

Research Note

Research note: Surrounding landscape and local tree structure explain wear in boreal urban forests

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HIGHLIGHTS

- Urban forest floors are susceptible to wear due to trampling.
- Surrounding landscape and local forest characteristics explain wear in urban forests.
- Higher residential density and smaller forest area are reflected in greater wear.
- Dense forest undergrowth mitigates wear.

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ABSTRACT

Natural urban green areas in cities are susceptible to degradation due to high levels of recreational use and trampling induced wear. The aim of this study was to relate the amount of wear (paths and worn ground) in boreal urban forests to landscape-scale and local-scale predictors to help assess risks associated with urban densification. Wear was measured in 73 forests in three urban centers in southern Finland and analyzed in relation to surrounding residential density, amount of nearby forest area, and local forest characteristics. Median observed worn cover was 12 % while the most affected sites were over 90 % worn. Higher residential density and smaller forest area had independent exacerbating effects on wear. Wear was also related to tree structure and tended to be larger in forest interiors than near the edge. Our findings showcase how landscape transformations in growing cities may translate into risks of ecological degradation in urban forests.

1. Introduction

Neighborhood forests in cities and their outskirts serve as important recreational areas for urban residents (Florgård and Forsberg, 2006, Neuvonen et al., 2022). As forest areas become increasingly embedded within expanding urban areas and residential density increases, the remaining forest fragments are subjected to increasing levels of recreational use. Despite the presence of maintained paths, people commonly venture off the established trail (Korpilo, Virtanen, et al., 2018). This off-trail activity creates networks of paths and worn areas, visible as reduced vegetation cover and soil erosion (Lehvävirta, 1999).

Replacement of the natural understory vegetation with paths and bare ground degrades the forest ecosystem (Ballantyne and Pickering, 2015) and may eventually prevent tree recruitment and forest regeneration (Lehvävirta et al., 2004, Hauru, Niemi, & Lehvävirta, 2012). Because the restoration of degraded ecosystems can be costly and

practically difficult, emerging risks to natural areas associated with urban densification and increasing recreational user pressure should be evaluated preemptively. Forecasting risks of excessive wear could help urban planners to evaluate alternative land-use scenarios, or to identify areas expected to be highly at risk.

So far, only few studies have attempted to relate the amount of wear to planning-relevant measures of landscape, such as residential density and forest area (see Kellomäki and Wuorenrinne, 1979, Lehvävirta, 1999, Malmivaara-Lämsä et al., 2008). In terms of spatial scope, these have been case studies focusing on single regions, and their results have been variable especially in terms of key landscape-scale drivers of wear. Lehvävirta (1999) and Malmivaara-Lämsä et al., (2008) emphasized the role of surrounding residential density, whereas Kellomäki and Wuorenrinne (1979) found forest area to be more significant. All studies have identified local forest characteristics such as site fertility and structural barriers as significant in explaining wear.

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In this study, we aimed to assess how nearby landscape and local forest characteristics explain the amount of worn ground cover in the contexts of boreal forest across three Finnish urban centers. Firstly, we hypothesized that (H1) the degree of wear is higher when residential density in the nearby area is greater. Secondly, we hypothesized that, (H2) in landscapes with similar residential densities, less forested areas are more worn than areas with more forest. In terms of local forest characteristics, we hypothesized that (H3a) high tree density, (H3b) abundance of dense woody undergrowth and (H3c) lying dead wood mitigate wear by restricting passage (Lehvävirta, 1999). Finally, we hypothesized that (H4) areas close to the forest edge could be more resistant against wear than forest interiors due to more vigorous and resilient understorey vegetation (Hamberg et al., 2008) and people's preference to move in forest interiors (Hauru, Lehvävirta, et al., 2012).

2. Material and methods

2.1. Study area and locations

The study was conducted in three urban centers in southern Finland: city of Lahti (population 121 k), city of Tampere (population 260 k), and the urban conglomeration of Helsinki and Espoo (combined population of ca. 1 million). The cities are embedded within landscapes dominated by boreal forest which have also been retained as urban green areas with the urban matrix. Study sites represented forest areas embedded within or bordering built-up urban areas. All sites had unmanaged ground vegetation and a canopy formed by mature trees. We avoided forests growing on shallow soils on rocky outcrops and swampy forests on peat soils, and landforms with steep slopes (>25 % incline).

Forests were dominated by Norway spruce (*Picea abies*; 48 sites), Scots pine (*Pinus sylvestris*; 15 sites) or deciduous tree species (10 sites). Forest understorey vegetation was most commonly representative of *Vaccinium myrtillus* type fresh heath (MT; 61.5 % of sampling units) or more herb rich (38.1 %), and only rarely *Vaccinium vitis-idaea* type dry heath (VT; 0.4 %; Cajander, 1926).

2.2. Forest and landscape variables

Field measurements at each site were based on a transect consisting of 10 by 10 m square cells (hereafter cells) extending in a straight line starting from the outermost trees toward the center of the forest (see [Supplementary Material S1](#) for graphical representation). Starting point of the transect along the forest edge was initially randomly assigned, and if necessary, adjusted so that the transect didn't intersect with built paths, large ditches or other major obstructions at least within the first 30 m. Transect was extended to up to 80 m, or until reaching the center of the forest. Ground cover and forest characteristics were measured individually in each cell. Areas of different ground cover types (worn, vegetated, intact forest litter, rocks, logs) were measured manually using tape measure. Visible footpaths and other trampled surfaces, where ground vegetation and/or litter cover had worn off, were interpreted as worn cover. Before calculating the cover-%, ground area covered by rocks and logs and basal area of tree stems were subtracted from the total area of the cell. Tree density was measured as the number of tree stems with diameter at breast height (1.3 m; DBH) ≥ 5 cm within the cell. Undergrowth abundance was measured as the number of tree stems with DBH <5 cm and height ≥ 1.5 m. Ground area covered by logs was measured as the cover-% of downed tree trunks that were ≥ 15 cm in diameter. All field measurements were conducted during May-June 2023.

Amount of forested area in the nearby landscape (250 m radius) surrounding a transect was calculated as the proportion of wooded grid cells within the buffer. We considering all grid cells with >10 % canopy cover of ≥ 10 m tall trees as wooded area (Syke, 2022). Respectively, we calculated the number of inhabitants in the nearby landscape within 500 m radius (Statistics Finland 2023).

2.3. Statistical analysis

Due to highly heterogeneous tree structures at forest edge zones, we focused our analysis on forest interiors >10 m inward from the edge. Thus, our data contained a total of 278 samples (cells) that were aggregated in 73 forest sites (transects) and three distinct urban centers (data provided in [Supplementary Material S1](#)). We fitted an ordered beta regression mixed model to test the effects of landscape and local scale explanatory variables on the worn cover. Worn cover (proportion) in individual cells was used as the response variable. Landscape-scale explanatory variables included the number of inhabitants within 500 m radius and the proportion of wooded area within 250 m radius. Correlation between these two landscape variables across sites was non-significant (Pearson's $r = -0.10$, $p = 0.412$). Local (cell) scale variables included tree density, undergrowth abundance (\log_e -transformed), log cover and proximity to the forest edge (<20 m to the edge; yes/no). Forest site (73 levels) nested within region (3 levels: Espoo-Helsinki, Lahti, Tampere) was included as a random factor to account for the spatial aggregation of observations at the transect and city levels. In model building phase, we also screened for potential effects related to forest vegetation type (two levels: VT-MT or herb-rich) and dominant trees (three levels: spruce, pine or deciduous), but found no significant effects related to them. Therefore, neither factor was included in the model. To alleviate heteroskedasticity, we allowed dispersion to depend on the proportion of wooded area, undergrowth abundance and region. The model was fitted with the *glmmTMB* package (v1.1.9, Brooks et al., 2017). Model validity was checked by inspecting model fit and residual diagnostics with the *DHARMA* package (v0.4.6, Hartig 2022). All analyses were performed in R software (v4.3.3, R Core Team 2024).

3. Results

Worn cover of forest floor varied between 0 and 99 % at the level of individual cells and between 0–91 % at the level of whole transects. Median worn cover at the transect level was 12 %, with 8 % median worn cover across cells near forest edge (10–20 m from edge) and 13 % in forest interiors (>20 m from edge). Among regions, worn cover was generally highest in the most populous region Helsinki-Espoo and lowest in the least populous region Lahti (Fig. 1).

Based on our model (Fig. 2), worn cover was larger with higher surrounding residential density (H1, $p = 0.001$). Respectively, worn cover was smaller with more wooded area (H2, $p = 0.002$), higher tree density (H3a, $p = 0.011$), higher abundance of undergrowth (H3b, $p < 0.001$), more log cover (H3c, $p = 0.023$) and with close proximity to the forest edge (H4, $p = 0.001$). Detailed model outputs and model predictions over crossed environmental gradients are reported in [Supplementary Material S1](#).

4. Discussion

Our results demonstrate that both landscape characteristics and local forest characteristics are relevant in explaining the amount of wear on urban forest floors, providing support for the hypothesized effects H1-4. Landscape-scale predictors reflecting potential user pressure and the amount of nearby forest had independent effects. Within the typical range on variation in our dataset (nearby area with 1000–4000 inhabitants and 25–75 % wooded area), residential density and the amount of forested area had approximately equal leverage in explaining wear. In practice, our results indicate that urban infill development on natural areas can increase the risk of wear, not only by increasing user pressure through increasing population (H1), but also by reducing the forest area available for recreational activity (H2), thus increasing user pressure in the remaining forest.

Within forests, the amount of wear was more strongly associated with the abundance of undergrowth formed by small trees and saplings (H3b) than with the density of larger trees (DBH ≥ 5 cm) (H3a). Dense

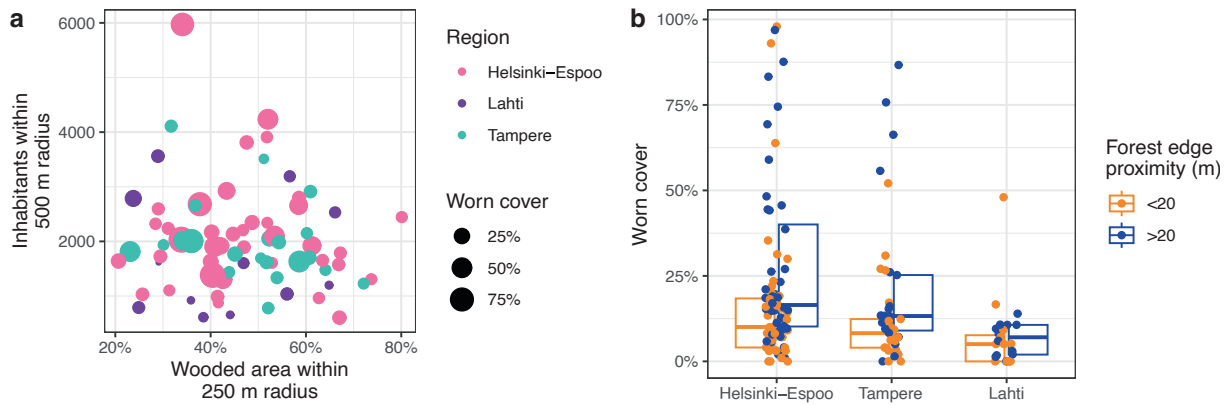


Fig. 1. Observed site-level worn cover across regions. Panel a shows sites (points) in relation to landscape setting. In panel b, worn cover is shown separately for forest edge (10–20 m from edge) and the forest interior (averaged over all cells >20 m from edge). Boxplots represent medians and interquartile ranges.

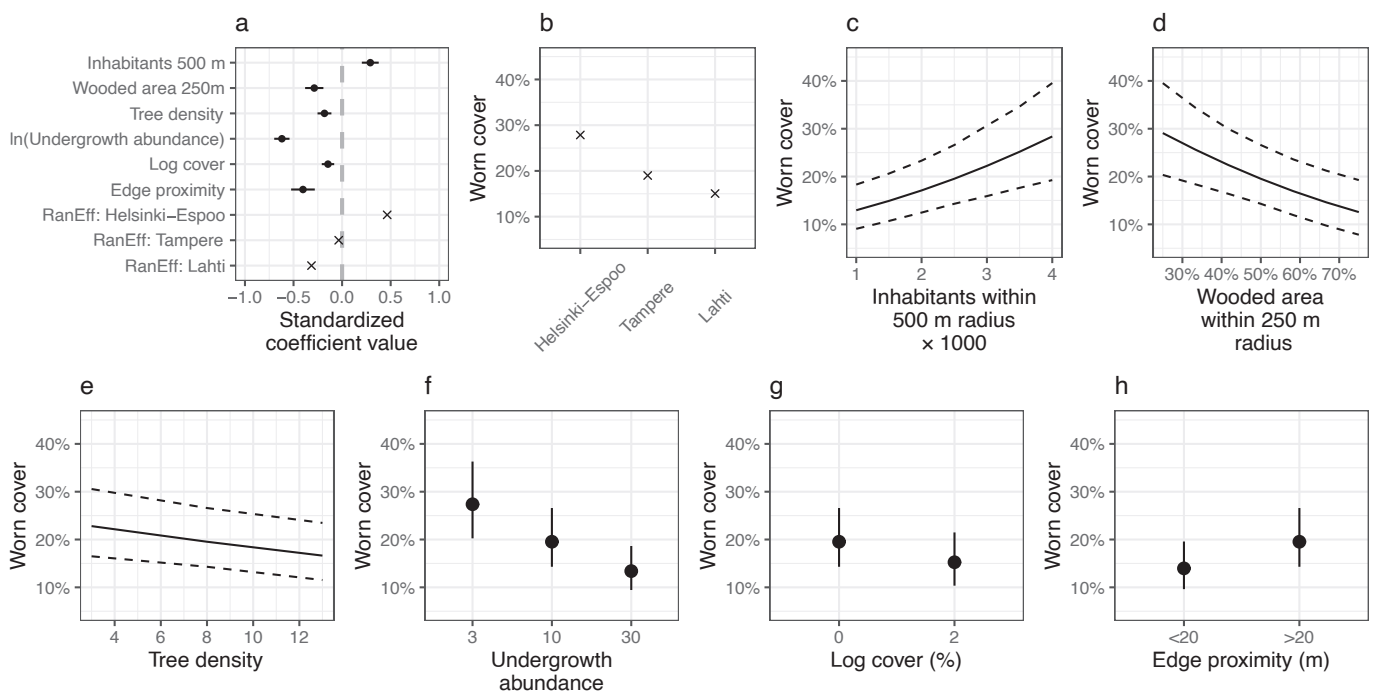


Fig. 2. Model coefficient estimates (a) and predictions of worn cover (b–h). Points in panel a represent standardized coefficient estimates (\pm SE) for fixed effects and crosses represent random effects. Panels b–h represent predicted values (\pm 90 % bootstrapped confidence interval) in relation to individual explanatory variables. When held constant in predictions, the number of inhabitants was set to 2500, wooded area to 50 %, tree density to 8, undergrowth abundance to 10, edge proximity to >20 m and log cover to 0.

woody understory vegetation can understandably thwart trampling as it forms a physical barrier obstructing both visibility and passage. However, as noted by [Lehvävirta \(1999\)](#), negative association between worn cover and undergrowth abundance can also be explained by reciprocal suppression of tree saplings by intensive trampling ([Hauru, Niemi, & Lehvävirta, 2012](#)). Wear was also negatively associated with fallen logs that occurred in urban forests sporadically (H3c), usually resulting from wind fall events and natural tree mortality. Strategic preservation and positioning of natural forest structures, such as thickets of undergrowth and fallen trees, thus represent potential approaches to channel passage at very local scales.

Lower amount of wear near the forest edge compared to forest interiors conformed to our expectations (H4), although opposite findings have also been reported in other studies ([Guirado et al., 2006](#)). Increased light penetration from open areas near forest edges favors fast-growing graminoids and herbs at the expense of more slowly growing and trampling-sensitive mosses and dwarf shrubs ([Hamberg et al., 2008](#)). We

also speculate that people going into urban forests seeking for outdoor recreation and refuge from the city might favor moving in forest interiors over edge zones, as the latter are more exposed to visual and auditory disturbance from surrounding built-up urban areas ([Hauru, Lehvävirta, et al., 2012](#)).

Finally, our results reveal notable differences in the levels of wear between urban regions. This is understandable considering that user pressure on urban green areas is not coming solely from the nearby residential areas, but also from outside of the immediate neighborhood. Urban forests situated in more populous cities are therefore subjected to larger background user pressure. However, there is probably substantial variation between forests in how much visitations they draw from further distances. Location specific attraction factors, such as good accessibility, special natural or cultural values and recreational facilities, probably play a major role in concentrating recreational use in certain areas over others ([Agimass et al., 2018](#), [Korpilo, Jalkanen, et al., 2018](#)). More precise prediction of wear would also necessitate

consideration of forest structural attributes and social factors that determine where people prefer to move within a forest as well as factors that encourage or discourage off trail activity (see, e.g., Coppes and Braunisch, 2013).

In conclusion, our results illustrate how the amount of wear varies in relation to landscape and forest scale variables that are easily available and understandable from the viewpoint of urban land-use planners and foresters. The results can be used in assessing how risk levels vary across urban landscapes and how risk levels might develop in future development scenarios. Yet, it is important to acknowledge that the actualized level of wear is the sum of many factors acting at different spatial scales, and that local condition should always be taken into account when assessing risks in specific locations.

CRedit authorship contribution statement

Aku Korhonen: Writing – original draft, Investigation, Formal analysis, Conceptualization. **Leena Hamberg:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.landurbplan.2025.105485>.

Data availability

Data is available in Supplementary material S1.

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