Environmental Management (2009) 43:299–310
DOI 10.1007/s00267-008-9194-3

Effects of Fireplace Use on Forest Vegetation and Amount of Woody Debris in Suburban Forests in Northwestern Switzerland

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Received: 3 September 2007 / Accepted: 12 July 2008 / Published online: 5 September 2008

Abstract Urban forests are popular recreation areas in Europe. Several of these temperate broad-leaved forests also have a high conservation value due to sustainable management over many centuries. Recreational activities, particularly the use of fireplaces, can cause extensive damage to soil, ground vegetation, shrubs, and trees. Firewood collection depletes woody debris, leading to a loss of habitat for specialized organisms. We examined the effects of fireplace use on forest vegetation and the amount of woody debris by comparing disturbed and control plots in suburban forests in northwestern Switzerland. At frequently used fireplaces, we found reduced species densities in the ground vegetation and shrub layer and changes in plant species composition due to human trampling within an area of 150–200 m^2. Picnicking and grilling also reduced the height and changed the age structure of shrubs and young trees. The amount of woody debris was lower in disturbed plots than in control plots. Pieces of wood with a diameter of 0.6–7.6 cm were preferentially collected by fireplace users. The reduction in woody debris volume extended up to a distance of 16 m from the fire ring, covering an area of 800 m^2 at each picnic site. In order to preserve the ecological integrity of urban forests and to maintain their attractiveness as important recreation areas, we suggest depositing logging residues to be used as firewood and to restrict visitor movements near picnic sites.

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Keywords Picnicking · Grilling · Outdoor recreation · Firewood collection · Human trampling · Nature conservation · Sustainable forest management

Introduction

Outdoor recreation in forests has become an important part of many people's lives, especially in urban areas, where forests are often the only freely accessible natural areas to spend some leisure time (Jacsman 1998; Niemelä 1999). Several of these temperate, broad-leaved forests were sustainably managed over centuries, giving them a high conservation value (Delarze and others 1999). Today, forests have become multifunctional, fulfilling ecological, economical, and social services (Führer 2000; Mather 2001). Large numbers of forest visitors can lead to conflicts between recreation and nature conservation and between recreation and wood production (Liddle 1997; Baur 2003). Numerous ecological studies have reported impacts of recreational activities on soil and vegetation (e.g., Cole 1995; Malmivaara and others 2002; Waltert and others 2002; Roovers and others 2004). The extent of damage depends on the kind of recreational activity and frequency of visitors, but also on the type of soil and vegetation (Kuss 1986; Cole 1987). In particular, activities, such as picnicking, barbecuing, and camping, can impact large areas and allow damages to spread to previously untouched areas (Jim 1987; Marion and Cole 1996; Kutiel and Zhevelev 2001; Amrein and others 2005).

The use of picnic sites to grill and barbecue can cause impacts other than trampling damage associated with picnicking and camping. A survey in Switzerland revealed that on average, 50% of fireplace users collect firewood from the surrounding area (Rusterholz and others 2000). The collection of firewood can deplete woody debris in the vicinity of fireplaces and lead to soil compaction and damages to shrubs and trees that extend further than the vegetation loss normally documented (Reid and Marion 2005). Several studies have shown that the amount of dead wood available is the key factor determining species richness of numerous specialized organisms, including mosses, lichens, fungi, and invertebrates, especially insects (Haase and others 1998; Kruys and Jonsson 1999; Jabin and others 2004; Jonsell and others 2007). In spite of this important ecological role of dead wood, only a few studies have examined the impact of fire building on the abundance of woody debris. Notable exceptions are Bratton and others (1982), Hall and Farrell (2001), and Smith and Newsome (2002), who found that the use of campfires reduced the biomass of woody debris.

Suburban oak-beech forests in northwestern Switzerland harbor remarkably diverse ground vegetation and are considered as local hot spots for insect diversity (Haase and others 1998; Delarze and others 1999). During the twentieth century, the area of this particular forest type decreased dramatically due to changes in forest management. Today, this forest type only covers 2.0% of the total forest area in Switzerland (Bonfils and others 2005). At the same time, these oak-beech forests are appreciated as recreation sites by the urban population due to their proximity to towns and cities (Baur 2003).

Grilling sausages in the forest is a traditional pastime in Switzerland. A nation-wide survey aimed at forestry experts showed that picnicking and grilling is the third most frequently observed activity in urban forests during the summer months (Hegetschweiler and others 2007a). In the following, we present a study designed to examine the effects of fireplace use on forest soil and vegetation and on the amount of woody debris. To our knowledge, this is the first study in Europe to quantify the depletion of woody debris and the subsequent habitat loss for specialized organisms due to the collection of firewood for recreational purposes. The following questions were addressed: (1) To what extent do ground vegetation characteristics, amount of leaf litter, and soil characteristics change as a result of picnicking and grilling? (2) What is the impact of picnicking and grilling on the shrub and tree layers and how far do forest-visitor-induced changes extend? (3) To what extent is the amount of woody debris depleted by building fires and what is the spatial dimension of this depletion?

Material and Methods

Study Sites

The study was conducted at nine fireplaces in oak-beech forests in the vicinity of Basle in northwestern Switzerland (Table 1). Common tree species in these forests are beech (*Fagus sylvatica*), sycamore (*Acer pseudoplatanus*), ash (*Fraxinus excelsior*), oak (*Quercus robur*), and hornbeam (*Carpinus betulus*). Frequent species in the understorey include *Ranunculus ficaria*, *Hedera helix*, *Carex sylvatica,* and *Galium odoratum*. Mean annual temperature at the study sites ranges from 8.9 to 10.4° C and annual precipitation from 778 to 979 mm (MeteoSwiss 2005a, b). All forests are frequently used for recreation by the public from the towns nearby.

In each study site, a plot containing a fireplace was chosen. Plot size ranged from 30 × 50 m to 100 × 100 m, depending on the size of the impacted area. Each plot was divided into three zones as recommended by Cole (1989): A core zone Z1 around the fire ring (heavily impacted; cover of ground vegetation <10%), an intermediate zone Z2 (moderately impacted; vegetation cover 10–50%), and a periphery zone Z3 (visually unimpacted; vegetation cover 50–100%; width 20 m). Data analysis revealed that the median vegetation cover in zone Z1 was 1%, in Z2 was 40%, and in Z3 was 70% ($n = 9$ in each case). As a control, an undisturbed plot of equal size was chosen at 50–150 m from the disturbed plot and divided into corresponding zones (C1–C3) of equal size. Within the control plots, there were no apparent gradients. The median vegetation cover was 50% in all three zones ($n = 9$ in each case). Pairs of disturbed and control plots did not differ in type of forest vegetation, soil type, and forest management.

Vegetation Mapping and Soil Sampling

Ground vegetation (<30 cm height) and soil characteristics were examined in five randomly chosen 1 × 1-m subplots in each zone. Species composition, mean plant height, and number of individuals were recorded in each subplot and total plant cover was visually estimated using Domin-Krajina scale between July and August 2003 (Mueller-Dombois and Ellenberg 1974). To control for the influence of different light conditions, light intensity was measured at 25 randomly chosen points within each zone, using a quantum meter with separate sensor (Apogee Instruments Inc., Model QMSS-ELEC). In order to calculate relative values, the light intensity was also measured in full sunlight outside the forest stand at the same time. In October 2003, leaf litter was collected from an area of 0.25 × 0.25 m in each subplot and weighed after oven drying at 80° C for 24 h. Soil compaction was measured as soil penetration resistance using a handpenetrometer (Eijkelkamp Typ IB) at five randomly chosen points in each subplot. Furthermore, a soil sample was taken to a depth of 5 cm using a soil corer (100 cm^3) in each subplot at the same time. Soil moisture (%) was determined from the fresh weight/dry weight ratio. Soil pH was measured in distilled water (1:2.5

Table 1 Characteristics of the nine study sites in forests near Basle, Switzerland

Study site	Altitude (m a.s.l.)	Forest vegetation type[a]	Soil type[b]	Type of fireplace[c]	Impacted area Z1 + Z2 (m^2)
1. Chuestelli	357	*Galio odorati-Fagetum luzuletosum*	Gleyic cambisol	O	1,943
2. Vögtenhägli	320	*Luzulo silvaticae-Fagetum typicum*	Haplic luvisol	V	343
3. Geiser	355	*Galio odorati-Fagetum typicum*	Gleyic cambisol	V	7,518
4. Fiechtenrain	414	*Galio odorati-Fagetum typicum*	Gleyic cambisol	V	86
5. Bruderholz	360	*Galio odorati-Fagetum typicum*	Haplic luvisol	V	248
6. Rütihard	300	*Galio odorati-Fagetum luzuletosum*	Haplic luvisol	V	72
7. Rothalle	410	*Galio odorati-Fagetum pulmonarietosum*	Haplic luvisol	V	164
8. Eigental	461	*Galio odorati-Fagetum pulmonarietosum*	Haplic luvisol	V	57
9. Galms	345	*Galio odorati-Fagetum typicum*	Gleyic cambisol	O	172

[a] Burnand and Hasspacher (1999)

[b] Walthert and others (2004)

[c] O = official picnic site, V = visitor-created fire ring

soil:water; Allen 1989). Total soil organic matter content (SOM) was assessed as loss-on-ignition of oven-dried soil at 500°C for 24 h (Allen 1989). Total soil organic nitrogen content was determined using the standard method of Kjeldahl (Bremner 1965).

The shrub layer (woody plant species, 30–150 cm height) was assessed along a 50-m transect starting at the edge of the fire ring and orientated perpendicular to the forest edge. At a distance of 0, 4, 8, 12, 16, 22, 28, 34, 42, and 50 m from the fire ring, species composition, plant height and number of individuals were recorded in 2 × 2-m subplots. Light intensity was measured once at the starting edge of each subplot and outside the forest stand.

Trees (height > 1.5 m) in each disturbed (containing a fire ring) and control plot were measured for diameter at breast height (dbh). Trees were classified and counted as either damaged by humans (e.g. nails driven in, broken branches, trunk scars) or undamaged.

Amount of Woody Debris

The line intersect method of Van Wagner (1968) was used to estimate the amount of woody debris in disturbed and control plots. Woody material was recorded along three randomly orientated transects radiating from the edge of the fire ring and ending at the outer edge of the periphery zone. In control plots, transects ran from forest edge to forest interior. Pieces of wood with a big end diameter ≥ 0.5 cm intersecting the sample line at intervals of 20 cm were measured for length and diameter at both ends. All branching segments of a single branch or twig were recorded as separate pieces. Pieces that were bent significantly were measured as separate, roughly linear sections (Woldendorp and others 2004).

Data Analysis

The impact of picnicking and grilling on ground vegetation and soil parameters was examined by calculating relative changes expressed by the difference between median values of each disturbed zone and median values of corresponding control zones divided by the median value of the entire control plot (Cole 1989). Negative values indicate a loss, positive values a gain of the respective parameter. Because the data did not fit normal distributions, generalized linear models assuming a quasi-poisson response and log link function were used to analyze relative changes of soil and vegetation parameters (Crawley 2007). The models included study site and zone as factors and the interaction between the two factors. In the models with vegetation data, relative light intensity was included as co-factor and the interaction between zone and light intensity. Significance was tested by deleting terms from the maximal model and comparing the changes in deviance with F-distributions (Crawley 2007).

Sign-tests were used to determine whether there were significant deviations from zero in the relative changes. Spearman rank correlations showed which vegetation parameters correlated with the cover of ground vegetation. As the division of the plots into zones was based on vegetation cover, parameters correlating with vegetation cover were left out of the analysis. This was the case for density of plant individuals (individuals/m^2; $r_s = 0.67$, $n = 9$, $p = 0.025$).

The recorded plant species were assigned to different plant strategy types following Grime and others (1988). Intermediate strategies were pooled according to Graae and Sunde (2000), which resulted in four groups of plant strategies:

- C+ (competitors); C, C/CR, C/CSR, C/SC;
- CSR+ (competitive and stress-tolerant ruderals): CR, CR/CSR, CSR, SC, SC/CSR, SR, SR/CSR;
- R+ (ruderals): R, R/CR, R/CSR, R/SR;
- S+ (stress tolerants): S, S/CSR, S/SC, S/SR.

Contingency tables were applied to analyze differences between the three zones and the control plots in the proportion of species belonging to different plant strategy types.

The relative change of shrub layer parameters was calculated in the same way as for the ground vegetation and soil parameters, using distances from the fire ring instead of zones.

First, we divided the trees according to the diameter at breast height (dbh) in two size classes following the recommendation of the USDA Forest Service: (1) Sapling trees (diameter ≤ 5 cm) and (2) larger trees (diameter >5 cm). Sapling trees (diameter ≤ 5 cm) were further assigned to 10 size classes: (1) 0–0.5 cm; (2) 0.6–1 cm; …; (10) 4.6–5 cm, and larger trees (diameter >5 cm) to 8 size classes: (1) 5–15 cm; (2) 16–25 cm; …; (8) >85 cm. Contingency tables were applied to analyze differences in diameter and number of damaged trees between disturbed and control plots.

Woody debris were assigned to four size classes according to their mean diameter: (1) <0.6 cm; (2) 0.6–2.5 cm; (3) 2.6–7.6 cm; and (4) >7.6 cm (Hall and Farrell 2001). The volume was calculated according to the formula for a cut cone (Nordén and others 2004a). For data analysis, each transect was split into the following sections (0–4; 4–8; 8–12; 12–16; 16–22; 22–28; 28–34; 34–42; 42–50 m). The total volume of woody debris was summed up for each section and expressed as volume per meter. The relative change in woody debris volume was calculated analogously to relative changes of soil and vegetation parameters (Hall and Farrell 2001; Appendix). The same generalized linear models were used to analyze relative changes of woody debris. The models included the factors' study sites, distance from the fire ring, and debris size class. All analyses were performed with R (R Development Team, 2008, version 2.6.2).

Results

Ground Vegetation and Soil Characteristics

Figure 1 illustrates the relative changes in ground vegetation and soil characteristics in the three zones caused by picnicking. Picnicking and grilling reduced the height of ground vegetation ($F = 76.24$, $df = 2{,}13$, $p < 0.0001$), species density ($F = 8.08$, $df = 2{,}13$, $p = 0.005$), and the amount of leaf litter ($F = 9.71$, $df = 2{,}16$, $p = 0.002$) in the zones of disturbed plots. Light intensity did not affect vegetation height ($F = 0.24$, $df = 1{,}13$, $p = 0.63$), but there was an interaction between zone and light intensity ($F = 5.43$, $df = 2{,}13$, $p = 0.02$), indicating that vegetation height was differently influenced by light intensity in different zones. Plant species density was also affected by light intensity ($F = 7.99$, $df = 1{,}13$, $p = 0.01$).

Soil compaction and soil pH were both higher in the zones of disturbed plots than in the corresponding zones of control plots (relative change of soil compaction: $F = 7.69$, $df = 2{,}16$, $p = 0.005$; pH: $F = 5.86$, $df = 2{,}16$, $p = 0.012$). Soil moisture, however, was not affected by picnicking and grilling ($F = 0.17$, $df = 2{,}16$, $p = 0.84$), reaching median values of 18.5% in disturbed plots and 21.0% in control plots. Similarly, soil organic matter content (SOM) and total organic nitrogen content were not influenced by picnicking and grilling (SOM: median of disturbed plots was 10.8%, of control plots 8.5%; $F = 0.64$, $df = 2{,}16$, $p = 0.54$). In disturbed plots, total organic nitrogen amounted to 0.25% and in control plots to 0.22% ($F = 2.10$, $df = 2{,}16$, $p = 0.15$).

Vegetation height, species density, leaf litter, soil compaction, and soil pH were significantly affected in the core zones compared to the corresponding control zones (sign-tests: $p < 0.05$). On average, the core zones comprised an area of 165 m^2. Soil compaction was also enhanced in the intermediate zones ($p = 0.04$). In the periphery zones, however, all ground vegetation and soil characteristics remained unimpacted.

Picnicking and grilling did not change the proportions of understory species belonging to different plant strategy types in the three zones compared to the corresponding controls ($\chi^2 = 8.33$, $df = 9$, $p = 0.50$, Fig. 2a). Considering the abundance of the species, however, the three zones in disturbed plots differed significantly in the proportions of individuals belonging to different plant strategy types from those of the corresponding control zones ($\chi^2 = 347.84$, $df = 9$, $p < 0.001$). For example, in the core zones of picnic areas, almost 10% of the individuals were ruderals such as *Poa annua*, *Polygonum aviculare*, and *Sonchus oleraceus* (Fig. 2b). In the disturbed intermediate zones, the proportion of ruderals accounted only for 0.6% and 0% in the periphery zones (Fig. 2b).

Woody Regeneration

Shrub layer characteristics along the transects in disturbed and control plots are illustrated in Fig. 3. In disturbed plots, all parameters showed a higher variability than in control plots. Picnicking and grilling reduced the height of the shrub layer (relative change: $F = 2.07$, $df = 9{,}72$, $p = 0.05$) and species density ($F = 2.12$, $df = 9{,}72$,

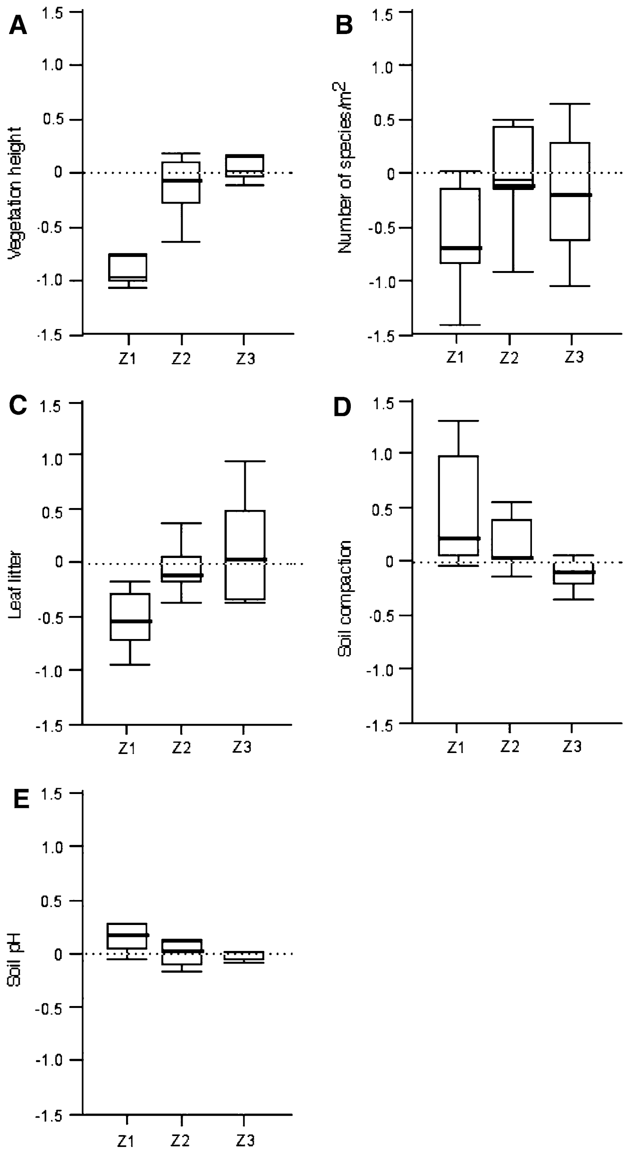

Fig. 1 Relative change in ground vegetation and soil characteristics in the core (Z1), intermediate (Z2), and periphery (Z3) zones of disturbed plots at nine fireplaces in northwestern Switzerland: (**a**) ground vegetation height (cm), (**b**) plant species density, (**c**) amount of leaf litter (g/m^2), (**d**) soil compaction (kg/cm^2), (**e**) soil pH. Boxplots show medians, 25% and 75% percentiles and ranges (minimum and maximum)

$p = 0.04$). The number of shrub individuals/m^2 was reduced by picnicking and grilling ($F = 3.82$, $df = 9{,}72$, $p < 0.001$). Light intensity did not affect shrub layer height, species density, or number of shrub individuals ($p > 0.38$ for all parameters). However, there were interactions between the distance from the fire ring and light intensity on species density ($F = 2.15$, $df = 9{,}72$, $p = 0.04$) and the number of shrub individuals/m^2 ($F = 7.17$, $df = 9{,}72$, $p < 0.001$). Thus, these parameters were differently affected by light intensity at different distances from the fire ring.

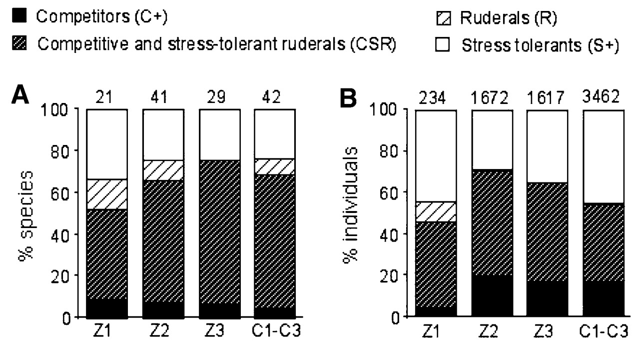

Fig. 2 Percentage of (**a**) plant species and (**b**) plant individuals belonging to different plant strategy types according to Grime and others (1988) in the core (Z1), intermediate (Z2), and periphery zones (Z3) of disturbed plots at nine fireplaces and in the corresponding control plots in northwestern Switzerland. In control plots, data from the three zones (C1–C3) were pooled. Figures on top of the bars indicate the number of species and individuals, respectively

Picnicking and grilling significantly reduced the height of the shrub layer and the number of shrub individuals/m^2 up to a distance of 8 m from the fire ring (sign-tests: $p < 0.05$). In addition, species density was reduced up to 4 m from the fire ring ($p < 0.05$).

Sapling and Larger Trees

Diameter at breast height (dbh) of larger trees did not differ between disturbed and control plots ($\chi^2 = 9.94$, $df = 7$, $p = 0.19$), confirming that disturbed and control plots had the same stand age. In total, 2,367 sapling trees were recorded in disturbed plots and 3,225 in the corresponding control plots. Picnicking and grilling caused significant changes in the age structure of sapling trees (Fig. 4; $\chi^2 = 103.66$, $df = 9$, $p < 0.001$). Even though there were 30% more trees with a very small diameter (0–0.5 cm) in disturbed than in control plots, the number of trees with a diameter $\leq$ 2.5 cm was reduced by 27% in disturbed plots. The group with a stem diameter of 1.1–1.5 cm was most severely impacted by recreational use: tree number was reduced by 45% in disturbed plots.

More larger trees were damaged in disturbed plots (39%) than in the controls (18%; $\chi^2 = 144.84$, $df = 1$, $p < 0.001$). Sapling trees also tended to be more frequently damaged in disturbed (4.4%) than in control plots (3.7%; $\chi^2 = 2.91$, $df = 1$, $p = 0.09$).

Woody Debris

Total woody debris volume reached median values of 0.3 cm^3/m transect length (range: 0–25,977 cm^3/m) in disturbed and 1.7 cm^3/m (range: 0–110,447 cm^3/m) in control plots (Fig. 5). This indicates an overall reduction of woody debris of 88% due to firewood collection. The

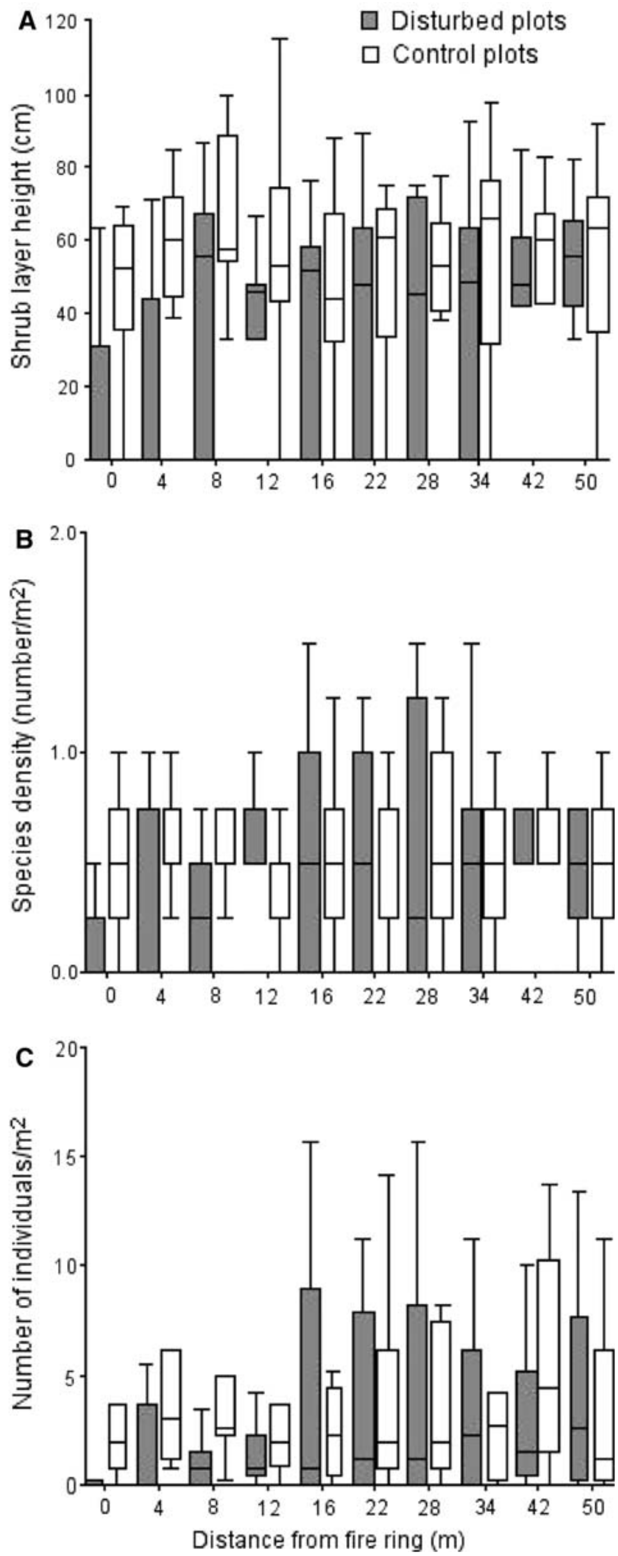

Fig. 3 Shrub layer characteristics in disturbed plots at increasing distances from the fire ring at nine fireplaces and at corresponding distances in nine control plots in northwestern Switzerland: (**a**) shrub layer height, (**b**) shrub species density, (**c**) number of shrub individuals/m^2. Boxplots show medians, 25% and 75% percentiles and ranges (minimum and maximum)

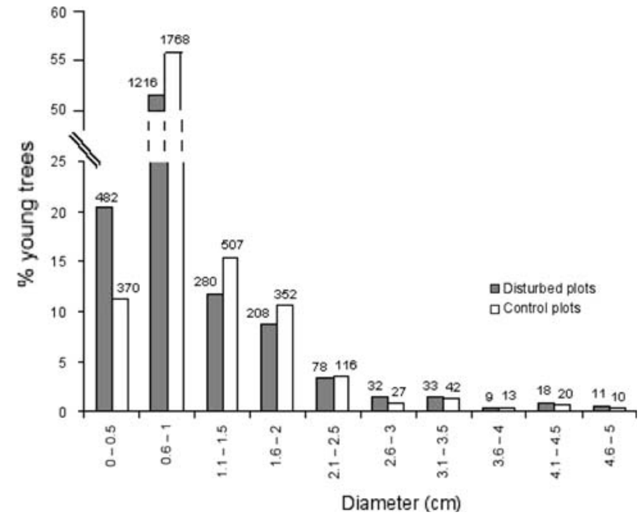

Fig. 4 Age structure of young trees recorded in disturbed and control plots at nine fireplaces in northwestern Switzerland. Percentages are shown for ten size classes. Numbers on top of bars indicate the number of trees

relative change in woody debris volume varied significantly with size class ($F = 3.45$, df = 3,168, $p = 0.02$). Woody debris <0.6 cm was not impacted by picnicking and grilling (Fig. 5a; $p = 0.5$; median of disturbed plots: 1.6 cm^3/m [range: 0–6.5 cm^3/m], control plots: 1.7 cm^3/m [0–7.8 cm^3/m]). In contrast, the amount of woody debris in the size class 0.6–2.5 cm was reduced by 61% in disturbed plots compared to control plots (Fig. 5b; $p < 0.001$; disturbed plots: 25 cm^3/m [0–354 cm^3/m], control plots: 56 cm^3/m [0–524 cm^3/m]). Furthermore, larger woody debris of size 2.6–7.6 cm was severely affected by firewood collection (Fig. 5c; $p = 0.001$; disturbed plots: 17 cm^3/m [0–2,335 cm^3/m], control plots: 47 cm^3/m [0–5,498 cm^3/m]). Woody debris >7.6 cm was not affected by picnicking and grilling (disturbed plots: 0 cm^3/m [0–8,659 cm^3/m], control plots: 0 cm^3/m [0–46,051 cm^3/m]).

The relative change in the amount of woody debris in disturbed plots did not differ with distance from the fire ring ($F = 1.10$, $df = 9,168$, $p = 0.37$). Woody debris volume was, however, significantly reduced up to a distance of 8–12 m (sign-tests: $p < 0.02$) and marginally reduced up to 12–16 m ($p = 0.08$) from the fire ring. The amount of woody debris in size class 0.6–2.5 cm was reduced by 92% in the section 0–4 m, by 44% in the section 4–8 m and by 75% and 73% in the sections 8–12 m and 12–16 m, respectively (Fig. 5b). At further distances, the reduction leveled off at 30–40%. In size class 2.6–7.6 cm, median woody debris volume in disturbed plots was 0 cm^3/m in all five sections up to 16–22 m from the fire ring. In control plots, median woody debris volume was also 0 cm^3/m in the sections 0–4 m and 4–8 m. In the sections 8–12 m and 12–16 m, woody debris amounted to 127 cm^3/m and 142 cm^3/

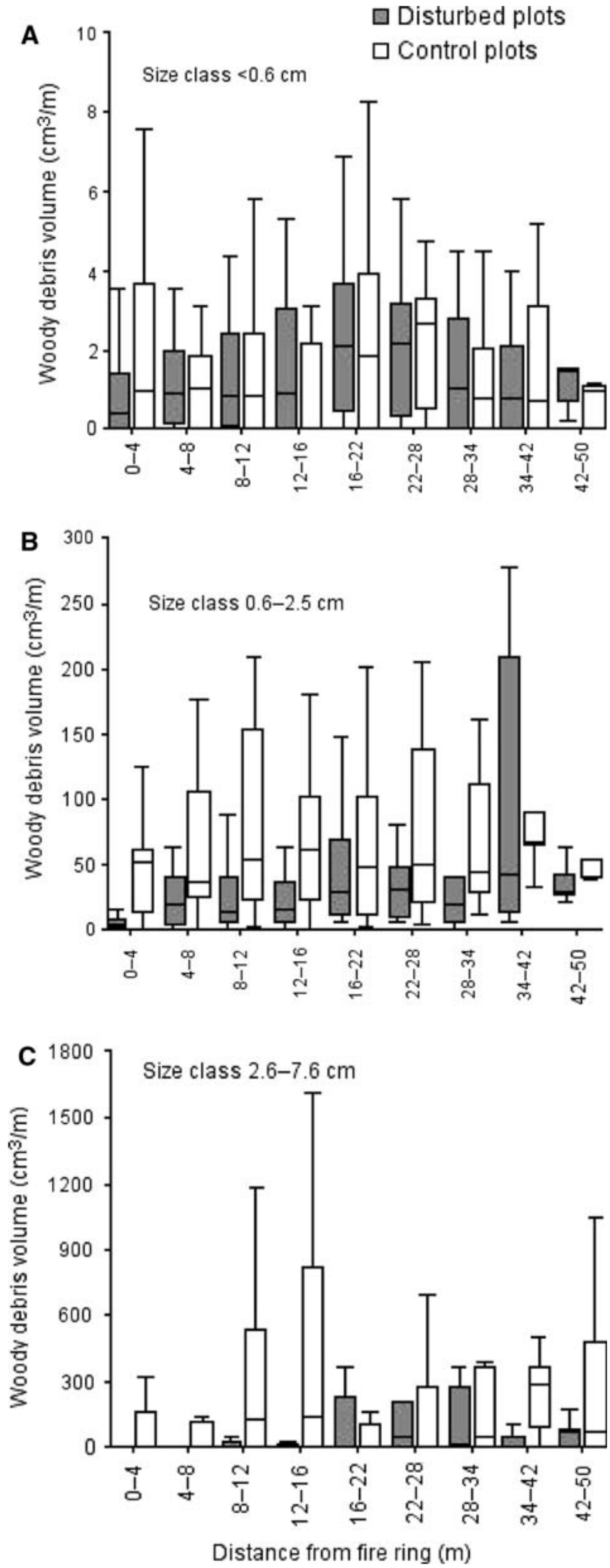

Fig. 5 Amount of woody debris in disturbed plots at increasing distances from the fire ring at nine fireplaces and at corresponding distances in nine control plots in northwestern Switzerland: (**a**) size class < 0.6 cm, (**b**) size class 0.6–2.5 cm, (**c**) size class 2.6–7.6 cm. Boxplots show medians, 25% and 75% percentiles and ranges (minimum and maximum)

m, respectively, implying a reduction of 100% in the corresponding sections in disturbed plots.

Discussion

Ground Vegetation and Soil Characteristics

The present study showed that the height of the ground vegetation, plant species density, and the amount of leaf litter were reduced and soil compaction and soil pH were increased in disturbed plots compared to control plots. These effects are commonly observed in areas impacted by human trampling (e.g., Liddle 1997; Kutiel and Zhevelev 2001; Thurston and Reader 2001; Cole and Monz 2003; Roovers and others 2004). The ground vegetation of forests is particularly sensitive to trampling, being shade-tolerant with broad leaves and thin cell walls and therefore vulnerable to mechanical influences (Kuss 1986; Cole and Monz 2003, 2004). Light intensity is a key factor determining plant growth and species composition of the above-ground vegetation in forests (Barnes 1998). Intensive use of fireplaces resulted in a small-scale mosaic of different light conditions that are responsible for the observed interactions between the different zones and species density and height of the above-ground vegetation.

Leaf litter can be broken up by trampling and either incorporated into the soil or blown away by the wind. This can lead to an increase or a decrease in organic matter, depending on which process prevails (Liddle 1997). In our study, the observed reduction in the amount of leaf litter was not reflected in any changes in SOM content. Possibly, the counteracting processes were neutralizing each other, or the loss of leaf litter had only occurred recently and was too small to result in changes in SOM content. Soil pH and soil organic matter content were also affected by the fire used for grilling. The increased soil pH in subplots closest to the fire rings can be explained by base cations released from dissolving ash (Boerner 2000), and the high soil organic matter content by the accumulation of charcoal around the fire rings. Charcoal degrades more slowly than non-charred woody materials (Hart and others 2005).

Fireplace use caused a shift in plant species abundance: ruderal and partly stress-tolerant species resistant to trampling became more frequent. This is frequently observed in areas with heavy recreational use (Jim 1987; Marion and Cole 1996; Andrés-Abellán and others 2005; Müller and others 2004). Trampling-tolerant plants are morphologically adapted to mechanical stress and produce seeds that can penetrate into deeper soil layers even under compacted soil conditions (Kuss 1986; Klug and others 2002). Disturbed conditions, trampling, and more light in the open space around the fire rings most likely caused the observed increase in ruderals in the core zones (Godefroid and Koedam 2004). This shift in species composition is likely to remain even after regenerating disturbed sites, especially when the changes are discernible in the seed bank (Klug and others 2002; Amrein and others 2005).

The impact of trampling is problematic in forests with a high density of visitor-created fire rings. In the urban forests the density of visitor-created fire rings exceeds four times the density of official picnic sites and averages 0.14 fire rings per hectare in Switzerland (Hegetschweiler and others 2007a). Therefore, trampling damage to ground vegetation can cover considerable areas. In two forests near Basle, 38.6% and 14.9% of the total forest area are highly damaged by recreational activities (Baur 2003). At these locations, the density of visitor-created fire rings can become so high, that trampling reduces ground vegetation cover to 5% or less (Baur 2003). Damage to above-ground vegetation caused by picnicking, grilling, and camping is perceived as a severe problem for forest managers in Europe, including France, Germany, Austria (COST Action E33, unpublished data), Spain (Andrés-Abellán and others 2005), Finland (Kangas and others 2007), North America (Reid and Marion 2005), and Asia (Jim 1987; Kutiel and Zhevelev 2001).

Woody Regeneration and Tree Structure

Picnicking and grilling reduced the height and changed the age structure of shrubs and sapling trees. At the same time, there were more sapling trees with a very small diameter (0–0.5 cm), but less trees with a diameter $\leq$ 2.5 cm in disturbed plots. This means that although sapling trees were present, their growth was either suppressed or they were soon eradicated by trampling. This result is consistent with the findings of Bratton and others (1982) who showed that trampling reduced the number of trees by over 50% in the 1 cm and 2 cm diameter classes. In urban forests in Finland, an increase in path area led to a decrease in the number of saplings (Lehvävirta and Rita 2002). Similarly, in frequently visited areas in Swiss urban forests, 80% of sapling beech trees only reached a height of 30–50 cm, and there were no sapling trees of 2–3 m height (Rusterholz and others 2000). The changed soil characteristics in disturbed plots such as an increased level of compaction and shifts in nutrient composition might be factors limiting the growth of shrubs and young trees. In New England, mean annual height growth of scarlet oak was significantly reduced at recreation sites compared to control plots (Brown and others 1977). Mycorrhiza are indispensable for the growth and survival of trees. Consequently, the growth of trees could be inhibited because mycorrhiza are affected by human trampling. Waltert and others (2002) showed that at heavily trampled sites with a reduced leaf litter layer, ectomycorrhiza formation of tree seedlings was lower than at control sites, thus making it harder for the seedlings to establish and grow. Therefore, in heavily trampled areas, the severely reduced establishment of tree seedlings inhibits the natural regeneration of forests.

Recreational use can also lead to a shift in the composition of shrub and tree species. We observed a reduction in shrub species density in disturbed plots, indicating that certain species could not withstand the trampling pressure. With increasing use, an enhanced proportion of saplings grow close to structures protecting them from trampling (e.g., trees, stones, fallen logs; Tonnesen and Ebersole 1997; Lehvävirta and others 2004). Species that can grow close to such structural elements will be the ones forming the future canopy.

Damages to mature trees caused by humans are frequently observed at picnic sites and campgrounds, but the extent varies greatly. Data from the USA show that the percentage of damaged trees ranges from 28% to 77% (Reid and Marion 2005). The 39% of trees damaged in our study lie within this range. Wounding of trees makes them susceptible to pathogens, which may lead to the spread of diseases (Brown and others 1977; Grünwald and others 2002). Furthermore, trees scorched by fire receive more bark beetle attacks, and mechanical wounding can reduce diameter growth (Lombardero and others 2006). If these forests are used for timber production, as is the case in Switzerland, damages to trees have serious consequences for the forest owner, as poor quality wood has to be sold at a lower price (Baur 2003). Two case studies in suburban forests near Basle revealed that the reduction in timber value due to visitor-related damage to the tree bark averaged 19–53 €/ha/year and exceeded 500 €/ha/year in heavily impacted forest areas (Baur 2003). In multifunctional forests, damage to trees is not only an ecological, but an economical problem as well.

Apart from the ecological and economical consequences, the unnatural age structure of young trees, insufficient regeneration, reduced species density, and unsightly damages to trees can lower the attractiveness of these picnic sites for forest visitors. Detailed field observations have shown that forest visitors move to undisturbed forest areas when frequently used forest sites become unattractive, causing an uncontrolled proliferation of visitor-induced damage on above-ground vegetation. Changes to the forest vegetation caused by trampling are not only perceived as unacceptable by forest managers, but also by forest visitors, highlighting the need for management actions.

Woody Debris

Total woody debris volume was reduced by 88% in disturbed plots compared to control plots, implying a massive reduction of woody debris due to firewood collection. The depletion of firewood in the suburban forests of our study was far larger than that found at montane and subalpine campsites in the USA, where the removal of woody debris averaged 40–50% (Bratton and others 1982; Hall and Farrell 2001). Possibly, the picnic sites in suburban forests are used more frequently, resulting in a higher reduction of woody debris. Furthermore, montane and subalpine areas have a shorter season for recreational activities than the forests at low altitude that we studied. Woody debris of size 0.6–7.6 cm were the most affected by fire building. This is consistent with the two studies conducted in the USA, in which size <0.6 cm was found to be less impacted than size 0.6–7.6 cm (Bratton and others 1982; Hall and Farrell 2001). Obviously, pieces <0.6 cm are too small to keep a fire going, while pieces bigger than 7.6 cm require a greater effort to be broken into smaller pieces to be burnt.

The reduction of woody debris reached a distance of 16 m from the fire ring. In comparison, the height and number of shrubs were only reduced up to a distance of 8 m. A radius of 16 m around each fire ring encompasses an area of 800 m^2. In most cases, this is far more than the area in which the ground vegetation is visually impacted. Hall and Farrell (2001) failed to detect a distance effect in the depletion of woody debris over a distance of 15 m and concluded that effects probably extended beyond this distance. While the situation in suburban deciduous forests might not be directly comparable to montane and subalpine campsites, it is possible that campsite users walk similar distances to gather wood for campfires, depending on the amount of wood available.

The constant removal of woody debris for recreational purposes has implications for the ecology of urban forests. Woody debris, and especially woody debris of oak trees, is a habitat for numerous specialized organisms (Albrecht 1991; Ammer 1991; Jonsell and others 2007). Woody debris collected for building fires is exclusively fine woody debris (diameter 5–10 cm; Kruys and Jonsson 1999) and very fine woody debris (diameter <5 cm; Küffer and Senn-Irlet 2005). Most studies on the biodiversity of dead wood focus on coarse woody debris (diameter $\geq$ 10 cm; e.g., Heilmann-Clausen and Christensen 2004; Jabin and others 2004). However, there is evidence that smaller pieces of dead wood harbor a multitude of species not found on larger pieces. In oak forests in southern Sweden, Nordén and others (2004b) recorded that 75% of ascomycetes had fruitbodies exclusively on fine woody debris, while basidiomycetes were distributed over all size classes. In Switzerland, 94.5% of woody debris pieces in managed forests belong to the category of very fine woody debris, which is an important refuge for fungal species even when larger pieces of wood would be available (Küffer and Senn-Irlet 2005). A number of saproxylic beetles also specialize in using the thinnest dead twigs (1–4 cm diameter; Jonsell and others 2007). Given the enormous reduction of fine and very fine woody debris within a radius of 16 m around each fireplace, building fires is likely to have a direct influence on the species richness of saproxylic organisms in urban forests, especially when there are several fireplaces close to each other. In frequently visited forests, about 10% of the total forest area can be impacted by recreational use (Baur 2003).

Conclusions

Intensive use of fireplaces reduces the diversity of the sensitive forest vegetation on several levels. In addition, large amounts of woody debris are removed as firewood, leading to a habitat loss for numerous highly specialized organisms. Apart from the ecological consequences, frequently used sites become unattractive to forest visitors. Therefore, one aim of forest management must be to preserve recreational areas as attractive and diverse forests. Many visitors to natural recreation areas enjoy making fires (Christensen and Cole 2000) and firewood gathering is an integral part of visitors' experience. In urban forests around Basle, Switzerland, fireplace users frequently complain about the shortage of firewood, indicating that in certain areas there is hardly any woody debris in the relevant size classes left (unpublished data). One possible measure is to deposit logging residues as firewood near picnic sites (Hasspacher 2007). A high amount of dead wood as part of an ecologically sound forest management is well accepted by the public (Hunziker 1997). This gives fireplace users the possibility of gathering firewood from the surrounding area without depleting the naturally occurring dead wood. Piles of branches and twigs can also be used to restrict the movements of forest visitors to a defined area. Providing fireplaces based on visitor preferences could help to limit the proliferation of visitor-created sites (Hegetschweiler and others 2007b; Hegetschweiler and others 2008). In order to reduce ecological and social conflicts due to recreational activities, including biking, dog walking, and riding, a management concept was developed for the forest of Allschwil near Basle. Forest areas were assigned to three zones with emphasis on recreation, wood production, or nature conservation. Recreation zones include new fireplaces based on visitor preferences. In addition, a restoration-rotation management strategy is implemented to allow the regeneration of areas heavily impacted by recreational use by fencing in these areas for 5–7 years (Hasspacher 2007). In the wood production and nature conservation zones, no visitor-created fire rings are tolerated and recreational infrastructure is kept to a minimum, so as not to attract forest visitors. These measures should help to maintain the high conservation value of oak-beech forests and at the same time ensure that these forests remain attractive recreation sites for the urban public.

Acknowledgments We thank the involved foresters and the authorities from the forestry department of the Cantons Basle-Town and Basle-Country for their cooperation on this project. Anette Baur provided valuable comments on the manuscript. The research was carried out in the framework of the COST Action E33 "Forests for Recreation and Nature Tourism (FORREC)" and funded by the Swiss State Secretariat for Education and Research (SER).

Appendix

Table A1 Description of ground vegetation and soil characteristics in the core, intermediate, and periphery zones and the corresponding control zones (C1–C3) at nine fireplaces in northwestern Switzerland

	Z1	C1	Z2	C2	Z3	C3
Ground vegetation						
Species density (number/m^2)	0 (0–6)	3 (1–6)	5 (1–9)	4 (1–7)	4 (1–7)	3 (1–6)
Vegetation height (cm)	0 (0–6.1)	9.7 (8.1–11.3)	9.4 (6.4–11.3)	9.8 (7.8–15.5)	9.5 (8.2–12.0)	9.1 (7.2–11.6)
Leaf litter (g/m^2)	443 (66–625)	824 (470–1,555)	850 (555–1,255)	862 (564–1,400)	1,089 (360–1,626)	1,072 (548–1,401)
Soil characteristics						
Soil compaction (kg/cm^2)	32.6 (27.2–35.1)	25.6 (11.6–33.3)	26.2 (13.5–35.0)	25.2 (12.0–33.5)	24.9 (9.8–33.5)	28.8 (13.4–32.5)
Soil moisture (%)	18.5 (11.5–34.0)	21.0 (12.7–30.0)	17.2 (15.3–25.4)	21.7 (12.2–27.1)	18.6 (12.1–27.9)	21.0 (12.6–28.4)
pH	6.8 (5.1–8.2)	5.5 (4.2–7.6)	5.5 (4.2–7.5)	5.4 (4.3–7.3)	5.6 (4.3–7.6)	5.4 (4.3–7.6)
SOM (%)	10.2 (5.3–20.6)	8.5 (5.6–20.5)	9.7 (5.5–22.1)	7.3 (5.2–23.2)	11.1 (6.5–20.4)	10.6 (5.5–20.5)
Organic nitrogen (%)	0.20 (0.11–0.32)	0.23 (0.15–0.51)	0.26 (0.15–0.38)	0.22 (0.15–0.49)	0.23 (0.15–0.42)	0.20 (0.17–0.54)

Values represent medians of nine study sites (ranges in parentheses)

Table A2 Relative change of shrub layer characteristics (woody plant species, 30–150 cm height) at increasing distances from fire rings at nine fireplaces in northwestern Switzerland

Distance from fire ring (m)	Species density (number/m^2)	Number of individuals/m^2	Height (cm)
0	–1.00 (−6.00 to 0.50)	−0.71 (−5.33 to 0.14)	−0.53 (−3.25 to 0.12)
4	−1.00 (−2.00 to 0.40)	−1.45 (−5.00 to 1.58)	−0.63 (−3.45 to −0.09)
8	−0.50 (−2.00 to 2.00)	−0.97 (−4.00 to 0.42)	−0.44 (−3.11 to 0.59)
12	0.00 (–2.00 to 6.00)	−0.38 (−1.86 to 3.00)	−0.38 (−1.09 to 3.12)
16	0.00 (−1.00 to 1.60)	0.00 (−3.00 to 2.84)	−0.19 (−1.02 to 0.38)
22	0.00 (−1.50 to 1.60)	−0.29 (−3.57 to 2.84)	−0.03 (−0.97 to 2.76)
28	0.00 (−2.00 to 1.60)	−0.29 (−3.14 to 3.05)	−0.05 (−0.99 to 3.44)
34	0.00 (−2.00 to 1.33)	0.00 (−1.05 to 0.91)	0.00 (−1.14 to 0.36)
42	0.00 (−6.00 to 0.67)	−0.29 (−8.00 to 6.00)	−0.05 (−2.00 to 3.97)
50	0.00 (−4.00 to 0.80)	0.12 (−16.00 to 3.26)	−0.01 (−0.36 to 0.48)

Values represent medians of nine study sites (ranges in parentheses)

Table A3 Relative change of woody debris volume at increasing distances from fire rings and in different size classes at nine fireplaces in northwestern Switzerland

	Relative change of woody debris (cm^3/m)
Distance from fire ring (m)	
0–4	−0.15 (−8.45 to 9.81)
4–8	−0.11 (−9.56 to 27.36)
8–12	−0.28 (−21.89 to 27.81)
12–16	−0.14 (−8.93 to 10.88)
16–22	0.00 (−2.24 to 46.58)
22–28	0.00 (−7.48 to 20.66)
28–34	0.00 (–26.72 to 15.74)
34–42	0.00 (−6.35 to 2.93)
42–50	0.00 (−0.58 to 1.29)

Table A3 continued

	Relative change of woody debris (cm^3/m)
Size class (cm)	
<0.6	0.04 (−4.76 to 7.39)
0.6–2.5	−0.43 (−17.80 to 4.12)
2.6–7.6	−0.27 (−26.72 to 27.36)
> 7.6	0.00 (–7.48 to 46.58)

Values represent medians of nine study sites (ranges in parentheses)

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