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Fuelwood depletion at wilderness campsites: extent and potential ecological significance

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Summary

Recreational camping in wilderness areas causes a number of biophysical impacts, including loss of woody debris through campfires. Although extensive research has documented trampling impacts to vegetation, few studies have explored the extent of woody material depletion. This study adapted planar transect methods to measure the relative loss of fine (<0.6 cm), small (0.6 to 2.5 cm), medium (2.6 to 7.6 cm) and large (>7.6 cm) diameter materials in three concentric rings extending 0–5 m, 5–10 m and 10–15 m from the centre of 58 campsites in different environments ranging in elevation from 1250 to 2225 m in the Cascades Mountains in Oregon, USA. Compared to matched controls, losses were greatest for small (40%) and medium-sized (63%) materials, but were evident for fine (25%) and large (30%) materials as well. Surprisingly, depletion (across all sizes) was no greater in the centre of sites than in the outer measurement ring, even though the outer ring was often in intact vegetation. This suggests that impacts on woody debris extend beyond those impacts to vegetation typically monitored at campsites. Such recreational impacts to woody debris have rarely been systematically described. However, research on woody debris removal related to forest management indicates possible ecological effects of fuelwood consumption.

Keywords: wilderness management, campfires, woody debris, recreation ecology

Introduction

Campfire building by recreational visitors to wilderness areas has resulted in the proliferation of fire sites. Blackened rocks, unsightly piles of charcoal, and bits of burnt foil are among the most obvious effects, but more extensive impacts such as soil sterilization and tree damage and loss also occur (Cole & Dalle-Molle 1982). In heavily used areas, a substantial amount of off-site trampling of vegetation occurs by visitors searching for firewood, and the loss of downed woody material may affect ecosystem processes on local scales (Bratton *et al*. 1982). Although some camping impacts, for example vegetation loss, have been widely studied, only a few studies have examined the impacts of campfire building on the abundance and distribution of woody debris. Wilderness areas are often protected as reserves of biological integrity, and understanding the range and extent of impacts from recreational use is important. Therefore, this study sought to describe changes in fuelwood availability on campsites compared to intact surrounding areas.

Wilderness managers must choose among many possible impacts to monitor. Fuelwood consumption may be a particularly good candidate because of the important ecological roles played by woody material. For example, it increases the physical, structural and chemical heterogeneity of the forest floor (Keenan *et al*. 1993; Clark *et al*. 1998; Corns & Maynard 1998; Kirby *et al*. 1998), contributes to soil organic matter, and helps maintain soil stability (Anderson & Winterton 1996). Abundant quantities of medium-sized material are important for wood-inhabiting lichens, mosses, and fungi (Rasmussen & Whigham 1998; Hagan & Grove 1999; Kruys & Jonsson 1999) and may contribute to tree and shrub seedling survival (Romme *et al*. 1995; DeLong *et al*. 1997). Removal of material larger than about 5–10 cm diameter may alter microsites and conditions necessary for germination, establishment, and survival (Eriksson & Froborg 1996; Caccia & Ballare 1998). Populations of vertebrates, invertebrates, and microbial organisms all depend on larger woody debris for habitat, transportation corridors, and nutritional requirements (Harmon *et al*. 1986; du Plessis 1995; Lee 1995; Aigner *et al*. 1998).

Most of the research on woody material has focused on larger materials, which may be too large to be consumed in campfires. However, smaller materials of the type used by campers also contribute significantly to productivity and nutrient cycling. Although small woody material (1–15 cm) makes up only a small fraction by mass (0.5–11.5%) of the total downed wood in forests, it contains most of the N, P, and K (Keenan *et al*. 1993). In alpine environments, the largest nutrient reservoirs reside in soil organic matter, and woody debris is a major contributor (Bowman *et al*. 1993). One study estimated that extended removal of litter on campsites in the Great Smoky Mountains would result in a 12 to 50 yr recovery period for soil carbon, possibly reducing site productivity (Bratton *et al*. 1982).

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Although there is evidence that removing woody material can have adverse effects on some species and processes, it is important to note that removal is not necessarily detrimental to all species. For example, woody debris may inhibit germination and establishment of some species by physically separating the seed coat and substrate (Anderson & Winterton 1996) or impairing the radicle's ability to reach reliable moisture supplies (Caccia & Ballare 1998; Greene & Johnson 1998). In such cases, removal of fine debris might actually enhance establishment of species like Douglas-fir (Caccia & Ballare 1998) or western hemlock, subalpine fir, and lodgepole pine (Wilson & Zammit 1992).

The differential impact of wood consumption on different species is an important question, but at a more basic level it is important first to describe the nature and extent of changes caused by recreationists. This study sought to answer three questions about the magnitude of impact from firewood collecting.

- How does the proportion of woody material lost on campsites vary by size of material? Because the ecological roles of different sized materials vary, it is of interest to know whether campers differentially deplete materials of a certain size.
- How does the proportion of woody material lost on campsites vary with distance from the centre of a campsite? To evaluate the ecological importance of wood consumption, managers need to know how extensive depletion is across the landscape and the extent of fuelwood loss around campsite areas.
- How far need a person travel to acquire a given amount of firewood? Widespread impacts may be of concern for ecological reasons, but may also be important because of the impact they can have on campers' experiences. Being unable to find wood near camping areas may detract from campers' enjoyment.

A secondary objective was to determine how fuel depletion related to vegetation impacts as measured by camp area. This objective was included because of the extensive body of research on vegetation impacts at campsites.

Methods

Study area

Fuelwood abundance was measured on 58 campsites and matched controls at several destination areas in Mt Jefferson and Three Sisters Wildernesses in the Cascades Mountains of Oregon. Sites ranged from 1250 to 2225 m elevation, with the majority located in montane or subalpine forests. Closed montane forests were dominated by mountain hemlock (*Tsuga mertensiana*) and Douglas-fir (*Pseudotsuga menziesii*), with occasional lodgepole pine (*Pinus contorta*), grand fir (*Abies grandis*), western hemlock (*Tsuga heterophylla*), Pacific silver fir (*Abies amabilis*), and Engelmann spruce (*Picea engelmannii*). The majority of higher elevation sites occurred in closed stands dominated by subalpine fir (*Abies lasiocarpa*) and mountain hemlock or in pockets of forest on the edge of clearings or meadows. Whitebark pine (*Pinus albicaulis*) was co-dominant on some higher sites. Several plant associations were present. Lower elevation densely forested sites were typically dominated by grouse whortleberry (*Vaccinium scoparium*) or big huckleberry (*Vaccinium membranaceum*) in the shrub layer and bear grass (*Xerophyllum tenax*) and dwarf bramble (*Rubus lasiococcus*) in the forb layer. At the lowest elevations, understory vegetation often included vanilla leaf (*Achlys triphylla*), queens cup (*Clintonia uniflora*), and twinflower (*Linnaea borealis*). On lower xeric sites, pinemat manzanita (*Arctostaphylos nevadensis*) and boxleaf myrtle (*Pachystima myrsinites*) were common. On more open mesic sites, arrowleaf groundsel (*Senecio triangularis*), false hellebore (*Veratrum viride*), and fan-leaf cinquefoil (*Potentilla flabellifolia*) were common. Higher elevation forested sites had primarily grouse whortleberry, pink heather (*Phyllodoce empetriformis*), and Merten's mountain heather (*Cassiope mertensiana*) in the shrub layer and woodrush (*Luzula hitchcockii*), partridgefoot (*Leutkea pectinata*) and Parry's rush (*Juncus parryi*) in the forb layer.

The sites in question ranged in level of use, with some occupied perhaps 20 times per year, while campers might use others for only one or two nights per year. Campers were allowed to build fires at all sites. Information about campsite size from a different study conducted during the same year was available for 39 sites. In that study, area was determined by the radial transect method (Cole 1989), where the edge of the site was considered the location at which visible impacts to vegetation ended. The sites varied in the areal extent of impacts to vegetation. Nearly half of the sites were less than 100 m^2, while about 30% were larger than 200 m^2.

Fuelwood measurements

In this study, a modified planar transect method was used to count the number of pieces of woody material on campsites and in control areas. Although many procedures (e.g. Bratton *et al*. 1982; Brown *et al*. 1982) use counts only as an intermediate measure for estimating fuel volumes or mass, we used untransformed counts in this study. Counts are easy to obtain, and in this study they served as the basis for computing relative change. One subsidiary goal of the study was to determine whether simple assessment techniques could be informative, and counts required less information and substantially less field time to collect than would be required for volume estimation.

Line transects and planar transect techniques provide cost effective and efficient means of estimating fuelwood counts and volumes (Brown *et al*. 1982). The line transect method uses systematically or randomly oriented transects to count intersections of woody pieces, and has become the basis of estimating fuels for fire modelling (Van Wagner 1968). The planar intersect method is based on a similar concept, but uses vertical sampling planes to count intersections of woody pieces (Brown 1974; Brown *et al.* 1982). Both methods are fairly reliable for counting pieces of woody material, particularly for material less than 5 cm diameter (Brown 1974). In some studies, larger material has tended to be over- or undersampled, although it has been suggested that longer transect lengths can help mitigate sampling problems (Green & Peterken 1997).

One significant modification was made to the standard planar sampling method. The technique was originally developed to assess fuels in areas where it could be assumed that material was randomly distributed across the landscape, such as forest harvest units. On campsites, this assumption does not hold, because depletion is greatest near the centre of the site and progressively lessens away from the centre. Thus, in this study, at each campsite three concentric circles extended 5, 10, and 15 m from campsite centre-points (Fig. 1). Sites varied from quite small to very large, but a 15 m radius (700 m^2 area) usually ensured that some or the entire outer ring was located in intact vegetation, beyond the visibly impacted portion of the site.

We placed the centre-points at what appeared to be the most impacted part of the site. The location was adjusted if needed to ensure a minimum radius of 15 m unobstructed by lakeshore or talus slopes. Within the inner circle and each of the two surrounding rings, six 5-m vertical sampling planes were arranged, resulting in a total of 18 transects per site.

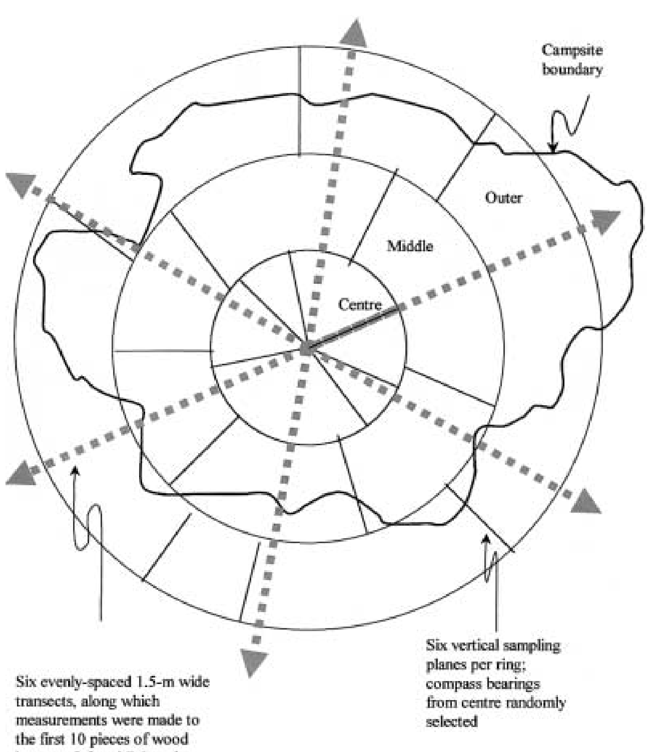

Figure 1 Diagram of layout for measuring woody material within three concentric circles around campsite centre-point.

The orientation of each transect within the inner circle and each ring was determined by randomly selected bearings radiating from the centre-point.

The total number of pieces of woody material intersecting each of the 18 transects was counted for four size classes of material. Transect lengths for each size class differed because of differences in the natural distribution of materials (cf. Bratton *et al.* 1982; Keenan *et al.* 1993). Lengths followed the recommendations of Brown *et al.* (1982), based on an expected acceptable error of 20% and interval distances commonly used to assess Pacific Northwest slash fuels. Pieces of material less than 0.6 cm diameter ('fine' material) were counted along the first 2 m of each plane. Pieces of material between 0.6 and 2.5 cm diameter ('small') were counted along the first 3 m of each plane. Pieces of material between 2.6 and 7.6 cm diameter ('medium') were counted along the entire 5-m length of each plane. The upper bound for this size class (7.6 cm or 3 in) was chosen because this is about the maximum size of material that is easily broken by hand. For each of these three size classes of material, any piece, regardless of length, that crossed the plane was counted, and the diameter at the point where the plane was intersected determined its size class. The diameter and length of each piece of wood greater than 7.6 cm diameter ('large' material) were recorded along the entire 5-m planar transect.

This 'concentric ring' approach to assessing woody material allowed quantification of the abundance of different sized materials at three distances from the centre of a site, but did not give a sense of how far from site centre depletion extended beyond 15 m.To assess this aspect, fuelwood availability was also measured using procedures similar to those used by Nalder *et al.* (1997). Along six 1.5-m wide transects radiating from the centre-point, we measured the distance to the first 10 pieces of wood between 2.5 and 7.6 cm diameter and greater than 30 cm in length. (This was intended to capture the type of material typically used for fires and to be sufficient for an evening fire.) This measure should give managers a more meaningful indication of the practical implications of fuelwood depletion (i.e., how much effort is required for campers to find wood and how widespread are the impacts beyond the sites proper) than might be derived from the counts alone. One of the six inner circle transects was randomly selected as the first transect (see Fig. 1), and the other five transects were measured at 60° intervals from the first transect (i.e., systematic sampling interval).

To interpret fuel abundance counts on the sites, a control area was selected for each campsite. Following Cole (1983), the control area was defined as a nearby area undisturbed by visitor use, located in an area with similar tree species composition, basal area, and canopy cover. After a centre-point was identified, woody material was counted along six randomly oriented transects originating between 0 and 5 m from the centre-point. The same size classes were used as for the campsite, with the same measurements. Additionally, the distance to 10 pieces of medium-sized material was determined for controls as for campsites. Thus, the only difference from campsite procedures was that only one ring was measured on controls, compared to three concentric rings on the campsites.

Statistical analyses

Because counts occurred over different length transects for different sizes of material, the raw counts were transformed into the number of pieces per metre for ease of comparison. To control for natural variability in abundance across sites with different characteristics, relative loss of material compared to the matched control was computed for each site. The mean number of pieces of each size of material within each of the three rings was subtracted from the mean for the same size material for that site's control. This number was divided by the control mean to generate a value representing the relative loss of material of each size within each ring for each site. (This procedure is analogous to the computation of relative loss commonly done in studies of vegetation impact.) In the rare cases where there was more material on the site than on the control, this computation generates results that are meaningless because the denominator is zero; in such cases, relative loss was assigned a value of zero.

Analysis of variance with Duncan's *post hoc* comparisons was used to determine whether loss varied by size of material or by distance from the centre of the site. A paired T-test was used to determine whether a person had to walk significantly further on campsites than on controls to collect a specified amount of wood.

Results

Woody material abundance varied considerably across the 58 sites (Table 1). Although the mean number of pieces per metre within each size class was similar across the three concentric rings (at least for fine, small, and medium materials), within each size class and ring the standard deviation was fairly large relative to the mean. This was especially true for material larger than the fine size class. Even on controls, standard deviations were generally large, reflecting the natural variability of material across different environments.

To address the first research question as to how depletion varies with size of material, the relative loss of material of each size was computed, combining data for all three rings of each site (Table 2). Whereas, on average, sites had lost 25% of their fine materials, they had lost about 40% of the small materials and 63% of the material between 2.5 and 7.6 cm. For materials larger than 7.6 cm, only 30% had been lost, suggesting that the primary materials desired by campers are large enough to sustain a fire but small enough to break by hand. Thus there was a significant relationship ($F = 15.6$, $p < 0.0005$) between size of material and relative loss.

Table 1 Mean (±SD) number of pieces of woody material per metre by distance from site centre.

Material size	*Centre*	*Middle*	*Outer*	*Control*
Fine (<0.6 cm)	16.5 ± 10.5	19.0 ± 13.0	19.8 ± 12.7	25.3 ± 14.5
Small (0.6–2.5 cm)	1.0 ± 0.8	1.4 ± 1.9	1.4 ± 1.7	2.3 ± 2.0
Medium (2.6–7.6 cm)	0.04 ± 0.08	0.08 ± 0.3	0.08 ± 0.2	0.2 ± 0.2
Large (>7.6 cm)	0.06 ± 0.1	0.3 ± 0.4	0.3 ± 0.3	0.4 ± 0.6

Table 2 Relative loss of woody material, by size of material. Numbers with different superscripts are significantly different ($\alpha = 0.05$).

Relative loss	*Size of woody material*			
	Fine	*Small*	*Medium*	*Large*
Mean	0.25 ± 0.18[a]	0.40 ± 0.22[a]	0.63 ± 0.33[b]	0.30 ± 0.38[a]
Median	0.22	0.43	0.67	0.43
Range	0–0.59	0–0.82	0–1.00	0–1.00

Table 3 Relative loss of woody material, by distance from site centre.

	Relative loss at distance from site centre		
	0–5 m (Centre)	*5–10 m (Middle)*	*10–15m (Outer)*
Mean	0.49±0.37	0.41±0.36	0.41±0.37
Median	0.52	0.40	0.38
Range	0–1.00	0–1.00	0–1.00

Surprisingly, relative loss did not vary significantly with distance from site centre (research question two, Table 3). Combining all size classes of material, the centre ring of the campsite had lost on average 49% of its woody material. The middle ring extending 5 to 10 m from the site centre had lost 41% of its material, and the outer ring, 10–15 m, had also lost 41%. Although an F-test generated a p-value of 0.02, *post hoc* comparisons identified no statistically significant differences (at $\alpha = 0.05$) between pairs of rings.

A two-way ANOVA found no significant interaction between size of material and ring, although the main effects for both ring and size class were significant (for ring, $df = 2$, $F = 4.3$, $p = 0.014$; for size, $df = 3$, $F = 34.8$, $p < 0.0005$; Fig. 2). The largest reductions were for medium-sized material on the centre ring of the site; on average, 77% of this material was lost.

The mean distance required to collect 10 pieces of wood differed significantly ($T = 8.73$, $p < 0.0005$) between sites ($M = 52.8$ m) and controls ($M = 30.1$ m). On half of the sites, a camper would have to walk more than 2.3 times further, and on 25% of the sites 3.5 times further, on the campsite as on the control to find the same amount of wood.

Information on site size (areal extent of impacts to vegetation) was available for 39 of the sites, distributed across the different environments. The correlation between site size and relative loss of material was not significant for any size of material within any of the three rings. However, the correlation

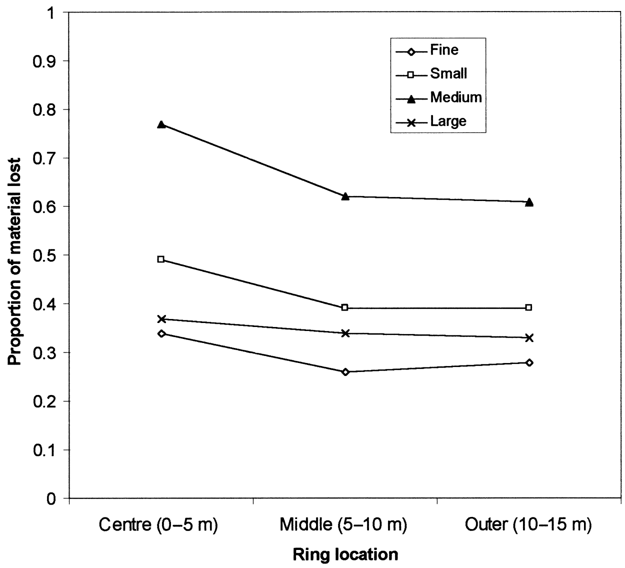

Figure 2 Relative loss of woody materials, by material size and distance from campsite centre-points.

between site size and the difference between site and control in distance to 10 pieces was significant ($r = 0.46$, $p = 0.005$).

Discussion

Extent of depletion

Taken together, counts of all sizes of material within the three on-site concentric rings and the measurements of distance required to collect 10 pieces of wood indicated significant reduction in materials on campsites compared to control areas. Across all sites, both high and low use, two-thirds of medium-sized material was gone and even the fine materials (whose only real value is as kindling) had suffered 30% reductions. In some of the heavily used higher elevation areas, it was difficult to find any burnable material within 100 m of a site.

Impacts from recreational camping, especially vegetation loss, have been widely studied, so that much is known about the areal extent of certain impacts. For example, average camp areas on 'heavily used' sites were up to 200 m^2 in the Eagle Cap Wilderness in Oregon (Cole 1982) and about 70 m^2 in the Grand Canyon (Cole & Hall 1992). Stock camps in the Eagle Cap had average camp areas between 350 and 700 m^2. Of more than 2600 sites evaluated in the Mt Jefferson, Mt Washington, and Three Sisters Wildernesses, only 6% had barren core areas larger than 200 m^2.

Compared to such findings, evidence from this study suggests that impacts to wood are more extensive than impacts to ground vegetation. Together, the three rings encompassed more than 700 m^2 of surface area, an area larger than those typically sustaining impacts to vegetation. In the outer ring at campsites, 40% of woody material had been lost, and it is reasonable to assume that impacts extended beyond the areas we assessed. On many sites, this outer ring was beyond the area of visible impacts to vegetation. (The largest of the sites studied here was 565 m^2.) Compared to other impacts that have received substantial amounts of attention, fire-building impacts have been neglected.

Although site size information was available for only 39 of the sites studied, the lack of a relationship between campsite size (essentially a measure of vegetation impacts) and fuel depletion for any size material suggests that different factors probably constrain site size (e.g. topography) and fuel abundance (e.g. forest cover, level of use). Therefore, the effects of campfires on woody material cannot be easily inferred from measurements of the areal expanse of impacts to vegetation.

Potential ecological significance of fuelwood losses

Because of their extent, fuel losses from recreation deserve greater research and managerial attention. Studies reviewed above highlighted the various important ecosystem functions played by wood of all sizes. Although wilderness recreation appears to affect large woody debris less than smaller woody debris, even the smaller materials play important roles. Nevertheless, considerations about the likely ecological significance of recreational removal of wood are largely speculative at this time. Most studies of impacts of debris removal on soil structure or nutrition involve complete removal of all sizes of material on a larger scale than typically occurs from recreational use. It is unclear whether removal that occurs on the scale of wilderness camping, a restricted range of sizes and less overall material lost, have ecological repercussions of concern. Because this study was intended only to describe the extent and type of fuelwood lost on wilderness campsites, additional research is needed to understand the full ecological significance of wood consumption.

Need for monitoring techniques and procedures

Contemporary wilderness management planning processes such as limits of acceptable change (LAC) and visitor experience and resource protection (VERP) suggest that management actions should be initiated once standards for environmental conditions have been exceeded. Fuel abundance could be an indicator for which standards are set. Because campfires are important to visitors' experiences (Cronn *et al.* 1992) and because wood depletion may have ecological impacts, this particular indicator might be better integrated than other possible indicators. If so, managers would find it helpful to have simple, standardized monitoring procedures for assessing woody material. Much work has been done to develop procedures for monitoring vegetation loss and other campsite impacts (Cole 1983, 1989; Marion 1991, 1995), but none of these contain procedures for assessing fuel consumption.

The techniques used to inventory forest fuels that we adapted here offer promise for site monitoring. However, future efforts should ensure that transect lengths are appropriate to the size classes of materials and their natural distributions, in order to most efficiently allocate monitoring time. For example, fine material could probably be measured over 1 m rather than 2 m, given the abundance of this size of material. On the other hand, large material was often absent on the 5 m transects used in this study, even on controls. In hindsight, longer transects probably should have been used, of the order of 10–25 m; Brown *et al*. (1982) recommend that the sampling plane be long enough so that, on average, at least one intercept occurs on at least three-quarters of the planes.

In developing monitoring procedures, the size categories used for material should also be carefully considered. Because they originated in fire modelling studies, the size classes adopted here were originally developed on the basis of the rate at which they lose fuel moisture, and other classes might be more appropriate for management purposes in wilderness. Nevertheless, the data obtained in this study suggest that these categories bound the range of materials most commonly used in campfires. The results are also similar to those found by Bratton *et al*. (1982) in a very different environment. Thus, measuring in 4–5 classes spanning the range of material from 0.5 to 15 cm may serve adequately to capture and describe recreational impacts to woody debris.

Although procedures like those used here can document how conditions change as a result of recreational use, the more difficult judgment is how much change is acceptable before management action is required (Hagan & Grove 1999). Wildernesses serve as an important ecological baseline of natural conditions, and understanding how they are affected, even in subtle ways such as indirect effects of wood removal on vegetation species composition, are important. A first step is to understand rates of fuel accumulation in different environments and document the range of changes.

Conclusion

Wilderness managers spend a great deal of effort managing campfires and their impacts. Marion *et al*. (1993) reported that 43% of US National Park Service wildernesses have prohibitions on campfires, and 37% require the use of backpacking stoves for cooking. Such regulations require investments of time and money for informing visitors and enforcement of regulations. Because of this, and because having a campfire is an important part of a wilderness experience for many visitors, managers should be confident that prohibitions are truly necessary. Such confidence might come from greater awareness of the extent of fuelwood loss and understanding of associated impacts. We encourage researchers to develop easy-to-apply and reliable monitoring procedures, and we encourage wilderness and protected-area managers to incorporate fuelwood measures into campsite monitoring programs. At the same time, we welcome additional research attention to understanding how the magnitude of fuel losses vary with factors such as ecosystem type or visitor numbers, and the experiential and ecological significance of changes brought by loss of woody material.

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