resource conditions and visitor experiences." They emphasize that managing visitor access and use for recreational benefits and resource protection is inherently complex, requiring consideration of natural and social science studies, management experience, and professional judgment. Guidance for implementing VUM, depicted in Figure 2, was developed for use by all federal land management agencies for managing visitor use and carrying capacity. It is expected to be widely adopted across U.S. PAs and the AT community has already proceeded with its implementation in high use/high impact areas.

VUM incorporates lessons learned from agency experience to address past planning and legal challenges (Graefe et al. 2011, Whittaker et al. 2011). VUM incorporates additional guidance for carrying capacity decision-making when needed, but its primary focus is on visitor use management topics. Because VUM provides a defensible and adaptive management decision-making framework, it offers an effective and efficient process that the AT community could apply for evaluating and managing all aspects of visitor use, including determinations of carrying capacities and the management of special events and the thru-hiker bubble.

The *Visitor Use Management Framework: A Guide to Providing Sustainable Outdoor Recreation* (IVUMC 2019b) describes the VUM framework in more detail:

> *"This framework will enhance consistency in visitor use management on federally managed lands and waters, since it will be used by all agencies. The elements of this framework are broadly applicable to all visitor use management issues and opportunities. The framework is applicable across a wide spectrum of situations that vary in spatial extent and complexity, from site-specific decisions to large-scale comprehensive management plans. This framework may also be used across multiple, tiered projects and may be applied to internally driven activities (e.g., analyzing a management action), as well as externally driven activities (e.g., a permit request or an action by another agency)."*

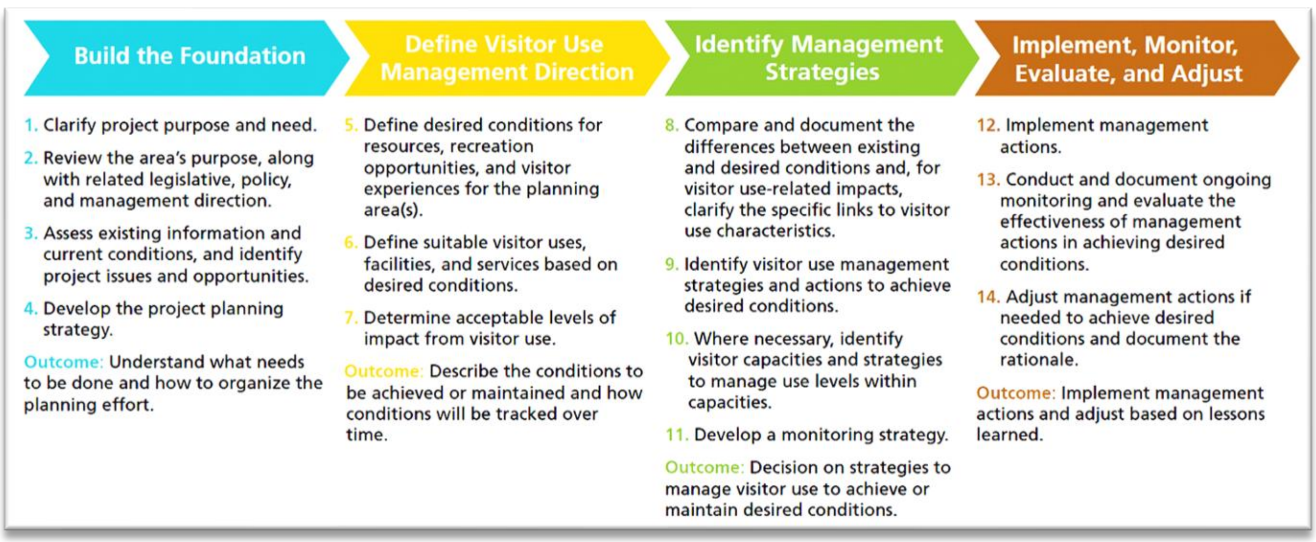


Figure 2. The Visitor Use Management (VUM) framework recommended by the IVUMC for adaptively managing visitor use and carrying capacities in protected natural areas.

The strengths of this framework are that it is "iterative, adaptable and flexible" to a variety of environmental settings and scales (IVUMC 2019b), and that it embraces a "sliding scale" concept to optimize the efficiency of the framework's application:

> *"Applying different levels of analysis can be likened to using a sliding scale in which one end of the scale requires a low level of analysis and the other a high level of analysis. In either case, the analysis still must satisfy all framework requirements. It is the investment of time and resources that varies along the sliding scale, not the elements in the framework; the same fundamental elements are used regardless of the placement on the scale.*
>
> *This sliding scale approach is consistent with direction given in the Council on Environmental Quality's interpretation of NEPA. This approach implements the instruction that agency NEPA documents shall "focus on significant environmental issues and alternatives" (40 CFR 1502.1) and shall discuss impacts "in proportion to their significance" (40 CFR 1502.2(b)).* (Note: Under the Council on Environmental

Quality's regulations and judicial rulings, the degree to which environmental effects are likely to be controversial with respect to technical issues is a factor in determining significance.)"

Applying this "sliding scale of analysis" seeks to match the investment made in analysis with the level of complexity and risk associated with the issues being addressed. For this reason, the VUM framework can provide structure to trail-wide or location-specific resource and social impacts, or to the management of temporal problems like the thru-hiker bubble or special events.

IVUMC places substantial emphasis on "proactive, professional, and science-based visitor use management on federally-managed lands and waters." Managers who make proactive decisions should be prepared to prove the viability of their strategies, or risk public disapproval or even legal action against the agency. Resource and visitor use monitoring programs provide the means for such demonstrations. Current legislation and agency documents establish mandates for monitoring, which is reviewed in the following section (Marion 1991). Recent legislative mandates allow managers more latitude to make proactive decisions that can be defended in the court of law or public opinion, when necessary.

Monitoring Visitor Impacts

This section reviews relevant NPS laws and management policies pertaining to resource monitoring. The NPS was selected because it's monitoring directives and guidance are more well-developed and illustrative than those of the other federal land management agencies. Monitoring is generally conducted to evaluate the occurrence and acceptability of resource impacts associated with visitor use and is generally an essential component of decision-making frameworks like VUM.

The National Parks Omnibus Management Act of 1998 established a framework for fully integrating natural resource monitoring and other science activities into the management processes of the National Park System. The Act charges the Secretary of the Interior to:

> *"develop a program of inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources."*

Congress reinforced the message of the National Parks Omnibus Management Act of 1998 in its text of the FY 2000 Appropriations bill:

> *"A major part of protecting [park] resources is knowing what they are, where they are, how they interact with their environment and what condition they are in. This involves a serious commitment from the leadership of the National Park Service to insist that the superintendents carry out a systematic, consistent, professional inventory and monitoring program, along with other scientific activities, that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data."*

Relative to the need for balancing visitor use and resource impacts, the NPS *Management Policies* (2006) state that:

> *"The "fundamental purpose" of the national park system, established by the Organic Act and reaffirmed by the General Authorities Act, as amended, begins with a mandate to conserve park resources and values. This mandate is independent of the separate prohibition on impairment, and so applies all the time, with respect to all park resources and values, even when there is no risk that any park resources or values may be impaired. NPS managers must always seek ways to avoid, or to minimize to the greatest degree practicable, adverse impacts on park resources and values.*

Monitoring programs are also explicitly authorized in Section 4.1 of the *Management Policies*:

> "Natural systems in the national park system, and the human influences upon them, will be monitored to detect change. The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions". (*Section 4.1*)

"Further, The Service will:

- *Identify, acquire, and interpret needed inventory, monitoring, and research, including applicable traditional knowledge, to obtain information and data that will help park managers accomplish park management objectives provided for in law and planning documents.*
- *Define, assemble, and synthesize comprehensive baseline inventory data describing the natural resources under its stewardship, and identify the processes that influence those resources.*
- *Use qualitative and quantitative techniques to monitor key aspects of resources and processes at regular intervals.*
- *Analyze the resulting information to detect or predict changes, including interrelationships with visitor carrying capacities, that may require management intervention, and to provide reference points for comparison with other environments and time frames.*
- *Use the resulting information to maintain-and, where necessary, restore-the integrity of natural systems" (Section 4.2.1).*

Thus, relative to visitor use management, managers must evaluate the types and extent of resource impacts associated with visitor activities and determine to what extent they are unacceptable and constitute impairment. Further, managers must seek to avoid or limit any form of resource impact, including those judged to fall short of impairment. Visitor impact monitoring programs can assist managers in making objective evaluations of impact acceptability and impairment and in selecting effective impact management practices by providing quantitative documentation of the types and extent of specific impacts to natural resources.

NPS has directives for carrying capacity decision-making, adaptive management, and monitoring as a tool to accomplish management goals. If managers are to avoid unacceptable visitor impacts to the park resources and experiences it is clear they should be focused, purposeful and proactive in their decisions. The application of the VUM framework offers an efficient structured process that can guide decisions. Again, the sliding scale of analysis offered by VUM means managers can provide any level of structure needed for evaluating and managing visitor impacts on a scale appropriate to the problem.

Visitor impact monitoring protocols are often developed by scientists to provide accurate and precise data on physical attributes (e.g., trail width or campsite size), vegetation cover, tree damage, and soil exposure, loss, or muddiness (Marion 1991, Cole 2006). Thorough reviews of the visitor impact monitoring literature, assessment methods, and examples of monitoring indicators can be found in publications for formal trails (Dixon et al. 2004, Hawes et al. 2006, Hill and Pickering 2009, Marion and Carr 2009, Marion and Leung 2011, Marion et al. 2006, 2011a), ITs (Leung and Louie 2008, Leung et al. 2011, Marion and Wimpey 2011, Marion et al. 2011a, b), and recreation sites and campsites (Cole 2013a, Cole and Parsons 2013, Marion & Leung 2001, Marion and Hockett 2008, Newsome et al. 2013). Newer guidance related to monitoring and the VUM framework are provided by a Monitoring Guidebook (IVUMC 2019a).

Many of the cited publications are reports that contain full sets of field assessment protocols that can be applied or adapted into visitor impact monitoring programs. We suggest careful attention to select protocols that can be efficiently applied, provide quantitative data, are focused on key indicators reflecting desired conditions, and are sensitive to the changes expected from special use events. We note that monitoring data can provide beneficial information needed for adaptive management decision-making. More guidance is included in the following section and in this report's Discussion section and Appendices.

Monitoring Indicators and Selection Criteria

Indicators are defined as managerially relevant measurable physical, ecological, or social variables used to track trends in conditions caused by human activity so that progress toward goals and desired conditions can be assessed. An indicator is any setting element that changes in response to a process or activity of interest (Merigliano 1990). An indicator's condition over time provides a gauge of how recreation has changed a setting.

Comparison to management objectives or indicator thresholds (standards) reveals the acceptability of any resource changes. Indicators provide a means for restricting information collection and analysis to the most essential elements needed to answer management questions such as:

- Are visitors experiencing an environment where the evidence of human activity is substantially unnoticeable?
- Are trail and campsite conditions acceptable given each management zone's objectives and desired conditions?
- Are management practices effective in minimizing the creation or degradation of campsites?

Before a monitoring program can be developed, appropriate resource indicators must be selected (IVUMC 2019a). A single, direct measurement of a campsite's condition is inappropriate because the overall condition is an aggregate of many components. Typically, then, monitoring evaluates various soil, vegetation, or aesthetic elements of a campsite that serve as indicators of that facility's condition. Cole (1989c), Marion (1991) and Merigliano (1990) review criteria for the selection of indicators (Table 2), which are summarized here. Management information needs, reflected by the management questions such as the examples above, guide the initial selection of indicators.

Preferred indicators should reflect attributes that have ecological, experiential, or managerial significance. Indicator measures should primarily reflect changes caused by the recreational activity of interest. Indicators should be measurable, preferably at an interval or ratio scale where the distances between numeric values are meaningful, i.e., a 1,600 ft^2 campsite is twice the size of 800 ft^2 campsite. In comparison, a categorical ratings system based on subjective assessments rather than measures provides data at an ordinal scale. Distance between categorical values are *not* meaningful so computing an average is inappropriate, though non-parametric procedures can be used to evaluate changes.

Table 2. Criteria for selecting indicators of resource condition.

Criteria	Rationale
Quantitative	Can the indicator be measured?
Relevant	Does the indicator change as a result of the process or activity of interest?
Efficient	Can assessments be applied by available staff within existing time and funding constraints?
Reliable	How precise are the measurements? Will different individuals obtain similar data?
Responsive	Will management actions affect the indicator?
Sensitive	Does the indicator act as an early warning, alerting you to deteriorating conditions before unacceptable change occurs?
Integrative	Does the indicator reflect only its condition or is its condition related to that of other, perhaps less feasibly measured, elements?
Significant	Does the indicator reveal relevant environmental or social conditions?
Accurate	Will the measurements be close to the indicator's true condition?
Understandable	Is the indicator understandable to non-professionals?
Low Impact	Can the indicator be measured with minimal impact to the resource or visitor experiences?

Adapted from Cole (1989c), Marion (1991), Merigliano (1990).

Potential indicators of resource condition are numerous and there is great variation in our ability to measure them with *accuracy*, *precision*, and *efficiency*. All assessments are approximations of an indicator's true value; a measurement method is *accurate* if it closely approximates the true value. A measurement method is *precise* if it consistently approximates a common value when applied independently by many individuals (i.e., repeatability). Accurate measurements correctly characterize current conditions; precise measurements allow valid comparisons of change over time (Cole 1989c, Marion 1991). *Efficiency* refers to the time, expertise, and equipment needed to measure the indicator's condition.

When choosing a method (protocol), managers must balance accuracy and precision, for each places constraints upon efficiency and cost-effectiveness. For example, campsite condition assessments range from highly efficient but subjective evaluations (e.g., condition class ratings), to rapid assessments (ratings based on numeric categories of damaged trees), to time-consuming research-level measurements (quadrat-based vegetation loss assessments). Regardless of the method selected, comprehensive procedural manuals, staff training, and program supervision stressing quality control can improve both accuracy and precision. However, poorly managed monitoring efforts can result in measurement error that confounds data interpretation or even exceeds the magnitude of impact caused by recreational activities.

Preferred Indicators

From these indicator criteria and knowledge of how recreation affects soil, vegetation, and aesthetics, managers select preferred indicators. Table 3 includes a listing of commonly employed indicators for assessing resource conditions on trails and recreation sites using measurement-based approaches. Generally, a small number of indicators are selected for use in visitor use management frameworks. However, that does not preclude monitoring of additional resource condition indicators or from also assessing various inventory indicators. Travel time to the sampling locations is often the most substantial portion of the time budget so assessing a few additional indicators can be negligible.

Table 3. Potential indicators of campsite conditions and measurement units.

Campsite Indicators	Measurement Units
Informal Campsites	#/unit area, #/unit length along formal trails
Campsite Size	Max. value, value/unit area, aggregate value/unit area
Area of Vegetation Loss	Max. value, value/unit area, aggregate value/unit area
Area of Soil Exposure	Max. value, value/unit area, aggregate value/unit area
Damaged Trees	Max. value, value/unit area, aggregate value/unit area
Fire Sites	Max. value, value/unit area, aggregate value/unit area
Litter	Max. value, value/unit area, aggregate value/unit area
Human Waste	Max. value, value/unit area, aggregate value/unit area

Indicator measures that are collected with Global Positioning System (GPS) waypoints allow greater flexibility in analyses at different spatial scales and comparisons across park zones or other strata. A final consideration is the measurement unit employed for reporting results and/or setting thresholds. Measurement-based approaches permit the most flexibility in this respect. For example, the aggregate campsite size can be assessed for a lake basin, trail segment, travel zone, or unit district, with thresholds/standards specifying maximum allowable values (Cole 1983, Marion et al. 2006). Thresholds could also be expressed as a value per unit length of trail or per unit area (e.g., a moving 50 acre circle).

In summary, managers must consider and integrate a diverse array of issues and criteria in selecting indicators for monitoring impacts on trails and campsites. Indicators will rarely score high on all criteria, requiring good judgment as well as area-specific field trials and direct personal experience. Tradeoffs are also required, such as a necessary reduction in accuracy so that precision and efficiency may be increased.

Use Impact Relationship

The relationship between levels of hiking and camping activity and resource impacts to vegetation and soils are examined in this section because they have significant implications for the management of visitor use impacts. Recreation ecology research indicates that even low levels of recreational trampling in shady forest plant communities can cause substantial damage and loss of vegetation cover (Cole 1987, Cole 1995a, c). This low threshold of trampling resistance is illustrated in a study by Cole and Monz (2003) in Wyoming's Wind River Range, which found that previously unused forested sites camped on just 4 nights/year for 3 years lost 95 percent of their vegetation cover. These substantial impacts are attributed to the morphological characteristics of plants growing in shady settings, which are dominated by broad-leafed herbs/forbs whose erect fragile stems are susceptible to trampling damage (Cole 1995b). Woody shrubs are also susceptible to trampling damage due to their brittle stems that break easily and recover slowly.

A large body of research has characterized this relationship as asymptotic in forested areas, with vegetation impacts increasing rapidly at initial and low levels of use and leveling off as near-maximum impacts are approached at moderate use levels (Cole 1995 a,b,c, Cole & Monz 2003, Marion and Cole 1996). However, other authors have more correctly pointed out that the relationship is sigmoidal (S-shaped) as depicted in Figure 2, and that forest ground vegetation is so fragile to trampling impact that the initial non-linear relationship is not accurately depicted in many studies (Cole 1982, 1995c). Forested settings simply have a very low threshold of trampling impact. Numerous campsite and experimental trampling studies (described in the next section) have demonstrated a more sigmoidal use-impact relationship for graminoids growing in sunny meadows or open shrublands and forests due to their substantially greater trampling resistance and recovery rates (Figure 3).

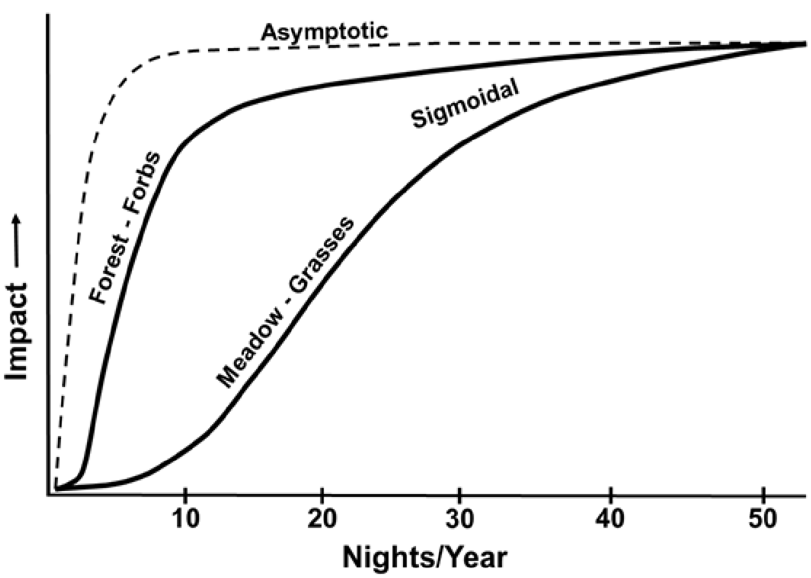


Figure 3. A generalized model of the use-impact relationship for trampling impacts to vegetation and soil. While many authors have referred to the relationship as asymptotic (dashed line) for forested plant communities, the relationship is more accurately sigmoidal (solid lines), with a low trampling threshold for impacts in shady forests and a high threshold for sunny meadow grasses and sedges, due to their substantial trampling resistance and resilence (ability to recover).

The loss of vegetative herb cover on new campsites in forests is quickly followed by the loss of tree seedlings, saplings, and small shrubs, whose woody stems prevent tenting, deter traffic, or are easily broken (Cole & Monz 2003, Marion & Cole 1996). This is followed by the pulverization and loss of organic litter and soil and the exposure and compaction of underlying mineral soil, changes that exhibit a more linear relationship with the amount of trampling (Cole 1982, Marion and Merriam 1985). Once most vegetation and litter cover have been lost, soil compaction occurs quickly and further increases in visitation result in diminishing per capital amounts of vegetation and soil impact as near-maximum levels of impact are reached (Figure 2). Cole's (1992) hypothetical campsite impact modeling supports these empirical findings and explains why campsite size tends to not expand with increasing use due to a natural tendency for activity concentration to increase as campsite use levels and sizes increase.

Implications for Sustainable Camping Management

The sigmoidal relationship between amount of use/trampling and vegetation impact has significant implications for the management of camping to minimize aggregate impact. As described in Table 4 and illustrated in Figure 1, when managers permit Unconfined (unregulated, at-large) camping visitors frequently create large numbers of campsites that receive mostly moderate levels of use (Cole 1993, 2013a). Managers often address these campsite proliferation problems by closing unnecessary campsites, often those too close to water, trails, or other sites. As illustrated in Figure 4, managers could close two campsites and shift use to a third, sustainable site (defined and discussed below). Because of the sigmoidal use-impact relationship, impact on this third site would increase only marginally, from “a” to “b,” and *aggregate impact would decline substantially*, from three sites with an “a” level of impact to one site with a “b” level of impact (Figure 4; Marion 2016). Effective application of this ***Containment*** strategy (Table 4) requires education and/or regulations directing visitors to camp only on a limited subset of sustainable and well-established or designated campsites. A significant social/experiential advantage is that problems with crowding and conflict can also be easily and permanently resolved by physically separating the selected campsites from each other and from trails (Manning et al. 2017, Marion, 2016).

Also note that the sigmoidal use-impact relationship *reduces* the potential effectiveness of use limitation for addressing camping impacts. Substantial use reductions would be necessary to achieve even modest improvements in most resource condition indicators on heavily impacted campsites (Figure 4). Use reductions can only lead to pronounced improvements at low use levels, where use and impact are more strongly related. More specifically, based on recreation ecology research, use reduction is effective primarily at between 3 and 10 nights of camping per year, or 50 to 250 passes per year along a trail (Leung & Marion 2000, Cole 1995a,b,c). Use limitations can also reduce campsite numbers, but *only* when effective camping containment and dispersal strategies are also employed (see Figure 1, Table 4).

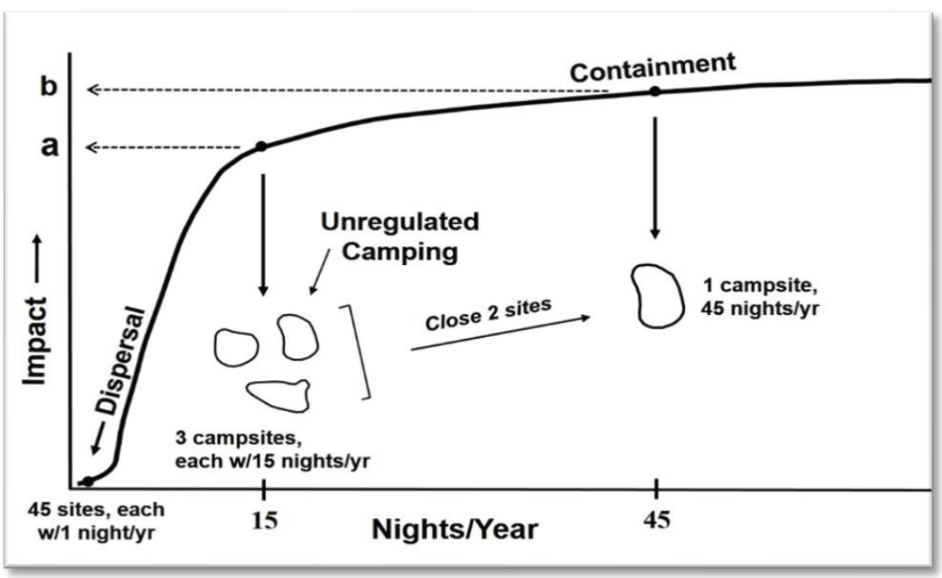


Figure 4. A generalized model of the use-impact relationship for trampling on vegetation and soil illustrating when use-reduction is and is not effective and the empirical basis for effective dispersal and containment strategies.

Table 4. Sustainable camping management strategies, options, and guidance (from Marion et al 2018a).

Camping Strategy	Use Level	Description and Guidance
UNCONFINED **(Unregulated, At-Large Camping)**	All	Visitors are free to select or create a campsite in the location of their choice, sometimes modified by guidance to avoid locations close to water or formal trails or to use an existing site. Campsite proliferation, excessive resource impact, and high-density camping are frequently significant problems in popular areas.
DISPERSAL STRATEGY **Pristine Site Camping**	Low-Mod	Visitors are asked to camp on durable *previously undisturbed* surfaces at low use levels that avoid lasting impact. Difficult to achieve in high use areas and requires visitors to learn and consistently apply low impact pristine site camping practices.
CONTAINMENT STRATEGY **Established Site Camping**	All	Visitors are *encouraged to camp* on a subset of well-established sustainable campsites selected by managers to promote resource protection and desired social qualities. Supporting actions include campsite maps to aid visitors in finding the selected campsites and a program to close and restore non-selected campsites.
Designated Site Camping	Mod - High	Visitors are *required to camp only* on a subset of sustainable designated campsites selected by managers to promote resource protection and desired social qualities. Managers generally mark designated campsites on maps, have signs and/or some facilities, and remove hazardous trees. Designated sites are managed as "first-come first-served" or, more rarely through a reservation system.

Figure 4 also illustrates the potential efficacy of a ***Dispersal*** strategy with pristine site camping for avoiding or minimizing camping impacts (Table 4). Camping use for any given spot would need to be limited to a level that prevents vegetative or soil impacts lasting more than a year. Such a level could be as low as 1-3 nights/yr in forested areas with substantial vegetative ground cover, or perhaps 4-10 nights/yr in dry grassy sunny meadows, shady dense forests, or extremely rocky areas with little ground vegetation.

The national Leave No Trace program's guidance to disperse use in remote or low-use areas and concentrate use in popular areas (www.LNT.org, Marion 2014) was derived from these recreation ecology findings. Containment is effective above moderate use levels because per capita impacts diminish substantially and campsite conditions stabilize, achieving a relatively constant equilibrium over time (Cole 2013a, Marion & Cole 1996). Even doubling use on a well-established campsite only marginally increases measurable resource impacts, particularly for sustainably selected campsites that resist site expansion (Figure 2). Cole (1992) attributes some of these counterintuitive findings to the natural tendency for activity concentration to increase as campsites become more heavily used and impacted. On the following pages we provide potential PCT Visitor's Guides for Dispersed Pristine Site Camping and Established & Designated Site Camping, each described in three steps: 1) finding a sustainable site, 2) appropriate low impact site use practices, and 3) restorative site departure practices.

What is a sustainable campsite? Marion and others (2018a) define a sustainable campsite as: "… one that can accommodate the intended type and amount of use over time without unacceptable levels of expansion, degradation, maintenance, and social crowding or conflict." Recreation ecology studies have only recently focused on identifying the most influential campsite sustainability factors, summarized here and described more thoroughly in the "Additional Attributes of Sustainable Campsites" section. Arredondo and others (2021) conducted the most comprehensive analysis on campsite sustainability, identifying topography, including sloping, uneven, and rocky terrain as the most important determinant of site size and area of vegetation loss and soil exposure. Campsites with a small "footprint" also have substantially fewer damaged and felled trees, fire sites, and reduced impacts to water quality and wildlife. Sunny campsites with limited tree cover support greater vegetative ground cover on and around sites, though selecting sites with low expansion potential in deep shade or rocky terrain that support little to no vegetation cover can also be considered "sustainable." Arredondo and others (2018a) also highlight how constructed side-hill campsites and facilities like anchored rock or steel fire rings, flat stove rocks, and improved tent pads can attract and spatially-concentrate camping activities. Managers must also ensure that visitor campsite preferences for necessity, experience, and amenity attributes (discussed later) are provided, or the sustainable campsites may receive little use. Finally, sustainable campsites can and should resolve the experiential impacts of crowding, conflicts, and noise by locating them apart from formal trails and other campsites, and protect water quality and wildlife through similar setbacks.

There are a few important caveats to these general findings. Limitations on the number of visitors or groups during times of peak use (e.g., annual thru-hiking "bubbles" of use) *can* help reduce the number or sizes of campsites. Campsites are often created by visitors during peak use periods or enlarged by large groups or large numbers of visitors who require more space than afforded on existing sites. Once created, subsequent use of new, enlarged, or closed campsites, even for just a few days/year, is often sufficient to prevent their recovery (Cole 2013b, Marion 2016, Scherrer & Pickering 2006). The key solution to these problems is to flatten and disperse the annual bubble of PCT use to reduce the number of campers within any given area and thus the number of campsites needed. Any events that regroup hikers after they have dispersed should be avoided where possible.

The timing and location of use also influence the amount of impact that the same number of visitors can have. For example, visitors have substantially greater impact on wet soils compared to dry soils, or on growing plants than on the senesced fall/winter plant remnants. Visitors can also travel or recreate on durable non-vegetated substrates such as bare soil, gravel, rock, and snow, or artificial substrates like gravel and rockwork on trails that support substantial traffic with very limited impact. Finally, Monz et al. (2013) notes the possibility of alternative use-impact response curves for other types of impact, including wildlife responses and aquatic systems that may have differing management implications.

Monz and others (2000) examined large group size impacts in wilderness areas, noting that large groups have the potential to create substantial impact on plants and soils unless their activities are sufficiently concentrated within the boundaries of one or more existing campsites, or widely dispersed when pristine site camping. As previously noted, campsite expansion often occurs when large groups use campsites with insufficient numbers of tenting spots. We note that this can be large unaffiliated "groups" of thru-hikers, or more socially cohesive groups like scouting units. Campsite boundaries quickly expand to encompass new offsite tenting spots, which may later be selected and reused by members of smaller groups, preventing their recovery (Marion et al. 2020a, b). Some PAs have developed group use campsites to address these problems, and social impacts such as crowding and conflicts that can be exacerbated with large groups. Monz and others (2000) also note factors that could alter this outcome, including "a group's level of minimum impact knowledge and behavior".

Land managers have commonly addressed this problem by establishing group size limits, particularly for wilderness, to address resource and social impact issues (Cole et al. 1987, Monz et al. 2000). However, few studies have examined the relationship between group sizes and resource or social impacts, nor is it expected that they could provide specific defensible guidance for selecting a meaningful size limit (Monz et al. 2000). Decisions about group size limits require subjective judgments and a limit of 10 is unlikely to be any more "correct" than 6 or 15, as resource and social impacts are primarily a function of visitor behavior rather than group size (Marion 2014, Monz et al. 2000). There is no magic "best" number; key management challenges are for groups to learn and use low impact practices, particularly matching their size with campsite sizes by finding a large site or splitting up to avoid campsite expansion or creation. A large group that effectively applies low impact practices could produce substantially less hiking and camping impact than the same or even larger numbers of visitors employing high impact practices.

A Visitor's Guide to *Dispersed Pristine Site Camping:* Three Easy but Critical Steps

You can truly ***Leave No Trace*** of your visit when you successfully apply the following Dispersed Pristine Site Camping practices in low use areas with durable surfaces.

Please do not use this style of camping unless *ALL* members of your group accept the responsibility to carefully follow the guidance – failure to do so can lead to the creation of new campsites. Otherwise please find and use an existing legal campsite.



Step 1: Find a pristine spot with *no evidence* of trampling disturbance that is out of sight or distant from existing trails and campsites with a **durable surface**: naturally non-vegetated rock or gravel (preferred) or organic litter (look in shady forests). Camping on low dry grasses/sedges in a sunny concealed spot is also fine, particularly if concentrated activities are shifted to more durable surfaces. Your spot should be >200 ft from water and *highly unlikely* for other visitors to find and reuse it.

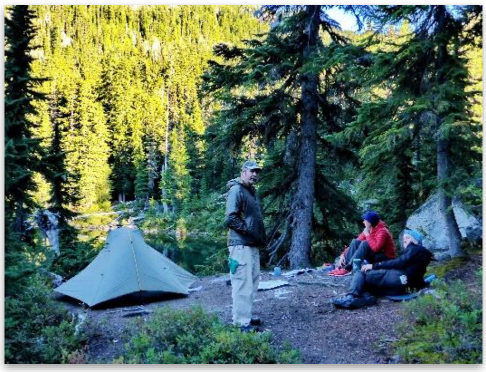
Step 2: Avoid ground disturbance by using a free-standing tent on bedrock or a hammock with wide straps (preferred), or place tents on non-vegetated organic litter or dry grass. Save any removed sticks, rocks, or pinecones. Disperse and/or limit all traffic and camping activities to the most durable non-vegetated areas – avoid stepping on plants. Camp one to a few nights but move camp if visible vegetation or soil disturbance begins to appear. No campfires for this style of camping.



Step 3: Pack everything up and naturalize the area, disguising the site by replacing/adding sticks, rocks, and pinecones or organic litter to remove all traces of your stay. Fluff up any flattened grasses.

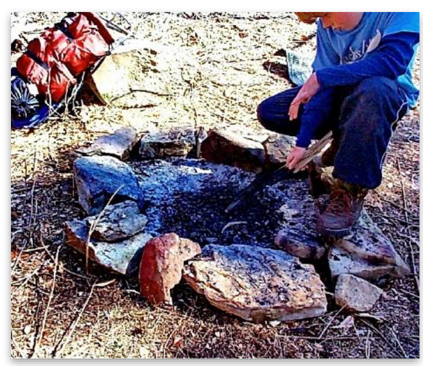
A Visitor's Guide to *Established & Designated Site Camping:* Three Easy but Critical Steps

Leave No Trace of your visit by selecting and concentrating your camping activities on sustainable Established or Designated campsites. Never create a new campsite and avoid using lightly impacted or closed sites to allow natural recovery - even limited use prevents their recovery. Check with land managers to obtain and follow their camping regulations and low impact guidance. Camp only on campsites designated by land managers; otherwise search out a sustainable well-established campsite.



Step 1: The ideal sustainable campsite is >200 ft from water, formal trails, and other campsites and, when possible, located in sloping terrain or rocky areas that discourage site expansion. Sunny dry locations surrounded by grasses are more durable than forested sites but try to camp out-of-sight of other groups. Select smaller sites but ensure they are large enough for your group, or split your group and use more than one campsite. Some of the best campsites are located away from water. Expect to spend some time searching for the perfect campsite knowing that you may need to walk past many imperfect sites.

Step 2: Teach and use Leave No Trace practices: concentrate activities on the most durable and core campsite areas and avoid trampling plants. Never move or create a new campfire site and build a campfire only if safe – keep it small to conserve wood. Collect only dead and down wood breakable by hand and burn all wood to ash. Store food and smellables from wildlife and pack out all trash and food waste. Use well-established trails or disperse off-camp traffic.



Step 3: Collect all your gear and clean the campsite and fire pit of all trash and spilled food. Make sure the fire is completely out and clean it of excess charcoal and ash – scatter these away from camp.

Vegetation Responses to Trampling: Forests vs. Meadows

Studies have clearly demonstrated a more flattened sigmoidal relationship between the amount of trampling and impact to grass and sedge growth forms (graminoids) that are dominant in sunny meadows (Figure 2). Scientists have conducted experimentally designed trampling studies using parallel sets of plots that receive varying numbers of randomly assigned trampling passes (e.g., 0, 25, 75, 200, 500…). Before and after measures of plant cover by species are taken within the plots and trampling can be continued over several years to simulate long-term responses after halting trampling to evaluate plant resilience (recovery).

These studies, conducted in a variety of geographic locations across the U.S. and other countries, all reveal that graminoids are substantially more resistant than broad-leafed herbs/forbs (Figure 3, Figure 5), largely due to the toughness and flexibility of their narrow stems and leaves, low growing stature, and higher growth rates throughout the growing season (Cole 1985, Cole 1995a, Marion 2016, Monz et al. 2013). For example, Cole (1985) found that 1200 trampling passes removed 80-90% of broad-leafed herbs (forbs) in forested plant communities but had no lasting effect on meadow grasses. In an experimental camping study, Cole and Monz (2003) found that vegetation loss on previously unused grassy meadow sites after four nights of camping for three years was less than half that caused by a single night of camping on forested sites, which lost nearly all their vegetation cover in core areas (the study used four campers with no campfire).

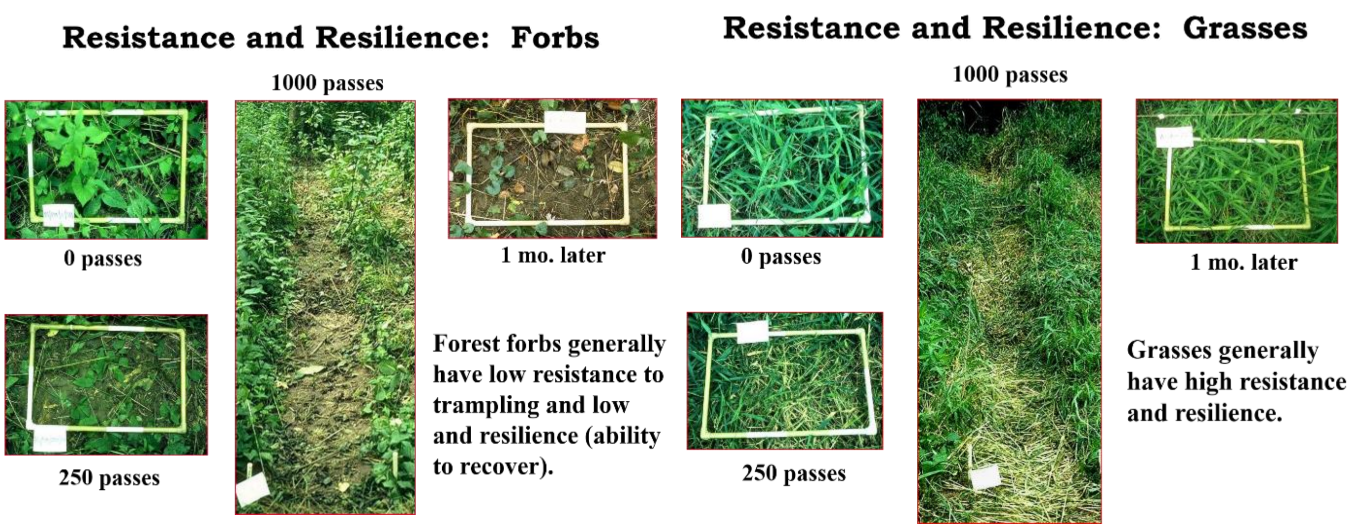


Figure 5. Photos of quadrats and lanes subjected to 0, 250, and 1000 trampling passes, followed by 1 month of recovery (Marion & Cole 1996). These findings reveal that grasses and sedges in sunny settings have a substantial ability to resist damage from trampling and to recover from such damage (e.g., high resilience) in comparison to forbs/herbs.

These findings can be easily seen along trails routed through shady forests and sunny meadows (Figure 6). Grasses and sedges are shade-intolerant due to their narrow leaves, making them less resistant/resilient in shaded areas, but relatively intensive traffic is required to reduce their cover in sunny locations. Also, due to their high resilience, grasses and sedges are also able to quickly colonize less disturbed peripheral use areas, acting to keep campsites small and trails narrow (Figure 6) in sunny areas. Despite these clear findings, throughout our PCT research and fieldwork we encountered FS and NPS managers who thought that grasses and meadows were more fragile and susceptible to trampling damage than forested ground vegetation. Our further inquiries suggest that this thinking likely arose from the substantial impacts caused by large groups of horseback riders and pack stock in the 1970's, which included grazing damage and trampling impacts to soils and steep streambanks in wet meadows. We note that such activities are no longer permitted and that impacts from large groups of grazing livestock on wet soils should not be equated with the impacts from smaller groups of backpackers on dry soils and grasses. Regardless, to address this issue we extended our review of literature on grasses and meadows to clarify the available scientific research and its management implications.

Cole (1995a) conducted the largest experimental trampling study on record, involving 18 vegetation types in five U.S. mountain regions, finding that plant morphology explained more variation in plant responses than site characteristics. Some vegetation types were at least 30 times more vulnerable to trampling damage than others, with erect forbs consistently found to be m ost susceptible to trampling damage, followed by woody shrubs, and low-growing grasses and sedges as the most resistant. For example, the most resistant plant investigated was a sedge (*Carex nigricans*) where relative cover exceeded 60% after 500 passes, while relative cover was only 33% after just 25 passes through erect ferns (*Dryopteris*). Other experimental trampling studies (Cole 1985, Marion & Cole 1996) and an international meta-analysis of these studies (Pescott & Stewart 2014) have consistently found that vegetation resistance is greatest for low-growing turf-forming grasses, intermediate for prostate herbs and low shrubs with flexible stems, and lowest for taller rigid-stemmed forbs and shrubs. These findings provide a compelling explanation for why we grow grasses on athletic fields and lawns and not broad-leafed forbs or ferns.

Figure 6. Vegetation along a short Crater Lake NP trail segment that receives the same type and amount of use under 100% tree cover (a), 50% tree cover (b), and 0% tree cover (c). Grasses are less resistant/resilient in shady areas (b), but substantial traffic is needed to remove them in sunny areas (d).

Vegetation resilience, its ability to recover following trampling, is another important plant characteristic that also varies considerably between forest and meadow vegetation types. In a western Montana experimental trampling study, Cole (1987) found that meadow grasses could tolerate up to 800 passes and still recover completely in one year, but in five forested areas the forbs and low shrubs could only tolerate 25 passes with complete recovery in a year. The most resilient sites were those with the most grass cover and longest growing season (lower elevations). In the Cole and Monz (2003) experimental camping study, the near-complete vegetation loss following just one night of use on the shady forest sites did not recover completely in three years, largely due to the slow recovery of low woody shrubs. In contrast, the sunny meadow sites recovered completely after each year, including after three successive years of four camping nights/year.

Experimental trampling studies have found that resilience is highest for non-woody low-growing plants whose buds are close to or underneath the soil surface (Cole 1995a, b). This explains why prostate herbs such as non-native dandelions, plantain, and clover survive so well in the less-trafficked portions of campsites, along with grasses and sedges. The meta-analysis study conducted by Pescott and Stewart (2014) concluded that these plant functional traits are likely more important than projected intensity of use when considering the siting of recreational activities (i.e., that low-intensity trampling can be as damaging as high-intensity trampling in vulnerable plant communities). They also concluded that the relative resilience of plant communities is of greatest importance in informing sustainable management decision-making. These same plant resistance and resilience relationships have also been consistently documented in other countries with diverse plant communities and soil types (Barros & Pickering 2015, Hill & Pickering 2009, Littlemore & Barker 2001, Newsome et al. 2013).

A somewhat surprising finding is that alpine plants were more resistant and resilient to trampling than many subalpine and lower elevation vegetation types (Cole 1995a). Since alpine plants grow in harsh conditions their leaves are tough and short and most of their biomass is protected below ground. Cole notes that results would likely be different if intense or long-duration trampling had been applied; recovery rates are slow due to exceptionally short snow-free growing seasons. The subalpine zone had greater variability in plant resistance depending on vegetation type, including some with low shrubs, ferns, and herbs that were less resistant and/or resilient.

These plant resistance and resilience findings are illustrated by a 32-year study (1982-2014) of campsites in the Boundary Waters Canoe Area Wilderness. Eagleston and Marion (2017) documented a 29% reduction in tree cover and a 42% reduction in shrub cover on campsites, resulting in a 16% increase in vegetation groundcover on campsites. The tree loss and increased sunlight on campsites supported increased graminoid cover on campsites (42%), compared to 3.2% in environmentally similar but undisturbed forested (more shady) control areas, while herb cover was 6.6% on campsites but 29.2% in controls. Graminoids are sun-loving and shade-intolerant so the presence and density of forest cover can be an easily applied gauge of plant resistance and resilience. Campsite studies have frequently found a significant correlation between decreasing canopy cover and increasing graminoid vegetation cover (Eagleston & Marion 2017, Marion & Cole 1996, Marion et al. 2018a).

The practical management implications of these findings for backpacking campsites are as follows:

- Camping impacts can be minimized by selecting or encouraging visitors to restrict camping activities to predominantly *non-vegetated* locations, such as barren rock, gravel, and soil, or sustainable established or designated campsites (Figure 6a-c). Particularly dense forests that support little ground vegetation cover can also minimize vegetation loss and have a less impacted appearance. However, topography is a more influential determinant of sustainable campsites than vegetation attributes; intensive camping in flat terrain often results in unacceptable levels of campsite proliferation and expansion (Figure 6f). Shifting camping to sloping or rocky terrain minimizes site expansion and proliferation and minimizes the aggregate area of camping impact.

- When camping on vegetation *is* necessary, impacts are best minimized by avoiding locations with tall forbs (shady areas) and favoring dry grassy meadows (sunny areas), including open shrub-lands and low density forests with substantial grasses and sedges that both resist trampling damage and recover more rapidly (Figure 6d). Such locations are even better when there are adjacent rock surfaces where more intensive cooking and social activities can occur. Grassy meadows can also be ideal locations for temporary "overflow" camping during peak use periods. Many PCT meadows are large and have patches of concealing trees/shrubs or have "fingers" of meadow reaching into forested areas offering numerous opportunities for dispersed camping away from formal trails or other campers.

- When camping under forest canopies is necessary, recognize that trees will eventually be lost without replacement, creating open overstories that will allow grasses and sedges to replace forbs over several decades. While this successional process results in more sustainable ground vegetation, the campsite vegetation cover will be compositionally and visually dissimilar from adjacent off-site vegetation.

- Low elevation vegetation can sustain greater trampling impact than high elevation vegetation, primarily due to longer growing seasons and greater resiliency. However, camping in rocky high elevation non-vegetated areas is acceptable, recognizing that these sites will be available for a much shorter use season due to extended snow cover (Figure 6a-b).

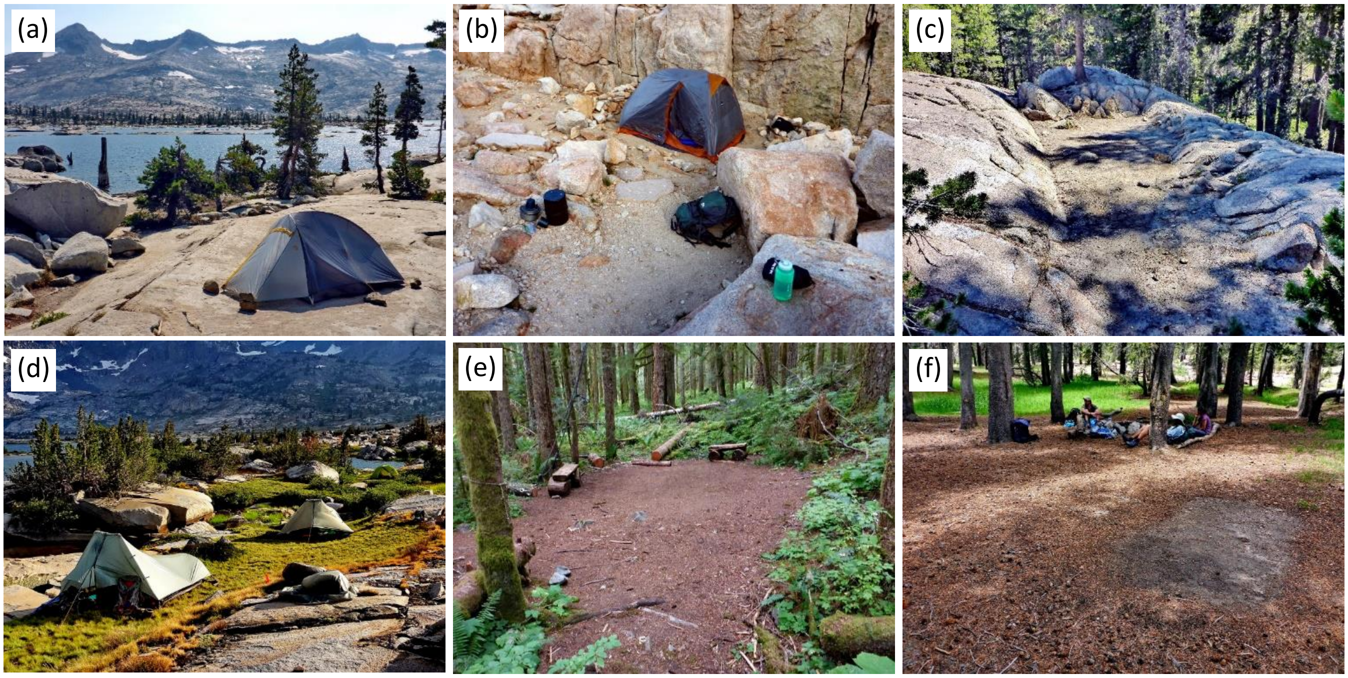


Figure 7. Minimize camping impacts by encouraging the use of rocky settings for camping (a-c) to concentrate traffic on durable substrates and minimize the areal extent of vegetation/soil impact. Encourage camping in shady forests that support little to no vegetation groundcover to minimize vegetation loss and aesthetic impacts (f), recognizing that camping in forested settings will remove all vegetation cover (e). Otherwise encourage camping on durable dry grasses in sunny settings with adjacent rock for cooking and social activities (d).

Additional Attributes of Sustainable Campsites

Recreation ecology studies frequently reveal that an array of use-related, environmental, and managerial factors significantly influence visitor-related resource impacts and that managers can effectively manipulate these factors to minimize impacts while sustaining large and increasing numbers of visitors (Eagleston and Marion 2017, Marion 2016, Marion & Farrell 2002).

As long advocated in the national Leave No Trace program, visitors can often search out and use durable surfaces like non-vegetated rock, gravel, snow, or bare ground for camping that avoids vegetation impacts. However, these types of areas can be rare or inappropriate for camping in some settings, and few groups use only free-standing tents. It's often easier to use designated or well-established campsites and concentrate camping activities on core areas with non-vegetated substrates. The literature suggests that dry soils with a wide range of particle sizes, generally loams and/or rocky soils, are most suitable for intensive traffic (Hammitt et al. 2015). Soil types to avoid include sandy soils, which are easily displaced or eroded, and organic soils, which retain water long after rains. Otherwise, soil texture is less important than many other factors. Intensive traffic will remove nearly all vegetation cover regardless of soil type, and compacted soils are beneficial as they shed water, minimize the formation of mud, and allow minimal displacement or loss from wind and water erosion. Soil compaction should therefore *not* be used as an impact indicator for campsite monitoring programs; a small intensively trafficked campsite with compacted soil would *always* be preferred over a larger less intensively trafficked site with lower soil compaction.

Soil loss is best limited by selecting, designing, and maintaining small sustainable sites that are slightly crowned or sloped to promote good drainage.

We've described how visitors can reduce the area of vegetation loss by camping on durable non-vegetated surfaces or dry grasses and sedges in sunny areas, but recent research indicates that topography is the most influential factor, followed by the provision of primitive facilities, in helping to spatially concentrate camping activities and limit the aggregate areal extent of camping impacts (Arredondo et al. 2020, Eagleston & Marion 2017, Marion et al. 2020b).

Flat, dry ground near water and formal trails have been the traditional requirements for a good backcountry campsite. However, research and management experience have shown that these are often poor locations for camping in popular high use locations (Arredondo et al. 2020, Marion et al. 2016). Large flat areas offer ***no*** resistance to campsite expansion and proliferation, the two most significant threats to camping management's goal of minimizing the areal extent of camping impact. Flat topography also permits high campsite densities and large sites that allow crowding, conflicts, and noise that threaten experiential qualities (Eagleston & Marion 2017, Marion et al. 2018a). To maximize campsite sustainability, it is always best to avoid large areas of flat terrain near water by moving trails entirely away from these areas, which are also less sustainable for the trails as flat terrain permits trail widening and the formation of mudholes and braided trails (Marion 2016, Marion & Wimpey 2017). When camping must be accommodated in flat terrain, the provision of anchored facilities like fire rings and visually obvious tent pads with log or rock borders offer perhaps the only effective tool for spatially concentrating camping activities.

Just as they do in trail management, many camping impact problems can be effectively minimized by indirectly or directly influencing the locations where visitors camp and managing the sites and their use. Both the areal extent and severity of camping impacts can be reduced through sustainable camping management policies that include the careful selection and/or design, construction, and maintenance of campsites. The location and spatial arrangement of campsites also determine the social conditions for visitors who use them. While the practice of closing undesirable or unsustainable campsites has been frequently adopted in some backcountry and wilderness areas (Cole & Parsons 2013, Marion et al. 2018a), the practice of actively selecting, designating, or constructing highly sustainable campsites remains rare (Daniels & Marion 2006b, Marion et al. 2018b). This section provides both empirical data and guidance demonstrating that replacing unconfined dispersed camping management policies with a containment strategy in moderate to high use areas can yield significant reductions in aggregate areal measures of camping impacts.

Cole's (1992) hypothetical models of camping impact suggest that increasing use can have a substantial effect on areal measures of impact, with peripheral and off-site vegetation disappearing as campsite boundaries expand. However, these models also demonstrate how the spatial concentration of camping activities can effectively limit such expansion when use increases, though increasing traffic within fixed campsite boundaries is likely to further reduce onsite vegetation cover. A key management objective related to campsite sustainability at a site scale is discovering and implementing actions that limit campsite expansion by promoting the spatial concentration of camping activities (Cole 1989a). Similarly, implications for a landscape scale, where managers seek to minimize aggregate camping impacts at a district or unit level require a strong focus on actions that limit campsite proliferation (Cole & Parson 2013, Leung & Marion 2004). These findings emphasize the need to shift camping in moderate to high use settings from flat to sloping and/or rocky terrain, which permanently constrains and effectively concentrates activities to limited numbers of small "footprint" campsites more effectively than reliance on education or regulation. When camping cannot be shifted away from flat terrain, the next most effective option is to confine camping to structures like shelters, huts, or visually obvious tent pads with rock or log borders. As will be described in this section, both actions can be effective in constraining both campsite expansion and proliferation, accommodating ever-increasing visitation while halting and even reversing aggregate areal measures of camping impact.

Using Topography to Limit Impact

A small but growing number of studies have investigated the influence of topography on camping impacts (Arredondo et al. 2020, Cole 2009, Cole 2013a, Daniels & Marion 2006b, Eagleston & Marion 2017, Leung & Marion 1999, Marion & Farrell 2002). The first study to empirically document and emphasize the significance of topography was a survey of campsites at Isle Royale National Park (Farrell & Marion 1998, Marion & Farrell 2002). Analyses of spatial camping impact indicators attributed the unusually small backcountry campsites and aggregate impact to the intentional selection and placement of campsites in sloping terrain. Termed "side-hill" campsites, these can be either naturally occurring or constructed through excavation and fill to create small clusters of "perfect" tent pads. Success in limiting the areal extent of impact was attributed to managers actively creating and maintaining smooth, well-drained tent pads and/or providing visually obvious site boundary cues that encourage campers to stay on-site (Marion & Farrell 2002).

More recently, statistical modeling of campsite data from a trail-wide study of AT campsites (Marion et al. 2020) revealed that the single best predictor of campsite size was the percent of a 33-ft wide buffer or "doughnut" configured around a campsite with slopes greater than 15% (Arredondo et al. 2020). The salient implication of this finding is that spatial concentration of camping activities is highest when a campsite is surrounded by steep terrain. High off-site rugosity (terrain roughness, micro-topography) and side-hill site construction were other significant predictors of small campsite sizes. Sloping topography or high rugosity in off-site areas confer an effective *permanent natural constraint* on campsite expansion and proliferation that doesn't require the perpetual use of artificial educational or regulatory controls or the addition of site facilities. Visitors are inherently attracted to optimal tenting spots and repelled by sloping or rocky/uneven terrain ("push-pull" forces), promoting the spatial concentration of their camping activities and campsites that remain small forever. In contrast, a 32-year study by Eagleston and Marion (2017) discovered that even dense woody trees surrounding campsites failed to deter expansion over time due to their inevitable loss by insects, disease, wildfires, or visitors with axes and saws.

Natural Side-hill Campsites. While visitors generally seek out large flat areas for camping, managers and volunteers can instead conduct GIS or ground-based searches for clusters of small flat spots surrounded by sloping topography or excessive rugosity (rocky or uneven terrain) and create campsites by preparing smooth well-drained tent sites with short access trails (Figure 8). Ideally these "naturally occurring" side-hill campsites would be located near water sources and perhaps between 100 and 200 ft from formal trails, with inter-site spacing of more than 100-200 ft to ensure/enhance privacy, solitude, and natural quiet. The authors' current research is developing efficient computer-based GIS analyses to locate potential new campsites along trail corridors that have accurate LiDAR-derived topography data. Managers and volunteers can then efficiently create additional

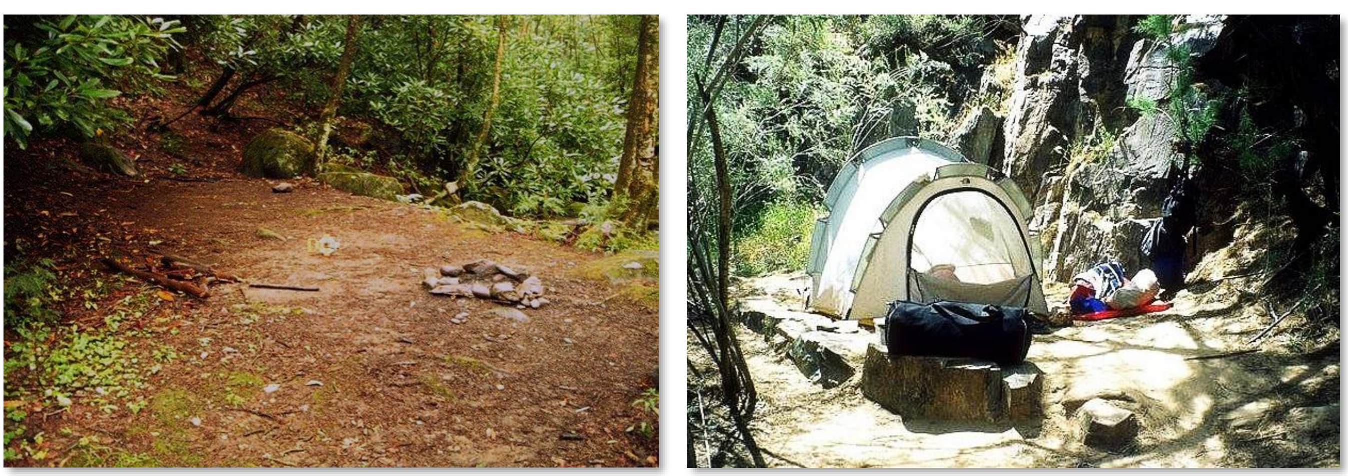


Figure 8. Careful searches can reveal small naturally occurring flat spots surrounded by sloping terrain and rockiness that inhibit campsite expansion and proliferation.

permanently sustainable camping capacity by developing clusters of naturally occurring side-hill campsites and communicate their locations through maps, guidebooks, paint blazes, posted GPS coordinates, or phone apps, which are increasingly being used by visitors for navigation.

Constructed Side-hill Campsites. Constructed side-hill campsites were first developed and used in Isle Royale National Park in the 1970s and 80s, though they may have been used in Canadian PAs prior to this period (Farrell & Marion 1998). Their consideration and use along the Appalachian Trail began in 1999 through a trail-wide camping impact management study that conducted case studies and consulting at 17 of the most impacted camping areas (Marion 2003). A formal problem analysis process was developed and applied by teams of scientists, land managers, and professional and volunteer club members to analyze and evaluate camping impact problems and effective strategies and tactics. Many trail clubs implemented the subsequent recommendations, but we highlight here the work at Annapolis Rocks in Maryland and at Slaughter Gap and Hawk Mountain in Georgia, the two worst "mega-campsite" impact areas in the A.T. corridor. We believe that the results from these case studies are applicable to the PCT and other similar backcountry and wilderness areas.

The popular Annapolis Rocks A.T.-proximate day-use and overnight destination area in Maryland is close to a major highway and offers an outstanding vista and ample flat camping areas near a spring. However, a "mega-cluster" of 19 visitor-created campsites developed by 2000, with 43,099 ft^2 of intensive camping impact and including 83 damaged trees, 137 stumps, and 32 fire sites (Figure 9) (Daniels & Marion 2006b). These unacceptable resource and experiential conditions caused land managers and trail club stewards to implement actions in 2003 shifting all camping to constructed side-hill campsites in adjacent sloping terrain. This reduced aggregate areal camping impact to 6,243 ft^2, an 86% reduction that also substantially enhanced experiential conditions due to enhanced spacing between the new side-hill sites. A questionnaire examined visitor satisfaction with camping on the side-hill campsites using a scale of 1 (highly dissatisfied) to 5 (highly satisfied) to evaluate 22 utility, environmental, and social indicators. The indicator that scored lowest for the clustered visitor-created campsites, "privacy of my campsite" (3.26), became the highest score for visitors camping on the new side-hill campsites (4.30). The next four highest indicators for the new side-hill sites were "number of people camped near me" (4.23), "security of my belongings" (4.23), "noise from other groups" (4.21), and "naturalness of the area near my campsite" (4.18) (Daniels & Marion 2006b), indicating that visitors were highly satisfied with these more ecologically sustainable campsites. Continued monitoring of these sites has revealed limited site expansion over time, found only on the sites with adjacent off-site terrain less than 15% grade.

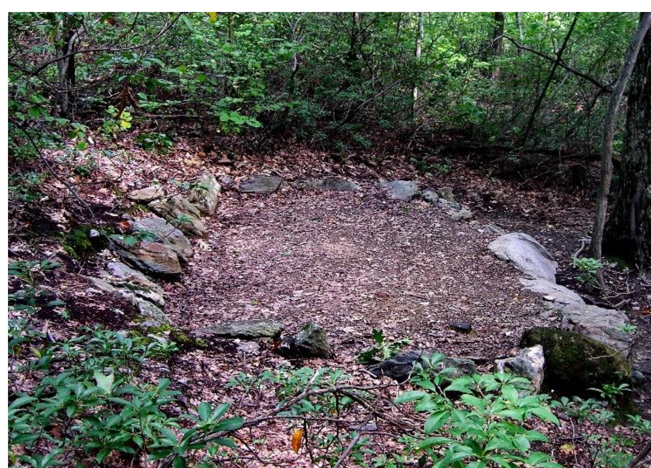


Figure 9. One of three "megasites" (left) within a mega-cluster of 19 campsites at Annapolis Rocks, MD. This illustrates the chronic problems that an unconfined camping policy allows: unacceptable resource and social conditions due to excessive site proliferation and campsite expansion in large flat areas. Camping was shifted to constructed side-hill campsites in nearby sloping terrain where topography constrains site expansion (right).

Figure 10. Substantial resource and social camping impacts in 2003 at Slaughter Gap in Georgia were addressed by replacing its camping capacity with new constructed side-hill campsites. The AT and another trail were purposefully relocated to "hide" this long-used popular camping location (left) and the area has since substantially recovered (right). Photos provided by Georgia Appalachian Trail Club volunteers.

An identical process was applied in 2003 at the second most impacted AT camping area at Slaughter Gap near Blood Mountain, GA, with similar success, as illustrated with photos (Figure 10). Portions of the A.T. and two other formal trails were moved away from the flat terrain at Slaughter Gap and the entire area was closed to camping. Side-hill campsites were constructed in several nearby locations to accommodate overnight use and monitoring revealed no use and steady natural recovery in the closed camping areas (Figure 10). Unfortunately, in Georgia a large "bubble" of peak use has steadily grown over time, with the number of thru-hikers reaching around 1,000 in 2006 and 3,000 in 2015. While the Appalachian Trail Conservancy (ATC) created a voluntary registration system in an effort to limit the number of long-distance hikers to 50/day, the recurring annual bubble of high camping demand has caused excessive camping impacts at locations like the Hawk Mountain Shelter just north of the southern A.T. terminus. Over time visitors created another mega-cluster of campsites in flat terrain around the shelter (50-100 campers/night during the "bubble" of high use) (Figure 11a). A recent A.T. study documented 31,390 ft^2 of aggregate area of impact and 2.8 miles of informal trails, making it the worst of the examined camping areas in recent times (Marion et al. 2020), with equally problematic social and experiential impacts.

A collaborative effort between the ATC, USFS, the Georgia Appalachian Trail Club (GATC), and this report's authors led to the development and implementation of work that shifted much of the camping to a new area with 30 constructed side-hill campsites (Figure 11a & b) (Marion et al. 2020). This area was found with the aid of a slope classification map targeting areas with >15% grades (Figure 11d). GATC members also installed an above-ground moldering privy, steel food storage boxes, rock armoring at the water source, and a sign with a map showing the campsite layout and best accessible and hammock sites (Figure 11c). The aggregate size of the new side-hill campsites is 7,247 ft^2, a 77% reduction in the former aggregate area of disturbance (median campsite size declined from 2,711 ft^2 to 227 ft^2).

Naturally occurring and constructed side-hill campsites can clearly concentrate camping activities onto small campsites that will stay small, a more permanent solution that resolves both social impacts and the traditional problems of site expansion and proliferation due to the natural influence of sloping terrain or rugosity. The long-term efficacy of side-hill campsites requires routine maintenance to retain smooth well-drained tenting sites that attract and spatially concentrate camping activity. These types of "small-footprint" campsites also effectively limit other forms of camping impact, such as number of fire sites, damaged or felled trees, soil exposure, and area of vegetation loss. Due to their smaller size, side-hill sites have considerably fewer onsite or adjacent trees that managers may need to survey and/or remove as hazardous trees. As previously noted, to enhance experiential qualities, reducing crowding, conflicts, and noise, managers can and should always separate side-hill sites by more than 100-200 ft (Daniels & Marion 2006b).

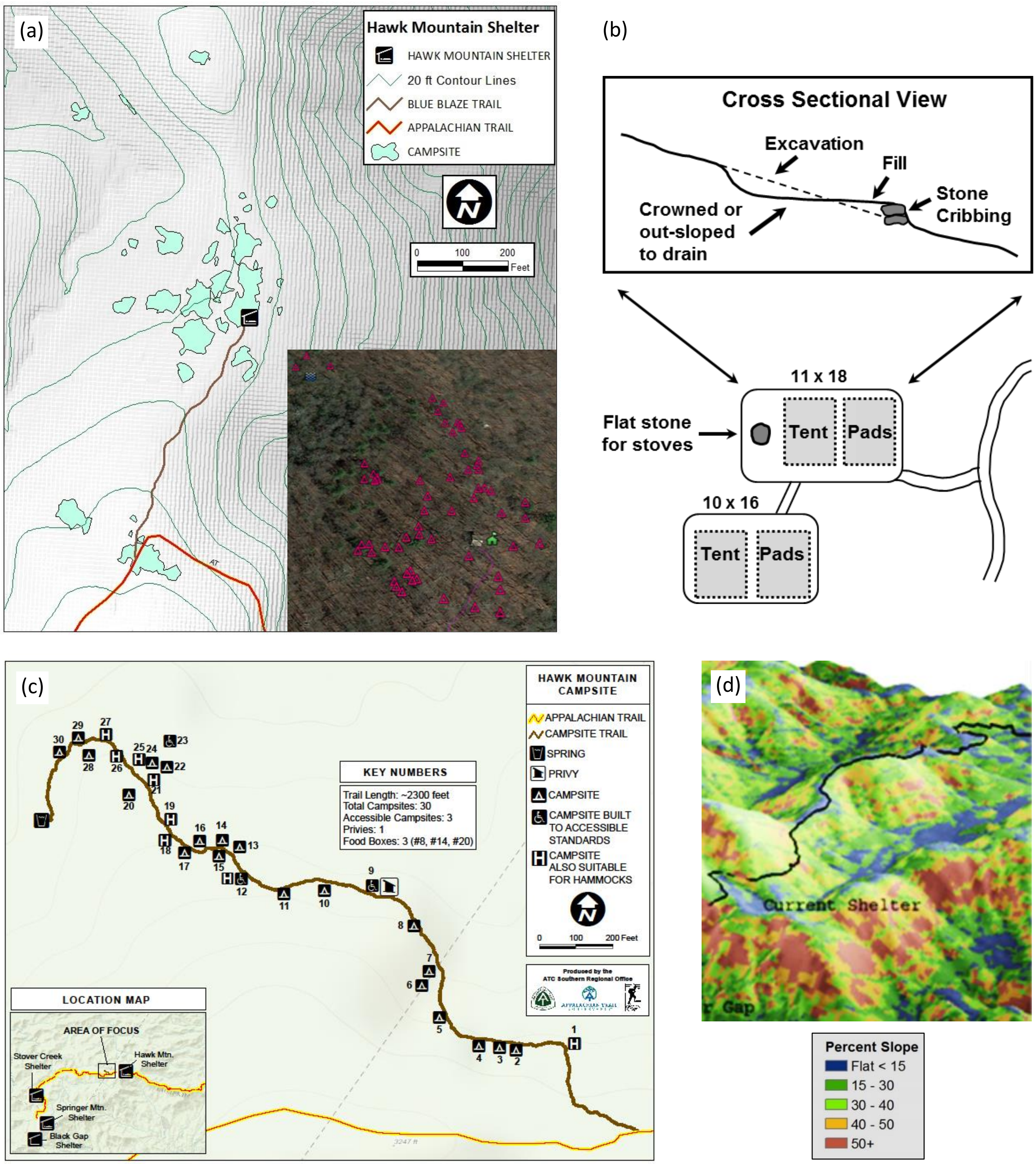


Figure 11. a) A GIS map showing the A.T. Hawk Mountain Shelter and numerous associated campsites. To mitigate the unacceptable resource and social impacts that had developed, most camping is being shifted to 30 side-hill campsites constructed as illustrated in (b) and (c). A GIS-generated slope map (d) reveals the flat terrain in the existing shelter area and was used by U.S. Forest Service staff to narrow the search for locating side-hill campsites in terrain with 15-30% slopes.

In summary, an important advantage of relying on topography and/or rugosity to spatially concentrate camping activity is that campers are simply interacting with the natural environment, which effectively compels innate "low impact" behaviors. It's simply uncomfortable to erect a tent or cook a meal in sloped, rocky, or uneven terrain. Reliance on these attributes is more permanent, natural, and effective than compelling similar behaviors with regulations (e.g., visitors must camp within 20 ft of a fixed camping post or fire ring). Similarly, reliance on education and low impact practices (e.g., please camp in the already barren central core campsite areas) is only effective when visitors are fully aware of and compliant with such voluntary practices (Marion 2014, Marion & Reid 2007).

Campsite Preferences

Studies of campsite preferences in backcountry and wilderness settings provide additional information that can aid managers in selecting sustainable campsites that will consistently attract visitor use (Brunson & Shelby 1990, Cole & Hall 2009, Heberlein & Dunwiddie 1979, Shindler & Shelby 1992, and White et al. 2001). In particular, Brunson and Shelby (1990) developed a useful campsite choice model describing a hierarchy of campsite attributes that provide a basis for campsite selection:

Necessity attributes: Sufficient level ground available for tenting and proximity to water.

Experience attributes: Site privacy (distance to trail and other campsites), scenic beauty, well-drained tent sites, screened from other sites, and lack of human noise.

Amenity attributes: Shade, lack of litter, campfire ring/seating, availability of firewood, and bug-free.

Careful attention to selecting campsites that include or rank high for important necessity, experience, and amenity attributes will ensure the selection of campsites that will be valued and used by visitors. This study of PCT campsites developed and applied site selection indicators based on these attributes that will be presented and discussed in following sections.

Facilities can Limit Impact

What can managers do when camping cannot be shifted to terrain where topography or rugosity acts to spatially concentrate camping activity? Research and management experience suggests the next best option is construction of camping facilities such as shelters, various types of visually-obvious tent pads, and other features like anchored fire rings (Arredondo et al. 2020, Marion et al. 2020). This section first examines research results on camping shelters like those on the AT, followed by a review of constructed tent pads. While these more "developed" site management options are somewhat artificial in appearance we note that all can be found within designated U.S. backcountry and wilderness areas, though their use is often debatable and generally approved only in more intensively visited settings.

Shelters. The provision of shelters is a long tradition for the AT that predates its designation and the Wilderness Act of 1964. Research has shown that these structures effectively concentrate visitor activities for those who use them so that areal measures of disturbance are substantially lower than for a similar number of visitors camping in tents (Marion & Farrell 2002, Marion & Leung 1997, Marion et al. 2020). However, some managers question their necessity or appropriateness in backcountry and particularly in wilderness. They are artificial permanent structures and some use dimensional lumber and are not rustic in appearance. Furthermore, when shelters are full, subsequent visitors often camp nearby, which can greatly increase the areal extent of camping impact around shelters.

In a study of backcountry and wilderness campsites at Isle Royale National Park, Marion and Farrell (2002) found the mean size of three-sided shelter sites (420 ft^2, including the shelters and adjacent trampled areas) to be 35% smaller than campsites (646 ft^2). Shelter sites also had about half the exposed soil and area of vegetation loss as campsites. These findings are even more consequential given that: 1) many Isle Royale campsites were side-hill constructed, while those in flatter terrain had embedded logs or rocks to define tent pads, and 2) shelter sites are popular and receive substantially greater use than campsites. This park has only 3.77 ft^2 of disturbed area per overnight stay, the lowest of seven other PAs for which this measure could be computed (Marion & Farrell 2002). This achievement was attributed to the following actions: 1) restriction of camping to a limited number of designated campsites with high occupancy rates, 2) substantial use of side-hill campsites and camping shelters that spatially concentrate camping activities, 3) restrictions on group sizes to six for most campsites and shelters, 4) communication of LNT messages to "confine your activities to these durable locations to preserve the natural conditions in surrounding areas," 5) an active park maintenance program that keeps the tent pads smooth and well-drained to attract and contain use, and 6) the loss of most campsite trees has provided sufficient sunlight to support grasses in the peripheral and offsite areas that limit site expansion.

Tent Pads. Constructed tent pads are more natural and require substantially less funding to construct and maintain than camping shelters, yet still effectively attract and spatially concentrate camping activities in flat terrain. Multiple tent pads could be constructed along access trails with sufficient inter-site spacing to provide whatever level of solitude and natural quiet are desired. Rock-lined tent pads are the most natural in appearance, require the least long-term maintenance, and allow water to filter out between the rocks (Figure 12a). Native soil is frequently used, but crushed gravel mixed with native soil is less easily displaced and better retains a slightly crowned or sloped shape for drainage; wood chips should not be used as these decompose to mucky organic soil that retains water. When rocks are unavailable, rot-resistant logs can be cut and embedded to provide a visual cue of the intended tent pad borders (Figure 12b). Treated lumber could also be used, with round timbers being more primitive in appearance than square dimensional lumber. Using two logs with their joint pointing directly uphill ensures drainage around the tent pad, with drainage from tents free to run downhill. Logs need to be pinned to the ground with two to three-foot rebar to deter campers from using them for firewood. Logs or treated timbers can also be placed on all four sides to create an elevated tent pad, but care must be taken to use crushed gravel or sandy loam fill for drainage, or to slope the structure and substrates to ensure adequate drainage (Figure 12c).

A wooden deck of treated lumber is a final option, though this is more artificial in appearance and expensive to purchase, transport, construct, and replace, and maintainers need to periodically replace rotten boards and fix protruding screws or nails (Figure 12d). Visitors without freestanding tents or those who use tarps or hammocks have difficulty using tent platforms. Additionally, the use of dimensional treated lumber is the least primitive option and is less appropriate in designated wilderness. Wood decks could be avoided in locations where the previous ground-based tent pad options are viable. However, these tent pad options effectively address problems with site expansion and proliferation when camping must be accommodated in flat terrain.

In flat terrain managers have also had some success by defining established or designated sites with camping signs, posts, or anchored steel fire rings. For example, managers at Delaware Water Gap National Recreation Area in Pennsylvania achieved a 50% reduction in the aggregate area of camping impact associated with canoe-accessed campsites in flat terrain by shifting to designated site camping, with signs and steel fire rings clearly marking each legal site (Marion 1995). An alternate and potentially effective approach is to anchor campsite posts engraved with the words "Camp within 5 yards" on each side.

Site Maintenance. Land managers have long placed an emphasis on maintaining trails to keep them in good condition for sustaining their intended type and amount of use. Their actions include moving substrates to promote drainage, cutting vegetation, adding and cleaning drainage features, installing rockwork, boardwalks, and signs, and relocating poorly designed segments. In contrast, maintaining campsites has traditionally been limited to cleaning or removing fire rings or possibly cutting dead or hazardous trees, though on designated sites some managers have improved tent pads and added border logs or rocks. We suggest that a containment strategy that seeks to encourage high use of the most sustainable campsites will be most successful if field staff more actively sought to improve several tent pads on each site and a single cooking area with anchored fire site and/or including a large flat "kitchen" rock for stoves (Figure 13). Large partially rotted campsite "border" logs can also help spatially concentrate camping activities on "small footprint" campsites.

Figure 12. a) Rock-lined tent pad, b) Embedded logs pinned with rebar, c) Wood-lined tent pad, and d) Wood-decked tent platform.

Figure 13. Managers of these designated campsites at North Cascades National Park have improved tent pads by removing rocks and creating effective borders by adding logs and rocks. These actions attract and concentrate activity within intended use areas and protect flat offsite areas that could allow expansion.

Much of the expertise gained in maintaining trails can be extended to maintaining campsites. Marion and Sober (1987) made the case for managers performing maintenance work on wilderness campsites to reduce their size, protect visitor safety, minimize erosion, and address campfire-related impacts. Site impact evaluations can reveal what problems require maintenance actions, for example, excessive site size may be addressed by subtly improving tenting locations or adding large logs to create protective visually obvious campsite borders. Visitors will be attracted to and consistently use smooth and well-drained tent sites (Figure 13), which may require removing rocks or redistributing soil to cover roots and slightly crown tent pads and improve drainage.

Unnecessary portions of campsites can be reclaimed by either easy frequently applied actions, such as scattering organic litter, branches, logs, and rocks on these areas (Figure 14 a, b), or by more intensive work such as ice-berging large rocks, felling or dragging dead trees, and installing interpretive signs (Figure 14 c, d). Where rocks are not available, the terrain can be made uneven simply by digging shallow depressions and mounding soil nearby. As previously noted, these actions are likely to be difficult and less effective in extensive flat terrain, so trails may need to be shifted to entirely hide flat terrain near water sources from campers.

Just as for trails, campsite substrates can be subtly shaped to promote water drainage around the perimeter of sites, particularly of tenting areas. Ensure that water is filtered through at least 10 lineal feet of relatively

Figure 14. a & b) An emerging off-site tenting spot can be restored and disguised by adding organic litter and branches. c) When repeat use is chronic, ice-berging (mostly burying) a large angular rock can be a more effective deterrence. d) Log borders and educational signs can also be effective (use large diameter, anchored, and/or somewhat rotten logs to deter their use as firewood.

undisturbed ground vegetation and/or organic litter before entering waterbodies (Marion et al. 2018b). A well-placed large log along the low side of a shoreline-proximate campsite can often force traffic slightly uphill and around the log to provide protection to an untrampled band of vegetation and litter that will filter campsite runoff. Otherwise, close and move the campsite further from water. Stonework to add steps or armor steep or muddy embankments at water sources is another maintenance improvement that can attract and concentrate trampling activity to durable surfaces and protect water quality. Some managers and volunteers have installed rockwork with a simple rock pour-off around springs to facilitate filling containers and protect water quality.

Figure 15. Managers have closed this unnecessary informal trail with both logs and embedded rocks.

Formal or useful and sustainable informal (visitor-created) trails (ITs) that provide access to overnight camping facilities or water sources also require routine maintenance to keep them in a usable condition and minimize associated resource impacts. The objective is to promote consistent traffic patterns within camping areas on sustainably designed, well-drained and maintained footpaths and to close and rehabilitate unnecessary and unsustainable ITs (Figure 15). Many excellent trail design and maintenance manuals have been developed to guide this work (Birchard & Proudman 2000, Hesselbarth et al. 2007, IMBA 2004, 2007). Active trail maintenance reduces impacts by providing a durable tread able to accommodate the intended traffic while minimizing problems with tread muddiness, erosion, widening or multiple tread development.

In areas where dispersed pristine site camping is practiced, routine maintenance consists of periodically locating and removing any fire sites and naturalizing disturbed spots to avoid their repeat use. In these areas, visitors should avoid building campfires or use LNT campfire practices, such as mound or pan fires, to leave no evidence of campfires. When possible, patrols should be conducted immediately following peak use periods when such sites are often formed. The management objective in these locations is to avoid the appearance of any campsites or visible impact. Guidance for restoring campsites is provided in a following Site Management: Close/Rehabilitate Sites section. *Note:* maintenance actions related to campfire rings is addressed in the following section to keep all related guidance together.

Campsite Resource Protection Site Facilities. Additional campsite features can also be provided on campsites, particularly in flat terrain, to attract and spatially concentrate use. These include fire rings, stone fire pits, stove rocks, logs for seating, food storage cables or boxes, and sumps. Such facilities should be anchored when possible, so they attract and spatially concentrate camping activities.

Campfires can be an essential element of a high-quality camping experience for many visitors, particularly youth. Unfortunately, problems related to campfire use, including the development of multiple fire sites (Figure 16a) and large trash-and food-filled fire pits, mounds of charcoal and half-burned logs, tree damage and felled trees, off-site vegetation trampling and wood removal, and the threat of forest fires, have caused an increasing number of managers to prohibit campfires (Cole & Dalle-Molle 1982, Reid & Marion 2005).

Many managers have had success keeping campfires small and contained to a single location by firmly anchoring small steel fire rings on campsites (Figure 16f). Using the smallest available options (e.g., 18 in diameter) promotes small low-impact campfires that conserve wood and promote using small-diameter sticks that burn completely to ash. Placing fire rings on or near bedrock attracts cooking activities to a durable surface. They should also be located near the center of campsites but away from the best tent sites, and from trees, roots, and off-site organic litter to lessen the risk of forest fires (Figure 16b). Steel fire rings are also frequently used to identify preferred established or required designated campsites and have been shown to consistently attract and concentrate cooking and social activities to their vicinity, thereby minimizing site size and expansion (Marion 1995).

Figure 16. a) It is not uncommon for visitors to build multiple fire sites on campsites, or to move fire sites around over time. b) Placing fire sites on exposed bedrock will attract and concentrate intensive cooking activities on durable substrates (though this one is too close to vegetation), c & d) two styles of ice-berged rock fire rings that fix the location of campfires, e) placing a large flat “stove rock” and log seating will consistently attract and concentrate cooking to a single location, f) small anchored steel fire rings fix campfire locations and can be used to denote preferred established campsites or required designated campsites.

When rock campfire rings are used, consider ice-berging large rocks around the preferred campfire site to identify its location to staff, volunteers, and visitors (Figure 16c&d) (Reid & Marion 2005). Permanently fixing the fire site's location attracts visitors to a common spot and spatially concentrates use. Multiple fire sites create more locations of camping activity; different groups will use different parts of a site, which promotes site expansion. Breaking up all but the intended single fire site will effectively concentrate activity in the same place over time, reducing the area of camping disturbance. Ice-berging fire ring rocks can easily identify the "intended" fire site to seasonal or volunteer staff. Where campfires are permitted, educational messaging can ask visitors to: 1) use stoves and avoid campfires when possible, 2) use only existing fire rings or sites, and 3) keep fires small, burn only wood, and leave a small fire site cleaned of all trash and food with all coals "dead out."

Some managers have removed all fire sites in areas where campfires are permitted. This practice promotes new fire scars at different locations and *should be avoided* except on closed sites and in areas where dispersed pristine site camping is encouraged. Migration of campfire sites is a significant impact because fires attract intensive trampling to their vicinity, kill soil biota, and alter physical and chemical soil properties for long periods of time (Marion et al. 2016). Cleaning fire sites of built-up charcoal and ashes, trash, and unnecessary rocks is a perennial maintenance function. When possible, encourage visitors, particularly youth groups, to dismantle and clean large overbuilt fire sites to leave small rock fire sites of less than two feet in diameter. Whether campfires are permitted or not, consider placing large flat "stove rocks" on campsites to attract intensive cooking activities to a single fixed location (Figure 16E).

While some land managers remove logs and rocks used by visitors for seating or stoves (e.g., camp "furniture"), these features *do attract and spatially concentrate* intensive visitor use activity to their vicinity and beneficially limit the areal extent of impact when left in place. The effect of anchored fire sites, stove rocks, and large logs/rocks for visitor seating should be quite similar to the attraction and spatial concentration of activity effect demonstrated for anchored picnic tables on Isle Royale National Park campsites (Marion and Farrell 2002). Campsites with anchored picnic tables had significantly smaller sizes and areas of vegetation loss and exposed soil than sites without picnic tables. However, campsite facilities should be kept "simple" and rustic, and the use of very large logs and rocks are preferred as these are less likely to be moved around on a campsite.

The Leave No Trace cat-hole method of human waste disposal is the most common universal practice for disposing of human waste in backcountry and wilderness settings (www.LNT.org). However, this option is ineffective in some environmental settings (alpine zones and extreme cold, dry deserts, rocky areas w/little soil, and permanently wet soils) (Marion 2014), and some visitors are either unaware, unprepared, or unwilling to use the practice effectively (Cilimburg et al 2000). The small percentage of visitors who don't follow this guidance can leave sufficient surface-disposed waste that make this option untenable in high use areas. The development of lightweight toilet Waste Alleviation and Gelling (WAG) bags approved for landfill disposal makes carry out options possible, though night-time storage of these kits has been problematic in some areas (e.g., the Mt. Whitney area). As presented and discussed later in this report, many visitors appear to be unwilling to store used WAG bags with their food in backpacking bear canisters, or inside their tents. Our survey found that wildlife commonly find and chew into the used bags at night and some visitors are then unwilling to carry out the leaky bags.

When cat-holing is practiced a perennial question is what to do with used toilet paper (TP), bury it or pack it out? Some land managers are asking visitors to pack out their TP, in part because they commonly find TP in areas surrounding campsites and they believe TP decomposition rates to be too slow, particularly in areas with low rainfall. We suspect that some visitors are not making sufficient efforts to deeply bury human waste and this leaves TP on or near the surface. Some have also suggested high rates of TP being dug up by animals. Regardless, unburied TP is unsanitary trash that's visually offensive.

Published research by Bridle and Kirkpatrick (2005) provides relevant findings by examining the decomposition rates of bleached and unbleached TP, tissues, and tampons buried at 2 and 6 inches in 9 different environments across Tasmania. Relevant conclusions were: 1) TP and tissues decomposed almost completely within 2 years in 7 of the 9 locations; tampons would likely require 3 years (*Note:* some are made of synthetic fibers that likely require longer), 2) decomposition was poorest at locations with very high rainfall or acidic peat soils, but was very good at locations with as little as 20 inches of rain/year (annual rainfall: Sequoia Kings Canyon NP is 26 in, Yosemite NP is 36.5 in, excludes snow), 3) of 750 burials, 34 (4.5%) surfaced from animal excavations or frost-heaving (30 of which had been buried only 2 inches deep), and 4) nutrient additions simulating the presence of feces and urine to some samples increased decomposition rates.

The rapid rate of TP decomposition (<2 yrs) indicates that TP burial is acceptable over carrying it out. To test this guidance managers can conduct their own informal studies by burying wads of TP and checking them one and two years later (field-tested protocols are available from the primary author). Exceptions include soils that are exceptionally cold, dry, or wet to support decomposition, or rocky areas that lack soil – all places where fecal waste *and* TP should both be carried out (Marion 2014). Burying TP deeply, by pushing it to the bottom of the cat-hole with a stick, is the recommended LNT practice to reduce the chance that it will surface before decomposing (Marion 2014). LNT practices also recommend carrying out all feminine hygiene products and disinfectant wipes due to their longer decomposition rates. Asking visitors to carry out TP, which many visitors view as an "extreme" or difficult, dangerous, or objectionable practice, runs the risk of alienating them from considering and applying many other low impact practices. Furthermore, visitors who are not digging cat-holes are likely to also ignore requests to carry out their TP – convincing them to dig cat-holes and bury TP deeply is likely an easier and potentially more effective practice.

Primitive toilets confer resource protection by attracting and concentrating camping use to sustainable campsites and safely containing/treating human waste. These facilities become necessary in some locations due to the problems described above for cat-hole and carry out disposal options. The determination of when to place a toilet could also be made based on monitoring the extent of improperly disposed human waste sites. A variety of toilet options have been developed, ranging from simple fiberglass models that lack privacy walls to various pit, composting, and vault toilets. While pit toilets remain common, an above ground moldering privy has provided the best option for many trail corridors where fecal containment has been deemed desirable, with numerous successful installations. A comprehensive review of the moldering privy and other toilet options is provided in the ATC's Backcountry Sanitation Manual (ATC 2014), and an international "Best Practice" workshop proceedings provides additional relevant findings, discussion, and options (Civil & McNamara 2000).

Low impact practices for greywater disposal from washing dishes and clothing are also described in the ATC Manual (2014) and in Marion (2014). Some land managers provide screened sumps at high use campsites, though these remain a rare facility. The most recommended practice is for visitors to filter greywater through a screen and then either broadcast (scatter) the water or pour it into the soil under organic litter at a location more than 100 ft from waterbodies or campsites.

Various options are also available for food storage to prevent wildlife from accessing and becoming attracted to human food, trash, and other odorous "smellables" (e.g., lotions, toothpaste, soap). Various types of cable systems and metal posts for hanging food have been developed, along with food storage boxes, or requiring visitors to carry food storage "bear canisters" (Figure 17). The attraction of bears to campsites all too frequently ends with threats to human safety and the relocation or killing of the bear (a "fed bear is a dead bear"). Many other small mammals, birds, and insects are also attracted to poorly stored human food/smellables and can also damage camping gear, threaten humans with injuries or diseases, or themselves be subject to injury or death. Proper food storage, including smaller "micro-garbage," is key to preventing wildlife behavioral changes for a variety of wildlife species. This is an increasing problem that involves facility, regulatory, and educational options and actions.

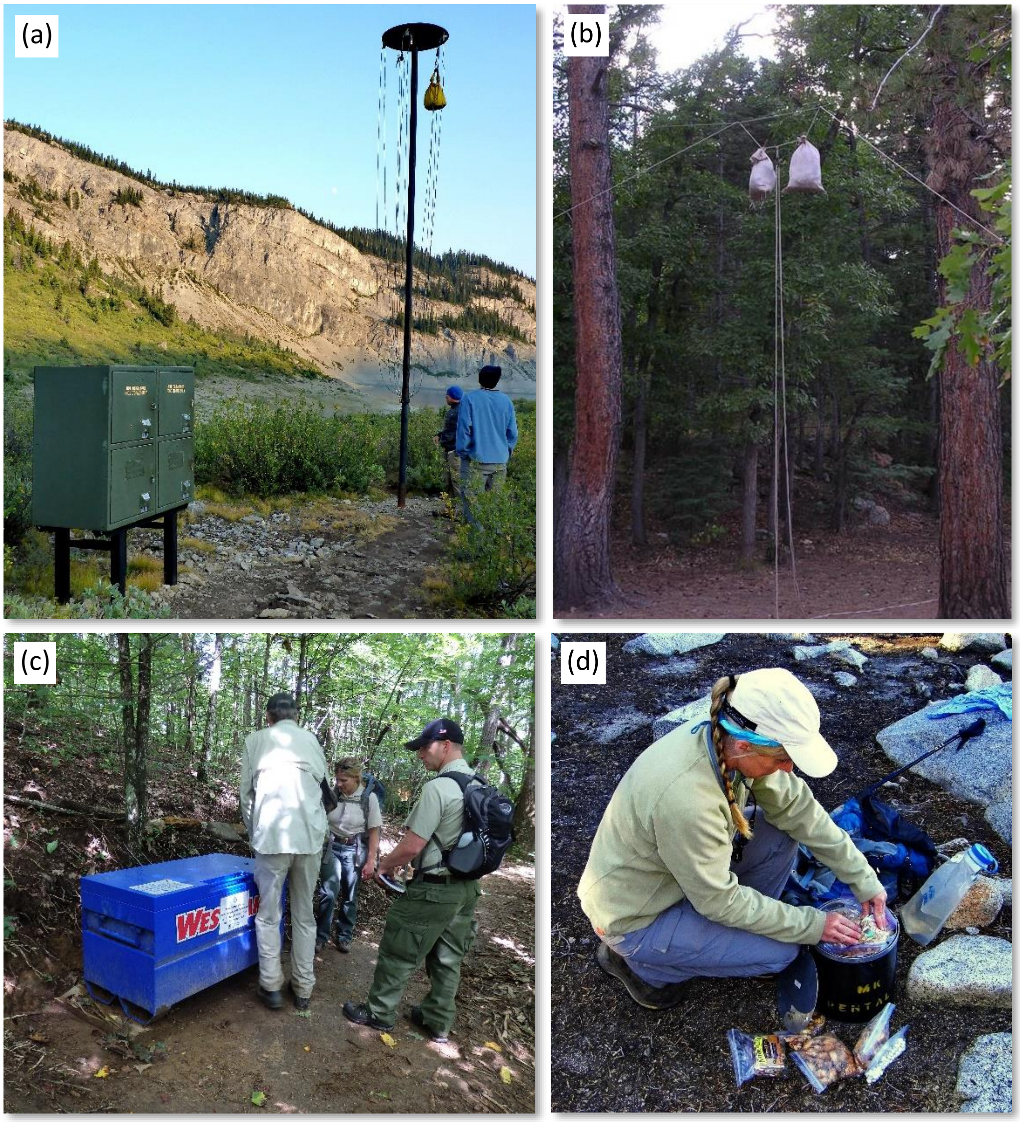


Figure 17. a & c) Steel food storage boxes. a & b) Steel cables for hanging food. d) Bear canisters carried by backpackers.

Land managers are increasingly placing the burden of food storage on visitors to hang their food, trash, and smellables from trees with ropes (Figure 18), or to store them in approved bear canisters or bags that they carry. Visitors who lack the willingness or skill to create effective bear-proof hangs, or the rarity of usable trees in some areas, prevents that policy from being substantially effective and may significantly damage trees and underlying ground vegetation. Alternative methods may be feasible in more developed and accessible areas. Cable systems are more effective and easier to use but are prone to breakage and require periodic maintenance and replacement (Figure 17). Aircraft cable is stretched between two trees and visitors throw their ropes over this to pull food bags up, taking care to hoist it at least 10 feet high and more than six feet from any tree. Alternately, pulleys and smaller cable can also be installed for hoisting food. Steel food storage lockers placed at campsites are easy to use, eliminate considerable trampling and tree damage, and require little future maintenance, though visitors sometimes leave their trash or excess food in them. The food storage box shown in Figure 17c was placed at the A.T. Hawk Mtn. side-hill campsites and has prominent signs with the message: “Leave No Food for Other Hikers, Not a Trash Can – Pack it Out!”

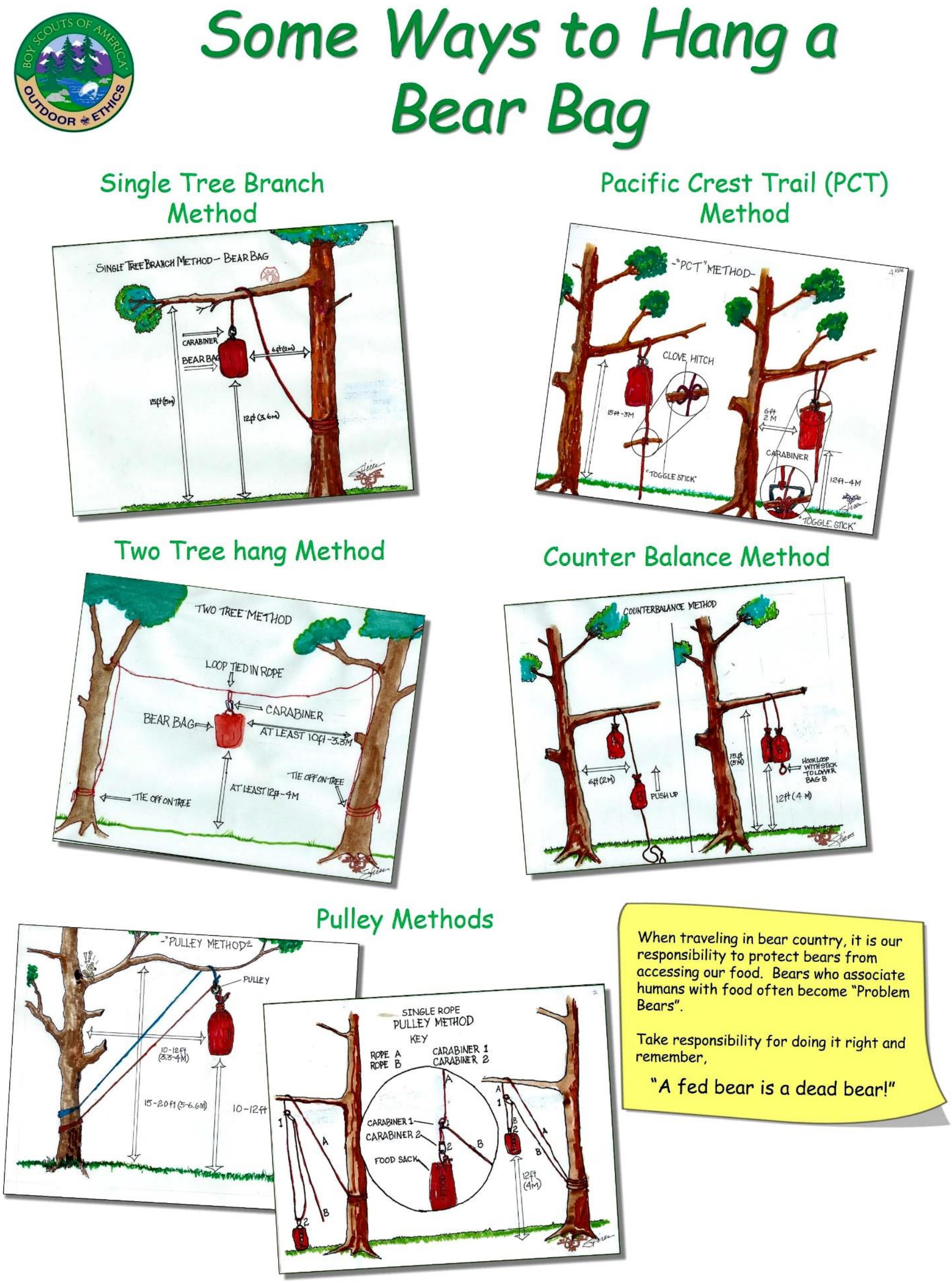


Figure 18. Alternative bear bag hang methods with ropes. Developed by the Boy Scouts of America, Outdoor Ethics Committee.

Yet another option (not pictured) are steel poles that resemble 15 ft tall coat racks with multiple arms and hooks for hanging food bags. These should be sufficiently strong and anchored in cement for stability. A 10 ft lifting pole with a hook on the end is provided for placing and retrieving food bags. The lifting pole should be secured to the bear pole with a six-foot length of chain or cable to prevent its loss.

Location/Proximity Attributes. Several attributes related to a campsite's location can be critical factors in the selection of sustainable campsites that also meet visitor's needs. The protection of important or sensitive resources is promoted by increasing campsite distances from waterbodies, wetlands, hazardous areas (e.g., cliffs), and rare or sensitive vegetation, soils, rare flora/fauna, wildlife habitats, and cultural/historic sites. Visitors who are camping often have greater free time to roam off-trail and trample or disturb these types of sensitive resources so shifting campsites entirely away from them is often a preferred management option, though visitors may have opposing opinions. Consider a common example - camping set-backs of 100-200 ft from waterbodies are quite common as either low impact suggestions or regulations (Marion et al. 2018b). Unfortunately, compliance is frequently low due to the substantial attraction of waterbodies, and day-use activities like swimming, fishing, and resting breaks are often enough to prevent recovery on shoreline recreation sites. Closure to day-use activities with signs may also be necessary, though efficacy may be governed by the ability to find and shift use to alternative sites with durable rock substrates (e.g., routing access trails to a shoreline area that is predominantly rock).

Similarly, the protection of experiential conditions is promoted by increasing campsite distances from other campsites, formal trails, popular attraction features (e.g., waterfalls, vistas), and roads or developed areas. Solitude, privacy, and natural quiet are all enhanced by increasing these distances and managers have established educational messaging and regulations to promote or require set-back or inter-site distances (Cole et al. 1987, Marion et al. 1993). A containment strategy and designated site camping is generally necessary to provide managers with effective tools to shift campsites entirely away from some features or achieve specified minimum distances that promote high quality visitor experiences (Marion et al. 2018a). Surveying visitors regarding their camping preferences is strongly suggested, as some visitors, such as youth-serving organizations and informal groups of thru-hikers, prefer the provision of group campsites or some clusters of campsites (though intersite distances might still be maintained). A planning process that establishes desired social conditions by zone is beneficial and provides guidance for such decision-making (IVUMC 2016).

As previously noted, campsite attributes and area attractiveness for camping are also important considerations – sustainable campsites that do not appeal to visitors may go unused (Brunson & Shelby 1990, Cole & Hall 2009). Selection criteria can be periodically reviewed and modified, particularly as management experience or monitoring data reveals how different campsites attract and tolerate intensive or long-term use.

This study experimented in the development of new campsite sustainability indicators and assessment protocols which could be developed into a weighted system to assist managers in evaluating existing campsites or potential new site locations (Appendix 1). An important decision is whether camping should be continued on existing campsites or shifted to new sites. Sustainable existing sites are generally used when possible as they are already impacted, and their effective closure may be difficult to achieve. However, existing visitor-created campsites often have one or more significant limitations, such as high expansion potential or proximity to water or other sites. Sometimes closure is necessary for these sites, though limited maintenance work, like the creation of attractive tent sites, may adequately address deficiencies to make them usable (Marion 2016). Alternately, use could be shifted to new sustainable naturally occurring or constructed side-hill campsites that will more permanently resist expansion and provide greater separation to improve social conditions.

Site Capacity and Design. In high use areas where a containment strategy guides camping management policies, it can be advantageous to group camping into larger clusters of sites to accommodate demand in the most sustainable locations, facilitate management, and/or provide facilities like toilets and food storage devices. However, just as the total amount of use in a management zone must sometimes be regulated to limit the deleterious effects of particularly high use and peak use, visitor capacities must also be considered when designing and managing areas with clusters of campsites. Resource and social conditions on campsites are substantially influenced by site design considerations, including capacity (number of campers) and site configuration, including spacing/density and arrangement of sites in relation to trails, other sites, vegetation, and topography.

Camping capacity is dependent on a variety of factors, including desired resource and social conditions that vary by management zone, camping demand, and environmental resistance. The process of determining camping capacity should begin with a review and consideration of zone-related management objectives and desired condition statements (IVUMC 2019b). What level of overnight visitation is most appropriate for the area? What are the maximum capacities for specific management zones and attraction areas with dependable water, such as lake basins or stream corridors? Other considerations are generally secondary to these strategic factors.

Objective evaluations of other factors are also essential, beginning with documenting existing use within the area by season, particularly for typical high use and peak use periods. Permit data may not suffice, as field surveys can provide more accurate information on overnight visitation by camping location and group types or sizes. For example, ridge-runners or club staff might check all campsites within a target area during the evening or early morning hours on four to six good-weather weekends during the most popular season. Phone apps provide an easy option for efficiently recording and sharing such data, including accurate GPS site locations. While data on a peak use weekend might also be of interest it should not be used for capacity determinations because visitation is often substantially higher than typical high use weekends. Accommodating peak use would result in sustaining exceptionally large numbers of sites and resource impact and many sites would be used infrequently throughout most of the year. Evaluations of use data in relation to the desired future conditions prescriptions will reveal the acceptability of current use levels and the ability to accommodate future growth. It is important to note that capacity decisions are inherently subjective and cannot be derived explicitly from scientific research or empirical formulas.

The next step is deciding where overnight visitation should occur and how much will occur at any single lake basin, attraction feature, or trail segment. An emphasis on establishing limits (thresholds) on the aggregate area of impact for these locations allows managers flexibility in trading off site numbers and site sizes over time, both of which strongly influence visitor numbers. Campsites are generally located near water sources along trail corridors arrayed singly or arranged in small or large clusters. Some particularly popular locations may require larger clusters of campsites, which may also have facilities like food storage boxes and primitive toilets. Planning for site capacities above 20 to 30 requires careful consideration of options for avoiding bottlenecks at these communal facilities, though more than one of each facility type could be provided. Severe limitations for any of these factors should initiate considerations for shifting overnight use to other locations. For example, clusters of 3-6 campsites could be located elsewhere along trails, including at locations that lack water sources. Additional guidance on site capacity decision-making is provided by Leonard et al. (1981) and the IVUMC (2019b).

Next, other factors should be examined to determine if the preferred level of camping use can or should be sustained within the area. Topography and the availability of dependable water are important considerations. The significant beneficial influence of topography, including micro-topography (rugosity) in limiting future site expansion and proliferation cannot be overstated. While many existing campsites are in flat terrain, over time these can be shifted to adjacent or more distant areas of sloping terrain, with trail alignments relocated to hide flat areas and allow natural recovery. Analyses using GIS and LiDAR topographic data have been developed by the authors to assist in efficiently identifying the best alternative locations for locating highly sustainable naturally occurring or constructed side-hill campsites. Surrounding terrain slopes of >15% are preferred for these side-hill campsites.

Careful thought should also be given to the spatial arrangement of campsites relative to waterbodies, other campsites, and communal facilities like toilets and food storage boxes or cables. This is particularly critical when larger numbers of overnight visitors are grouped within a single area. Travel patterns within the area should be anticipated so that intended use areas can be linked by a limited number of sustainably designed and constructed trails rather than a haphazard network of visitor-created trails. Figure 19 illustrates some preferred arrangements of side-hill campsites when higher demand creates a need for larger numbers of sites. Note that the clustered arrangement of sites occurring when visitors create campsites (see Figure 11A) often maximizes the creation of IT

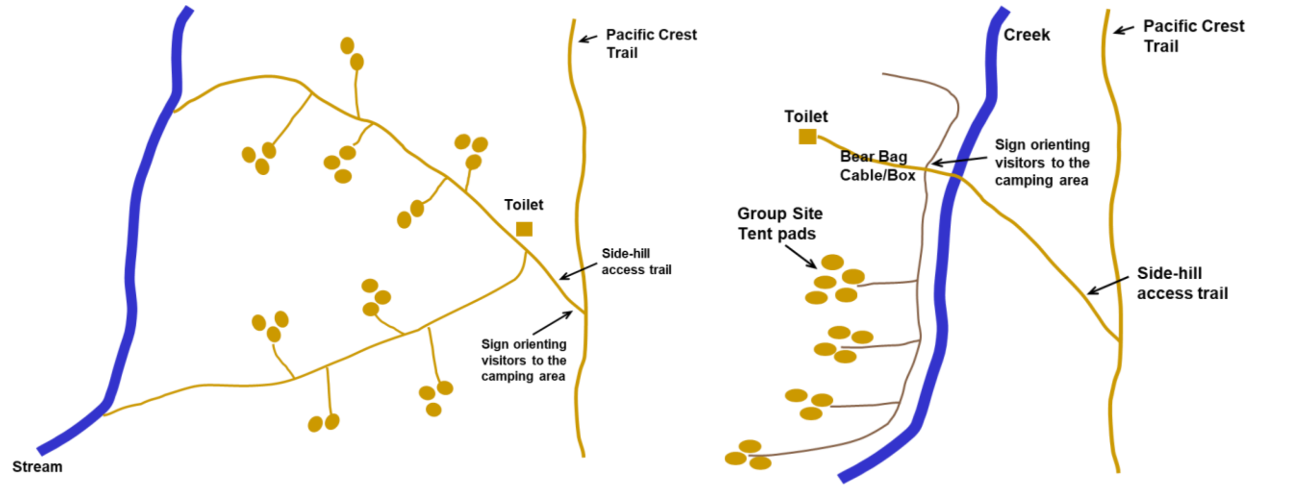


Figure 19. While campsites can be individually located along trails the common need for water often creates high demand for clusters of campsites that when unmanaged often lead to unacceptable resource and social conditions in moderate to high use settings. These alternative site design examples illustrate how constructed side-hill campsites could effectively resolve both resource and social impacts through carefully planned designs.

networks. Where possible, a linear arrangement of sites and facilities promotes traffic along a single trail, protecting surrounding areas from trampling (Figure 11C & Figure 19) (Leonard et al. 1981). Assume that visitors will want to directly access water, toilets, food storage boxes, and the formal trail - providing more direct access trails from campsites to these locations will reduce avoidable trampling impacts and IT creation.

The ability to select campsite and tenting locations provides managers with a powerful tool to shape social and experiential conditions on campsites, where visitors spend a considerable amount of time. There is a direct trade-off between intersite spacing required to provide and protect the intended or desired social conditions and the aggregate size or "footprint" of the backcountry campground. Spacing sites a 100-200 feet apart enhances visitor solitude and privacy and conversational voices generally become unclear beyond this range. Such intersite distances could be specified and vary by management zone (e.g., >200 ft in wilderness).

On individual sites, the area of camping disturbance can be minimized by identifying a desired number of tenting spots that have some separation from one another but are clustered as a campsite for use by a single group (Figure 11B and Figure 19). Also consider the sizes of tents used by your visitors and ensure the tent pads created can accommodate them. Generally, a minimum size of 10x10 ft will accommodate most two-person tents but groups and families often use larger tents so some tent pads should be 15x15. Care should be taken to ensure that planned campsites embody as many of the necessity, experience, and amenity campsite preferences as possible. At a minimum, the construction and long-term maintenance of smooth slightly crowned and well-drained tenting sites will encourage campers to consistently tent on the same sites so that camping activities and disturbance are spatially concentrated (Leung & Marion 1999, Marion & Farrell 2002). New tent sites should be checked and maintained during the first year and every few years afterwards to add and smooth soil; some spots will settle following rains and intensive use.

Access trails should also be sustainably designed, constructed, and marked to promote use of preferred established or designated campsites and to avoid the development of numerous and poorly located ITs. Individual campsite access trails, generally 25-50 feet long, can branch off this trail when multiple campsites are provided so that campers do not walk through or around the edge of other visitor's campsites when traveling to their own site. Main campsite access trails could be marked with a standardized triangular campsite paint blaze and should preferably exit formal trails in a perpendicular fashion to discourage the creation of "short-cut" trails.

When constructing naturally occurring or side-hill campsites look for the flattest existing spots within terrain having >15% slope; this reduces the amount of excavation needed to create the intended number of cooking and tenting spots. During excavation work it is best to remove all organic litter and soils to piles located along the contour on either side of the pad. Add excavated plants as well and water them. Find rock and build stone cribbing along the downhill sides to contain fill material, or substitute rot-resistant logs if rock is unavailable. Excavate uphill and fill in behind the cribbing; any rocks in the soil can be used in the cribbing or placed deep and covered with mineral soil. Lower the slope of the uphill cut face by digging further uphill - a steep slope will be prone to erosion and is more difficult to revegetate. Avoid making tent pads in precise geometric shapes (rectangles or circles) due to their artificial appearance - uneven sinuous boundaries are preferable. Compact, smooth and gently crown or slope the fill material and dig a shallow drainage dip around the uphill side of the tent pad to collect and drain water to the sides. Finally, relocate the organic soil, litter, and any plants to the cut and fill slopes. This will naturalize the construction work and promote rapid natural recovery.

The number of tent sites should match and accommodate the typical range of group sizes for the area, generally one to three pads and up to five for "group" sites. If group sites are not provided direct groups to use only sufficiently large sites or to split up and camp separately on two or more campsites to avoid site expansion. A separate pad can be created for cooking and even a communal campfire ring might be provided in areas where they are permitted. Placement of a flat "stove/kitchen table rock" in the intended cooking area will help to attract kitchen activities to this location. Use of large, heavy partially buried rocks will help discourage visitors from shifting them and disturbing different areas.

The aggregate area of disturbance will be substantially greater when camping must be accommodated in flat terrain, but several site construction practices can help to define and constrain camping disturbance. Begin by applying the site selection criteria and site configuration recommendations to identify approximate site locations. Look for locations with features that could help constrain site expansion, including rocky and uneven ground or an ample supply of large, downed trees. The previously described tent pad options or camping posts are recommended in flat terrain, with site ruination work in adjacent offsite areas to deter expansion. Anchored fire rings, ice-berged rock fire rings, and large stove rocks can assist in attracting and concentrating camping activities. Lining some or all campsite boundaries with large semi-rotten logs or embedded rocks can help clarify campsite boundaries and may even be necessary initially to identify preferred site access trails.

Campsite development and maintenance work can be accomplished by volunteers, but it should involve close cooperation with land management agency staff. Soil and vegetation disturbance generally require environmental assessments and archaeological surveys and approvals, activities that can be expensive and time-consuming. Federal agencies can often obtain a categorical exemption for archaeological surveys when side-hill campsites are constructed in sloping terrain (>15% slope) as prehistoric inhabitants lived almost exclusively in flat terrain or cliff- and alcove-associated settings. Construction work should strive to use native and/or rustic materials that match natural conditions (Marion & Sober 1987). Avoidance of long straight borders or perfect geometric shapes in campsite boundaries is one of the easiest ways to accomplish this. Using rock or short rot-resistant timbers rather than pressure-treated dimensional lumber is another. There is a fine line between making the intended use areas sufficiently obvious so visitors will consistently use them and artificial or visually obtrusive so that natural or wilderness character values are degraded. However, more artificial work may be justified in high use or flat areas. Our consulting experience suggests a general maxim: "Intensive use requires intensive management," if unacceptable resource and social conditions are to be avoided.

Wilderness Character. Camping management decision-making in designated wilderness areas must also consider wilderness character (Landres et al. 2015), including five core qualities:

1) *Untrammeled* – wilderness is essentially unhindered and free from the actions of modern human control or manipulation (e.g., stocking fish, unnatural fire regimes, manipulating wildlife populations).
2) *Natural* – wilderness is substantially free from the impacts of human activity.
3) *Undeveloped* - wilderness retains its primeval character and influence without permanent improvements (e.g., non-recreational structures, motorized equipment, inholdings).

4) *Opportunities for solitude or primitive and unconfined recreation* – wilderness provides for personal challenge and self-reliance, which are degraded by facilities, management restrictions on visitor behavior, and crowding/conflicts with other visitors.
5) *Other features of value* (paleontology, heritage, etc.)

Camping management decision-making related to implementing a containment strategy that employ developed structures or required behaviors must consider and seek to balance the advantages or benefits of such actions against the disadvantages or impact to wilderness character. For example, the resource and social impacts associated with excessive numbers of unnecessary visitor-created campsites and large visitor-created clusters of campsites in high use areas (Figure 1) represents a clear threat to *natural and social* conditions in wilderness that has been too often ignored. Shifting camping use to a smaller number of well-spaced sustainable campsites with a reduced aggregate area of impact that visitors are encouraged to use improves *natural* conditions and *opportunities for solitude*. We suggest that managers take a long-term perspective (e.g., >500-year time horizon) when making such decisions. Shifting use and impact to locations where impacts are constrained by sloping terrain or rocky, uneven ground is the most optimal *permanent* solution to most visitor impacts where areal measures are paramount. Further, if achieving the resource and experiential impact reduction benefits in popular high use areas requires the use of designated side-hill sites there is an added "cost" to the *unconfined* quality of recreation associated with requiring the use of designated sites. Such decisions are, however, appropriate, necessary, and have precedence in wilderness, particularly at popular lake basins. The selection and marketing of sustainable established sites is often a more optimal and preferred solution in wilderness. Employing established or designated site camping is generally more protective of wilderness character than employing regulatory use limitation with trailhead quotas.

Finally, while the *undeveloped* quality of wilderness might be degraded by using "constructed" side-hill campsites and/or toilets and food storage boxes when needed, this quality has historically been judged to exclude primitive recreational structures such as constructed side-hill trails, rock staircases and tread armoring, and engineered tread drainage features – all of which are visually obvious but have been common in wilderness for many decades. Managers should not hesitate to apply the same impact-management practices developed on trails to campsites, including the careful selection of sustainable locations, side-hill campsite construction, attention to drainage and access trails, and routine maintenance of soils and vegetation.

A containment strategy that emphasizes the selection and use of sustainable campsites offers both advantages and disadvantages for managers and visitors:

Advantages: Mangement benefits include the ability to select sites in settings that are environmentally resistant/resilient, that topographically constrain site expansion and proliferation, promote solitude, protect water quality and rare or sensitive natural and cultural features, and minimize wildlife habitat disturbance. Visitor benefits include knowing where preferred established or designated sites are located, having assurance of a good campsite in designated site areas, the presence of high quality tenting sites and in some areas the availability of toilet and food storage facilities.

Disadvantages: Managers must have staffing/funding to identify sustainable sites, construct and maintain sustainable established or designated sites, and provide/maintain camping-related facilities. Visitors may lose the freedom to select a preferred campsite or be bothered by the development of backcountry campgrounds with facilities in backcountry or wilderness areas.

Managers must consider these advantages and disadvantages and achieve a balance that allows them to meet their objectives for protecting natural conditions and processes while accommodating appropriate types and amounts of visitation. Decision-making will vary by management zone. A pure dispersal strategy with pristine site camping may avoid the creation of impact in remote low use zones with experienced campers. Unconfined camping policies can also be employed in these areas, but this policy frequently allows excessive site creation in moderate and high use zones. A containment strategy with established site camping is frequently a much more successful policy for moderate use areas. In high use zones a more intensively implemented established site camping policy can be effective, but in the most popular areas designated site camping is generally necessary, possibly with use rationing to redistribute peak use in time and space. As noted, *intensive use requires intensive management*, or resource and social impacts are likely to exceed management thresholds of acceptability. A VUM framework applied to management zones, along with adaptive management decision-making, can substantially aid managers in implementing the most optimal camping management policies and practices.

Visitor Management: Education and Regulation

Education and regulations developed to modify visitor behaviors are effective methods for avoiding or minimizing resource and social impacts associated with overnight visitation. Common avoidable camping-related resource impacts include littering, enlarging campsites, creating new campsites, moving or building new fire sites, improper disposal of human and food waste, cutting or damaging trees and shrubs, and feeding wildlife. Management efforts can also effectively minimize unavoidable impacts, such as vegetation disturbance caused by foot traffic and tents. Visitor education is favored by both managers and visitors as an indirect or light-handed voluntary approach that fosters a deeper appreciation for protecting natural areas and encourages voluntarily applied low impact behaviors and ethics (Marion 2014, Marion & Reid 2007). Most impacts are not from malicious acts but result from a lack of awareness regarding the consequences of outdoor activities and lack of knowledge regarding appropriate low impact practices (Manning 2003).

Generally, visitor education should be given an opportunity to resolve problems before regulations are imposed, unless more direct regulations and management is needed to address impacts that occur very quickly, are severe, or long-lasting (Cole 1997). An incremental adaptive management approach ensures that actions are effective and visitor freedoms are not unnecessarily restricted. The national Leave No Trace (LNT) program has been adopted by the PCT's land managers and collaborating stewardship organizations and trail clubs. This well-established educational program has developed a comprehensive array of low impact practices and ethics for hiking, backpacking, and camping to address every common camping management problem (Cole 1989b, Hampton & Cole 2003, Marion 2014), along with an array of education techniques for conveying such practices to visitors (Doucette & Cole 1993). The list includes selection of sustainable campsites away from streams, trails, shelters, and other occupied campsites, confining activities within core use areas to avoid enlarging sites, using stoves and low impact campfire practices, proper food storage and cleanup, proper human waste disposal, and practices to avoid impacts to wildlife and the recreational experiences for other visitors. These practices are taught in LNT training courses offered by a variety of organizations.

As an illustration, consider campsite selection to minimize campsite expansion and proliferation and what an educational program might do to address this common management challenge. Peak use in popular areas can be reduced by asking visitors to shift use to alternative locations or less busy times. Describing the long-term impacts caused by campsite expansion and proliferation provides a compelling rationale to visitors encouraging them to consider new camping practices: 1) planning trips and hiking schedules so avoid peak use times or places so that existing campsites can always be used, 2) matching their group size to campsite sizes so that small groups use small sites and large groups use large sites, or split up to camp on two or more sites, 3) restricting all camping activity to the most durable and barren core campsite areas, 4) improved searching for existing sites that may be more distant or hidden from view and/or sharing available space on campsites used by others, and 5) effective application of dispersed pristine site camping practices.

PCT managers may wish to target specific groups of hikers with different types of messaging. Targeting novice campers with introductory LNT information and practices focused on the predominant local impacts or problems can be an effective action (Manning 2003, Marion & Reid 2007). Targeting youth and novice visitors best addresses careless, unskilled, and uninformed high impact behaviors as these are more highly related to visitor knowledge and skill level (Hendee & Dawson 2002). Long distance hikers can be targeted with more comprehensive or "advanced" low impact information (e.g., dispersed pristine site camping practices). These individuals are important because of their substantially greater number of camping nights and because they serve as role models during their numerous interactions with novice PCT hikers. PCT managers may also consider the benefits of targeting organized groups. Most outdoor enthusiasts are introduced to the out-of-doors by some type of group-related outdoor program. The organizations that operate these largely novice and youth-oriented programs can be efficiently targeted, allowing cost-effective education of large numbers of public land visitors by their group leaders. Inexperienced youth are also more receptive to learning and adopting LNT practices, providing an opportunity for instilling lifelong low impact skills and ethics. An LNT pamphlet that specifically targets LNT practices for groups has been developed (http://www.LNT.org).

Education works. A comprehensive review of studies that investigated the efficacy of educational interventions by Marion and Reid (2007) found that most were effective in increasing visitor knowledge and altering visitor behaviors. However, sometimes the stated problems were not entirely or sufficiently resolved, requiring additional interventions such as site management actions or regulations: combined actions are often more effective than singular actions (Hockett et al. 2017). Relevant examples include studies that demonstrated the efficacy of the LNT Trainer and Master Educator courses (Daniels & Marion 2006a, Bromley et al. 2013), of communication interventions to reduce tree damage, littering, and improper human waste disposal (Settina et al. 2020), selecting less sensitive campsite locations (Christensen & Cole 2000), not feeding wildlife (Marion et al. 2008), remaining on formal trails (Hockett et al. 2017), and theft of petrified wood (Widner & Roggenbuck 2000).

Regulations

Although more restrictive to visitor freedom and experiences, regulations offer another option for altering visitor behavior to reduce impacts, or reducing the amount of use (Cole et al. 1987, Lucas 1982, Manning et al. 2017). Examples include requirements on the location of camping, such as restricting camping to designated sites or prohibiting camping in certain areas or within a set distance from trails or waterbodies (Cole et al. 1987, Marion et al. 2018b). Axes, saws, or campfires may be prohibited, or campfires may be restricted to designated fire rings. Proper food storage may be required and feeding wildlife may be prohibited. The most restrictive regulatory control is to limit the amount of use, generally by imposing trailhead quotas through permitting. This prohibits visitors from achieving a desired recreational experience, possibly shifting their use to alternative areas that may provide lower quality opportunities. Finally, managers must consider that the remote nature of the trail environment and limited agency budgets make it difficult to enforce regulations. While trail stewards and volunteers can remind visitors of regulations, they cannot enforce them.

Regulations may not necessarily be more effective than educational practices. In a survey of managers at NPS parks with backcountry and wilderness camping, 44% of respondents reported that their park had prohibited campfires, partially in response to tree damage and felling (Marion et al. 1993). However, Reid and Marion, (2005) evaluated campfire-related impacts and polices in seven PAs, finding that fire bans *did not* substantially reduce tree damage and cutting due to continued illegal campfire activity. Prohibitions on axes, hatchets, and saws were identified as a potentially more effective response. To further illustrate these decision-making "trade-off" the following section provides an in-depth examination of damage and felling of trees on campsites using research data to illustrate the challenges of both educational and regulatory actions in promoting the disassociation of camping and woods tools.

Tree Damage and Felling – A Common "Avoidable" Impact

In 1993, field crews surveyed all backcountry campsites (N=327) in Great Smoky Mountains NP to establish baseline conditions (Marion & Leung 1997). For campsites with trees, findings revealed that 63% of onsite trees had visitor-caused damage rated as moderate to severe. A total of 1,128 trees were tallied as damaged within campsite boundaries with an additional 1,249 damaged trees in adjacent offsite areas. Tree stumps were found on 60% of campsites, with a total of 724 stumps within campsite boundaries and 2,642 found in adjacent offsite areas. So many trees had been removed from once forested campsites that 25% of campsites no longer had *any* trees within their boundaries.

Similar findings were reported from a 32-year study of 81 designated campsites in the Boundary Waters Canoe Area Wilderness (BWCAW) (Eagleston & Marion 2017). A 2014 survey found 384 tree stumps within campsite boundaries and 1050 stumps in adjacent offsite areas, this equates to an estimated 35,600 tree stumps when extrapolated to all 2000 BWCAW designated campsites. A substantial majority of stumps were less than 6 inches in diameter, suggesting they were cut by visitors for firewood, as opposed to agency removal as hazardous trees. While only 4 campsites had no trees in 1982, an additional 21 campsites became treeless by 2014, nearly a third of all study sites. These impacts have occurred despite low-impact educational messaging that has been in the BWCAW permitting process since the 1970's, including statements about collecting dead and downed wood and a regulation prohibiting the cutting of live vegetation. These actions have been ineffective in deterring the continued damage and cutting of trees, promoting the authors to suggest a prohibition on woods tools to more completely disassociate camping and woods tool use.

LNT messaging to visitors related to such findings include the following:

- Land managers are increasingly prohibiting campfires due to their many associated impacts. However, most of these impacts are *entirely avoidable*. Do your part by adopting safe and low impact campfire practices or consider not having a campfire. Build a campfire only if there is a plentiful wood supply and gather only dead and downed wood that you can break by hand. Never leave a campfire unattended and before you leave ensure campfires are dead out and cleaned of all trash and food.
- Leave axes, hatchets, and saws at home – woods tools are dangerous, heavy, and unnecessary. Small-diameter wood is more easily burned to ash and extinguished, avoiding the build-up of unburned wood and charcoal in fire pits and the dangers of igniting a wildfire from long-burning coals (see Figure 20).

Options for communicating this and related low impact camping practices include websites, social media, and phone apps; visitor centers and agency offices; and associated verbal and media communications through educational talks, videos, pamphlets, posters, and signs. Low impact practices can also be effectively communicated by ridge-runners and at workshops and courses that target hikers and backpackers. If impact problems are not successfully resolved by traditional educational efforts, such work can be intensified, focused on specific problems, or specifically target organizations or groups identified as being associated with the impacts in question.

Figure 20. Tree damage from woods tools (axes, hatchets, and saws) is an entirely "avoidable" camping impact that over time removes campsite trees. Low impact campfires should be built using small-diameter dead and downed wood that is broken by hand; woods tools such as axes, hatchets, and saws are unnecessary.

Site Management: Close/Rehabilitate Sites

Closure and restoration work on campsites deemed unacceptable for continued use is also beneficial. While accommodating visitor use on recreation sites and trails is a primary management goal, visitors often create unnecessary sites and trails, sometimes at sensitive or unsustainable locations where impacts may quickly exceed acceptable levels of degradation. Camping closures represent a final resource protection strategy in the management toolbox, generally most appropriate for protecting sensitive environments, rare flora and fauna, and fragile historic or archaeological sites (Hammitt et al. 2015, Marion 2016). Closures, with unassisted recovery and/or active restoration to achieve natural conditions may also be necessary to limit resource and social impacts near popular attraction features such as lakes, waterfalls, cliff vistas, and hot springs, or to separate overnight campers from intensive day use (Therrell et al. 2006).

Management experience reveals that closures of popular areas and highly impacted campsites can be ineffective unless recurring enforcement is possible and clearly communicated alternatives are provided. Research reveals that little recovery will occur unless nearly all overnight and day use is removed, and displaced visitors have frequently created new campsites with the same or greater aggregate impact in nearby areas (Cole & Ranz 1983, Therrell et al. 2006). As previously noted, relocating a formal trail away from an area where a cluster of campsites must be closed can be the most effective action. Generally, closures of high-impact areas and sites are warranted only when use is shifted from impact-susceptible locations to impact-resistant locations that constrain site expansion and proliferation, although social considerations (crowding, conflict, or visitor safety) may also provide justification (Cole & Ranz 1983). Successful closure of the old sites can be enhanced by making the new sites more attractive (e.g., improved tent sites), creating and/or signing an access trail, improving the ability of visitors to find sustainable sites with enhanced maps or use of phone apps and GPS technologies, conducting site ruination and naturalization work on the old sites, and temporarily signing them as closed to all overnight and day use.

Substantial restoration work on recently closed sites is best avoided until staff can confirm that closure actions have effectively halted nearly all visitor use; continued trampling can quickly negate staff-intensive restoration work and expensive plant stock (Therrell et al. 2006). Applying an incremental or phased process is often the most pragmatic approach. ***Phase 1*** activity might include efficient naturalization work, such as dragging large woody debris and spreading organic litter across the site (Reid & Marion 2004). When possible, a few larger rocks and partially rotted logs placed across tenting areas or felling/moving large dead trees across the site are even more helpful. The objective is to naturalize and hide the site, and to obstruct tenting with logs or rocks that are not easily moved. Monitoring the efficacy of this work, particularly after busy or peak use weekends is helpful, with reapplication to quickly restore sites that are reused.

If Phase 1 work is ineffective, then more intensive ***Phase 2*** work is necessary, including actions such as encircling the site with nylon cord as symbolic fencing to deter entry, posting temporary site closure signs, and ice-berging large rocks or digging shallow depressions and mounding soil in the tenting areas. Felling or moving large trees onto the site is also effective if that was not done in Phase 1. Although most commonly applied to restore closed campsites, some of these techniques can also be used on open campsites to close unnecessary portions to reduce their size (Marion & Sober 1987). Discussing the closures with visitors and providing educational messages that convey compelling reasons for the closures can also be helpful. Enhanced visitor patrols, contact, and enforcement activity of site closures may also be necessary for particularly challenging areas, though moving formal trails away from the problem area is likely the most effective long-term solution.

If sites are effectively closed by the activities described above, then managers may elect to allow natural unassisted recovery to occur over time (Therrell et al. 2006). Recovery rates are dependent on many factors, including length of growing season, soil texture, fertility, moisture, sunlight penetration, elevation, and size of the disturbed area and severity of disturbance (Reid & Marion 2004, Cole 2013b). For example, recovery rates on large highly impacted campsites can require decades in subalpine and alpine ecosystems because of the low rates of plant establishment and growth (Zabinski et al. 2002, Scherrer & Pickering 2006, Willard et al. 2007, Cole 2013b). In contrast, Marion and Cole (1996) found substantial vegetative recovery of moderately impacted campsites over just five years in a Pennsylvania riparian floodplain.

As noted, defer ***Phase 3*** work that involves expensive or time-consuming modifications to substrates and vegetative plantings until the site has been effectively closed to visitor use. In open settings the most efficient practice is to seed grasses, using locally obtained pure sources of native species. Agricultural extension specialists can be contacted to locate companies in the region that provide weed-free sources of native grasses, or they could be collected within the PA from similar environmental settings. Forbs and woody shrubs and trees can also be transplanted from adjacent areas, or they can be cultivated in a greenhouse from local native stock and planted to speed recovery on closed campsites. Soil amendments, including a variety of organic materials, can be added to retain soil moisture and improve soil fertility. Therrell and others (2006) and Hanbey (1992) provide more comprehensive guidance of restoration planning, guidance, and methods.

Several recent studies have evaluated the efficacy of various restoration treatments designed to accelerate recovery processes. Cole (2013b) assessed recovery over 15 years on six wilderness campsites in Oregon's Eagle Cap Wilderness, finding virtually no vegetation cover on campsite plots that received no restoration treatments (i.e., unassisted natural recovery). Treatments included soil scarification to 6 inches followed by application of several types of organic mulches and locally collected vegetative transplants or seeds. After 3 years about 85% of the transplants had survived, and their growth and cover were significantly greater on plots with organic and compost amendments than on scarified plots. Scarification improved the establishment of volunteer seedlings, but seedling density on seeded plots was more than five times higher. A treatment with organic matter and compost soil increased seedling survival during hot, dry periods and enhanced seedling growth; supplemental watering was also critical during the germination period of the first growing season.

Continued assessments over an additional 12 years found that scarification alone yielded plots with only 4% vegetation cover, whereas plots receiving the most effective treatment (scarification, organic and compost amendments, and transplants) had 28% cover, compared with 50% in adjacent undisturbed control plots (Cole & Spildie 2007, Cole 2013b). The authors note that study treatments were not very effective in restoring native plant composition; graminoids comprised 69% of the vegetative cover on closed campsites but only 26% on control plots (likely due to increased sunlight on campsites with no or low tree cover). A similar study was conducted in Idaho's Sawtooth Wilderness, finding that staff-intensive restoration work can reduce recovery times from more than 100 years to several decades (Cole et al. 2012). This study demonstrated the benefits of using larger transplants, fertilization, and watering during dry periods over the initial years.

Finally, careful consideration should be given to the selection and use of any plant seeds used in restoration work. Forest Service scientists have reviewed knowledge of seed collection, production, and delivery to develop international standards and guidelines to assist managers in designing sustainable seed supply chains for sourcing, procuring, and using native seeds. To aid in the selection of seed sources adapted to local landscapes and future climates, Forest Service scientists developed and maintain several online tools, including the Seedlot Selection Tool, the Climate-Smart Restoration Tool, the Climate-Adapted Seed Tool, and the Threat and Resource Mapping Seed Zone Applications.

Tort Liability Considerations

This section reviews the concepts relevant to tort liability to provide some guidance on achieving an appropriate balance of risk management related to campsites and hazardous trees.[1] It was researched and included to address the concerns of some federal managers regarding the use of established and designated site camping options, and the development and use of side-hill campsites.

The tort liability of a federal agency is based upon principals of negligence. The need to ensure safety must also be weighed against the degree of risk and the likelihood and severity of a potential hazard realizing. The types of decisions where potential tort liability come into play are broad and include such decisions as requiring the use of

[1] USDA Attorney Elise Foster, Office of the General Counsel in Missoula, MT, provided a careful review of this section and we thank and acknowledge her writing and edits in this section.

designated facilities, the maintenance level of facilities, and hazard warnings. While promoting public safety in recreation management decision-making is an important consideration, overly cautious decisions can result in reduced recreational access and/or acquiescence to substantial levels of avoidable recreation impact.

Under the Federal Tort Claims Act (FTCA), the federal government can be sued for damages resulting from injuries or death caused by the negligent or wrongful act of an employee acting within the scope of their employment. The FTCA is known as limited waiver of sovereign immunity and entails a number of exceptions. Liability under the FTCA is most commonly based on *negligence*, which is the breach of a duty that causes injury or damages. The question of duty is the threshold inquiry in a tort analysis. Generally speaking, everyone has a duty of reasonable care to avoid injuring others. Duty, however, is a relative term and changes based on the relationships between parties and the circumstances involved. For instance, the duty owed to a trespasser is far less than the duty owed to an "invitee", a person invited to the premises for the benefit of the owner. Similarly, in a recreational context, agency-managed recreation areas with developed recreation sites impose a higher duty to ensure safety upon the agency than dispersed recreation in backcountry and wilderness areas.

Liability questions are also determined according to the law of the place where the incident occurs. Many states have what is called a "recreational user statute" which absolves a landowner of liability to the public if they allow free recreational access to their property. The purpose of such statutes is to encourage making recreation opportunities open to the public by alleviating liability concerns. If an agency charges a fee to access a recreation site, then the limitation on tort liability under such a statute would not apply.

An important exception to the FTCA is the "*Discretionary Function exemption*" (McAvoy et al. 1985). Grounded in the doctrine of separation of powers between the three co-equal branches of government, the exemption states that the FTCA does not apply where Federal agencies exercise discretion and make policy decisions based on such factors as research, budget realities, and agency goals and objectives. This is because the federal courts are not permitted to "second guess" the policy decisions of an executive branch agency. For the exemption to apply, there must be discretion to act, and the agency must exercise its discretion by weighing *policy* considerations. If these elements are present, the agency may be shielded from FTCA liability even if negligence occurred.

The Supreme Court devised a two-part test to determine if the Discretionary Function exemption applies (Berkovitz v. U.S., 486 U.S. 531, 536 (1988): 1) whether a federal statute, regulation, or policy specifically prescribes a "mandatory" course of action for an employee to follow. *Id*., 486 U.S. at 536., and 2) whether the exercise of judgment or choice at issue "is the kind that the discretionary function exception was designed to shield." *Berkovitz*, 486 U.S. at 536. Only governmental actions and decisions based on considerations of public policy are protected by the exception. *Id.*, 486 U.S. at 537. If policy considerations are involved (e.g., balancing agency goals, resource allocations, visitor safety), negligence doesn't matter, courts cannot second-guess agencies in the exercise of their discretion.

A relevant example is provided in Snider v. U.S., 2013 U.S. Dist. LEXIS 105580 (W.D. Ok. 6/29/2013), a federal district court applied the discretionary exception to dismiss a case where a hazardous dead tree only ten feet from a picnic table killed a camper at an Army Corps of Engineers (COE) campground (Kozlowski 2015b). The court found that "Decisions involving tree removal can quite clearly be policy-driven matters. On government property (or any other property) that is wooded, there will inevitably be dead trees. Dead tree removal, if it is to occur at all, must get in line for government resources along with all of the other demands on the operator of a campground." COE also claimed a policymaking decision "not to place warning signs of general hazards at campsites" also fell "squarely within the scope of the discretionary function exception." The court concurred: "Faced with limited resources and unlimited natural hazards, defendant must make a public policy determination as to which dangers merit the intrusion of a sign. Too many signs would reduce the impact of individual warnings on the public. Defendant must balance the goal of public safety against competing fiscal concerns as well as the danger of an over proliferation of warnings." They are "policy-driven" decisions "that balance safety concerns, wildlife and ecosystem preservation, and recreational uses - all while working within a limited budget."

In a 2014 USFS case within Idaho's Boise National Forest (Amstrong v. U.S., 1:13-cv-00163-BLW) the U.S. District Court in Idaho dismissed a case for lack of jurisdiction involving a tree injuring a youth on a dispersed campsite.

The plaintiffs argued that the tree had been dead for between 10 to 25 years and that the USFS should have inspected, identified, and removed the dead tree or closed the campsite. However, the court found that "identifying and managing hazardous trees in dispersed campsites…is the sort of conduct or decision the discretionary function exemption was intended to shield." Considered in this case was whether the campsite was a "developed recreation site" as defined by the USFS. Attributes of developed recreation sites include USFS classifications that qualify car-accessed campgrounds as developed sites and exclude primitive sites in dispersed backcountry settings. According to the USFS guidance "A developed recreation site requires a "concentration of facilities" evidencing a "significant investment" by the Forest Service."

In a similar 2009 USFS case within New Mexico's Gila National Forest (Gallegos v. U.S., CIV 08-0014 RB/LFG), a man died after a tree that had been dead at least five years fell on his tent when camping in a road-accessed area that permitted camping and had USFS bulletin boards, parking areas, two public toilets, trash receptacles, and some fencing. However, in this case the U.S. District Court determined that the area was a developed recreation site and that USFS guidance to remove hazardous trees or limbs was not followed: "Consistent with preserving the recreation resource, remove trees or tree limbs identified as hazardous at developed recreation sites" (U.S. Forest Service Manual 2300 – Developed Campsites, 2332.11 – Tree Hazards). The Court found that this guidance was specific and mandatory, prescribing a course of action that the USFS did not follow and fulfilling part one of the Berkovitz test (but the court also noted that the Public Safety, 2332.1, and Other Natural Hazards, 2332.12, sections did not provide *mandatory guidance*). The Court also found that part two of the test was satisfied, noting that the area was not pristine or wilderness, where a multitude of hazards exists and where warnings might detract from the area's character, or where safety actions might be costly. In this case the USFS had signs and fencing to close part of the area to vehicles but had no signs or closures to camping or visitor use and that hazard trees had been left standing in an area that received "long-term heavy public use."

In a 2015 NPS case in a Yosemite National Park developed campground, two teenagers were killed by a large oak branch that fell on their tent during the night (Daniel Kim v. U.S., 1:16-cv-01656-LJO-SKO). The plaintiffs claimed the NPS was negligent in safely maintaining the campsite trees and not posting any warning signs. While NPS Directive # 25 establishes that "trees with a high or very high hazard rating will require some type of abatement/mitigation," NPS policies and guidelines vest considerable discretion in park staff to determine the level of hazard posed by park vegetation. Therefore, despite the mandatory NPS hazard tree management guidance the court found that the NPS has considerable discretion in addressing hazard trees, therefore not fulfilling part one of the Berkovitz test. The court further concluded that the NPS conduct involved broad policy considerations (e.g., environmental and cultural impacts as well as visitor safety and experience policy concerns) before taking particular actions to address hazard trees. These policy concerns are the type of decisions protected by the discretionary function exception, therefore not fulfilling part two of the Berkovitz test. The court concluded with a statement that "Even where a condition presents a known danger, so long as the implementing decision itself is susceptible to a policy analysis it falls within the discretionary function exception."

The "*Recreational Landowners Liability Acts"* provide a basis for deciding many other cases and almost every state has enacted some version of this statute that limits the landowner's liability to encourage them to open unimproved property for recreation uses. The FTCA states that the federal government is liable for negligent acts "in the same manner and to the same extent as a private individual under like circumstances" so the courts use the relevant state law in determining liabilities. There are three common exclusions in these state laws:

1) An injured party must demonstrate that the landowner's actions constituted a willful or malicious failure to guard or warn against a dangerous condition, use, structure, or activity.
2) If a fee is charged for admission to an area, then the responsibility to protect the visitor increases.
3) If a landowner merely permits access to their property, they have much less responsibility for visitor safety than if the visitor was expressly invited to recreate there. As an example, a USFS visitor to some thermal pools was attracted by a sign which read: "We invite you to marvel at the natural wonders of this great forest." He left a designated trail, fell into a thermal pool and suffered severe burns, and sued. The court ruled that the sign did not constitute an express invitation and found in favor of the USFS.

McAvoy et al. (1985) conclude that the implications for federal backcountry and wilderness land managers are that if an agency decides to build trails, campsites, or structures then the responsibility to ensure safety increases and the policy decision must be followed by sound operational decisions. The constructed features must be maintained in a manner commensurate with the duty to ensure safety.

The duty to warn of hazards may also arise in areas where recreation is managed. A landowner has a duty to warn of known hazards that are not obvious. There may also be a duty to warn of potential hazards such as falling rocks or wild animals, in the context of natural resource land management on vast areas that may present numerous potential but unknown hazards. The decision whether to warn is often a discretionary decision.

There is an important distinction between constructed developments and natural surroundings. Agencies have more control over developed facilities they construct than over the natural environment. Questions of negligent design, engineering, and maintenance of a developed facilities, like a bridge's ability to support a string of horses or a camping shelter's ability to tolerate an expected maximum snow load are more likely to be outside of discretionary decision making. Courts may be more willing to review questions of negligence and tort liability where there are elements of man-made control involved than they are where the matter involves solely the forces of nature.

For state land management agencies Kozlowski (2015a) provides a legal review regarding case law associated with two campground visitors in a Colorado State Park (Burnett v. Colorado Division of Parks and Outdoor Recreation, 2015 CO 19; 346 P.3d 1005; 2015 Colo. LEXIS 216 (Colo. 3/23/2015)). These visitors were required to camp in a campground site of their choosing and paid a fee for its use, setting up their tent under the canopy of four mature cottonwood trees. During the night a large limb fell and injured both of them, one severely. This camper sued the state to compensate "for injuries caused by a dangerous condition of any public facility located in any park or recreation area maintained by a public entity."

The camper and the state agreed that the "improved campsite" was a "public facility," but the state denied any liability because they retained immunity for "an injury caused by the natural condition of any unimproved property" (Kozlowski 2015a). The trial court, appeals court, and state supreme court all found in favor of the state. In particular, the state supreme court: 1) distinguished between dangerous conditions arising from man-made and natural objects, 2) it suggests that immunity turns on the precise mechanism of the injury (e.g., injuries cause by negligence in the construction or maintenance of artificial, manmade objects vs. the natural conditions of the land), 3) it expresses a clear intent to exempt public entities from a duty to maintain any natural conditions, and 4) it reaffirmed the policy goals of encouraging public entities to open up to the public unimproved, government-owned property without exposing the entities to the burden and expense of defending claims brought by individuals who are injured while using the property.

More specifically, the state supreme court concluded "the legislature intended to retain immunity for injuries caused by native trees originating on unimproved property regardless of their proximity to a public facility, such as the improved area of the campsite here" (Kozlowski 2015a). The state supreme court noted that courts in other jurisdictions with similar statutory immunity for natural conditions had also concluded that "the exact mechanism of a plaintiff's injury [the tree], not her location at the time of injury [a developed state park campground] determines immunity." Kozlowski (2015a) also relates that the state supreme court held the natural condition provision "does not create a duty to maintain natural features, nor does a duty arise merely because of the features' proximity or contiguity to improved property." The state supreme court further held that "even where the State chooses to maintain unimproved property to protect the public health and safety," they retained immunity *even though* the State had previously pruned the trees bordering the campsite on which the injury occurred. The principal reason supporting these decisions was an explicit recognition of the "limited fiscal resources" to engage in the maintenance of various natural conditions and that the burden and expense of defending claims for injuries would likely discourage public land managers from opening and improving lands for the public to enjoy.

It's important to note that in the 2009 Gallegos case the USFS cited the New Mexico Recreational Use Statute (NMRUS) (N.M. Stat. Ann. § 17-4-7) as barring the plaintiff's claims. However, the U.S. District Court found that the NM Court of Appeals had issued two opinions that the NMRUS does not apply to federal agencies and therefore does not confer immunity on the U.S. Such recreational user statutes are applicable to federal agencies in other states and have conferred immunity.

One can never be certain how the justice system will interpret the relevant laws, which vary by state, but the preponderance of case law reveals that land managers have higher liability for injuries related to man-made facilities like structures and bridges and developed recreation sites within frontcountry areas of higher visitation. They are less liable for primitive sites and natural conditions and processes in dispersed recreation areas, including backcountry and wilderness. For the federal agencies, management guidance is also pertinent, particularly when laws or agency policies specifically prescribe a "mandatory" course of action for an employee to follow (e.g., "Remove trees or tree limbs identified as hazardous at developed recreation sites," as opposed to wording like "To the extent practical" or "If possible." However, even in the case of clear negligence, the federal agencies are protected by the Discretionary Function exemption when actions and decisions are based on broader considerations of public policy. This academic review of relevant case law is not offered as legal opinion or advice: agency counsel should be consulted for such legal opinions and advice with consideration for state laws.

STUDY AREA

The study areas for this project were many and varied, including federal lands traversed by the PCT managed by the Bureau of Land Management, National Park Service, and the U.S. Forest Service. We note that this study includes fieldwork conducted from 2017 to 2021 and it was funded through multiple agreements that added new study areas and objectives over time. The core study goals were to evaluate camping impacts along some of the most popular PCT segments to document resource conditions and resolve salient camping impact management challenges through the development of improved BMPs for sustainable camping management. Thus, the study primarily focused on higher use segments of the PCT with study sites identified by the management agencies. Fortunately, one lower use segment (Crater Lake NP) and an intermediate use area (North Cascades NP) were also included to provide some diversity for comparison to the high use areas.

Table 5. PCT study areas by federal agency, location, management subunits, campsite numbers, and fieldwork dates.

Federal Agency & Location	Management Subunits & Campsites Assessed	Fieldwork Dates
Cleveland NF & BLM (CA); Southern California	Barrel Spring (6), Fred Canyon (2), Hauser Canyon (2) & 3 campgrounds	Mar, 2017
San Bernardino NF	Splinters cabin - Devils Hole (16), Deep Creek Hot Springs – Spillway (42)	Aug, 2019
Sequoia & Kings Canyon NP	Lower Crabtree Meadow (10), Upper Crabtree Meadow (28)	Aug, 2017
Inyo NF	Trail Camp (59), Outpost Camp (10), Thousand Island Lake (85)	Aug, 2017
Yosemite National Park	Glen Aulin (27), PCT Tuolumne (66)	Aug, 2017
Desolation Wilderness, Eldorado NF & Lake Tahoe Basin Management Unit	Dicks Lake (23), Lake Aloha (110), Gilmore Lake (25), Lake of the Woods (28), L. Velma Lake (53), M. Velma Lake (29), Fontanillis Lake (3)	Jul, 2018
Mt. Hood NF	Lower Twin Lake (17)	Jun, 2019
Crater Lake NP	Mazama group (3), Dutton Creek (3), Lightning Spring (3), Grouse Hill (3), Bybee Creek (2), Red Cone (3)	Jul, 2021
North Cascades NP	Bridge Creek (8), Fireweed (9), Hideaway (1), High Bridge (1), North Fork (4), Shady (2), Six Mile (1), South Fork (4), Tumwater (2)	Sep, 2018

METHODS

As noted, the PCT segments and study sites were largely identified by federal land managers and cannot be considered "representative" of the larger PCT campsites. All campsites within the selected segments and study areas were then assessed by field staff.

Description of Fieldwork

The selection of indicators and development of field methodologies and protocols employed were based on substantial research in protected natural areas similar to the PCT. However, this research sought to experiment with new indicators, revised field assessment protocols, and field testing in a variety of PCT corridor environmental settings. In particular, research was focused on developing, evaluating, and refining new indicators and protocols for assessing campsite sustainability. The product of this work was development of a "recommended" field manual of preferred indicators and protocols included as Appendix 1. Some protocols were only applied during a subset of the fieldwork and are thus omitted from the other study area tables. An overview of the assessment methods follows.

Campsite Assessments

Within each study area field staff located and assessed all campsites. In the rocky and uneven terrain common within many of the study areas campsites often consist of several separate but small tenting or cooking sites in a cluster. Judgement was applied in assessing and combining the most proximate clusters of sites into a measured "campsite" that single groups would reasonably use. Some monitoring programs might assess all individual cooking or tenting sites as separate campsites, so readers should be wary of comparisons based on campsite numbers. However, with accurately georeferenced data, GIS analyses and comparisons of polygons should be possible. Regardless, we suggest that managers primarily focus on the aggregate area of camping impact and disturbance rather than campsite numbers. For example, a campsite of a few hundred square feet should be less consequential than a 3000 ft^2 mega-site, a new term defined in our A.T. study for campsites exceeding 2000 ft^2 in size (Marion et al. 2020). Comparisons for other impact indicators, such as damaged or felled trees, can also be aggregated and compared for management sub-units or geographic areas of concern.

Field staff experimented with emerging technological advances in refining field assessments, investigating the use Trimble Geo7X or GeoXH GPS receivers (~2-6 ft accuracy) vs. smartphones that can access up to five GNSS constellations of satellites (GPS (US), QZSS (Japan), BEIDOU (China), GALILEO (EU), and GLONASS (Russia) (~12-20 ft accuracy). Both GPS options exhibit lower accuracy in areas of dense tree cover. Trimble GPS data collected in the field were imported, differentially corrected using Trimble's Pathfinder Office software, and converted to shapefiles for editing in ArcMap and ArcGIS Pro software (ESRI, Redlands, CA, USA). Limited editing was necessary to correct horizontal errors. Professional judgement and site photos were used to aid the editing process. Based on our experimentation, the best current practice is to use high-end GPS receivers when available to capture the center points of campsites and any associated nearby "satellite" use areas. However, we had good success using smartphone GPS receivers and the Fulcrum data entry phone app to capture and store these center points directly with collected campsite data and this is now a viable alternative when more expensive/accurate GPS units are not available.

Campsite boundaries were identified by pronounced visually obvious changes in a combination of vegetation cover, vegetation height/disturbance, vegetation composition, and surface organic litter caused from trampling-intensive camping activities (Marion 1995). Our experience is that smartphone GPS accuracy is currently insufficient to walk campsite boundaries to map campsite polygons and obtain sizes. However, submeter GPS receivers allow post-processing to improve accuracy and these were found to be sufficiently accurate to compute site sizes, except in rare areas of dense tree canopies (see also D'Antonio et al. 2013). To mitigate possible accuracy issues, polygons were visually checked in the field for accurate representations of shape and area on the GPS receiver. Sites for which accurate GPS readings could not be obtained, generally very small sites, were measured using the Geometric Figure Method (Marion 1995). This practice resulted in the most optimal tradeoff of accuracy vs. efficiency. Our experience and findings were consistent with focused studies that found greater errors when assessing the sizes of small polygons (130 ft^2) vs. large polygons (>1300 ft^2) (Dauwalter et al. 2006).

We used the Fulcrum phone app installed on smartphones for all campsite data entry and describe here the advantages of this option. Field data collection forms are created at the Fulcrum website and then downloaded to smartphones for use. Beneficial features include the ability to enter categorical data by simply tapping the correct category, or for interval/ratio data by tapping the screen and entering a number, which can be automatically error-checked to ensure that only numbers (not letters/symbols) are entered within specified ranges (if desired). Comment fields allowing extensive text can be typed in or dictated. Complete protocol descriptions/guidance can also be copied in for each indicator and accessed by pressing an information icon. The app allows the automatic creation of submenus based on entered data, for example, a submenu to enter data for several satellite use areas. GPS coordinates can be automatically stored when the app is opened and saved separately for each satellite use area. The app directly accesses the phone's camera to capture, check, and retake images, and permanently link them to each campsite data record. The app does not allow the user to complete a record until all required indicators have been completed (no missing data). All data is stored on the phones until transferred when the phone has a cellular signal or WiFi hotspot, then the user clicks a sync icon to automatically upload all field data, including the linked photos. Data and photos from prior surveys can also be transferred to phones and consulted while in the field. We had no problems using the phones for data-collection on multi-day backpacking trips, carrying small back-up batteries to recharge our phones each night.

Within each campsite boundary, a percentage estimate of six cover classes (0-5%, 6-25% 26-50%, 51-75%, 76-95%, 96-100%), was recorded for live vegetation groundcover and exposed soil. A percentage estimate of vegetation groundcover and exposed soil was also recorded for an adjacent offsite, environmentally similar control or reference area that lacked human disturbance (Marion 1995). Area of exposed soil was computed by multiplying the midpoint of the cover class for exposed soil by site size. Similarly, estimates of the area over which vegetation loss has occurred were computed by subtracting the midpoint values of onsite vegetation cover from offsite values and multiplying percent vegetation loss by site size.

Other characteristics recorded in the field include estimated use level, tree canopy cover, and offsite woody vegetation density. Reliable and accurate campsite use data were unavailable for all surveyed campsites, a problem for nearly all campsite studies in wildland settings (Cole 1986, Cole & Marion 1988, Eagleston & Marion 2017). In general, the majority of campsites assessed in this study should be considered as moderate to high use, relative to all PCT campsites. Tree canopy cover was estimated using the six groundcover categories as the percentage of the site shaded by the tree canopy when the sun is directly overhead.

Campsite Sustainability

Research was also focused on developing and refining various new indicators reflecting campsite sustainability. Many potentially influential attributes were considered from examinations of the literature and staff discussions. The primary campsite impact indicators that managers seek to minimize are aggregate measures of campsite size, area of vegetation loss, and area of exposed soil. Campsite sustainability indicators should reflect attributes that significantly limit these areal measures of campsite impact. However, we also developed and included indicators of visitor campsite functionality and preferences for necessity, experience, and amenity attributes (discussed previously). Assessment protocols for sustainability indicators were developed, refined, and applied during fieldwork at one or more study areas. These indicators are listed and briefly described:

Site Expansion Potential – a count of potentially usable "off-site" 2-person tenting spots within a 30-ft buffer of existing campsite boundaries. This indicator considers topography (slopes), rugosity (unevenness of the ground and rockiness), soil wetness, and woody vegetation density (see Eagleston and Marion 2017). Alternate measures of campsite expansion were also developed and investigated, including a categorical descriptive assessment and a percentage estimate of the 30-ft buffer.

Offsite Rugosity – a rating of low, medium, high based on uneven ground and rockiness of adjacent offsite areas.

Offsite Woody Density – a rating of low, medium, high based on the spacing of woody vegetation in adjacent offsite areas.

Offsite Grass Cover - An estimate of the percentage of grass or sedge (graminoid) cover in the adjacent offsite areas within 50 feet of campsite boundaries using the categories below. Graminoids are resistant and resilient to traffic and campsites surrounded by grasses should have smaller areal measures of impact than those surrounded by broad-leafed forbs.

	0-5%	6-25%	26-50%	51-75%	76-95%	96-100%
Midpoints:	**2.5**	**15.5**	**38**	**63**	**85.5**	**98**

Tree Canopy Cover – An estimate of the percentage of the campsite shaded by mid-day sun using the categories above. Sunny campsites allow substantial grass cover, intermediate shade allows substantial forb cover, and deep shade allows very little vegetation cover.

Rock Substrate – An estimate of the percentage of bedrock, boulders, or cobble within the campsite boundaries using the categories above. Campsites with substantial rock may have limited areal measures of vegetation loss and exposed soil

Bedrock – An estimate the percentage of usable bedrock for cooking and/or tenting within campsite boundaries. Sustainable campsites would have higher values.

Campsite functionality and preferences – Usable tent pads, intersite visibility, seating, dead/hazard trees, stove rocks, bear bag hanging trees, cathole potential, ease of water access, and attractiveness (defined and described later in this report).

RESULTS AND DISCUSSION

Study results are presented for each study area separately and include discussion of salient findings and implications for sustainable camping management. Summarized data for each study area are presented in Table 6 for two core indicators of concern: site size and area of vegetation loss. The size of recreation sites and campsites is widely recognized as the most important single measure of their resource impact (Marion 2016) and this is the most used indicator in carrying capacity and visitor use management frameworks. Cole (1989a) supports area of vegetation loss as another important indicator reflecting both the proportion of vegetation lost and the areal extent of vegetation loss. This measure is easily interpretable and standardized across all study areas, though we note and emphasize that maximum values of absolute vegetation loss are determined by the vegetation cover present in adjacent undisturbed control areas (e.g., up to 100% when control vegetation cover is 100% but much lower when control vegetation is sparse). Cole (1989a) also emphasizes how reliance on this indicator reinforces adaptive management decision-making to: 1) concentrate use on a small number of sites rather than spreading use over a larger number of sites, and 2) concentrating use on as small a part of the campsite as possible (e.g., already denuded core areas). His direct comparisons of indicator data across several study areas reveal and document the advantages of these impact-minimization policies: 1) spreading use on larger numbers of sites results in substantially greater aggregate vegetation loss than concentrating use on a smaller number of high-use sites, and 2) factors that spatially concentrate camping activity, including physical factors like sloping topography, rugosity, and dense woody vegetation, or LNT messaging to concentrate activity on already barren areas, is the "most effective means of minimizing vegetation loss" (Cole 1989a). Our current research strongly agrees with and supports this guidance.

Additionally, we present and emphasize several different measures for these two indicators. The aggregate sum measure for a given management unit and/or geographic subunit or travel zones is perhaps the most important and when managers set standards/thresholds on this value they *retain flexibility* in accommodating increasing use over time by reducing the sizes of campsites *and/or* their numbers. We therefore also include maximum values and present data on the numbers of larger sites. Finally, we present median and mean values of central tendency, with median values generally preferred when sample sizes are larger (e.g., ≥10) and/or have skewed distributions; mean values can also be unduly affected by relatively small numbers of extremely large values (outliers).

Cleveland National Forest

In recent years the PCTA has issued between 6000-8000 thru-hike or long distance permits per year, including 3000-5000 northbound thru-hiking permits that start at the U.S.-Mexican border in southern California. Historically, in April and May each year a large "bubble" of peak use develops in southern California that has the potential to produce recurring problems with crowding and campsite proliferation, expansion, and associated resource impacts. To address this salient challenge and protect the region's arid and semidesert soils, vegetation, and wildlife, the PCTA now limits daily northbound permits to 50. In particular, managers are concerned with large gatherings of campers at the limited number of locations that provide water, with improper disposal of human waste, increased wildfire threats from campfires, and threats to rare species like the Southwestern Arroyo toad.

Following dialogue with Lindsey Steinwachs, USFS, Cleveland NF, who served as our principal federal contact, our field staff collected data at three well-established camping locations in March, 2017: Barrel Spring (PCT mi 101.5, 6 sites), Fred Canyon (PCT mi 32.0, 2 sites), Hauser Canyon (PCT mi 15.4, 2 sites), all of which were flat riparian areas with clusters of campsites. Each site was visited and field staff conducted comprehensive searches to locate and measure all campsites with visual evidence of camping use and impact. When adjacent small tenting "satellite" sites were found we combined them with the nearest campsite.

We also visited three large campgrounds at Lake Morena County Park (PCT mi 20.0), Burnt Rancheria (PCT mi 41.5), and Laguna (PCT mi 47.5), the latter two are managed by the Cleveland NF within the Laguna Mountain Recreation Area. These well-established campsites and fee-based campgrounds are optimally located to accommodate the great majority of camping by PCT hikers within the study area, the southernmost 102 miles of the PCT. Finally, we visited a former U.S. Air Force station site (PCT mi 43.3) within the Recreation area to investigate its potential for use in developing additional camping capacity in the future.

Along the PCT in this section visitors generally seek out flat riparian areas that provide shade and water. Unfortunately, this creates conflicts with the protection of the rare Arroyo toad, which burrows into the non-vegetated dry sandy creek beds during hot daytime hours and during droughts. Such locations are also used by backpackers for both tenting and catholes during most of the dry season, a significant concern of managers. Shifting camping out of flat sandy dry riparian washes would resolve this resource protection conflict.

Hauser Canyon

This camping area is located at PCT mile 15.4 and had two campsites in a riparian zone – it is the first good camping location north of the border. Both sites are less than 15 feet from an intermittent stream with an aggregate area of intensive camping impact of 2,277 ft^2 (Table 6). Expansion potential ratings indicate that approximately a third of offsite areas around these sites would support expansion (Table 7). Both sites are large, with a mean value of 1,138 ft^2. Because these are open forest campsites area of vegetation loss was high, with a mean value of 567 ft^2 (Table 6). Other salient problems include proximity to the stream and threats to the Arroyo toad, trash, surface-disposed human waste, and illegal campfires. Management alternatives include closing the area and moving camping to the Lake Morena campground at PCT mile 20, creating new campsites as depicted in **Error! Reference source not found.** to shaded locations away from the stream with more sloping topography, or relocating camping to open (non-shady) locations with more distant access to water.

Fred Canyon

This camping area is located at PCT mile 32.0 and had one larger streamside campsite with two associated tenting areas and another small campsite located 25 ft from the stream. The aggregate area of camping impact is 1,941 ft^2 (Table 6) and salient problems were similar to Hauser Canyon. Expansion potential ratings indicate that approximately a third of offsite areas around these sites would support expansion (Table 7). However, this area's more open canopy allowed much greater grass cover on the campsites, so area of vegetation loss was low, with a mean value of only 107 ft^2 (Table 6). Alternatives include closing these sites and shifting camping to the Cibbets Flat campground 0.6 mi off the PCT along a dirt road where a PCT group camping area could possibly be developed. Another option is to relocate the camping to the outermost trees in the widest band of woody riparian vegetation, providing shade and shifting the camping further from the stream into more sloped terrain that deters campsite expansion. Figure 21 illustrates this option, along with shifting the PCT to avoid two crossings of the stream and the flat riparian corridor. Shifting camping to naturally occurring or constructed side-hill campsites that provide shade and access to water is the more optimal long-term solution.

Barrel Springs

This camping area is located at PCT mile 101.5 and has six larger campsites (mean size of 1,209 ft^2) with many additional associated tenting sites and an aggregate area of disturbance of 7,256 ft^2 (Table 6). Expansion potential ratings indicate that approximately a third of offsite areas around these sites would support expansion (Table 7). While some of these campsites had substantial onsite grass cover, many did not, as reflected by a high area of vegetation loss mean value of 554 ft^2 (Table 6). A spring feeds an intermittent stream that runs quite close to most of the campsites. In addition to the previously described camping impacts, this area has also experienced considerable site expansion and proliferation pressures due to higher use, and all camping occurs within a Riparian Conservation Area. Closing the area to camping would be challenging to enforce and there appear to be no good alternatives that offer both shade and water. However, camping within the area could be shifted away from the intermittent stream by placing anchored camping posts, creating visually obvious campsite boundaries with rocks, and providing an adequate quantity of ideal tenting spots to attract use. Unfortunately, there is very limited potential within the area to shift camping to sloping terrain due to rockiness and the lack of shade.

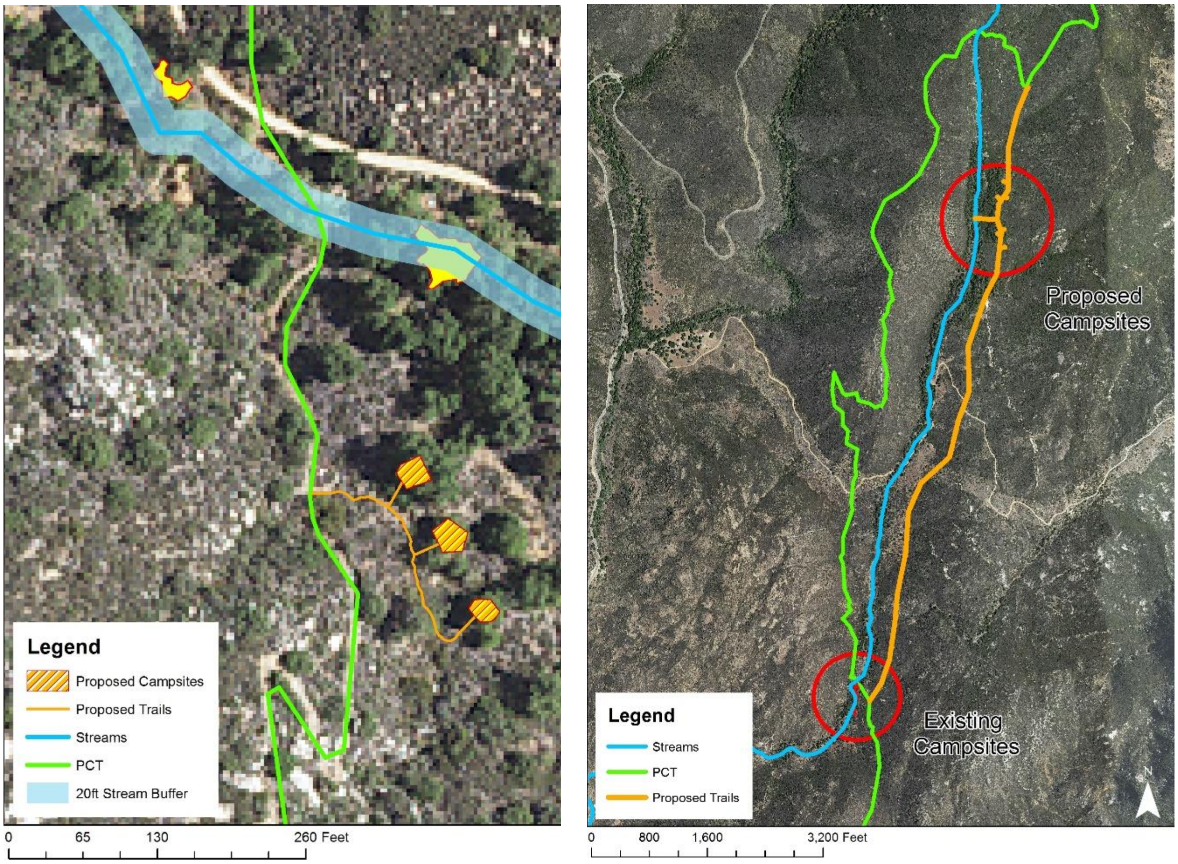


Figure 21. Existing riparian camping locations within Hauser (left) and Fred (right) Canyons, including illustrated potential new sustainable camping locations that avoid riparian impacts by shifting camping to the outermost band of tree cover. In Fred Canyon the trail might be relocated to avoid creek crossings and revealing the flat shady riparian areas to campers.

Proposed Campsites at a Retired Air Force Station

This potential camping area is at PCT mile 43.3 and consists of a large previously developed but restored flat area located at the top of the ridge with an excellent sunset vista. Trees provide shade around the perimeter and the area is accessible to vehicles beyond a locked gate, which could be used to refill a water tank at the site, or visitors could carry water from the Desert View Picnic Area 0.77 mi to the south. Individual campsites would need to be developed as described for Barrel Springs to avoid campsite expansion and proliferation problems within the large flat area. The area does have some potential to develop campsite locations where topography and existing rockiness and uneven ground can be employed to constrain future campsite expansion. Horse corrals would need to be included to contain and concentrate their impacts if camping with horses is permitted. A composting or pump-out vault toilet would also likely be needed if the area becomes well-used.

Commercial Campgrounds

Visits to three large campgrounds at Lake Morena County Park (PCT mi 20.0), Burnt Rancheria (PCT mi 41.5), and Laguna (PCT mi 47.5), revealed no problems with crowding, conflicts with other campground guests, use/abuse of campground facilities, and resource impacts. Despite repeated questioning with campground managers, none were able to describe any issues of concern. Campground managers stated that even during peak use periods they were able to accommodate the thru-hikers without resource or social impacts/problems. We also visited and examined the camping areas used by PCT hikers at each campground and found no resource impacts of concern, or that were different from use of the other campground areas. Most were group sites situated on resistant/resilient grassy surfaces.

Discussion

The most salient finding is that the use of commercial campgrounds that host PCT hikers in special group site camping areas has been highly successful. The hikers we met and spoke with during visits to these campgrounds liked them and the campground managers and hosts reported no problems, in spite of multiple prompts and follow-up questioning. Clearly, the use of these larger campgrounds has prevented the substantial problems with campsite proliferation, expansion, and social crowding/conflict that has long occurred in Georgia from the large spring "bubble" of A.T. use, though the PCT's permit ceiling of 50 has also been a significant constraint. When we inquired about large clusters of visitor-created campsites within the first hundred miles of the southern terminus the land managers cited the Barrel Spring's area. Thus, the primary issue of consequence is whether using these campgrounds is consistent with the intended PCT backcountry "experience." Perhaps their use is acceptable to accommodate the large bubble of spring use until it can disperse, particularly in areas of limited shade and water.

Camping impacts at the undeveloped sites reveal and illustrate the common problems associated with accommodating camping on sites originally selected and developed by visitors, which in this PCT section occur in flat riparian areas providing water and shade. Such locations are generally not sustainable when visitation increases, inevitably enlarging existing sites, creating new campsites in dense clusters, and increasing the likelihood of severe resource impacts, crowding, and conflict. With considerable initial and sustained long-term actions, camping can be intensively managed with site design, anchored facilities, maintenance, and visitor education/regulation to deter site expansion and proliferation-related impacts in flat terrain. However, the most optimal permanent solution is to completely shift camping to locations where these impacts can't happen – to sloping and/or uneven topography. Using topography to permanently separate and constrain the expansion of camping impact to small resistant locations provides the best long-term protection of riparian areas and rare species habitat. In this area, an additional requirement is to find sustainable locations outside of Arroyo toad habitat with shade and reasonable access to water.

In conclusion, this southern section of the PCT has experienced few of the very substantial camping impacts that have long plagued the A.T., which we attribute to the regulatory 50-person limit on PCT hikers departing from the southern terminus, and to use of large commercial campgrounds. Only one location (Barrel Springs) reveals the beginnings of common problems of campsite expansion and proliferation that are far more severe at numerous locations on the southern A.T. For example, five A.T. "mega-clusters" of campsites larger than 10,000 ft^2 occurred within a 9% representative sample of the first 100 miles of the A.T. (Marion et al. 2020). The lack of similar significant PCT problems suggests that additional capacity could be accommodated with limited additional camping management effort to expand camping capacities in a relatively small number of locations. However, we did not evaluate more northern proximate PCT areas that may be experiencing campsite expansion and proliferation problems.

Table 6. Summary data on campsite size and area of vegetation loss for the PCT study areas.

Unit	Area	N	Site Size (ft2)				Area Vegetation Loss (ft2)			
			Median	Mean	Sum	Max	Median	Mean	Sum	Max
Southern Border	Barrel Spring	6	909	1,209	7,256	2,272	500	554	3,325	860
	Fred Canyon	2	970	970	1,941	1,637	106	107	213	213
	Hauser Canyon	2	1,138	1,138	2,277	1,786	567	567	1,133	1,072
San Bernardino NF	Splinters Cabin -	16	619	969	15,504	3,085	237	333	5,328	1,095
	Deep Creek Hot	42	445	911	38,251	12,835	98	163	6,839	1,669
Sequoia & Kings Canyon NP	Lower Crabtree	10	481	548	5,478	1,580	58	99	988	561
	Upper Crabtree	28	388	584	16,374	2,733	34	65	1,832	615
Inyo NF	Trail Camp	59	269	490	28,891	2,757	35	64	3,756	358
	Outpost Camp	10	385	901	9,007	2,796	49	112	1,115	363
	Thousand Island L.	85	274	358	30,422	2,141	97	138	11,766	751
Yosemite NP	Glen Aulin	27	860	1,088	29,378	3,724	615	787	21,239	3,091
	PCT Tuolumne	66	466	1,054	69,586	10,393	133	421	27,767	4,276
Desolation Wilderness	Dicks Lake	23	329	527	12,126	2,330	127	240	5,528	1,934
	Fontanillis Lake	3	243	259	778	512	147	155	465	310
	Gilmore Lake	25	918	1,214	30,361	3,446	547	769	19,236	2,822
	Lake Aloha	110	158	338	37,180	3,052	40	107	11,818	1,934
	Lake of the Woods	28	337	1,539	43,108	11,768	72	700	19,592	7,120
	Lower Velma Lake	53	163	271	14,342	1,035	33	92	4,869	720
	Middle Velma Lake	29	382	500	14,496	2,043	97	162	4,696	751
	PCT Trailside	4	353	338	1,352	563	98	134	536	341
Mt Hood NF	L. Twin Lake	17	1,265	2,925	49,734	8,854	624	1020	17,347	3,360
Crater Lake NP	Bybee Creek	2	1,566	1,565	3,131	2,429	477	477	954	862
	Dutton Creek	3	581	599	1,796	688	480	494	1,482	568
	Grouse Hill	3	1,237	1,059	3,176	1,305	0	0	0	0
	Lightning Spring	3	1,071	1,057	3,171	1,187	718	619	1,856	758
	Mazama Group	3	1,147	927	2,780	1,491	803	719	2,158	1,238
	Red Cone Springs	3	347	323	968	366	154	135	405	174
North Cascades NP	Bridge Creek	8	1,898	3,322	26,576	10,899	1,088	2313	18,503	9,047
	Fireweed	9	330	1,047	9,422	6,371	273	798	7,178	5,288
	Hideaway	1	1,654	1,654	1,654	1,654	1,373	1,373	1,373	1,373
	High Bridge	1	4,898	4,898	4,898	4,898	1,225	1,225	1,225	1,225
	Illegal	1	71	71	71	71	43	43	43	43
	North Fork	4	952	1,107	4,429	2,141	790	898	3,590	1,777
	Shady	2	652	652	1,304	744	358	358	716	450
	Six Mile	1	3,127	3,127	3,127	3,127	2,986	2,986	2,986	2,986
	South Fork	4	541	719	2,878	1,660	372	611	2,442	1,585
	Tumwater	2	1,820	1,820	3,641	2,679	1,210	1,210	2,419	1,621
All Units		695		764	530,864			312	216,718	

Table 7. Data on three measures of expansion potential and offsite rugosity for PCT study area campsites.

Unit	Area	N	Expansion Potential (%)[1]			Expansion Potential (%)[2]			
			Low	Medium	High	Mean	Median	Min	Max
Southern Border	Barrel Spring	6				63	67	30	90
	Fred Canyon	2				65	65	60	70
	Hauser Canyon	2				58	57	50	65
San Bernardino NF	Splinters Cabin - Devils Hole	16	19	13	69	1	0	0	5
	Deep Creek Hot Sprs – Spillway	42	5	17	79	25	0	0	10
Sequoia & Kings Canyon NP	Lower Crabtree Meadow	10	30	10	60	69	83	10	100
	Upper Crabtree Meadow	28	32	57	11	44	45	5	80
Inyo NF	Trail Camp	59	0	0	100	100	100	100	100
	Outpost Camp	10	20	30	50	73	73	40	100
	Thousand Island L.	85	5	22	73	86	90	25	100
Yosemite NP	Glen Aulin	27	0	33	67	83	90	30	100
	PCT Tuolumne	66	20	44	36	64	65	0	100
			Offsite Rugosity (%)[3]			Expansion Pot., Tent Pads (#)[4]			
			Low	Medium	High	Mean	Median	Min	Max
Desolation Wilderness	Dicks Lake	23	17	39	44	1.0	1	0	3
	Fontanillis Lake	3	0	0	100	0.0	0	0	0
	Gilmore Lake	25	80	20	0	6.8	6	1	10
	Lake Aloha	110	3	20	77	1.1	0	0	8
	Lake of the Woods	28	32	21	47	3.1	2	0	10
	Lower Velma Lake	53	6	31	63	1.6	1	0	8
	Middle Velma Lake	29	6	0	94	0.7	0	0	3
	PCT Trailside	4	50	0	50	3.0	3	1	5
Mt Hood NF	L. Twin Lake	17	100	0	0	4.5	4	0	10
Crater Lake NP	Bybee Creek	2	0	100	0	3.0	3	3	4
	Dutton Creek	3	100	0	0	4.0	4	3	5
	Grouse Hill	3	100	0	0	5.7	5	3	9
	Lightning Spring	3	67	33	0	3.0	4	1	4
	Mazama Group	3	100	0	0	1.3	2	0	2
	Red Cone Springs	3	100	0	0	3.7	4	3	4
North Cascades NP	Bridge Creek	8	50	50	0	7.9	9	4	10
	Fireweed	9	22	67	11	5.7	4	0	10
	Hideaway	1	0	0	100	2.0	2	2	2
	High Bridge	1	100	0	0	10.0	10	10	10
	Illegal	1	100	0	0	10.0	10	10	10
	North Fork	4	0	50	50	2.1	1	1	5
	Shady	2	0	100	0	9.0	9	8	10
	Six Mile	1	0	0	100	2.0	2	2	2
	South Fork	4	0	25	75	1.3	1	0	3
	Tumwater	2	0	50	50	6.0	6	2	10

1 – L = Low expansion potential - off-site areas are completely unsuitable for any expansion due to steep slopes, rockiness, dense vegetation, and/or poor drainage, M = Moderate expansion potential - off-site areas moderately unsuitable for expansion due to the factors listed above, and H = High expansion potential - off-site areas are suitable for site expansion, features listed above provide no effective resistance to site expansion.

2 – Estimate the percentage of area within a 100 ft “doughnut” buffer zone beyond the current campsite boundary that would inhibit all tenting activity due to sloping topography or substantial rockiness.

3 – Estimate of surrounding offsite areas with low, medium, and high rugosity (uneven and/or rocky terrain) sufficient to deter camping activities.

4 – Count of the number of 10x10 ft offsite (pristine) spots where someone could create a new tent pad within a 10m buffer based on topography (flatness) and/or rugosity (uneven ground, rockiness), ignoring bedrock spots.

San Bernardino National Forest

Deep Creek River Corridor

This fieldwork was conducted in August of 2019 by Johanna Arredondo with the assistance of Rari Marks and Tracy Carter, of the San Bernardino NF, and PCTA volunteer Timothy Morris; our planning contact was Togan Capozza. The group assessed camping management challenges along a 17-mile segment of the PCT (mile 298.5-311.2) in the northwestern part of the national forest along the Deep Creek River from Splinters cabin to Devils Hole, and from Deep Creek Hot Springs (DCHS) northbound to the Spillway. This section of the PCT is closed to camping within one mile of each side of Deep Creek, yet a substantial amount of illegal camping occurs. Fieldwork focused on the more easily accessed and heavily used camping areas to assess resource conditions and identify potential sustainable camping options. This segment includes the very heavily used DCHS and Aztec Falls areas.

Notable findings included documentation of large numbers of illegal campsites, (N=58), extensive networks of intensely eroded non-sustainably aligned ITs, and an exceptionally large mega-cluster of campsites at DCHS with 34,095 ft^2 of intensive trampling and impact (Arredondo 2020) (Table 6). This exceeds the size of the largest mega-cluster of campsites found on the A.T., the Hawk Mountain Shelter, with an aggregate area of 31,390 ft^2 (Marion et al. 2020). However, field staff noted that there was difficulty in determining if the sites assessed were impacted from day or overnight use; some sites were clearly impacted largely from day use activities due to their proximity to the hot springs or other popular day-use swimming locations. Regardless, the majority of sites were located in riparian areas, along the Deep Creek shoreline and floodplain, and included numerous sandy beach areas that are a sensitive habitat for the rare Arroyo toad. Furthermore, site expansion potential data revealed that the majority (69-79%) of sites have high expansion potential (Table 7), though median site sizes were intermediate (619 and 445 ft^2) and area of vegetation loss values relative low (237 and 98 ft^2) (Table 6).

ITs were walked with a Trimble GPS unit to provide geospatial documentation of their aggregate length (18,072 ft) and aggregate areal extent (34,245 ft^2). Other notable impacts included trash, graffiti, and improperly disposed human waste within riparian zones.

Discussion

This section of the PCT does have significant visitor impact problems with both campsite expansion and proliferation. Recreation sites predominantly used by day visitors are associated with the hot springs and other high-quality swimming holes. Without a high management presence and enforcement, fully separating camping from popular day use destinations would be difficult. A possible management option is to promote the shifting of land-based activities to either rock surfaces, and where necessary, a limited number of stream-side beaches that are naturally devoid of vegetation due to frequent flooding. While these beaches may be Arroyo toad habitat, it is perhaps unrealistic to expect that any management actions could effectively prohibit recreational activity near the most popular swimming areas. Their intensive use has likely already displaced the toad during the most popular seasons.

IT network impacts are widespread and extensive amounts of soil are being displaced down and eroded from steep informal trails into Deep Creek, a Wild and Scenic River. Many areas had multiple parallel non-sustainable ITs where a single sustainable trail could suffice. This is a significant form of impact that has not been mitigated. In locations where there are well-used non-sustainable trails down to Deep Creek, a preferred solution is to close and replace these by developing a single sustainable trail in each high use area and shifting all traffic to it through improved signage, trail maps/guidance, and other educational media. Additional site management actions could include blocking the initial sections of connecting ITs with rocks and brush or fencing, and signage directing visitors to the sustainable formal trail. While some visitors may continue using ITs, this is better than blocking existing non-sustainable trails and having visitors create entirely new parallel trails that are also non-sustainable.

Ideally, camping should be accommodated outside of the immediate riparian corridor – sandy shorelines of Deep Creek are ideal habitat for the endangered Arroyo toad and flooding within the riparian zone makes any management facilities costly to maintain. Management actions that effectively address both site expansion and proliferation are needed. A designated site camping policy is likely necessary and the most effective practice for this high use area. Field staff were able to locate some representative sustainable existing campsites within this corridor (Arredondo 2020). Approximately 0.2 mi north of Aztec Falls at PCT mi 299.5, there are two sites located outside of the riparian zone and surrounded by sloping terrain, rugosity, and thick understory vegetation. Two campsites located at PCT mi 300.8 just south of Devils Hole were also rated as highly sustainable, though they are rather close to the PCT and to OHV access at Devils Hole. Finally, two Rainbow Bridge campsites (PCT mi 310) located on rocky benches well above the creek were identified as sustainable.

Managers could likely find additional similar sustainable locations that are constrained by sloping or uneven/rocky terrain and proactively develop them as campsites, promoting their use through a formal established or designated site camping policy. Use could be attracted to these sites by developing perfect tenting sites, a sustainable water access trail, and ensuring their inclusion in existing phone apps, guidebooks, and backpacking maps. In areas that receive intensive use the provision of toilet facilities may also help attract use and prevent impacts to water quality. These actions would shift use from more sensitive riparian areas, which would be easier to close and restore. Report authors are available for further consulting.

Sierra Nevada Range

Our research team conducted fieldwork and consulting in the high-use Sierra Nevada range in July and August, 2017 and 2018, including Sequoia Kings Canyon NP, Inyo NF, Yosemite NP, and Desolation Wilderness. Contacts included Theresa Fiorino, SEQU; Diana Pietrasanta, INYO; Ed Dunlavey, YOSE; Michelle Zuro-Kreimer and Charis Parker, Eldorado NF; and Shannon Maguire, USFS Lake Tahoe Basin Management Unit. In selecting the Sierra study areas we sought to assess and evaluate camping conditions and management options in several unique environmental settings that receive high use: 1) trailside camping (Yosemite NP), 2) a backcountry campground (Yosemite NP, Glen Aulin), 3) camping in and near lake basins (Inyo NF, 1000-Island Lake Basin; Eldorado NF, Desolation Wilderness), 4) meadow camping (Sequoia NP, Crabtree Meadows), and 5) high elevation areas below a mountain summit or pass (Inyo NF, Trail and Outpost Camps). We note that Trail and Outpost camps are somewhat removed from the PCT but included them due to their exceptionally high use and elevation. We expected to find different camping impact management challenges and solutions within these differing high-use settings. In each location we conducted comprehensive searches for campsites with clear recent use-related vegetation or soil disturbance (i.e., old unused fire rings and meadow or bedrock areas w/no obvious camping impact were omitted). As noted for other areas, when adjacent small tenting “satellite” sites were found within 75-100 feet we frequently combined them with the nearest campsite – other studies may treat these as separate campsites.

Sequoia-Kings Canyon National Park

Our research team traveled in July and August 2017 to conduct fieldwork and consulting in Sequoia-Kings Canyon NP (contact: Theresa Fiorino).

Crabtree Meadows

This has long been a popular PCT camping area located about 3.5 mi southwest from Mt. Whitney and includes a seasonally staffed ranger cabin located at the upper meadow. We assessed 21 campsites around the meadow and 7 campsites on the opposite (north) side of Whitney Creek. These campsites are not formally marked, and site expansion/proliferation problems were evident as most are located in flat to slightly sloping terrain. These sites included 65 separate tenting and other use areas totaling 16,374 ft^2. This area has a pit toilet; we found only two instances of improperly disposed human waste and two instances of toilet paper. We also surveyed all campsites located along a 2.6-mile triangular trail loop that included Lower Crabtree Meadow, a segment of the PCT and of the JMT. This loop yielded 10 additional campsites, including 14 use areas with an aggregate area of 5,478 ft^2. Expansion potential is low to medium for most Upper Crabtree Meadow campsites (median size of 388 ft^2) but low for nearly a third of the Lower Crabtree sites and high for nearly two-thirds of the rest (median size of 481 ft^2)

(Table 6 & Table 7). No improperly disposed human waste or toilet paper was found in the areas around these sites.

Inyo National Forest

Fieldwork for the Inyo NF occurred in Aug of 2017. Mt. Whitney is the highest mountain in the lower 48 states and an 11-mi well-maintained trail to the summit has made it a popular destination for both day-hikers and overnight campers. Annually, approximately 16,000 hikers attempt to climb Mt. Whitney from Whitney Portal on the east side, with another 4,000 approaching from the PCT in Sequoia NP on the west side. We surveyed all designated campsites at Trail Camp (59 sites) and Outpost Camp (10 sites), situated along the primary Mt. Whitney hiking trail on the east side. Due to the extreme popularity of this area, special zoning has been established for visitors to the high-elevation Mt. Whitney Zone, requiring that overnight and day-use hikers obtain rationed permits, and carry out their solid human waste. A lottery limits use to 100 day-hikers and 60 overnight visitors per day during the peak use period. Overnight visitors are also required to store food and smellables in bear-proof canisters carried in their backpacks.

The summit, Trail Camp, and Outpost Camp used to have toilets beginning in the 1960's. However, the high elevation and cold temperatures, high use, poor visitor compliance (discarding trash in toilets), poor functioning of the solar dehydrating/composting toilets at the camps, and management expense of using helicopters to fly out more than 4,000 pounds of human waste each year led to their removal. A waste pack-out program using WAG (Waste Alleviation and Gelling) bags was implemented in 2004, and the toilets were removed from Outpost Camp and the Whitney summit in 2006, and from Trail Camp in 2007.

Outpost Camp

While this is a designated camping area, individual campsites are not marked and visitors are free to create new campsites or expand existing sites. Field staff identified and assessed 10 campsites with 40 separate use areas at this camp, located 3.8 mi from the Whitney Portal trailhead at 10,400 ft. Aggregate area of disturbance was 9,007 ft^2 and median size was 269 ft^2 with median area of vegetation loss of 49 ft^2 (Table 6). These low areal measures are attributed to the mostly uneven and rocky terrain surrounding these campsites, which in most places inhibits site expansion (Table 7). We found 3 instances of improperly disposed human waste, 17 instances of toilet paper, and no WAG bags in the vicinity of these campsites.

Trail Camp

This camp, also known as High Camp, is located 6 mi from the Whitney Portal trailhead at 12,000 ft of elevation, the highest staging camp for Whitney hikers. We assessed 59 campsites with 87 separate use areas, a total area of disturbance of 28,891 ft^2, with among the very smallest median site size (269 ft^2) and area of vegetation loss (35 ft^2) values (Table 6). While this area is designated, individual campsites are not marked or designated, so site proliferation is possible and has occurred. However, the entire camping area is extremely resistant to visitor impact, consisting largely of sparsely vegetated areas of exposed rock with small barren patches of soil used for tenting. All 59 campsites were rated for site expansion potential at the lowest possible ratings. However, a significant and consequential finding for this location were 56 instances of improperly disposed human waste, 362 instances of toilet paper, and 37 discarded WAG bags, nearly all of which had been chewed into by local wildlife. Many of these instances occurred in a boulder field through which snow melt water constantly flows toward the shoreline of the nearby tarn, which is the primary water source for campers. This is a critical management issue.

We observed that this area has a surprisingly large number of food-attracted pika, marmots, ground squirrels, mice, and even American marten that, given their numbers and food attraction behaviors, must be frequently accessing human food and trash. We found clear evidence that these animals are chewing into used WAG bags, and that some to many visitors are unwilling to pack out leaking WAG bags that have been chewed and "opened" by animals. This problem is of significant concern because few visitors appear to be willing to store used WAG bags (day or night) in their tents. We also note that agency staff prohibit storing used WAG bags in their rented bear canisters. Facilities for their safe storage appear to be needed.

1000 Island Lake Basin

This iconic and highly popular but remote lake basin is located southeast of Yosemite NP and northwest of Mammoth Lakes. Visitors to this area may camp anywhere except within a hundred feet of lakes, streams, and trails, or within a quarter mile of the lake's outlet. We conducted a comprehensive survey of campsites around the entire lake basin, from the lakeshore up to and including portions of the surrounding higher elevation forested areas. We located and measured 85 campsites, including 142 separate use areas with an aggregate area of camping disturbance of 30,422 ft^2. Most campsites are located in open grassy meadow settings, interspersed with rock, bedrock, and uneven terrain. These terrain characteristics and the large size of the lake basin may encourage campsite proliferation and contribute to very low campsite expansion potential ratings and very small median site size (274 ft^2) and area of vegetation loss (97 ft^2) values (Table 6 & Table 7).

Despite the large aggregate area of camping impact, the numerous small campsites are well-distributed over a very large area, with minimal clustering that might degrade social conditions. Only four (4.7%) of the 85 campsites in this very high use lake basin exceeded 1000 ft^2 in size. Despite extensive searching we found only two instances of improperly disposed human waste and two instances of toilet paper (another surprising finding). We encountered Wilderness Ranger CJ Blankenship at the lake and he indicated that USFS staff had not cleaned the area of exposed human waste or TP in any recent patrols. However, we note that this area has received somewhat less use compared to prior years at this time due to late snowmelt from substantial winter snow cover, a recent road closure (Reds Meadow), and partial trail closures (Rush Creek drainage). The lack of lasting impact from prior years is attributed to the high resistance/resilience of the grassy meadow vegetation, which rapidly recolonizes barren substrates except in areas of frequent heavy traffic.

We discovered that snowmelt and subsequent standing water in this lake basin likely plays a role in forming some campsites by creating natural barren areas, which after drying out, have a "campsite-like" appearance that attracts camping use. We included only those locations with clearly visible visitor use impacts; some still retained standing water while others had dried out and had the appearance of campsites, though no actual evidence of human disturbance. Some of these areas may be erroneously assessed as campsites during monitoring assessments, and/or also used as campsites when dried out during periods of high use.

Yosemite National Park

In Aug of 2017 our crew began at Tuolumne Meadows and surveyed all campsites heading north along the PCT for 23 miles, including designated sites at the Glen Aulin backcountry camp.

Glen Aulin

Conditions were assessed on 30 forested heavily used campsites with an aggregate area of disturbance of 29,378 ft^2 and large median site size (860 ft^2) and large area of vegetation loss (615 ft^2) (Table 6). This popular backcountry camp had designated commercial use areas (included in our assessment but their commercial use was suspended) and non-commercial campsites in the same general area. This camp was well-designed and managed, though some site locations were not optimal with respect to sustainability or proximity to other sites. About two-thirds of the campsites had low campsite expansion potential ratings and these sites were primarily located in a forested setting where trampling eliminates virtually all on-site vegetation cover (Table 7). Eleven of the 30 campsites exceeded 1000 ft^2, including 4 greater than 2000 ft^2. This area has a toilet facility, and we found no occurrences of improperly disposed human waste.

PCT Segment

Excluding Glen Aulin, we found and assessed 64 dispersed campsites along this 23-mile segment with an aggregate area of disturbance of 69,586 ft^2, median size of 466 ft^2, and area of vegetation loss of 133 ft^2 (Table 6). Campsite expansion potential ratings were diverse, though 64% of the campsites are located in medium to high expansion potential terrain in forests ranging from complete to relatively open canopies (Table 7). Significant campsite expansion problems were evident along this PCT corridor. Eighteen of the 64 campsites exceeded 1000 ft^2 and 7 of these were "mega-sites" exceeding 2000 ft^2 in size, including one measuring 10,393 ft^2. Our data and photos indicate that these excessively large sites were located in flat moderate to closed forest canopy settings, while a much larger number of smaller campsites were located under open forest canopies that allowed nearly complete grass cover.

It was evident from our survey that park staff have achieved high compliance with their visitor guidance to select a "previously impacted campsite at least 100 ft from water sources and trails." We encountered two rangers on patrol during our 5-day engagement and presume that their common presence is a likely explanation. We also discovered evidence of Yosemite's campsite active restoration program, finding many campsites located >100 ft from the trail and water with small cleaned and even unused fire rings, most situated out of sight from the trail. Some had no visible or measurable impact and could be viewed as "proposed" campsites created by the restoration crew. We found only four occurrences of improperly disposed human waste sites and two instances of toilet paper, indicating high compliance with the cat-hole disposal practice.

Desolation Wilderness: Eldorado NF & Lake Tahoe Basin Mgmt. Unit

Our field crew visited the Desolation Wilderness in July, 2018 to assess 275 campsites at seven high-use lake basins: Dicks Lake (23 sites), Lake Aloha (110 sites), Gilmore Lake (25 sites), Lake of the Woods (28 sites), Lower Velma Lake (53 sites), Middle Velma Lake (29 sites), and Fontanillis Lake (3 sites) (Table 6). A sustainable camping management workshop was also presented to staff from both national forests. This research included a more in-depth focus on further developing: 1) bio-physical and social indicators of campsite sustainability and functionality/amenities, and 2) exploratory GIS analyses designed to identify highly sustainable new campsite locations based on topography using LiDAR data. We performed field-based sustainability assessments on existing campsites and at the potential "highly sustainable" campsite locations identified by the GIS-LiDAR analyses conducted prior to fieldwork. This work evolved from and extended statistical modeling research from the A.T. corridor designed to evaluate sustainability factors that substantially influence areal measures of camping impact (site size, area of vegetation loss, area of exposed soil).

The A.T. work identified sloping terrain as the most influential factor that managers can employ to constrain areal measures of camping impact and we have sought to verify this finding from our PCT fieldwork. This work and our continuing GIS analyses with PCT datasets is allowing us to develop GIS protocols that employ LiDAR high resolution topography data to evaluate the sustainability of campsites with respect to macro-topography (sloping terrain) and micro-topography (rockiness and uneven ground). The focus of this work is on identifying campsites that can receive intensive use over time while resisting expansion and proliferation to retain a small "footprint" of impact (Arredondo & et al. 2021, Marion & others 2020).

The Desolation Wilderness fieldwork also enabled a focus on evaluating camping impacts in seven Sierran lake basins. For most of the lake basins an "unconfined" camping policy directs visitors to camp at least 100-200 ft away from shorelines and 500 ft from shoreline restoration areas. We assessed 243 campsites within lake basins managed under this policy with an aggregate impact of 109,283 ft^2 and small median site sizes (excepting Gilmore Lake) ranging from 158 ft^2 to 382 ft^2, with extremely low area of vegetation loss values (40–147 ft^2) (Table 6). A noteworthy finding here is the occurrence of substantial campsite proliferation and the resulting large number of campsites, many of which appeared to receive low use. Most campsites are in rocky terrain that effectively limits campsite expansion. Starting with this study area we switched to two new campsite expansion potential indicators, including a categorical rating of offsite rugosity (rockiness/uneven terrain) and a simple count of potential "new" tenting spots in adjacent offsite areas (see Table 7, descriptions in footnotes). As expected, these new indicators for the Desolation lake basins generally characterized offsite areas as resistant to campsite expansion (with some exceptions discussed below). For example, the Lake Aloha basin with 110 campsites had 77% of the sites rated "high" for offsite rugosity and a median of 0 potential new tent pads in adjacent offsite areas: median site size was an incredibly low 158 ft^2 with median area of vegetation loss of 40 ft^2 (Table 6).

The Desolation dataset also permitted an evaluation of designated site vs. unconfined camping. The USFS has implemented designated site camping at several of the most popular lake basins, including Lake of the Woods (assessed in this study) and Eagle, Grouse, and Hemlock Lakes. However, our data indicate that the designated site camping policy has been unsuccessful in restricting the areal extent of camping at Lake of the Woods, where we found 9 designated campsites and 19 illegal sites accounting for 43,108 ft^2 in aggregate area of impact (median/mean size = 337/1,539 ft^2), compared to 110 campsites and 37,180 ft^2 in the entire Lake Aloha basin (median/mean sizes = 158/338 ft^2), or 53 campsites with 14,342 ft^2 at Lower Velma Lake (median/mean size = 163/271 ft^2) (Table 6). The non-designated use areas we located were attributed to day use activities, illegal camping, and some recovering sites signed for restoration (with some appearance of continued use). While many of the designated Lake of the Woods campsites are sustainably located, camping is also permitted on three very large and highly unsustainable designated campsites located on a flat peninsula on the northwest side of the lake, including several adjacent illegal sites with one mega-site assessed at 11,768 ft^2 (Table 6). Eight of the 28 campsites assessed were greater than 1000 ft^2, most were located on the flat peninsula.

The Gilmore Lake basin is atypical in that only 25 campsites accounted for 30,361 ft^2 of camping impact, with large median and mean campsite sizes (918 ft^2 and 1,214 ft^2) and area of vegetation loss (Table 6). There are also 12 campsites >1000 ft^2, including 4 mega-sites (>2000 ft^2) in the Gilmore basin. This lake basin includes large areas of flat terrain with substantially less rock and mostly closed forest canopies, resulting in fewer opportunities for sustainable camping. Offsite rugosity ratings for Gilmore campsites found that 80% of the sites have low rugosity with the rest in the medium category and the new campsite expansion potential indicator had a very high mean of 6.8 offsite tenting sites – these values make the Gilmore Lake basin exceptionally "non-sustainable" for camping compared to all other lake basins (Table 7).

The Desolation Wilderness fieldwork provided a new opportunity to develop and refine GIS analytical protocols to efficiently locate highly sustainable campsites which could then be quickly field-inspected to verify or further evaluate their potential use. Such tools can be useful in areas like the Gilmore Lake basin where new sustainable campsites may be needed. Prior to fieldwork our staff developed slope maps using LiDAR topographic data for each lake basin within which we conducted fieldwork. GIS analyses were developed and applied to search and identify prospective highly sustainable "naturally-occurring" relatively flat campsite locations in two size classes, 200-500 ft^2 and 501-1000 ft^2, situated within more steeply sloped terrain (Figure 22). These were output as georeferenced pdf files used during fieldwork in the Avenza phone app to permit easy navigation to the prospective candidate campsites. A sample of these locations were visited during fieldwork for ground-based evaluations. Most of the candidate campsites were judged to be highly sustainable, though a few were somewhat proximate to flat areas. Some had been discovered and used by visitors while others were pristine. Use of some would require the removal of shrubs, saplings or rocks and/or substrate leveling to develop usable tenting spots. Some candidate sites had excessive rockiness that would possibly prohibit their use as campsites, though some of these had flat bedrock areas for freestanding tents and/or "kitchen" sites (Figure 22).

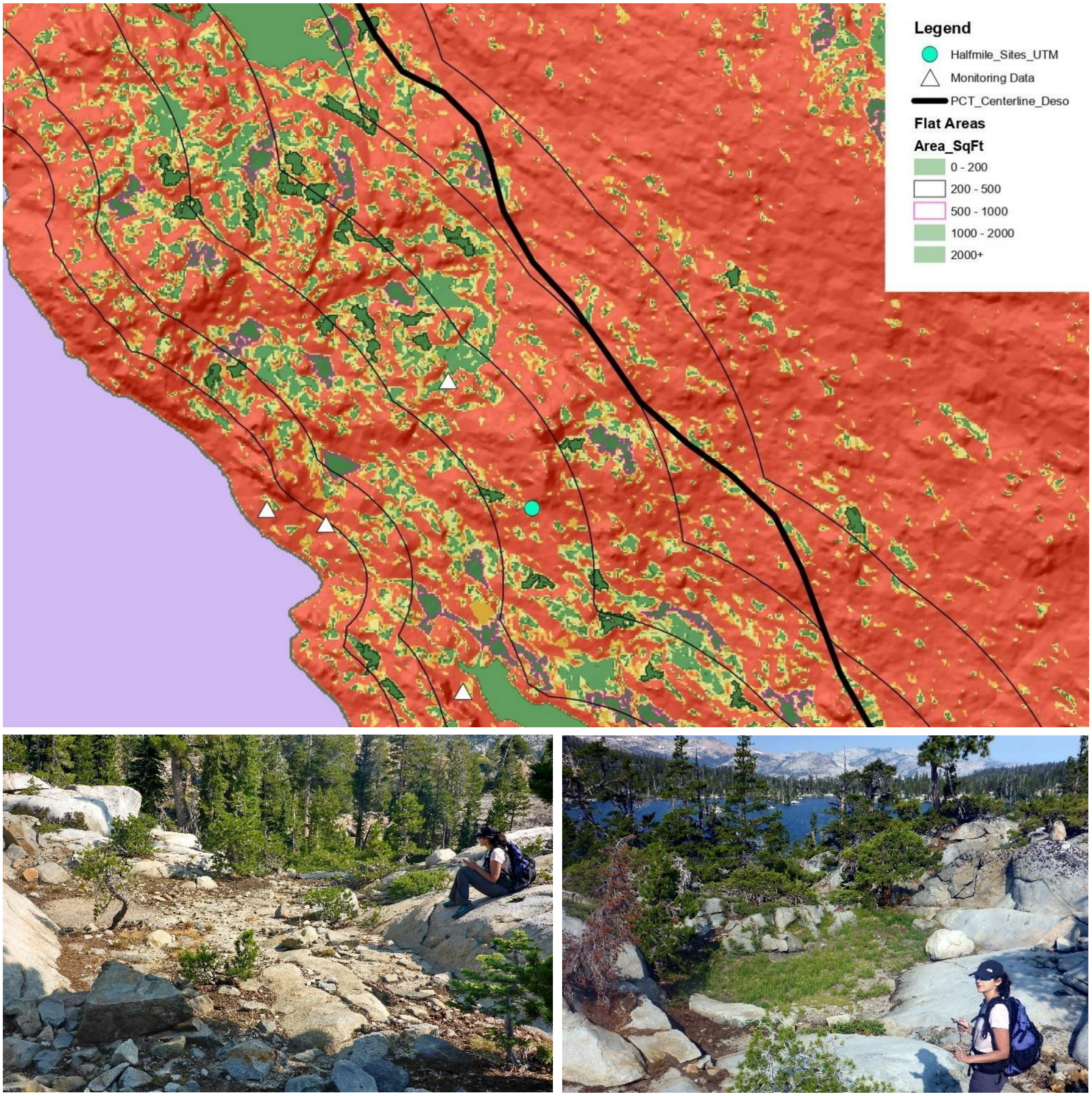


Figure 22. Top: slope map of South Fontanillis Lake shoreline showing flat areas of various sizes (green) surrounded by sloping terrain (yellow, tan, red); GIS analyses identified the areas outlined in black as the most sustainable prospective candidates based on size and surrounding terrain. Existing campsites monitored by USFS (white triangles) and included by Halfmile (green dots) are also shown. Bottom: Field staff located and evaluated a sample of black-outlined prospective candidates, including those shown here. Both these spots had evidence that visitors had found and used them, while others were completely pristine.

Discussion (Sierra Nevada Range)

Sequoia-Kings Canyon National Park

Cole and Parsons (2013) reported on campsite monitoring results for this park conducted in the 1970s compared to remeasurements of a 44% sample in 2006/7. Of 2,955 remeasured campsites, only 1,795 were still actively used with the balance judged to be restoration sites no longer used for camping. Park staff had undertaken an intensive program to close and restore unnecessary campsites deemed too close to water, and reduce the sizes of the largest sites. There is no mention in the report about intentionally retaining the most "sustainable" campsites. Regardless, their work was cited as a primary reason for success in achieving a two-thirds reduction in aggregate camping impact from the late 1970s to 2007. Also, though not specifically called "Established" site camping in the report, their actions are indicative of such a policy: they selected a subset of preferred well-established campsites to promote resource protection and desired social qualities, and they closed and restored non-selected sites. Supporting management efforts also included eliminating campfire evidence where fires are illegal and maintaining small campfire rings on the remaining sites.

Our data revealed mixed success, though our sample was purposive and quite small. On the positive side, campsite median sizes were small (388 and 481 ft^2) and area of vegetation loss measures were extremely small (58 and 34 ft^2) (Table 6). However, six of the 31 sites were larger than 1000 ft^2, these were generally located in flatter terrain. Another issue was a relatively high density of campsites around the Upper Crabtree Meadow, some of which are quite close together, jeopardizing social qualities during busy periods. We suggest that managers consider site sustainability as described in this report and improved camping density/site spacing (discussed later in this report) whenever selecting a subset of preferred Established campsites. Given the more developed nature of camping at the Upper meadow and presence of the staffed cabin here, it may be acceptable to mark the preferred campsite locations in this area to maximize inter-site distances and promote improved social conditions.

Inyo National Forest

Campsite sustainability research from the A.T. corridor found sloping terrain and offsite rugosity to be core factors that constrain campsite site, compelling campers to spatially concentrate their activities (Arredondo et al. 2021). Our campsite data from Trail Camp high on the shoulder of Mt. Whitney scored the lowest possible values for our campsite expansion potential measures, achieving a very small median site size (269 ft^2) and area of vegetation loss (35 ft^2) (Table 6). Given that this area experiences extremely heavy camping use, these areal measures of impact are quite astounding. However, 10 of the 59 campsites still exceeded 1000 ft^2 in size, including two that were greater than 2000 ft^2. While some of these may have resulted from our merging proximate use areas, managers might be able to use scree walls, common in this area, to reduce the sizes of any larger contiguous sites.

Regardless, since individual campsites are not designated site proliferation is both possible and evident. Campsite occupancy surveys are needed to determine the extent to which there is an excessive number of campsites at this location. We also note that a great many of these campsites were close together and within sight of each other, posing concerns for social conditions in this high-density camping area. This is a common but unfortunate finding in popular areas where visitors have the freedom to select campsites. However, there are numerous outer sites that were separated by much greater distances should visitors desire solitude and be motivated to search them out. Managers could close some of the sites with large rocks in areas with the highest site density and shift use to the outer sites by including all "preferred" established sites in phone apps and a map posted at the camping area. Monitoring site occupancy rates may also reveal excess (unnecessary) campsites that could also be closed. Marking a limited number of well-spaced "designated" campsites might also be considered.

Also of concern was the very large and diverse number of wildlife seen at this camp, an indication of poor food storage practices despite the requirement that food and trash be stored in bear canisters. Wildlife are clearly accessing human food and trash and we saw 37 discarded WAG bags, nearly all had been chewed into by wildlife. Additionally, we found 56 instances of surface disposed human waste and 362 instances of toilet paper behind boulders and rocks in offsite areas, an unprecedented number compared to all other study areas. We documented clear evidence that many visitors are not using the WAG bags and others are not carrying them out. Animal-proof

WAG bag containers may be necessary unless toilets are restored. Improved and expanded visitor education and enforcement related to effective food/trash and WAG bag storage appears to be a critical management issue.

The very popular Thousand Island Lake basin was a particularly interesting study area. Despite a large aggregate area of camping impact (30,422 ft^2), this was spread across 85 well-distributed campsites with low median site size (274 ft^2) and area of vegetation loss (97 ft^2) (Table 6). A campsite occupancy survey would be helpful to evaluate the extent to which campsite proliferation has created an excessive number of campsites and avoidable impact. The low area of vegetation loss is attributed to the extensive cover of durable exposed bedrock and grass cover in the basin. Many groups placed their tents on small bare patches or grass but concentrated all other activity on bedrock surfaces. Even mean campsite size was small (358 ft^2), only 4 sites exceeded 1000 ft^2, and only two instances of surface-disposed human waste were found, suggesting substantial success with both resource protection and higher quality social experiences for this high use area. Some of the most sustainable sites with the best vistas were located furthest from the lake in more upland terrain or on the southeast side of the lake, though most visitors were unaware of these. Putting site locations into a phone app could assist visitors in finding them; further research is needed to evaluate the efficacy and advantages/disadvantages of this proposed practice. We also note that a bear visited and obtained food from other visitors during our survey work (two Ursaks that were not properly closed or tied to trees).

<u>Yosemite National Park</u>

The very popular Glen Aulin High Sierra Camp has both outfitted commercial and primitive backpacking accommodations; our survey documented a large aggregate area of camping impact, median size, and area of vegetation loss (29,378 ft^2, 860 ft^2, and 615 ft^2, respectively) (Table 6). The high area of vegetation loss values were due to a combination of flat terrain allowing large site sizes, open canopies supporting high offsite vegetative cover, and high use that eliminated all onsite vegetation cover. Though offsite grasses were common, these are not very resistant or resilient in partial sun (full sun is required). Resource and social conditions could be substantially improved by closing some of the larger campsites in flat high-density areas and shifting use to more sustainable peripheral sites.

The 23-mile PCT segment we assessed was another interesting study area as it had numerous sinuous areas of open grass cover interspersed with forests, along with some areas of exposed rock and shallow soils. Visitors are asked to camp on a previously impacted campsite at least 100 feet from water sources or formal trails. This PCT corridor had the largest aggregate area of impact (69,586 ft^2) of all study areas, though this was distributed along 23 miles of the PCT. There were contrasting median and mean site sizes (466 ft^2 vs. 1,054 ft^2), expected given that 18 of the 64 campsites (28%) exceeded 1000 ft^2, including one enormous site measured at 10,393 ft^2 (Table 6). However, nearly all the sites were nicely situated to promote solitude, >100 ft from water and the PCT (often hidden from view), and 35 campsites (55%) were smaller than 500 ft^2. Like Sequoia-Kings Canyon National Park, this park's camping policy is also essentially one of "Established" site camping and they have a campsite crew that actively manages camping. However, there is no evidence that the staffs "preferred" sites are selected based on sustainability – 64% were in terrain with moderate to high expansion potential and site expansion is a significant problem within this corridor. The Park Rangers we met actively urge campers to avoid camping in grassy areas, asking them to find previously used campsites in the forests. Our results support the closure of larger and less sustainable campsites in flat terrain to shift camping into more sloping terrain, rocky areas, or to grassy meadows with full sun that frequently intersperse the forested areas. Inclusion of sustainable campsites in phone apps is one option for promoting their use by visitors.

<u>Desolation Wilderness</u>

Camping within this wilderness is "unconfined," visitors are asked to camp at least 100-200 ft from lakeshores. Limited staff activity focuses on deterring lakeshore camping, primarily by ice-berging rocks in the best tenting areas. Our data reveals some problems with campsite proliferation but not with site expansion, due to the substantial prevalence of rocky, uneven, terrain throughout most of this wilderness. A significant finding from our fieldwork in the Sierras was the observation that there are often ample opportunities to shift camping into sloping and/or rocky terrain that effectively constrains campsite expansion and to some extent proliferation impacts while enhancing solitude. Examples of this are the high elevation camping at Trail Camp (Figure 23, top photo), and similar lower elevation rocky areas in the Desolation Wilderness, Yosemite NP, and Thousand Island Lake (Figure 23). More visitors might be encouraged to camp on bedrock using freestanding tents or rocks to anchor their tents, or to search for small patches of soil or dry grassy sites for tents, with cooking and other activities focused on durable rock surfaces.

Campsite proliferation problems in the Desolation wilderness is indicated by our finding 243 campsites; the lack of site expansion is indicated by extremely low median site sizes ranging from 158 ft^2 to 382 ft^2, and even lower area of vegetation loss values (40–147 ft^2) (Table 6). For example, of the 53 campsites at Lower Velma Lake only two barely exceed 1000 ft^2. Due to the rockiness most campsites consist of single or small clusters of highly confined tenting sites and cooking spots, with others on bedrock and/or grasses that showed little to no permanent visible impact (for examples see Figure 7 a-d and Figure 23). These findings indicate that the unconfined camping policy has allowed visitors to create large numbers of campsites (site proliferation), but the rocky terrain in most areas has effectively constrained their sizes (site expansion). Surveys of campsite occupancy rates can assist managers in evaluating the extent to which there are excessive numbers of campsites (avoidable impact).

Managers had expressed particular concern for campsite proliferation in the popular Lake Aloha basin and that was validated by our thorough searches. We found 110 campsites with an aggregate area of camping impact of 37,180 ft^2 but surprisingly small median and mean site sizes (158 and 338 ft^2) (Table 6). This suggests that the current policy for this basin may be acceptable, though we did find a fair number of what appeared to be low use campsites that could be eliminated to reduce the aggregate area of impact. A containment policy with established site camping (discussed further in a later section) could be implemented by selecting a subset of the most preferred sustainable campsites and including them in phone apps to attract greater use. However, managers would also require greater restoration effort to extend their closure and restoration work to the non-selected campsites, though their smaller sizes and the ample availability of rock would facilitate such work. Such efforts could substantially reduce both site numbers and aggregate area of camping impact and could also improve visitor experiences if some sites were closed in areas of higher campsite density. There is ample terrain with both topography and rockiness for selecting preferred yet hidden campsites.

Another concern expressed by managers was the chronic problem of visitors choosing to illegally camp <200 ft from water. While managers here have pioneered and perfected the craft of effectively ice-berging rocks in shallow soils, this has often proven to be an ineffective solution as visitors continue to “move over” or in some cases camp between ice-berged rocks. We did notice some shoreline camping locations in areas of extensive bedrock or that allow drainage to be filtered that were quite sustainable, though it may require designated site camping to “authorize” their use while disallowing camping in nearby unsustainable locations (Figure 24). For additional information on managing camping impacts near waterbodies, including why some sites do not pose a threat to water quality, see Marion and others (2018b).

The Lake of the Woods basin is managed with designated site camping, including 9 designated and 19 illegal sites with aggregate area of impact of 43,108 ft^2. Both median and mean campsite sizes were considerably larger than other Desolation lake basins, though this was largely related to extremely large designated and illegal sites located on a flat peninsula on the northwest side of the lake. For example, our data suggest that closing the entire peninsula to camping would reduce the aggregate area of disturbance by an incredible 32,600 ft^2! Additional visitor education and enforcement is also needed to reduce illegal camping. In an informal guidance document provided to USFS staff in 2015 (available on request) the first author reported on a separate personal field survey visit to Lake of the Woods that identified six possible new sustainable campsite locations (with GPS coordinates) on the eastern side of the lake, where most current designated campsites are located. Potential sustainable campsite locations along the southeastern shoreline of Lake Aloha were also identified. Designated site camping offers managers the clear advantage of restricting camping to highly sustainable campsites, but this has clearly not been achieved at Lake of the Woods.

Figure 23. The Sierran terrain offers numerous opportunities to shift camping into sloping and/or rocky areas that constrain campsite expansion and proliferation while also separating camping to preserve solitude. Many visitor-created campsites in these areas are extremely small and well-separated from other sites due to inhospitable topography. Managers can take advantage of these terrain characteristics by actively marketing such areas for camping.

Figure 24. This shoreline site (left) had clear evidence of soil erosion directly into the lake and of numerous successful and failed efforts to ice-berg tenting sites with large angular rocks. Visitors have either extracted the rocks or created new tenting spots. A highly sustainable shoreline campsite (below) with bedrock to the water, opportunities for tenting and cooking sites on flat bedrock, and a soil tenting area to the back that does not contribute soil to the lake.

The Gilmore Lake basin was an exception in terms of sustainable camping opportunities. Due to abundant flat non-rocky terrain, most existing campsites have low rugosity and poor campsite expansion potential ratings. Because of this nearly half of the 25 campsites exceeded 1000 ft^2, including very high values for area of vegetation loss because the campsites are under forest canopies sufficiently open to allow substantial off-site plant groundcover yet too shady to support durable on-site grass cover. While some sloping and rocky terrain does exist in the area for sustainable campsites, current campers have avoided it. Therefore, established site camping could be tried, but managers would need to develop many new sustainable campsites, market them through phone apps, and initiate closure and restoration on many large non-sustainable sites. A designated site camping policy would likely be considerably easier and more effective to implement, particularly if education and enforcement could also be increased. We also note that this area was exceedingly prone to successful bear raids during our fieldwork, with considerable amounts of trash strewn through the woods and showing up in bear excrement. Food storage lockers may be necessary.

Our work to develop and field-test GIS analyses using high-quality LiDAR data to identify potential new sustainable campsites was successful and we believe this practice could assist managers and volunteer stewards trail wide. Our campsite surveys indicate that relatively few visitors choose to camp more than 300 ft from trails or water sources so GIS analyses can be efficiently restricted to trail corridors and/or near water. Field staff found it very easy to navigate to these locations using the created georeferenced maps in Avenza, and inventory data can easily be recorded for each potential campsite in a phone data collection app (we used Fulcrum). A ground-truthing process with field evaluations is necessary to verify these GIS analyses in selecting the most optimal sustainable campsites – some locations had been found and used by visitors, others could be easily turned into campsites, while others had excessive amounts of rugosity that would likely prevent their use as campsites.

Mt. Hood NF, Lower Twin Lake

Fieldwork and a sustainable camping workshop for area managers and volunteers were conducted in early June 2019 in Parkdale OR, focused on the Lower Twin Lake basin in the Mt. Hood Wilderness, Mt. Hood NF. Camping in the lake basin is unregulated so visitors may choose any location to camp. Preceding the workshop, we located and assessed all campsites (n=17) within the lake basin, which is near, but not directly on the PCT. This forested lake basin has long received extremely heavy visitation by PCT backpackers, weekend campers, day users, and horse riders, who also occasionally camp. Over many decades campsite proliferation and expansion at the lower (north) end of the lake basin has created a single 40,647 ft^2 "mega-site" (Table 8, Figure 25), which we arbitrarily broke into 7 areas for measurement purposes. We also located and assessed 10 more campsites around the rest of the lake (Figure 25), 8 of which exceeded 2000 ft^2 in size (the largest was 8,850 ft^2). All sites were located predominantly in smooth flat terrain (0-5%), illustrated in green in the slope map.

Table 8. Resource condition data on 17 campsites assessed within the Lower Twin Lake basin. This is the largest "mega-cluster" of campsite impact identified from this PCT study.

Lower Twin Lake Basin	**Mega-site** (n=9)	**Isolated Sites** (n=8)	**Totals** (n=17)
Campsite Size (ft^2)	40,647	9,087	49,734
Damaged Trees (#)	102	57	159
Tree Stumps (#)	65	17	82
Trees w/Exposed Roots (#)	78	18	96
Hazardous Trees (#)	26	41	67

Discussion

The most surprising finding was that the L. Twin Lakes mega-site size substantially exceeded those found on the A.T. or elsewhere on the PCT, and that the aggregate size of all 17 campsites (49,734 ft^2) exceeded the largest "mega-cluster" of A.T. campsites (31,390 ft^2), a new term for proximate clusters of campsites that exceed an aggregate area of 10,000 ft^2. The largest A.T. mega-cluster had been located at the Hawk Mountain shelter in Georgia. The USFS (Chattahoochee-Oconee NF), ATC, and Georgia Appalachian Trail Club reached the conclusion that both resource and social impacts at the Hawk Mountain mega-cluster was unacceptable and in 2016 began shifting camping to 30 new side-hill campsites constructed in sloping terrain a mile away, with an aggregate size of 6,934 ft^2. As described in the Literature Review, research and management experience commonly reveals that intensive camping activity in flat terrain allows unfettered site expansion and proliferation like those seen at L. Twin Lake, often accompanied by substantial social/experiential impacts (crowding, conflicts, noise). An optimal long-term solution is to shift camping to sloping terrain, where steeper offsite slopes naturally and permanently act to constrain expansion and proliferation, and site spacing preserves desired social conditions.

The workshop included classroom presentations and discussions on sustainable camping management and a field visit to L. Twin Lake to observe the campsites and adjacent sloping terrain where camping could be moved to. Discussions with staff and knowledgeable volunteers revealed that only recently have use levels exceeded the historically high use of the 1970's and that the area now attracts many inexperienced campers, including large groups. The area is forested, and even limited trampling removes all vegetative ground cover, while the shade prevents plant recovery (Figure 25). Impacts considered “unacceptable” by the group include: a) the extremely large areal extent of trampled non-vegetated ground, b) social/experiential impacts (crowding, conflict, noise), c) numerous large campfires that have damaged trees and tree roots, d) surface-disposed human waste due to lack of facilities, and e) lack of tree regeneration.

Following the workshop, we developed some written guidance for alternative camping management options, such as shifting the camping to sustainable side-hill campsites and/or rehabilitating the mega-site area to separate and contain future camping with large logs that are plentiful in the area (Figure 26). Full closure of the flat areas is also an alternative. We remain available for further consultation on this or similar projects in the PCT corridor.

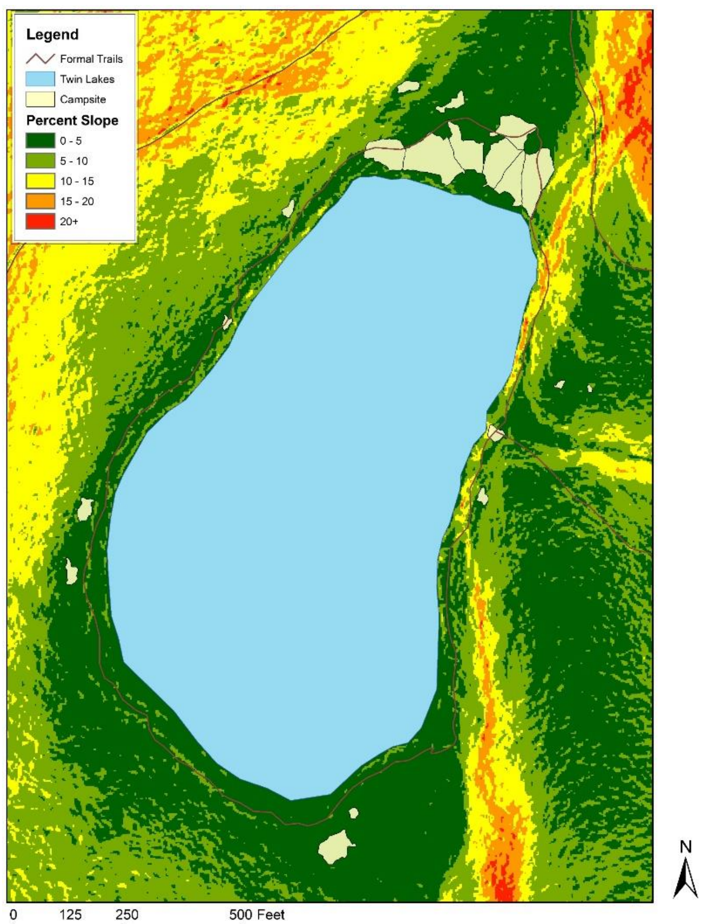


Figure 25. Photo of the Lower Twin Lake camping “mega-site” and slope-map illustrating campsite locations around the lake in flat terrain (0-5% slope). Also note that there is adequate nearby terrain with 15-20% grade where camping could be moved to enable side-hill campsite construction.

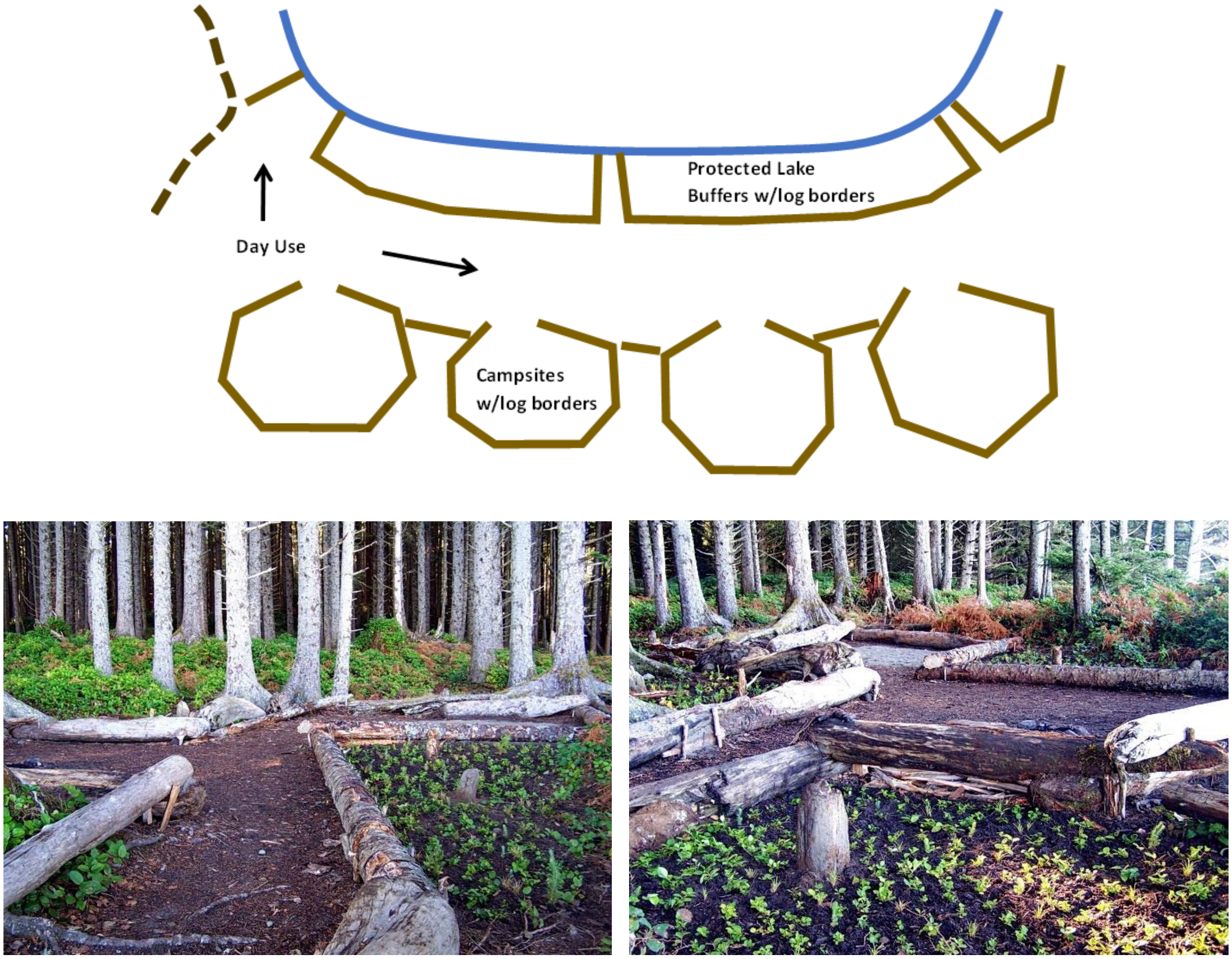


Figure 26. Schematic illustrating a possible sustainable arrangement of camping within the existing L. Twin Lake mega-site using the ample supply of locally available large logs. Note the protection of shoreline areas, provision of day use areas, and separation from camping, which is moved further from the lakeshore. Photos illustrating what this might look like are from a large camping management and restoration project at the Norwegian Campsite area of Olympic NP, courtesy of their Wilderness Specialist Ruth Scott.

Crater Lake NP

Field staff conducted assessments of all designated campsites in July 2021 at Crater Lake NP. Our staff contacts at this park were Andrew Hoeg (Trail Crew Supervisor) and Heidi Barker (Backcountry Manager). There are 33 miles of the Pacific Crest Trail (PCT) within Crater Lake National Park, though many PCT hikers take an 11.7-mile Crater Lake Rim Alternate route that bypasses 16.2 mi of the official PCT. This route follows the Dutton Creek, Discovery Point, and Rim Trails. Over 95% of the park is managed as wilderness. Visitors must obtain free backcountry camping permits and may camp at designated campsites (17 sites at 6 locations), or disperse their camping >1 mi from roads, >100 ft from water sources or meadows, and out of sight from trails or other campers. Most campers stay at the designated campsites, with permit quotas to limit overuse and shift visitors to dispersed camping. Many thru-hikers choose to camp at the Mazama Campground PCT group site near the Annie Spring Entrance Station due to opportunities for resupply, showers, and restaurants. We assessed the walk-in Mazama group campsites (n=3) and all designated campsites at Dutton Camp (n=3), Lightning Spring Camp (n=3), Grouse Hill (n=3), Bybee Creek (n=2), and Red Cone (n=3). A few designated campsites were closed due to the presence of hazard trees and were not assessed. Individual campsites are designated within these camping areas and we found only one visitor-created illegal campsite near the three Mazama group campsites.

Campsite sizes ranged from 142 to 2,429 ft^2, with an aggregate area of campsite impact of 15,022 ft^2 and a mean size of 884 ft^2 (Table 6). Many of the campsites are larger than in other study areas, the largest campsites were at Bybee Creek, which is one of the few horse camping areas included in this study. Most campsites are in flat forested terrain which does little to prevent site expansion (Figure 27). Off-site rugosity ratings were predominantly low, with offsite expansion potential tenting sites ranging from 1.3 to 5.7, indicating that most campsites trend to the "non-sustainable" end of the scale. However, managers have effectively limited site expansion at some campsites by installing site borders of logs and stones (Figure 27b,c). This practice was extensively implemented at the Red Cone designated campsites, resulting in the smallest median campsite size (347 ft^2) and aggregate size (968 ft^2) (Table 6).

Figure 27. Crater Lake NP staff have sought to address extremely large campsites like this one at Bybee (a) by using logs and rocks to create confined campsite borders (b & c). Dispersed site camping regulations currently prohibit camping in resistant meadows like this one (d).

Discussion

Compared to other PCT study areas the Crater Lake designated campsites are quite large, similar to the designated campsites at Desolation's Lake of the Woods. However, we failed to find illegal campsites in these designated site camping areas. The larger size of the Crater Lake campsites is largely attributable to their placement in flat terrain and the lack of extreme rockiness commonly found in the Sierran study areas. If their sizes are unacceptable, the most permanent long-term management action would be to shift use from flat forested areas to naturally occurring or constructed side-hill campsites within sloping terrain. Alternately, we note the substantial success achieved at Red Cone Springs in flat terrain, where downed logs have been moved to form visually obvious trail and campsite boundaries that effectively constrain trampling to small use areas (like those depicted in Figure 26). This action could be replicated in other camping areas.

Dispersed Camping - Crater Lake NP supports considerably less camping than at many of the Sierran lake basins or Mt. Whitney areas. Park permit data indicate that hundreds of visitors use a dispersed site camping option along the trail corridors that is similar to the dispersed pristine site camping option described in the Literature Review section. Finding and assessing these dispersed campsites were not part of our survey, though we looked for these sites during our hikes and searched more comprehensively in the most promising lower Dutton Creek area. Surprisingly we failed to locate *any* of these dispersed campsites, suggesting that this is an effective camping option in lower use areas along the PCT (as characterized by the PCT corridor through this park). Park seasonal staff do occasionally find these camping locations and perform restoration work, but they reported that such sites are rare and very lightly used in appearance. This option could be enhanced by specifically asking visitors to follow the full guidance for dispersed pristine site camping included in this report, specifically, by asking them to only camp on pristine sites and allowing/promoting the use of resistant grassy meadows in sunny locations.

North Cascades NP

Our research team traveled to North Cascades NP in September 2018 to assess all 32 designated campsites along 18 miles of the PCT though the park. Park Resource Manager Jack Oelfke coordinated our visit, and we assessed all designated campsites (n=32) at the following camping locations: High Bridge (n=1), Tumwater (n=1), Shady Camp (n=2), Bridge Creek (n=8), North Fork (n=4), Six Mile (n=1), South Fork (n=4), Hideaway (n=1), and Fireweed (n=9). We found and assessed only one illegal campsite. Nearly all these campsites are located in heavily forested valley-bottom settings. A sustainable camping management workshop was also provided to park staff long with a presentation and close-out meeting to present and discuss findings. A document titled “North Cascades National Park, PCT Campsite Sustainability Assessments” was prepared.

High Bridge Campsite

This is a large communal campsite (4,898 ft^2) located on a flat bench above the Stehekin River near the High Bridge shuttle stop (Table 6). Facilities include a three-sided camping shelter with several picnic tables, a large food storage locker, bear proof trash can, two fire rings, and an outhouse. The lack of tree cover over the site supports substantial durable grass cover in less trafficked areas; area of vegetation loss is 1,225 ft^2. While the site is quite large, it has expanded on three sides to constraining sloped terrain. There is no off-site rugosity but off-site terrain on one side is sufficiently flat to allow at least 10 additional tenting spots (Table 7). Large logs could be placed to deter site expansion on the remaining side and/or to reduce the size of the existing site if desired.

Tumwater Campsite

This area has two campsites with an aggregate area of disturbance of 3,641 ft^2 and mean area of vegetation loss of 1,210 ft^2 (Table 6). One campsite is on a flat bench close to the river, though it drains away from the river initially, allowing for runoff to be filtered by vegetation and organic litter. Topography limits site expansion on this site. The other site is located higher and further from the river but in flatter terrain more prone to expansion, as indicated by the presence of two offsite tent pads. The site is accessed by trail and a dirt road and facilities include an outhouse, food storage box, picnic tables, trash can, and fire grates.

Shady Camp

This area has a large barren central campsite in deep shade with a second smaller sunny grassy site near the creek, along with several offsite tenting sites. The aggregate area of impact is only 1,304 ft^2 with a mean site size of only 652 ft^2, despite its non-sustainable location in an area where site expansion could easily occur (Table 6, Table 7).

All areas are adequately drained through organic litter to minimize soil erosion to the creek. Facilities include a picnic table, bear cable, outhouse, and fire ring.

Bridge Creek Campsite

This is an exceptionally large sprawling camping area with a very large aggregate area of impact (26,576 ft^2), a large mean size (3,322 ft^2), and large mean area of vegetation loss (2,313 ft^2) (Table 6). This area receives high use, with eight campsites located in a large flat heavily forested valley bottom setting with open understories. These sites also have facilities as previously described, including a 3-sided shelter used for cooking on one site. Campsite expansion potential (Table 7) is quite high for most of these campsites due to their location in smooth flat terrain, and a few sites are close to and drain water directly into Bridge Creek. The entire area has been largely picked clean of firewood, though there are many large, downed logs that could be moved to form campsite boundaries to deter site expansion and proximity to the creek.

A group site and PCT hiker campsites are located much further from the Bridge Creek water source. These campsites are poorly arranged in a circle around a large central area that is crisscrossed by traffic. The expansion potential for this area is high – a lineal arrangement of campsites would greatly reduce the aggregate area of disturbance. Alternately this area could be more easily closed and recovered since it is away from the main trail and camping area. A separate horse camping area is also present and includes a corral and hitching rail. While this area is quite flat there is little evidence of site expansion, likely due to the presence of the horse facilities.

In summary, this entire area is likely to always have an exceptionally large aggregate area of disturbance due to its flat terrain, open understory, and high use. Of greatest concern are the campsites directly along and sloped to Bridge Creek (Figure 28a). While logs might be used to shrink and restrict site sizes, shifting camping to more sloping terrain would result in substantially less camping impact (Figure 28b-d).

North Fork Campsite

This camping area has four apparent sites grouped together on benches of different elevations. While sloping terrain does often restrict site expansion there yet remain some flat shrubby areas that have been protected with large log barriers (Figure 28c). The lowermost stream proximate site was scheduled to be closed and restored so the remaining areas may need to be expanded. Tenting sites are not always ideal and could be improved in several locations to further attract and spatially concentrate that activity. A single sustainable and stone-armored water access trail is also desirable.

Six Mile Camp

A single very large campsite here is only 25 ft from Bridge Creek but it drains away from the water into undisturbed areas that filters runoff. Shifting the fire grates away from the best tenting areas and using logs to deter site expansion should make this area sustainable to heavy use.

South Fork Campsite

This area has separate hiker and horse campsites. Much of the core horse site area has roots and protruding rocks that prevent tenting, forcing an expansion of the site into peripheral areas where tenting is possible. Creating improved tent sites within the core area or shifting the site to a more sustainable location would minimize the area of disturbance. A side-hill tenting site (Figure 28d), illustrates this effective practice. A large recently felled tree along the stream side of the campsite effectively blocks expansion in that direction, illustrating another effective practice.

The hiker site is arranged in a very sustainable linear fashion with sloping offsite areas. Additional tent spots could be made with limited excavation work if desired.

Hideaway Campsite

This is another creek-side site that drains away from water and through undisturbed areas that filter runoff. The tenting areas are mostly sub-optimal due to poor drainage or roots; improving them will attract and concentrate activity, removing site expansion pressures.

Figure 28. Camping in large expansion-prone flat areas that drain unfiltered water into creeks, like this site at Bridge Creek (a), should be replaced when possible with campsites on flat benches in sloping terrain, like this site at North Fork (b). Placing large logs along campsite borders can sometimes be effective in protecting offsite flat areas (c), but shifting camping to sloping terrain with side-hill constructed tent sites (d, at Southfork campsite) is the most optimal long-term solution.

Fireweed Campsite

This is an extremely large well-used camping area in flat terrain with high expansion potential; it is also located in dense forest that allows for exceptionally little ground vegetation. Site closure may be the best option if camping can be shifted to a more sustainable location. While there were only two fire grates in the area, we assessed nine separate use areas due to the extensive site proliferation and expansion. If the area is retained some strategically placed logs and a fair amount of tent pad improvement could be effective in constraining expansion pressures and site size.

Discussion

The heavily forested North Cascades NP offered yet another unique environmental setting to examine the challenge of sustainable camping management. The park has used designated site camping to limit camping impacts, but like the Desolation Wilderness (Lake of the Woods) and Yosemite NP (Glen Aulin), their designated campsites include both sustainable and non-sustainable sites. We emphasize that a core benefit of employing a designated site camping regulation is the ability to shift use to the most sustainable locations possible to minimize the areal extent of impact. However, knowledge about evaluating and selecting such sustainable camping locations has only recently emerged from recreation ecology studies, and this study was specifically focused on that task. We also averaged this park's campsite use data from 2013-18 and compared it against mean campsite size, finding that extremely large campsites like High Bridge and Six Mile had lower use (373 and 325 nights/yr), than much smaller campsites like South Fork and North Fork (431 and 439 nights/yr). An exception was High Bridge, which had the highest use and second-highest mean size. Regardless, it is evident that campsite sizes are more strongly influenced by topography (flat vs. sloping terrain) than amount of campsite use.

In general, we conclude that settings like the Bridge Creek Campsite, with large areas of smooth flat terrain and very limited ground and understory vegetation, should be avoided because campsite expansion and proliferation problems will forever be chronic and costly to manage. In contrast, camping on topographically constrained flat benches, such as occur at North Fork Campsite, will forever require very little regulation or education to constrain and concentrate visitor activities on small campsite footprints. Many of the designated campsites are unnecessarily large, are located along shorelines that threaten riparian vegetation and water quality, and compel high density camping that can diminish social/experiential qualities (crowding/conflicts/natural quiet) for campers. More sustainable locations with sloping topography and more rarely, rugosity, do exist in the vicinity of the existing designated campsites; side-hill campsite construction would be a realistic and highly effective long-term practice in all locations. While grasses and meadows were rare in the river valleys, they could be a sustainable camping option in somewhat higher elevations.

In many PAs, managers simply selected former visitor-created campsites when designated site camping policies were implemented, similar to the use of old "legacy" fire-fighting trails and early logging roads when forming most PA trail systems. Managers have repeatedly discovered that old legacy trail and road alignments are rarely very sustainable in accommodating heavy recreational traffic. The best long-term or "forever" management option is always to shift visitation to new highly sustainable campsites and trails. It may be possible to reroute the PCT to avoid areas of flat terrain, particularly if there are difficulties in closing/restoring campsites. When shifting use is not possible, managers can apply secondary management actions such as the "push-pull" actions involving the construction and improvement of onsite tent pads, creating/maintaining log campsite borders, and ice-berging rocks or creating uneven terrain in the most attractive offsite areas. However, these options are always more costly, require intensive ongoing management actions, and create more artificial "hardened" recreational settings that require significant long-term management efforts.

Finally, based on informal conversations with thru-hikers, we heard that a number of them do not get camping permits and reservations as they hike through the park. One option to consider would be to market a subset of campsites to the thru-hikers that could be used without a permit or reservation, these could be new highly sustainable campsites in locations preferred by thru-hikers. Permits, reservations, and quotas would continue to be required for thru-hikers desiring to use the other designated campsites.

Campsite Sustainability Indicators

This PCT research provided an opportunity to continue, extend, and perfect our research from the A.T. on developing indicators and protocols for evaluating campsite sustainability. Such indicators were quite rare in earlier recreation ecology literature yet offer substantial benefits to managers for accommodating increasing visitation over time while constraining associated resource and social impacts. Our initial PCT fieldwork considered only "ecological" sustainability and included two indicators developed and refined from our A.T. studies. Beginning with our Desolation Wilderness fieldwork, we developed and tested new ecological indicators and integrated additional measures of "social" and "managerial" sustainability. For example, if highly sustainable campsites are not attractive or functional for visitors, they are unlikely to use them. Specifically, we examined the scientific literature on campsite preferences (e.g., functional *necessity* attributes like adequate level tenting space, *experience* attributes like privacy and scenery, and *amenity* attributes like tent spots cleared of organic/rock materials) and we incorporated additional social/experiential attributes into our ground-based assessments. Managerial attributes considered alternative factors like campsite proximity to water, trails, other sites, sensitive flora/fauna/cultural sites, and capabilities to educate/regulate visitors or to locate/open sustainable campsites and close/restore non-sustainable or unnecessary campsites.

Note: the following campsite functionality/amenity indicators were assessed for the Desolation Wilderness, Crater Lake NP, Twin Lakes, and North Cascades NP. These are described and reviewed here, but not summarized separately for each study area. We sought to develop and refine indicator protocols (Appendix 1) and suggest that managers may wish to assess and consider some of these indicators if they choose to select a subset of sustainable campsites for established or designated site camping options.

Usable Tent Pads: A count of the number of usable 10x10 ft tent pads within campsite boundaries. Mean values for this indicator were consistently low in the rocky Desolation Wilderness study areas (2.7-4.6) and highest in North Cascades NP (3.3-30). We also assessed the number of "good" tent pads and as expected the mean values were somewhat lower. Campers often want to know about how many tent pads there are when selecting a campsite; phone apps like FarOut (formerly Guthook) generally include this indicator. It's a particularly important attribute for larger groups, including "informal" groups of thru-hikers who like to camp together.

Intersite Visibility: A count of the number of other campsites that would be visible if occupied. Mean values for this indicator ranged from 0 to 3.3 but were generally quite low, in the 0-1.2 range. The maximum value for all study areas was 8 at Twin Lakes, but seven study areas had maximum values of 3. Wilderness managers generally prefer to have all campsites out-of-sight from other sites to preserve opportunities for solitude and natural quiet.

Seating: An assessment of campsite seating based on permanent natural rocks or larger less-movable rocks and logs: (None, 2-3 people, 4+). This indicator was typically 4+, followed by 2-3 people.

Dead/Hazard Trees: Number of trees that could fall or easily drop a limb on the campsite. This indicator ranged from 0 to 50 with mean values most commonly in the 1 to 3 range. As expected, the Desolation Wilderness's rocky and often tree-less terrain had very low mean values (0.5-2.2) while the heavily forested North Cascades NP had higher values (1.5-7).

Stove Rocks: A count of visually obvious kitchen rocks (flat rocks appropriate for camping stoves). Relatively few campers routinely build campfires along the PCT and campfire sites were rare in most areas (mean values close to 0). Our findings also reveal that purposively placed flat stove/kitchen rocks are quite rare (whether placed by visitors, agency staff, or volunteers). Only 2 were found on North Cascades NP sites, though mean values ranged from 0.3 to 0.6 in the Desolation Wilderness study areas, and 0-2.3 at Crater Lake NP.

Bear Bag Hanging Trees: Rating of nearby bear bag hang options, based on presence of tall trees w/good limbs for bear bag hanging: (Poor, Fair, Good). As expected, this indicator varied by the density, size, and type of trees. Finding good trees for hanging bear bags was most challenging in the Desolation Wilderness but fairly easy at Crater Lake and North Cascades NPs.

Cathole Potential: Ease of cathole potential based on the ease of digging, privacy, topography, and soil depth: (Poor, Fair, Good). This indicator varied with rockiness and soil depth, again being most challenging in the Desolation Wilderness but with good ratings in Crater Lake and North Cascades NPs.

Ease of Water Access: Ease of access to water based on distance, terrain, and elevation difference: (Low, Med, High). As expected, campers prefer to have easy access to water so this indicator was predominantly rated high, followed by medium. However, some campsites in each area were rated low, including 14 campsites (10%) of those in Desolation's Lake Aloha basin.

Attractiveness: In the Desolation Wilderness the scenic attractiveness of campsites, their vista, their surroundings, and for day use activities were also subjectively rated. Nearly all campsites were judged to be attractive, along with their surroundings. There was a greater range in attractiveness ratings of campsite vistas, though most sites were rated high, followed by fair due to the lack of trees around many sites.

CONCLUSIONS

Congress has mandated the federal land management agencies to protect the lands under their jurisdiction while also providing for visitation and recreation activities. Although public use and enjoyment is often a central purpose for creating and managing PAs, research has shown that even limited recreational activity can measurably alter natural resource conditions (Marion *et al.* 2016). These impacts must be balanced against the many personal and societal benefits that PA visitation confer, including physical and mental health benefits associated with exercise and immersion in nature, and local community benefits from visitor expenditures, volunteerism and stewardship support, and positive media exposure.

Recreation may endanger the goal of resource protection just as protecting resources may restrict opportunities for recreation. These apparently conflicting dual mandates present a management dilemma. PA stewards recognize the need for effective visitor management and resource protection programs to balance visitation with its associated resource impacts. The recurring question, "are we loving our PAs to death?" increasingly challenges managers to assemble and implement policies, strategies, and actions that permit recreational activities within PAs while continuing to maintain ecological and aesthetic integrity. In the Literature Review section of this report we describe the full complement of “toolbox” visitor impact management strategies, options, and practices available to stewards seeking to balance resource protection and visitor use.

Land managers are charged with applying professional judgment in evaluating the type and extent of recreation-related impacts that may constitute unacceptable impact or impairment. This report provides useful data and findings from a large survey of camping impacts within the PCT corridor to partially inform such determinations. It also provides a comprehensive toolbox of effective impact reduction practices to enhance management of visitors and resources and avoid or minimize camping impacts. Research findings describe current conditions that highlight some common camping impact management problems within the PCT corridor. These findings are reviewed considering the larger body of recreation ecology literature and management implications to suggest effective new sustainable camping management practices.

As revealed in the results section, the most extensive and unacceptable impacts occur due to intensive camping in non-sustainable locations such as smooth, flat, shoreline settings. PA managers more than a century ago learned that using visitor-created non-sustainable trails was unacceptable, seeking to replace these with sustainable formal trail systems with lower-grade side-hill alignments and engineered drainage features (e.g., grade reversals and water bars). We suggest that professional camping management is little different. This report and the larger recreation ecology literature is replete with examples of extensive and unacceptable camping impact occurring under unconfined (unregulated) camping policies that permit extensive camping in large, smooth, flat areas. This and other recent studies describe how heavy camping in non-sustainable terrain inevitably promotes campsite expansion and proliferation that create mega-sites and/or mega-clusters of sites with unacceptably large areas or resource impact and visitor crowding, conflict, and/or noise. The proactive professional camping management solution is to adopt a containment strategy in moderate to high use areas and shift camping to sustainable but distributed locations where permanent factors like sloping and uneven or rocky terrain effectively act to constrain the areal extent of camping impact and separate campers to achieve high quality experiential conditions.

In virtually every PCT study area reviewed we found the largest campsites and aggregate impact occurring in smooth flat terrain and the smallest campsites and aggregate impact in sloping, uneven, or rocky terrain. We emphasize that this is a new and consequential finding in the recreation ecology literature. Furthermore, the presence of woody vegetation rarely constrains site expansion/proliferation over time and a three-decade study found it not to be a long-term constraint (Eagleston and Marion 2017). In contrast, this study and many others prove that grasses in sunny settings resist and rapidly recover from trampling impact, indicating that camping sustainability is enhanced by concentrating use on the sunniest campsites. This combined sustainability guidance allows PA managers and stewards to proactively limit both resource and social visitor impact by shifting camping to well-separated sustainable camping locations that require substantially less education, regulation, and site management effort. While some existing campsites may rate as sustainable, managers may also wish to use GIS or ground searches to find sustainable naturally occurring locations or terrain with slopes >15% or to construct side-hill campsites.

Extensive regression modeling performed by Arredondo and others (2020) revealed that managers can use macro- and micro-topography to effectively constrain a campsite's ability to expand. This is similar to side-hill trail alignments, where steep side-slopes act to concentrate traffic on a narrow tread (Wimpey & Marion 2010). Perhaps the most important finding of this study is that campsites located in sloping terrain will spatially concentrate camping activities to the available flat terrain, effectively constraining site expansion when offsite areas are sufficiently steep. The best campsite size predictor yielded by modeling analyses was the percent of 33 ft wide "doughnut" buffers around a campsite occupied by greater than 15% slopes (Arredondo et al. 2020). The implication of this finding is that spatial concentration of camping activities is highest when a campsite is completely surrounded by steep terrain. Both "naturally-occurring" and constructed side-hill campsites in terrain with >15% slopes provide the most sustainable campsites for intensive long-term use; our analyses in the Desolation Wilderness developed new protocols for locating these campsites within trail corridors using ground-based and GIS surveys where LiDAR data is available.

Unconfined (Unregulated) Camping

As described in the Literature Review and illustrated in Figure 1, the *unconfined camping* option (Table 4) allows visitors substantial freedom in selecting or creating campsites, though managers can still promote or require visitors to camp away from water or formal trails. However, visitors frequently choose large smooth flat areas to camp where campsite expansion and proliferation often occur. When use reaches moderate to high levels, particularly during peak use periods, these chronic problems often create exceptionally large and unnecessary numbers of high-density campsites that can develop significant and unacceptable resource *and* social impacts. In particularly popular locations unconfined use creates large mega-sites or mega-clusters of campsites with extensive vegetation loss and soil exposure that threaten water quality, diminish aesthetic qualities, and create experiential problems with visitor crowding, conflict, and noise. Depletion of woody fuel materials and damage to and felling of trees can also be substantial problems when campfires are permitted, along with improperly disposed human waste and wildlife feeding and attraction behaviors. We conclude that this policy is generally only tenable when visitation levels are relatively low.

Dispersed Pristine Site Camping

The *dispersed pristine site* camping option is possible within most of the PCT corridor, yet it has rarely been actively promoted; it is the only policy that avoids nearly all visitor resource and social impacts. Further, the PCT passes through many environmental settings that provide excellent opportunities for this camping option, such as deep forests with little ground vegetation cover (Figure 29a), rocky terrain where most camping activity can occur on durable rock surfaces (Figure 23), and trampling-resistant sunny grassy meadows with sufficient topography or woody vegetation to limit visibility (Figure 29 b-d). The goal is to shift camping to highly resistant substrates (e.g., rock, snow, gravel) that do not show impact, ***or*** disperse camping activities to grassy areas at levels that prevent the creation of lasting vegetation and soil impact. Suggested guidance has been included in the Literature Review section describing effective pristine site camping practices. Visitors are asked to select the most durable substrates available in pristine locations unlikely to be found and reused by other visitors, camp a single night, and restore the site to its original condition so as not to attract repeat use. Such practices could be effectively communicated to experienced outdoor visitors, particularly long-distance backpackers. For example, all backpackers granted thru-hiking or section-hiking permits could be required to take and pass an online short-course before reaching a permitting screen. The national Leave No Trace program has developed an Online Awareness Course that provides an example, though not the necessary content: https://lnt.org/learn/online-awareness-course. As described previously, this option is best promoted for more experienced backpackers who are willing to camp away from trails, lakes and existing campsites. This option is most appropriate and effective in areas that are out-of-sight from designated trails, often in remote or low to medium use zones. A failed dispersal strategy can lead to campsite proliferation problems so monitoring to evaluate and perfect the efficacy of this option is strongly encouraged.

Figure 29. In the Sierras there are many opportunities to camp on naturally non-vegetated organic litter in dense forests (a), either as pristine campsites (if visitors return organic litter to naturalize their use areas), or established/designated campsites. There are also numerous settings where meadows sinuously integrate with forested areas that offer opportunities for camping on grasses out of sight from the trail and other groups (b). We camped on grasses one night during fieldwork (c) and returned two days later to document the lack of visible impact (d). Grass resistance and resilience increases with increasing sun exposure.

Established Site Camping

A *containment strategy* with *established site* camping is suggested as preferable in moderate and some higher use areas along the PCT, providing an optimal balance between resource protection and visitor freedom from regulation. Guidance provided in this report, including Appendix A, could be applied by PA staff or volunteers to identify existing or new sustainable campsites with functionality/amenity attributes desired by visitors. Camping setbacks from water, formal trails, other sites, and sensitive cultural or biological areas of concern can also be applied in the campsite selection process. The locations of "preferred" sustainable campsites could then be widely communicated, and visitors asked to use only these "well-established campsites," and avoid lightly used and closed/rehabilitated campsites. The goal is to substantially reduce use of campsites that are less sustainable, too close to water or other features, unnecessary, or undesirable to visitors. Managers or volunteers could allow natural recovery or seek to actively close and restore the non-selected campsites. Some PCT corridor managers have already been informally using components of this policy by actively closing and restoring some non-preferred campsites, which increases use of the remaining preferred campsites. However, we suggest that the campsite sustainability guidance included here be integrated into these existing programs. This guidance expands existing practices, promoting a more comprehensive and focused program of sustainable site selection able to substantially reduce the aggregate area of camping impact.

It's important to recognize that the proposed established site camping option is entirely voluntary, not regulatory. Visitors retain the option to also practice dispersed pristine site camping, and unless regulations are added, nothing would prevent them from creating a new campsite in a popular area near an existing campsite, on a flat lake shoreline, or close to the PCT. Thus, while this camping option has the advantage of promoting sustainable camping that preserves resource and social conditions while retaining substantial visitor freedom, it also retains visitor freedom to camp in non-sustainable/undesirable locations. Visitor education, the professional selection of preferred sustainable campsites, and ease of navigation to these sites is critical to the successful implementation of this option. Supplementary regulations could/should be added to an established site camping policy, such as required camping setbacks from water, formal trails, attraction features, cultural sites, sensitive resources, or other campsites. Individual campsites in non-sustainable/undesirable locations could also be formally signed as closed, with a restoration program developed to speed their recovery.

New technologies/tools greatly enhance the viability of this option. In the past it was difficult to accurately show and have visitors navigate to preferred campsite locations, and updates were problematic once maps showing campsite locations were printed and widely circulated. New GIS capabilities now facilitate the selection of preferred sustainable campsites, provide accurate locational data that can be quickly posted and periodically updated on agency websites where visitors and map/phone app makers can find and use it. These digital data can be easily used by visitors with GPS units (e.g., Garmin) or a variety of phone apps using downloaded maps and satellite signals to accurately navigate to the preferred campsites. An increasing number of visitors have discovered and are using these technologies, which are positionally accurate to 15-20 ft on new smartphones even in remote mountainous terrain. These technologies are rapidly replacing paper maps, which are often relegated to "back-up" status.

An added advantage of digital maps is their ability to show shaded "no camping" setbacks/zones, individual closed campsites, or zones where different camping options are employed (e.g., pristine, established, and designated site camping), with an easily accessed listing of relevant LNT camping practices and regulations provided for each zone. These technologies all work on smartphones in remote locations, revealing in real time the visitor's current location on maps, so visitors know when they are in a no-camping zone or on a closed campsite. This would provide an effective solution to the chronic shoreline set-back dilemma, visually showing campers the extent of such zones and their culpability when enforcement tickets are written. Finally, all information can be easily updated and communicated, substantially improving the efficiency of adaptive management, whereby managers implement actions, evaluate success, and alter their tactics iteratively until desired conditions are achieved. We also note that app makers could collect and make available anonymous visitor distributions and camping locations for input to travel modeling and campsite supply decision-making of great value to managers.

Designated Site Camping

A *containment strategy* with *designated site* camping is suggested as preferable in the most popular high use areas along the PCT. Areas like attractive lake basins sometimes have nearly "unlimited" demand that can necessitate a designated site camping policy, and agency managers have already accepted the need for such regulations within the most popular backcountry and wilderness camping destinations (e.g., at Lake of the Woods and Eagle, Grouse, and Hemlock Lakes, Desolation Wilderness). Recognizing the maxim that "intensive visitation requires intensive management," managers have concluded that such regulatory controls are justified and necessary to balance high visitation with the protection of resource and social conditions. However, there are yet options and tradeoffs to consider here as well, including:

1) Designated camping zones – camping is restricted to designated sites within specified zones and visitors traveling through the zones must be prepared to keep moving until they find an open site or exit the zone.

2) Designated camping zones with quotas – camping is restricted to designated sites within zones but quotas on the number of required camping permits issued ensure site capacities are not exceeded.
3) Designated camping zones with reservations – camping is restricted to designated sites within zones but required camping permits specify the campsites used each night.

All three options enable managers to select an optimal number of preferred sustainable campsites that effectively limits the aggregate area of camping impact and preserves desired experiential conditions, though visitor freedom is increasingly diminished from option 1 to 3.

This study also revealed that PA managers have often adopted previously visitor-created campsites when site designations were made, often including campsites that this study revealed to be "non-sustainable" – for example in flat, smooth terrain where campsite expansion and proliferation will be chronic problems. This suggests the need for managers to perform sustainability assessments of their existing and future designated campsites to replace less sustainable or desirable campsites with improved sites. Guidance is contained in this report for performing this task.

Other considerations include the ability of managers and volunteers to manage designated campsites, including their selection, construction, facilities, maintenance, and monitoring over time. For example, PCT managers voiced concerns about their potential liability and responsibility for removing dead or hazardous trees from designated campsites that visitors are required to use. Case law in the Literature Review section summarizes existing case law to provide guidance; land managers must consider relevant federal and state laws, the Berkovitz test and their "mandatory" guidance, and level of facility development.

The development and administration of educational messaging, permitting systems, and quotas, along with enforcement patrols, are also important considerations. There are also wilderness character considerations for designated campsites in wilderness, including trade-offs between regulatory requirements and visitor freedom, or the possible need for signage and site facilities like anchored fire sites and food storage devices. Promoting the use of new technologies like visitors using cell phone apps to discern zoning boundaries that govern camping policies, provide regulatory or educational guidance, or that facilitate navigation to more sustainable and preferred established or designated campsites can also present wilderness character concerns. However, we note that visitors make the decision to use or not use such devices, and their use in backcountry and wilderness are rapidly increasing.

Selecting a Preferred Camping Policy

An important metric for evaluating the relative efficacy and success of alternative camping management options is the campsite occupancy rate: either as the number of nights/year a campsite is used or the percentage of campsites used/night during periods of high but not peak use (Marion 2016, Marion & Farrell 2002, Reid & Marion 2004). Effective dispersed pristine site camping requires just one night/year when camping occurs in forests with substantial herb/forb cover, perhaps 4-6 nights/year in sunny meadows on dry grasses or in dense shady forests on non-vegetated organic litter, and permits higher use of barren bedrock or cobble.

Unconfined camping in areas that receive moderate to high use frequently result in relatively large numbers of campsites, most with low occupancy rates (e.g., 5-15 nights/year or 10-30%). Unconfined camping has often been found to maximize the aggregate area of camping impact, along with related impacts (area of vegetation loss and exposed soil, numbers of damaged and felled trees, etc.) (Cole 2013a, Cole & Parsons 2013, Cole et al. 1997, Reid & Marion 2004). Agency staff, ridgerunners, or volunteers could conduct campsite occupancy surveys for a sample of 10-12 nights stratified by weekend/weekday, and within/outside of the thru-hiker bubble to provide information for campsite supply decision-making. This requires mapped campsite locations with unique site numbers and evening or morning visits to tally number of tents and/or campers. Low occupancy rates (<30%) indicate an over-supply of campsites and "avoidable" visitor impact, as compared to a smaller number of sustainable frequently used campsites.

The established site camping option can shift camping to a smaller more sustainable subset of intensively used campsites. For example, managers implementing this option in Shenandoah National Park reduced campsite numbers by 49% and the aggregate area of camping impact by 50%, while increasing occupancy rates from 16 to 50% (Reid & Marion 2004).

Designated site camping offers even greater control in reducing campsite numbers and increasing campsite occupancy numbers. For example, Phantom Ranch campsites on the Colorado River in Grand Canyon National Park are booked and used for nearly every night of the year at rates approaching 100%. Another useful metric suggested by Farrell and Marion (2002) is to divide the aggregate area of camping impact by aggregate overnight stays/year to obtain area of camping impact/overnight stay. This metric was calculated for ten PAs with available data, finding that Isle Royale National Park achieved the smallest area of camping impact per overnight camper, only 3.7 ft^2. This success was attributed to a designated site camping policy, wide use of side-hill constructed sites, and restricted numbers of campsites with high occupancy rates.

The Resistance and Resilience of Grasses

Through discussions with Sierran USFS and NPS staff, and reviews of their websites, educational literature, and permitting guidance, we discovered a widely communicated but erroneous perception that meadow vegetation is particularly susceptible to trampling impacts, with associated guidance that visitors should not camp in meadows. Agency staff met during fieldwork cited as "common practice" their patrol efforts to move campers off meadows and into more forested settings. For this reason, we more comprehensively reviewed the scientific literature on this topic earlier in this report, including experimentally designed trampling studies. This body of research conclusively documents the substantial resistance and resilience of grasses and sedges growing in sunny settings, as compared to herbs and ferns that grow in shady forested areas. In seeking to understand the source of this thinking we were told about the substantial impacts of large horse groups that commonly targeted Sierran meadows associated with streams and lakeshores for camping back in the 1950's, 60's, and 70's. In areas with smaller meadows and/or wet soils, these large groups caused substantial resource impact through a combination of intensive grazing and trampling, particularly along stream and lake shorelines with wet soils. However, group sizes, horse use, and camping with horses have all declined and horse camping locations have been altered to effectively resolve meadow and shoreline impacts. Yet the policies related to meadows continue and are applied to backpackers, who more commonly travel in small groups, avoid wet meadows, and apply LNT practices.

In Yosemite NP we met and had discussions with the U.S. Geological Survey meadow research group, and they agreed that meadow grasses are highly resistant to traffic, adding that while Sierra meadows have high plant diversity, they have few rare species and are resistant to invasion by non-native plants due to their higher elevation. Their research also shows that meadows, particularly those with wet to moist soils, are highly resilient, and quickly recover from trampling and grazing. We also verified the applicability of these findings by camping on dry grassy sites and returning one and two days later to find no evidence of tent locations or lasting grass damage (Figure 29, photos b-d). However, as indicated in Leave No Trace guidance (Marion 2014), we agree that, when possible, camping activities *should preferably be* concentrated on the most resistant, largely "non-vegetated" substrates, such as those occurring in dry open rocky areas or in densely forested shady settings that have little to no natural ground vegetation. There are also social reasons for moving campers off meadows and into forested or rocky areas where they are often less visible. In other words, camping should be directed to the most durable non-vegetated locations first, but in their absence, camping on sunny meadow grasses out of sight from trails and campsites is *substantially less impacting* than camping on herbs that grow in shady forested areas.

Side-hill Campsite Construction

As previously described, shifting camping activity to either naturally occurring or constructed side-hill campsites can be an effective management action to spatially concentrate camping impacts and protect experiential qualities. The practice is widely used in Canadian PAs and more than 725 side-hill campsites have been developed along the Appalachian Trail, almost entirely by volunteer stewards, with more added each year in areas that receive intensive camping pressures (Marion & others 2020a). This practice is either unknown or not actively applied within the PCT corridor, though we found clear single examples of cut-and-fill side-hill tent pads in the 1000 Island Lake Basin and Outpost Camp, Inyo NF, Alpine Lakes Wilderness, and at Southfork Camp, North

Figure 30. Side-hill campsites at Mt. Whitney's Outpost Camp (a), Alpine Lakes Wilderness (b), and Thousand Island Lake (c), compared visually to the development used to create a side-hill trail with stone steps (d).

Cascades NP (Figure 30); we suspect these were constructed by visitors. While one manager expressed some wilderness character concerns, we note that large numbers of side-hill campsites have been developed in numerous NPS and USFS wilderness areas along the A.T., and that they are visually similar to or more benign than many engineered side-hill trail segments (Figure 30d). We suggest that the PCT community seek to identify some areas where this new practice can be experimentally applied as case studies to provide opportunities for further evaluation of their merits. Study authors are available for any further consultations.

Studies have demonstrated the efficacy of constructing tent pads with wood or rock borders, including in flat terrain. Dixon and Hawes (2015) describe how the construction of camping platforms in the alpine zone of the Arthur Range of Tasmania "successfully focused camping pressure and so constrained or limited impacts." Similarly, a longitudinal study of the popular Overland Track in Tasmania by Dixon (2017) found improved conditions at locations where wooden camping platforms had been installed, with track rangers reporting a greater concentration of camping use after the structures were installed. While similar wooden camping platforms have been constructed in the U.S. New England region, we highlight the advantages of soil tent pads outlined by wood or preferably rock borders that allow tents to be staked in soil. These are less costly to construct and maintain over time and are substantially more natural in appearance. As described in Daniels & Marion (2006b), well-spaced side-hill campsites effectively improve both resource protection and social/experiential conditions. The most effective actions managers can apply to reduce impact in popular high use camping areas are those that increase the spatial concentration of camping activity, like the installation of sustainable side-hill campsites, or visually obvious tent pads when camping must be accommodated in flat terrain.

Condition Class Ratings

During our PCT fieldwork we noticed a significant shortcoming associated with the common use of descriptive Condition Class rating systems, which we applied in addition to numerous other indicators of campsite condition (Appendix 1). Condition Class ratings overestimate camping impact in some settings due to a failure to compensate for undisturbed offsite locations that may have little to no vegetation or litter cover due to standing water, dry substrates (shallow soil over bedrock), and rockiness. For example, when visitors simply remove a few rocks or limited organic material (e.g., sticks and pinecones) in non-vegetated areas to erect a tent the site is assessed at Condition Class 4 due to the exposure of soil. However, this involves little environmental "impact" when compared to similarly rated campsites in vegetated areas, where complete exposure of mineral soil signifies substantial impacts to previously present vegetation and organic litter.

In response, we employed a comparative research design with onsite and comparable offsite (control) measures of vegetation cover, exposed soil, and rock using the following categories: 0-5%, 6-25%, 26-50%, 51-75%, 76-95%, 96-100%. These comparative measures allow computation of absolute difference values by subtracting onsite from offsite midpoint values (see Appendix 1). These data more accurately characterize the *actual* extent of camping impact in all settings and reveal considerably less impact than the more commonly used Condition Class ratings. We suggest adoption of these more comprehensive and accurate protocols.

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APPENDIX 1: FIELD RESEARCH PROTOCOLS

Monitoring Indicator Library: Recreation Sites & Campsites

This library of indicator protocols represents an effort to develop "standardized procedures" for conducting visitor impact assessments using the best available practices that have been informed or peer reviewed by the scientific literature. Monitoring program staff are encouraged to download and apply these indicators and protocols "as is," with minimal revisions when necessary to adapt them to local environmental conditions or information needs. Such edits should carefully consider the trade-offs between assessment accuracy, precision, and efficiency, along with improvements in technological devices for measuring and inputting data. Some indicators may be unnecessary (omitted) while others may be added. Before using this monitoring indicator library, please consult the more comprehensive guidance on monitoring objectives, legislative guidance, and use of monitoring data in visitor use management planning and adaptive management practices in the publications listed at the end of this document.

The procedures in this section are for recreation sites, including day use sites, but with a focus on overnight campsites. Three types of indicators are included: Inventory – pertaining to general attributes like site locations and types or use, Sustainability – pertaining to attributes that limit the areal extent of site impact, ensuring experiential quality, and functional attributes, and Impact – pertaining to site conditions and the extent of resource impact. Monitoring staff are encouraged to incorporate technological advances in their monitoring, particularly the use of smartphone apps that allow efficient electronic data entry with accurate GPS coordinates and high-resolution digital photos. Additional advantages are integrated real-time protocol "look ups," data quality assurance procedures (e.g., out-of-range checks, inability to close/save records with missing data), automated linking of GPS coordinates to data and photos, and easy transference and safe "cloud" storage of *all* collected data whenever phone apps are "synched." Other advances include use of increasingly accurate GPS units and distance-measuring devices. On return from each fieldwork trip staff should follow a checklist to synch all smartphones and download/double-check all data stored in the cloud. Data from any separate GPS units should also be transferred, checked, and backed up. Any problems with field assessments should be immediately discussed based on fieldnotes, with clarifications or edits made to the protocols, which must be updated to all devices or printed guidance.

Assessing Site Sustainability: Recent recreation ecology research has yielded information enabling the selection of sites able to accommodate heavy use over time while minimizing the chronic problems of site expansion and proliferation. A primary objective for most land managers is to minimize the aggregate areal extent of visitor impact (e.g., the sum of site sizes for a management unit or travel zone). For example, this can involve restricting campsite numbers through a *containment strategy* that focuses use on limited numbers of established or designated campsites, sustainably selected in areas where sloping topography, rockiness, or uneven terrain will *permanently* restrict campsite expansion and proliferation. Alternately, a *dispersal strategy* and pristine site camping practices that prevent the creation of campsites can be applied, most effective with more experienced campers outside of popular trail corridors.

Including sustainability indicators allows managers to avoid and minimize camping impacts proactively and permanently. Research and monitoring data reveal that visitors most frequently select campsites in flat terrain near water or attraction features that facilitate rather than restrict campsite expansion and proliferation over time. The *campsite expansion potential* indicator promotes selection of campsites in areas where topography, instead of education or regulation, compels activity concentration and minimizes the aggregate areal extent of camping impact. This is the most important sustainability indicator. *Tree canopy cover* is also an influential indicator because sites with low tree cover have a lower threat from hazard trees and greater sunlight enhances the cover of trampling resistant and resilient grasses. If camping on forested sites is necessary, this indicator reveals the most densely forested sites that support little to no plant groundcover – using these sites results in less loss of plant cover than compared to campsites under intermediate canopies that support more substantial plant groundcover. *Intersite visibility* and/or distance is the most important social/experiential indicator as this attribute can be considered or manipulated to ensure a desired level of solitude and natural quiet for visitors. Campsite *functionality* indicators should also be considered to ensure the selected sustainable sites will be desirable to visitors and meet their needs. Site management work, like improving tent pads or installing site facilities, can improve a number of these attributes if sites with multiple negative ratings are needed.

Recreation sites and campsites are defined as areas of visually obvious disturbed vegetation, surface litter, or substrates caused by human recreational use within the geographic areas prescribed for monitoring. Recreation sites receive mostly day-time activities whereas campsites receive predominantly overnight use, though both uses can occur on the same sites. Note that both types of sites may be a single degraded area, ***or*** a proximate (adjacent) collection of separate disturbed spots caused by recreational uses. For example, a core campsite area with a fire ring or cooking area may include several nearby visually obvious smaller “satellite” tenting spots that would likely be used by a single group. Consistent judgment is needed to assign, and in later surveys reassign, these proximate disturbed areas, capturing changes in their size, merging, and/or creation of new spots. Assessing each of these areas as a separate site is an option, but one that is generally substantially less efficient.

Careful searches of all trail corridors are conducted to locate and assess a census of all recreation sites and campsites, generally found by following all formal and informal (visitor-created) trails, however faint. Efficiency can be gained by monitoring a stratified random sample of the geographic areas, within which a census of all sites is conducted. When sites are found, a determination will be made if there is sufficient human trampling-related disturbance to produce visually obvious site boundaries. If affirmative, then all assessments will be performed, if not, then only a subset of Inventory Indicators will be assessed.

Assessments are best restricted to the latter two-thirds of the visitor use season, but before leaf fall and/or the threat of snowfall (*specify approximate range of dates*). This restriction recognizes that site conditions generally recover during off-season periods of lower visitation, and reflect a rapid increase in impact during early season use. Site conditions and impacts are most pronounced and stable during the mid- to late-use season and reflect the resource impacts of that year’s visitation. When practical, site assessments in subsequent monitoring cycles should be completed as close in timing to the original year’s measures as possible to avoid phenological or use-related differences (plus or minus two weeks is best).

This monitoring guidance includes commonly used indicators calculated from field data, along with the computational descriptions. Perform these after field data has been checked/cleaned of any errors. Finally, recreation ecologists have developed and refined many analytical procedures and data presentation formats that aid in summarizing and communicating monitoring data findings. For examples, see Marion (2006) and Marion and others (2020a,b) for reports that include such presentations and how data can be used in VUM adaptive management decision-making.

Recreation Site Library of Monitoring Protocols

(*version xx/xx/xxxx*)

Field Materials

Check carefully before leaving for the field

- ☐ Topographic maps with roads, trails, and recreation sites from most recent survey (paper and/or digital).
- ☐ Submeter GPS unit w/charged or backup batteries, all cords, stylus, antenna/lead, and pack. Loaded with necessary maps, previous data, guidance, and data dictionaries.
- ☐ Sonin Combo Pro distance measuring unit w/new batteries and/or tape measure (100 ft. <u>in tenths</u>).
- ☐ Cell phones or tablets with data entry phone apps and backup batteries and cords. Loaded with necessary maps, previous data and photos, and error-checking data entry screens with look-up capability to view all protocols. Otherwise include printed field manuals and sufficient numbers of field forms.
- ☐ Umbrellas and zip-lock bags as needed to protect electronic gear from rain.
- ☐ Wire pin flags (15) *optional*.
- ☐ Small notebook and pens for recording progress or notes regarding monitoring issues, progress, and problems.

Inventory Indicators

<u>Date</u>: Assessment date (e.g., 07-12-22).

<u>Staff</u>: Identify the field personnel who conducted the site assessment.

<u>Site Number</u>: A unique alpha-numeric number with letters denoting management units, travel zones, or geographic areas (list these and their letters), and numbers for consecutive sites within these areas.

Comments: Record descriptive comments as needed. Include any old site numbers from prior surveys that should be tracked. If two former sites have merged use one of the site numbers and record the other site number as "merged." If the site is recovering with no recent use and/or clear boundaries indicate this under use type.

<u>GPS Coordinates</u>: From the center of the site, record its location using a sub-meter GPS device if available (the WGS84 decimal degree datum is suggested). Otherwise use a smartphone data collection or GPS phone app (accuracy generally about 15-30 ft). Also collect coordinates for the center of any affiliated satellite use areas (e.g., separate visually obvious tent pads).

<u>Designation</u>: Designated, Established, No Designation, Closed/Recovering, Recovered

<u>Use Type</u> <u>(predominant)</u>: Day Use/Vista, Campsite, Horse Campsite, Group Use, Commercial, Recovering (no recent use/no clear site boundaries – *omit assessments for all following indicators*)

<u>Estimated Use Level</u>: Low (1-10 nights/yr), Moderate (11-20 nights/yr), High (21-30 nights/yr), Heavy (>30)

Note: For the following three indicators actual distances could be derived from GIS procedures.

<u>Distance: Other Campsites</u>: Distance between site center points of closest other site: (<100 ft, 101-200 ft, 201-300 ft, >300 ft)

<u>Distance: Formal Trail</u>: Distance between the site center point and the nearest formal (designated) trail: (<100 ft, 101-200 ft, 201-300 ft, >300 ft)

<u>Distance: Water</u>: Distance between the site center point and the nearest permanent water source: (<100 ft, 101-200 ft, >200 ft but < 10 min walk, >200 ft but >10 min walk)

General Comments: As needed, describe significant impacts, difficult assessments, needed protocol edits, and site recommendations.

Campsite Sustainability

Campsite Expansion Potential: Walk the campsite's boundary looking offsite and count the number of potentially usable 2-person tenting spots within a 30-ft buffer considering topography (sloping terrain), rugosity (rockiness, uneven terrain), and wet substrates. ***Disregard*** the presence of *any* herbaceous or woody vegetation and moveable woody debris and rocks (i.e., include counts in these areas if sufficiently flat and dry). For campsites that consist of several separate but proximate use or tenting areas conduct counts for each separately and sum, but do not double-count. Larger counts indicate less sustainable campsites.

Tree Canopy Cover: Imagine that the sun is directly overhead and estimate the percentage of the site that is shaded by the tree canopy cover; record the best mid-point value. Note: use "85.5" for nearly full tree canopy cover over the site; use "98" only if the cover is sufficiently dense that ground vegetation cover is substantially diminished (e.g., <50%): 0-5% **(2.5),** 6-25% **(15.5),** 26-50% **(38),** 51-75% **(63),** 76-95% **(85.5),** 96-100% **(98)**

Intersite Visibility: Number of campsites within 100 yrds that would be visible if occupied. This indicator reflects the relative opportunity for campsite solitude and natural quiet. A possible substitute measure is the calculation of inter-site distances with GIS software.

Usable Tent Pads: Number of usable tent pads within site boundaries. Usable pads should be large enough for a 2-person tent and relatively smooth and slightly sloped (well-drained). When considering this indicator consider that limited site maintenance work can often increase this number if needed; most good campsites should have 2-3 usable tent pads. Consider that sites with >4-5 tent pads could also be considered "too large" to be sustainable.

Campsite Functionality Indicators	Rating
Rate each attribute as *negative*, *ok*, or *positive,* or *number* for the last three. Use the *Comment* field to describe any noteworthy problems for selected indicators.	
Ease of water access: Distance, terrain, and elevation difference.	– ok +
Cat-hole potential: Ease of digging, soil depth, and privacy.	– ok +
Bear bag hang: Presence of tall trees w/good limbs for hanging bags.	– ok +
Scenic attractiveness: Of campsite, surroundings, and vista.	– ok +
Seating: Presence/quantity of usable rocks or logs.	– ok +
Stove rock: A large flat "kitchen" rock for camping stove and pots (#).	#:____
Fire site: Fire site (regardless of legality) (#).	#:____
Dead/hazard trees: Dead campsite-proximate trees that could fall or drop limbs (#). Field staff are ***not*** technically trained/qualified to make these assessments relative to visitor safety. This indicator provides an approximation of standing dead trees and trees with dead limbs on or near the site.	#:____
Comments:	

Impact Indicators

<u>Condition Class</u>: Compare site conditions to descriptive classes and record the most apt class number.

Rock (0)	Site is predominantly on rock surfaces; the effects of trampling are difficult to see or assess.
Class 1	Site barely distinguishable; slight loss of vegetation cover and/or minimal disturbance of organic litter.
Class 2	Site obvious; vegetation cover lost and/or organic litter pulverized in primary use areas.
Class 3	Vegetation cover lost and/or organic litter pulverized on much of the site, some bare soil exposed in primary use areas.
Class 4	Nearly complete or total loss of vegetation cover and organic litter, bare soil widespread.
Class 5	Soil erosion obvious, as indicated by exposed tree roots and rocks and/or gullying.

Note: An efficient but subjective method with categorical/ordinal ratings that limit analytical operations and omit areal measures of disturbance (e.g., a very large Class 3 site is likely worse than a small Class 5 site). This method also overestimates impact in areas with little natural vegetative cover or organic litter.

<u>Site Size</u>: Recreation sites are defined as areas of visually obvious disturbed vegetation, surface litter, or substrates caused by human recreational use within the geographic areas prescribed for monitoring (Figure 1). Recognize that some sites, such as those with dense overstories, may be too shady to support much ground vegetation cover, requiring determinations based on organic litter (dead leaves/needles) that are pristine and intact vs. litter that is pulverized or absent. For rock or barren surfaces compare to offsite pristine areas to focus on visually obvious trampling disturbance differences in plant (include moss/lichen) and organic litter cover, and/or the presence/absence of pinecones, small rocks, and gravel that are generally absent from use/tenting areas. Omit areas for sand or fine gravel substrates (e.g., along shorelines) that lack vegetation and organic litter; footprint densities are too dynamic and ephemeral to support objective boundary determinations.

Sometimes sites may include a proximate (adjacent) collection of separate disturbed spots caused by recreational uses. For example, a core campsite area with a fire ring or cooking area may include several smaller separate but proximate visually obvious tenting spots that would likely be used by a single group. It is most efficient to combine these as a single site and assess them together.

If other agents of disturbance are present (e.g., grazing or trampling by livestock/wildlife, flooding) examine off-site areas to determine if their effects can be objectively assessed and omitted from boundary determinations. Apply judgement based on interpreting standard photos in Figure 1 (*with any necessary substitutions or additions to represent local vegetation and substrate types*). <u>Do not assess any **Impact indicators** if >40% of site boundaries are indistinct (highly subjective) and/or if other agents of disturbance excessively interfere with determinations.</u>

GPS Measurement – After boundary determinations are made position a sub-meter GPS unit at the approximate center of the largest disturbed area and record a >50 point average location position and label it with a unique campsite code. Next, put the GPS in vector mode and walk the site boundaries, ensuring that a point is collected at each significant boundary (polygon) vertex required to accurately render the site's shape and size. Close and examine the feature and its area measure to verify that it provides an accurate representation of the site shape and area, if not then delete and repeat the process. If satellite reception problems prevent accurate site size data collection, substitute size measurements using the Geometric Figure method. Otherwise, continue to walk and collect the boundaries of all proximate disturbed spots associated with this site, labelling each with the same campsite code and a satellite site number. Averaged center points are not necessary but check each satellite use area to ensure that collected data continue to accurately reflect the site's location, shape, and size. Sometimes it is more accurate and efficient to use the Geometric Figure Method on all small use areas (e.g., <12x12 ft).

Figure 1. Photographs illustrating site boundary determinations: defined as the most pronounced ***outer*** boundary of visually obvious human recreational disturbance in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation is reduced or absent, as pronounced changes in organic litter cover (intact vs. pulverized), or on rock of lichen or moss cover.

Geometric Figure Method – Campsite size is computed by measuring the dimensions of one of more geometric figures that closely correspond to a site's shape and boundaries (Figure 2). This is an efficient method that can be quite accurate and precise if carefully applied using good judgement. Initially it is helpful to place wire pin flags at the geometric feature vertices. Study the site shape as though looking down from above to determine the optimal geometric figure, or combination of figures. Look both directions along site boundaries as you place the flags and try to mentally balance areas of the site that fall outside the lines with off-site (undisturbed) areas that fall inside the lines. Pins do not have to be placed on site boundaries, as demonstrated in Figure 2. Project site boundaries straight across areas where trails enter the site. Measure and record the essential computational dimensions of each geometric figure (nearest 0.1 foot) using a tape measure or accurate electronic device. Always conduct area computations in the office to reduce field time and avoid errors.

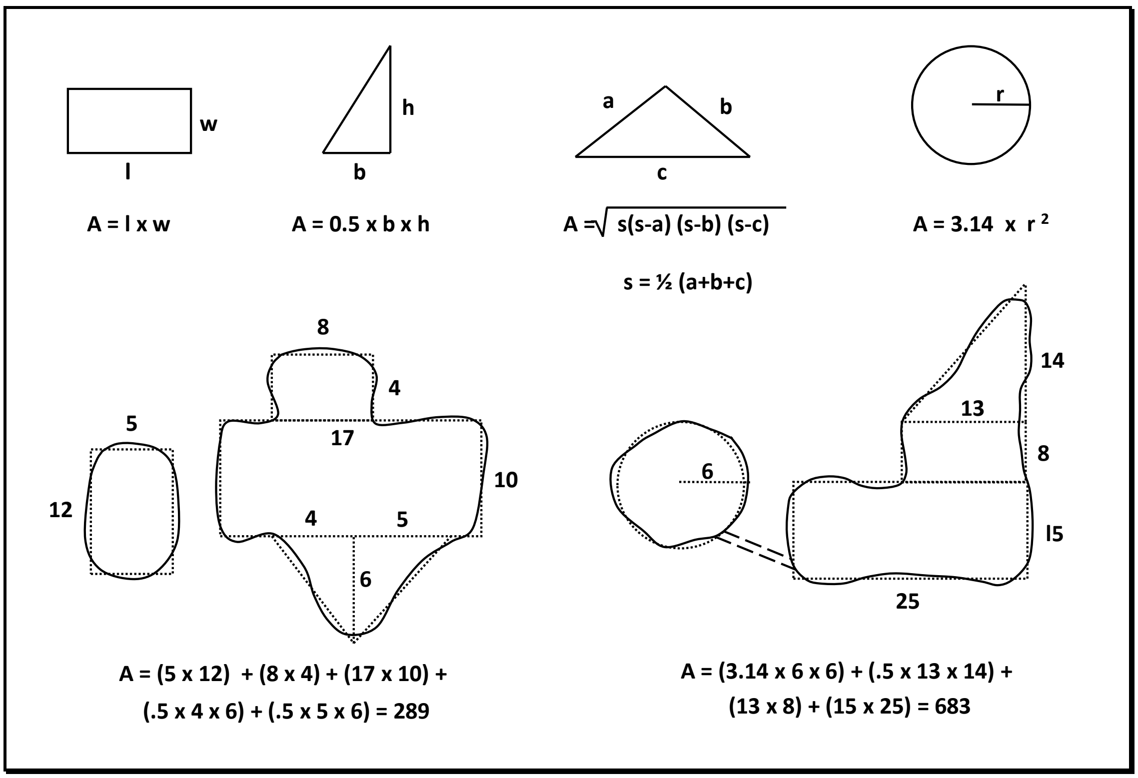
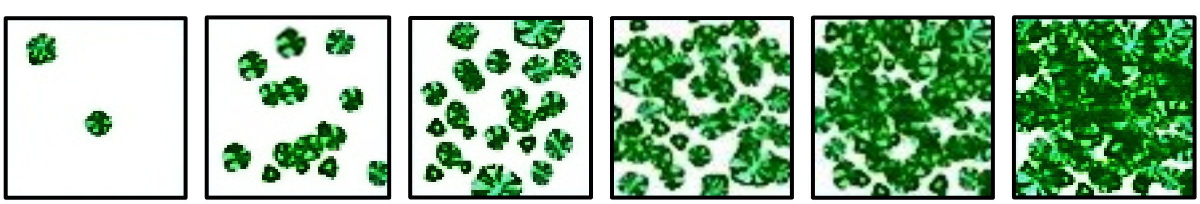


Figure 2. Illustration of the Geometric Figure Method for measuring site sized based on recording the dimensions of one or more superimposed geometric figures.

<u>Onsite Vegetation Ground Cover (%)</u>: Estimate the percentage of live vegetative ground cover <2 ft tall within site boundaries, including herbs, grasses, tree seedlings, shrubs, mosses, and folios (leaf-like) lichens. Include nearby "satellite" use areas and exclude undisturbed "islands" of vegetation within site boundaries. Refer to the categories and reference photos but record the midpoint values. For this and other indicators, it is helpful to narrow your decision to two categories and select the best midpoint value.



0-5% (**2.5**) 6-25% (**15.5**) 26-50% (**38**) 51-75% (**63**) 76-95% (**85.5**) 96-100% (**98**)

Offsite Vegetation Ground Cover (%): Select a "control" area the site would resemble if never used; it should have similar topographic attributes and substrates, though use may have altered onsite (not control) vegetative attributes. As above, estimate the percentage of live vegetative ground cover <2 ft tall in the control area, selecting the best midpoint value.

Percent Vegetation Cover Loss (%) *(calculated)*: Subtract onsite vegetation cover from offsite cover (midpoint values). Rarely, negative values can occur when woody cover is removed from sites, allowing resistant grass cover that can exceed the cover of plants under dense canopies in control areas.

Area of Vegetation Cover Loss (ft^2) *(calculated)*: Multiply percent vegetation cover loss by campsite size (in ft^2) to obtain an estimate of the area over which vegetation cover has been lost on the site. This is the most ecologically significant indicator of vegetation impact.

Onsite Exposed Soil (%): Estimate the percentage of exposed mineral or organic soil, defined as ground with little to no recognizable organic litter (decomposing leaves, twigs, pinecones) or vegetation cover within the site boundaries and satellite use areas (refer to reference photos). If the exposed soil has patches of organic litter or vegetation, then mentally combine and exclude the patches from estimates. Refer to the categories and record the best midpoint value.

Categories: 0-5% (**2.5**), 6-25% (**15.5**), 26-50% (**38**), 51-75% (**63**), 76-95% (**85.5**), 96-100% (**98**)

← Exposed Mineral Soil → **Organic Soil** ← **Organic Litter** →

Offsite Exposed Soil (%): As above, estimate the percentage of exposed soil in the undisturbed control area, recording the best midpoint value.

Percent Exposed Soil Loss (%) *(calculated)*: Subtract offsite exposed soil cover from onsite cover (midpoint values).

Area of Exposed Soil Loss (ft^2) *(calculated)*: Multiply percent exposed soil loss by campsite size (in ft^2) to obtain an estimate of the area over which soil has been exposed on the site.

Tree Damage (#): Count the number of live trees (>1 in. diameter) within or on site boundaries (include islands, exclude satellites) that are damaged from visitor use, consisting of numerous small trunk scars and/or nails or 1+ larger cut branch or scar with exposed inner wood. Ignore slight damage such as broken or cut small branches, a single nail, a few superficial scars, or damage from lightning and natural causes. Assess damage to a multiple stemmed tree (joined above ground level) as one tree, including a stem that is cut off.

Tree Damage (#/acre) *(calculated)*: Divide the number of damaged trees on the site by site size (in ft^2) and multiply by 43560 to obtain the number of damaged trees/acre.

Root Exposure (#): Count the number of live trees (>1 in. diameter) within or on site boundaries (include islands, exclude satellites) that have at least the top half of many major roots exposed more than one foot from the base of the tree. Ignore root exposure from natural causes like flood erosion.

Root Exposure (#/acre) *(calculated)*: Divide the number of trees with root exposure on the site by site size (in ft^2) and multiply by 43560 to obtain the number of trees with root exposure/acre.

<u>Tree Stumps (#)</u>: Count the number of new and old tree stumps (> 1 in. diameter) within or on site boundaries (include islands, exclude satellites).

> ***<u>Tree Stumps (#/acre)</u>*** *(calculated)*: Divide the number of tree stumps on the site by site size (in ft^2) and multiply by 43560 to obtain the number of tree stumps/acre.

<u>Access Trails (#)</u>: Walk the campsite boundary counting all obvious trails leading away; for trails that branch or merge just beyond site boundaries make the count 10 ft from the boundary. Omit faint trails with untrampled plants or organic litter in their tread.

<u>Fire Sites (#)</u>: A count of fire sites within campsite boundaries (include satellites). Include old inactive fire sites as exhibited by blackened rocks, charcoal, or ashes. Omit locations where charcoal/ashes have been dumped, unless uncertain.

<u>Human Waste (#)</u>: Conduct an “intelligent” rapid search of likely "toilet" areas, typically screened areas just out of sight of the campsite. Count and record the number of individual human waste sites, defined as separate locations with human feces present (not just TP, which could be dug up or from peeing). The intent is to quantify surface disposed human feces.

<u>Site Photograph</u>: Select a vantage point that provides the best view of the entire site. Take a photo with the camera pointed down to include as much of the site groundcover as possible, turning to take a second photo if needed. The objective is to positively identify the site *and* record a visual image of its condition. Delete and retake the photo(s) as needed to obtain optimal exposure and focus. If prior site monitoring photos exist, position yourself as needed to replicate the earlier photos, moving or altering zoom settings to obtain the same coverage based on the positioning of trees or rocks.

Photo Documentation: Some photo apps reliably link photos to site data records. If not, then record the date and time of each photo to the site record, or possibly a photo number if you are certain that numbers are retained as part of the photo name when transferred to a computer (take great care in this!).

*** Collect all gear and personal items before leaving.**

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