ENVIRONMENTAL AUDITING
Sociological Edge Effects: Spatial Distribution of Human Impact in Suburban Forest Fragments

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ABSTRACT / Suburban forest fragments often experience heavy recreational and waste disposal use, with considerable damage to the vegetation. To suggest strategies for conservation of the forest flora, spatial distributions of human impact were described in 40 fragmentary stands in northern New Castle County, Delaware. The distribution of human impact showed a significant bias to the forest edge, with 95% of localized damage occurring in the first 82 m. Forms of impact related to lawn maintenance fell significantly closer to the edge than impacts related to recreation and showed the strongest edge orientation. Edge distances of campsites, vandalized trees, and firewood gathering were negatively correlated with distance to the nearest graded road, indicating the importance of road access. Several forms of impact were also clustered near footpaths, although distance to paths was independent of edge distance in all cases. In terms of penetration of the forest and severity of damage, human impact greatly exceeds natural edge effects reported for this community. These findings suggest that damage may be minimized by limiting road access and avoiding the creation of small forest fragments.

In large areas of the eastern United States the native deciduous forest has been severely fragmented by human activity. In the piedmont zone of northern Delaware these fragments preserve a rich herb and shrub flora, but they increasingly also serve the needs of nearby residents. If a fragment is situated near a large housing development, heavy use may lead to radical changes in both the structure and composition of the forest flora (Hoehne 1981). Human activity is not randomly distributed within fragments, however. An understanding of patterns of use may allow protection of biological diversity in a mixed-use forest. This article describes the spatial distribution of human impact relative to such easily recognizable landscape elements as paths, roads, houses, and the forest edge.

The impact of human traffic in forest ecosystems is best known from studies of large wilderness areas, but the findings can be generalized to suburban forest fragments. At the most intensive levels of use, all forest floor vegetation is lost. Trampling strips away leaf litter and humus and causes soil compaction in the top 5–15 cm, changing the drainage and nutrient exchange properties of the site (Kuss 1986, Cole 1987, Cole and Marion 1988). Tree species suffer from wounding of the bark, root damage, and suppression of seedlings (Hinds 1976, Cole and Marion 1988, Hall and Kuss 1989). At low to moderate levels of trampling, vegetation persists, but species composition shifts to species with basal meristems and/or flexible, woody stems (Hinds 1976, Leonard and others 1985, Hall and Kuss 1989). Herbaceous flora appears to be particularly vulnerable to trampling, often showing major changes in cover and composition at relatively low levels of use (Leonard and others 1985, Cole and Marion 1988, Kuss and Hall 1991).

In wilderness areas, human impact is concentrated in campsites and along trails. At wilderness campsites, several studies have identified concentric zones of impact with damage decreasing from the camp center into the surrounding forest. The size of the affected area is generally proportional to the level of use (Merriam and others 1971, Kuss 1986, Cole and Marion 1988) but varies depending on the character of vegetation and other site features (Bratton and others 1982, Cole and Marion 1988). Narrower impact zones are produced along trails (Hall and Kuss 1989, Kuss and Hall 1991, but see Garay and Nataf 1982).

In large western parks, such damage is usually negligible relative to the total area of a biological community, and management efforts have been directed to the aesthetic experience of the park user (Stankey and Schreyer 1987, Martin and others 1989). In suburban

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fragments, however, human traffic can influence a significant portion of the stand (Hoehne 1981, Loeb 1989). Effective management requires a precise understanding of traffic patterns within the stand. This study describes the spatial distribution of 14 forms of human impact in suburban forest fragments in northern Delaware on the east coast of the United States. Guidelines are suggested for protection of the forest flora by land use planning and recreation management.

Study Sites

Human impact was surveyed in 40 forest fragments lying in the piedmont zone and nearby coastal plain of New Castle County, Delaware (75°, 30′–75°, 47′W; 39°,40′–39°,53′N). Fragments consisted of closed-canopy second-growth forest, 40–120 years old. Stands were characterized by a rich and patchily distributed herb flora, with the exact composition dependent on local soil condition and disturbance history. Small areas of old-growth forest were embedded in the matrix of successional stands. This community typifies the moist eastern deciduous forest, which has been shown to be highly vulnerable to human activity (Bratton and others 1982, Cole and Marion 1988).

Sites were of moderate or low slope without fences, ditches, wetlands, or other features that might limit access or direct patterns of human activity. Sites ranged in size from 0.7 to ca. 20 ha. All were considered suburban, having at least ten detached residences within 100 m of the forest margin. Most stands were traversed by leaf litter-free paths. In addition to the forms of impact reported in wilderness studies, stands were used for disposal of lawn-related organic debris, building rubble, and assorted household and automotive trash. In many cases, lawns had been extended under the tree canopy. Occasionally junked cars were encountered.

Three forms of recreational activity could be distinguished: campsites, children's huts, and treehouses. Campsites were defined by fire rings, large areas of bare soil, and much broken glass and food-related litter. Forms of shelter were generally absent. By contrast, children's huts rarely had fire rings and usually showed very little bare soil. A special class of hut was the treehouse, in which lumber was crudely nailed to tree trunks 2–10 m above the ground. Randomly hacked trees were common around all forms of recreational activity. Sawed trees and piles of sawdust indicated firewood gathering. These categories were not mutually exclusive, and a large amount of less clearly defined damage was also observed.

Methods

Traces of human activity were inventoried at the 40 sample sites in February 1992. The study focused on localized forms of impact; no attempt was made to quantify stand-scale impacts such as power lines, footpaths, or lumbering. Carving on trees was not recorded unless the wound exceeded 50% of the tree's circumference. Isolated pieces of trash were similarly ignored. If two cases of damage occurred within 20 m of one another, their locations were assumed to reflect the same decision to create an impact. To ensure statistical independence, only one impact was recorded. For example, wounded trees were not recorded in the neighborhood of campsites.

For each case of impact, distance was measured to the nearest forest edge, the nearest footpath, the nearest graded road, and the nearest residence. Measurements were taken from the part of the impact most distant from the forest edge. At sites where the edge position had shifted through successional time, distance was recorded to both the original and the modern edge. Successional development of the nearest forest edge was noted (open or closed side canopy), and the impact was placed in one of 14 categories according to the type of damage.

Roads were defined as graded and surfaced avenues sufficient to carry a vehicle; all other thoroughfares were considered to be paths. Trash dumps were classified as recent if they contained a substantial amount of undegraded paper, rust-free ferrous metals, plastics, and/or specific items that suggested they might be <10 years old. The general level of human traffic in a stand was estimated as the proportion of the length of a diagonal transect that showed bare and compacted soil. Because unused areas were quickly covered with fallen leaves, this is an index of very recent use.

The small size of some fragments caused areas close to the forest edge to be oversampled. To avoid this problem when characterizing impact distributions, locations of impacts were considered in three groups according to stand size (100, 200, 300 m diameter). Mean distance from the edge was calculated from that subset of stands that allowed the largest impact sample size with a <10% difference in mean distance from the next larger stand size class.

The null hypothesis of random distribution relative to the forest edge was tested by a Kolmogorov-Smirnoff two-sample test. The observed distribution of impacts was compared with an expected uniform distribution. Distribution relative to forest paths was tested in the same way. The 14 classes of impact were

Table 1. Distributions of human impact at forty suburban forest fragments in the piedmont zone of northern Delaware[a]

Forms of impact	Geometric mean (m, $X \times/\div$ SD)	N	95% of impacts (m)	95% without roads[b] (m)	Nonuniformity (P) Forest edge	Footpaths
Whole data set	21.1 ×/÷ 3.6	426	82	67	<0.0001	<0.0001
Grass clippings	3.7 ×/÷ 2.8	14	19		<0.01	<0.05
Woodpiles	5.3 ×/÷ 3.2	23	19		<0.01	<0.05
Recent dumps	6.8 ×/÷ 3.8	11	82	16	ns	ns
Christmas trees	9.5 ×/÷ 4.1	36	34		<0.05	ns
Leaf piles	11.6 ×/÷ 2.7	36	38		<0.01	ns
Building rubble	12.0 ×/÷ 2.1	21	107	56	ns	ns
Old dumps[c]	12.8 ×/÷ 2.5	28	53		ns	ns
Pruned limbs	13.5 ×/÷ 2.5	34	53		ns	<0.05
Lawn extensions	14.6 ×/÷ 1.8	15	38		ns	ns
Children's huts	20.3 ×/÷ 2.1	22	79		ns	ns
Treehouses	34.4 ×/÷ 2.4	49	107		ns	<0.05
Hacked trees	41.2 ×/÷ 2.2	46	76	70	ns	<0.0001
Campsites	41.3 ×/÷ 1.6	25	114	67	ns	ns
Firewood gathering	41.4 ×/÷ 2.0	26	130	69	ns	ns

[a]Forms of human impact are ranked by increasing geometric mean distance from the forest edge. "Nonuniformity" indicates the significance level of Kolmogorov Smirnoff two-sample tests for uniformity of distribution with respect to distance from a) forest edge and b) paths.

[b]For those forms of impact that showed significant road effects in multiple regression.

[c]The mean distance for old dumps is calculated relative to old, rather than modern, edges.

compared on the basis of distance to the edge by a Kruskal-Wallis test and Tukey's hsd procedure. The importance of various landscape elements was determined by stepwise multiple regression: for each class of impact, distance from the edge was regressed on distance to the nearest footpath, nearest road, and nearest residence, plus stand width and the general estimate of traffic levels.

Results

Data were recorded for 426 cases of human-generated damage, most of which fell into the 14 categories (Table 1). Most damage occurred within 30 m of the forest edge, but some extended much further into the forest (Figure 1). A convenient measure of forest penetration is the width of a zone parallel to the edge that includes 95% of recorded impacts. Considering all forms of impact, 95% fell within 82 m of the edge. Individual forms of impact ranged from grass clippings and woodpiles clustered near the edge (95% within 19 m) to firewood gathering, extending far into the stand (95% occurring up to 130 m). Forms of impact fell into two distinct groups with regard to edge distance: Lawn-related impacts (leaf piles, discarded Christmas trees, grass clippings, wood piles) all occurred significantly closer to the forest edge than recreation-related impacts (treehouses, campsites, firewood gathering, hacked trees; Kruskal-Wallis $\chi^2 = 95.6$ 13*df* $P = 0.0001$; Tukey hsd test; $P < 0.05$). Both groups were internally homogeneous. Other forms of impact generally occurred at intermediate distances (huts, lawn extensions, recent and old dumps, rubble, pruned limbs) and overlapped both groups.

Forms of impact related to lawn maintenance were most strongly clustered at the edge, displaying significant nonuniformity with respect to distance in four categories (Table 1, column 6). Other impacts were not oriented to the edge individually, but showed a significant nonuniformity when tested collectively (Kolmogorov-Smirnoff $D = 0.286$, $N = 159$, $P < 0.0001$), suggesting a more subtle relationship to edge proximity.

Edge canopy condition did not influence the distance to which humans penetrated the forest. No form of impact showed a significant difference in edge distance between sites with open and closed side canopies (Mann-Whitney U; $P > 0.05$). It is interesting to note, however, that old dumps occurred closer to original edges than to modern edges (mean $\text{distance}_{\text{original}} = 7.4$ m ± 17.0 SD, $\text{distance}_{\text{modern}} = 27.4$ m ± 18.1 SD). A paired *T* test shows this difference to be significant ($t = 5.37$ 1*df* $P = 0.0002$), indicating a historical element in impact location.

Stepwise multiple regression suggests that the location of human impact was often influenced by prox-

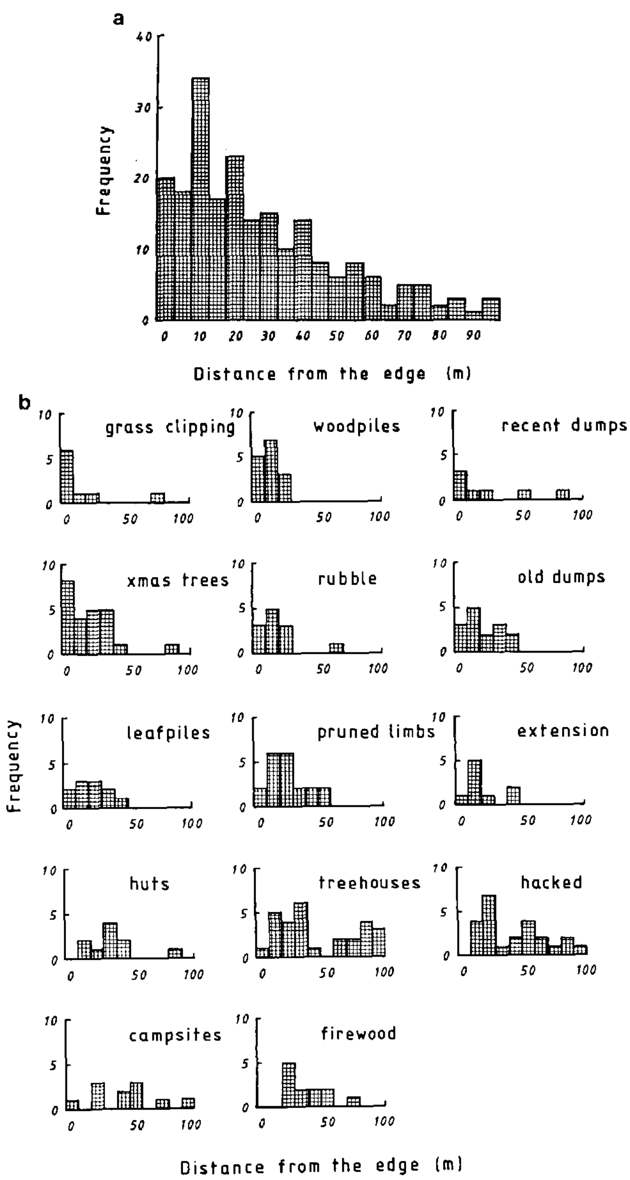

Figure 1. Distributions of the principal forms of human impact relative to the forest edge in suburban forest fragments, New Castle County, Delaware: (a) all cases of impact; (b) the 14 principal forms of impact. Distributions are based on stands with width ≥200 m and forms of impact <100 m from the edge in order to compensate for undersampling at greater distances.

imity to other landscape elments (Table 2). Considering the entire data set, impacts were observed at greater distances into the forest in wide stands than in narrow ones, indicating undersampling at greater distances from the edge. In general, impacts occurred at greater distances into a forest when a road was present, a pattern also observed in individual regressions of campsites, firewood gathering, hacked trees, both recent and old dumping, and building rubble. The frequent selection of $\log_{10}$ values of road distance in this analysis (Table 2) indicates that nearby roads were more important than distant ones. Pruned limbs showed a similar effect with regard to footpaths.

If fragments penetrated by roads were considered separately from those that merely had roads passing outside of them, no significant road regressions were observed. When stands without any internal roads were considered, significant road effects occurred in only one impact category (old dumps). Thus, the effect of roads on edge distance depends on having a road inside the forest. Indeed, if 95% penetration distances are tabulated for stands that were not penetrated by roads (Table 1), the distances are considerably less.

Proximity to homes influenced the locations of grass clippings and hacked trees (Table 2), but the effects differed in sign and were apparently controlled by different mechanisms. Treehouses were closer to the forest edge in more heavily used stands.

Human impact was often clustered around footpaths. Hacked trees, grass piles, pruned limbs, treehouses, and woodpiles showed significant nonuniformity with distance to footpaths (Table 1, column 7), but when these forms of damage were removed from the analysis, the collective impact still showed significant distance effects (Kolmogorov-Smirnoff $D = 0.373$, $N = 178$, $P < 0.0001$). Although forms of impact were generally path-oriented, the absence of path distance from multiple regression equations suggests that paths did not facilitate penetration into the stand in the same sense that roads did.

Discussion

Human impact in suburban forest fragments is generally aligned with the forest edge and may be considered an "edge effect" by analogy with microclimatic and vegetational edge zone phenomena. In the absence of human traffic, local microclimate is affected by edge proximity up to 50 m into a stand in this forest community (Wales 1967, Matlack, 1993a). Forest vegetation responds to edge proximity up to the same distance (Gysel 1951, Wales 1972, Ranney and others 1981, Matlack, 1993b). Physiological damage to vegetation only occurs in the first 5 m, however, and the effect is much reduced as succession closes the side canopy (Matlack, unpublished).

By contrast, forms of human impact may occur up to 70 m into the forest, and considerably farther if there is access for vehicles. Human impacts are locally

Table 2. Dependence of recreational impact on distance to various landscape elements in the piedmont zone of northern Delaware[a]

All forms of impact	F = 38.83	360 *df*	$P = 0.0001$	$R^2 = 0.246$
	Edge distance = 181.106 + 0.164 road distance + 0.055 stand width − 88.485 $\log_{10}$ road distance			
Grass clippings	F = 17.91	13 *df*	$P = 0.0003$	$R^2 = 0.765$
	Edge distance = 6720.973 + 10.317 house distance − 3749.834 $\log_{10}$ house distance			
Recent dumps	F = 69.88	7 *df*	$P = 0.0002$	$R^2 = 0.921$
	Edge distance = 244.394 − 105.276 $\log_{10}$ road distance			
Building rubble	F = 13.05	16 *df*	$P = 0.0026$	$R^2 = 0.465$
	Edge distance = 177.751 − 72.492 $\log_{10}$ road distance			
Old dumps	F = 4.48	21 *df*	$P = 0.0471$	$R^2 = 0.183$
	Edge distance = 138.673 − 53.312 $\log_{10}$ road distance			
Pruned limbs	F = 4.32	26 *df*	$P = 0.048$	$R^2 = 0.148$
	Edge distance = 16.576 + 6.761 $\log_{10}$ path distance			
Treehouse	F = 15.07	36 *df*	$P = 0.0001$	$R^2 = 0.470$
	Edge distance = 30.110 − 121.495 use + 0.703 path distance			
Hacked trees	F = 6.87	42 *df*	$P = 0.0027$	$R^2 = 0.256$
	Edge distance = 67.774 − 64.126 $\log_{10}$ road distance + 44.199 $\log_{10}$ house distance			
Campsites	F = 21.91	22 *df*	$P = 0.0001$	$R^2 = 0.687$
	Edge distance = 160.266 + 0.314 path distance − 59.831 $\log_{10}$ road distance			
Firewood gathering	F = 18.95	21 *df*	$P = 0.0003$	$R^2 = 0.487$
	Edge distance = 168.641 − 62.439 $\log_{10}$ road distance			

[a]Stepwise multiple regressions of distance to the edge on distance to several suburban landscape elements.

more damaging than the natural edge effect, and, unlike light or temperature, local severity of damage does not diminish with distance from the edge. Studies in a variety of eastern deciduous forest communities suggest that recovery of soil and understory vegetation would take 10–20 years after cessation of traffic (Leonard and others 1985, Cole and Marion 1988, Loeb 1989, Kuss and Hall 1991). If reestablishment of hacked trees is included, recovery may require several decades (Bratton and others 1982, Hinds 1976). Hence, in both scale and severity, human traffic is by far the more serious form of edge effect.

Management Recommendations

In addition to their waste disposal and recreational functions, forest fragments contribute to the biodiversity and aesthetic appeal of the suburban landscape (Hoehne 1981, Herzog 1989, Hull and Harvey 1989). To protect their broad value to the community, suburban woodlands should be managed to promote long-term health. In the forest fragments considered here, severity of use appears to be linked to access, mirroring traffic patterns in managed parklands (Roggenbuck and Lucas 1987, Loeb 1989, Furuseth and Altman 1991). Penetration of the forest by the most damaging forms of human impact could be greatly reduced by closing roads and denying vehicular access. In the absence of roads, 95% of stand penetration by campsites was reduced from 114 m to 67 m. Penetration by recent dumping was reduced from 82 to 16 m. Assuming equal human use pressure on all sides of a forest stand, vulnerability to human impact becomes an issue of stand area: in a fragment with a minimum diameter less than twice the 95% penetration distance, all parts will be vulnerable to damage. Thus, to ensure protection of forest habitat, land use planning should (1) restrict road access and (2) avoid creating fragments with a diameter less than ca. 150 m. Small stands will be thoroughly explored by foot regardless of road access, and their conservation value is probably limited.

Footpaths contributed a second level of organization to damage in these stands. Unlike roads, the availability of a path did not increase distance of impacts into the stand, implying that the location of pedestrian impact is not determined by access (except, perhaps, in the near-edge disposal of pruned limbs). Hence, limiting paths is probably not as high a priority as controlling road access. Because people preferentially travel on preexisting paths, carefully managed paths might be used to channel traffic away from floristically sensitive areas, while continuing to allow enjoyment of the forest. A well-maintained footpath might also affect the positioning of campsites by reducing the perceived isolation of the fragment interior.

Caveats

Several qualifications are in order. First, the study measured only the most obvious forms of human impact in the sample stands. Less obvious factors also may have important biological consequences. Hunting by domestic pets, for example, may reduce populations of woodland animals with corollary effects on the flora. Second, the study concentrated on the most severe examples of damage. More moderate levels of impact have been shown to have measurable effects on forest flora (Garay and Nataf 1982, Cole and Marion 1988, Kuss and Hall 1991), and it is likely that the floristic response extended well beyond the point impacts recorded here.

Finally, the study ignores differences in the intensity of fragment use. Intensity of use varied considerably between stands and was almost certainly affected by features of the surrounding landscape. Such features probably included the density and demographics of nearby housing, number of public access points, and whether the stand was bordered by a through-road or by residential streets.

Over large areas of the eastern United States, suburban forest fragments serve local residence-associated and recreation needs in addition to their default conservation roles. Human impacts are concentrated near forest edges, but greatly exceed natural edge effects in both the severity and spatial extent of damage. Results in the present study suggest that recreational, aesthetic, and conservation needs can be reconciled in stands of moderate size through intelligent land-use planning and careful management. This can only be achieved, however, if the surrounding community recognizes the broad social and biological value of these small woodlands.

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