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Original article

Forest biodiversity indicators correlate with perceived forest qualities but not with psychological well-being in urban forests

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ABSTRACT

Provision of recreational opportunities and biodiversity are among the most significant values associated with urban forests in Nordic cities. However, catering to both demands with a limited forest area can result in conflicts, which need to be accounted for in urban forest management and land-use planning. In this study, we examined associations between forest biodiversity and on-site experiences of city residents (n = 153) in spruce-dominated urban forests (n = 15) in five Finnish cities. Biodiversity values were assessed from four complementary perspectives including (1) tree species admixture, (2) abundance of dead wood, (3) heterogeneity of ground vegetation, and (4) late-successional ectomycorrhizal fungal richness in the soil. People's experiences were investigated in terms of perceived forest quality and change in felt restoration and energy level before and after the forest visit. We found several correlations between people's perceptions of forest quality and measured biodiversity indicators. The correlations indicated mostly synergistic relationships between forest biodiversity and human preferences. Yet, differences in biodiversity indicators were not reflected in felt restoration or energy level changes. Our results suggest that promoting forest structural features that benefit biodiversity in boreal spruce-dominated forests is mostly in line with urban residents' preferences regarding forest qualities, but that management within forests should enable easy passage through them.

1. Introduction

Forests in cities and their outskirts provide urban residents with space and opportunities for outdoor recreation, contact with nature and refuge from built-up urban environments. Furthermore, urban forests regulate microclimates, contribute to stormwater management, and function as habitats for wildlife. Striking a balance between the needs and wants of a growing urban population and the ecological quality of urban green areas is a key challenge in urban planning (Haaland and Konijnendijk van den Bosch, 2015). A central question is how to best integrate biodiversity, recreational experiences, and human well-being into the management of urban green areas, such as forests.

There is strong evidence supporting the benefits of nature exposure for human well-being (e.g., Van den Bosch and Sang, 2017; Barboza et al., 2021; Brito et al., 2022). Spending time in natural environments releases stress and elevates mood (White et al., 2013; Tyrväinen et al., 2014). In addition, nature exposure has numerous positive physiological effects, such as reducing saliva cortisol level and blood pressure, both indicators of stress relief (Shuda et al., 2020). Theoretical frameworks such as the attention restoration theory (Kaplan and Kaplan, 1989) and the stress reduction theory (Ulrich et al., 1991) suggest that natural environments are particularly effective in supporting mental restoration and stress relief in terms of mood change and raised energy level. Forests have been shown to be among the best environments for these well-being effects (e.g., Tyrväinen et al., 2014), particularly when personal needs fit with the visited environment type (Ojala et al., 2019). In the highly forested Nordic region, people commonly use their local neighborhood forests for everyday outdoor activities, such as dog walking, jogging and playing (Florgård and Forsberg, 2006; Neuvonen et al., 2022).

Beyond their recreational value, urban forests also play a role in human health by providing contact with diverse natural environments and associated microbial assemblages (Hanski et al., 2012; Haahtela, 2019). A lack of exposure to microbial biodiversity in modern urban

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settings has been linked to an increase in inflammatory diseases. It is also hypothesized that environmental microbes may influence brain function and mental health (Lowry et al., 2016).

Psychological well-being effects of nature environments have been associated with perceived biodiversity, such as perceived species richness or perceived nature quality (e.g., Marselle et al., 2016). In contrast, links between well-being and actual biodiversity are less clear, partly due to the varied ways of measuring biodiversity (e.g., different greenness and diversity indices, species richness of various taxa or prevalence of a single species, etc., see e.g. Marselle et al., 2019). Therefore, there is further need to develop understanding about how actual biodiversity relates to human mental health and well-being in urban forest environments, and to identify suitable biodiversity metrics for studying these associations.

Urban forestry policies in Nordic countries increasingly recognize the importance of recreational use of forests. Consequently, management of Nordic urban forests has been moving away from production-oriented and even-aged silviculture towards lower-intensity management (Gundersen et al., 2005). This development has also contributed positively to forest biodiversity by enhancing compositional diversity and by increasing the amounts of old forest and dead wood (Korhonen et al., 2020, 2021). Although the value of urban forests as natural ‘wild’ habitats has been acknowledged (Alvey, 2006), there is still debate about the extent to which natural and recreational values can be simultaneously promoted in the same forest areas. For example, forest characteristics that are important for biodiversity, such as large amounts of dead wood and a dense understory, have previously been shown to be undesirable for recreational purposes (Tyrväinen et al., 2003, Gundersen and Frivold, 2011).

Studies on human responses to ‘wild’ nature environments in comparison to managed forest environments have yielded varying results. While some studies found no significant differences in well-being outcomes between managed and unmanaged forests (Takayama et al., 2017; Simkin et al., 2020), others reported more positive affect in managed forest (Martens et al., 2011). However, only Simkin et al., (2020) included a forest classified as being in natural state (Natura 2000 network of protected areas) in their experimental setting. Although some quantitative proxies of biodiversity, such as tree species richness have been studied (see e.g., Rozario et al., 2024), studies have rarely assessed how different aspects of biodiversity affect human experiences and well-being outcomes. Considering the variety of biodiversity in forest habitats, we need a broader view on biodiversity characteristics that contribute to species richness and nature conservation value.

The aim of this study was to explore potential synergies and conflicts between forest biodiversity and human well-being benefits in neighborhood forests using multiple complementary biodiversity indicators. The assessed indicators were (1) tree species admixture, (2) dead wood abundance, (3) ground vegetation heterogeneity, and (4) late-successional ectomycorrhizal fungal richness. The ecological justifications of these indicators are presented in Table 1. The novelty value of this study lies in combining multi-faceted biodiversity data with visitors’ responses collected through on-site questionnaires measuring perceived forest qualities and psychological well-being effects.

We hypothesized that forest characteristics important for biodiversity influence visitors’ perceptions of the environment and their feelings related to stress recovery. Two hypotheses were formulated:

H1. Forest biodiversity indicators correlate with urban inhabitants’ evaluations of forest qualities.

H2. Forest biodiversity indicators correlate positively with forest visit induced stress recovery indicated by mental restoration and raised energy level.

Table 1
Biodiversity indicators.

Biodiversity indicator	Ecological justification
Tree admixture	Tree species admixture promotes biodiversity by increasing the variety of available resources for organisms that depend on living trees (Ampoorter et al., 2020), such as herbivores and epiphytes (Uliczka and Angelstam, 2000; Salingre and Heliövaara, 2001; Huuskonen et al., 2021). Mixed tree stands also support higher richness of bird species (Uliczka and Angelstam, 2000; Felton et al., 2011).
Dead wood	Dead wood abundance predicts species richness of dead-wood dependent organisms (Lassauce et al., 2011). In the boreal forests of northern Europe, about 20–25 % of all forest species are dependent on dead wood as a habitat or source of nutrition (Siitonen, 2001). The largest taxonomic groups in this ecological guild are beetles and fungi.
Ground vegetation heterogeneity	Variation in ground vegetation within forest stands reflects the diversity of microhabitats on the forest floor and links to the diversity of soil-dwelling microbial and micro-arthropod communities (Ziesche and Roth, 2008; McIntosh et al., 2013, 2016; Bonari et al., 2017).
Species richness of late-successional ectomycorrhizal fungi	Species richness of late-successional ectomycorrhizal fungi (see Vlk et al., 2020) indicates forest continuity and integrity, i.e., long-term successional development without major disturbances such as clear-cutting (Spake et al., 2015).

2. Material and methods

2.1. Study sites

The study was conducted in 15 mature spruce-dominated urban forest sites in five Finnish cities, with three sites in each city (Fig. 1). Cities included Helsinki (population 684 k), Espoo (population 320 k), Lahti (population 121 k), Tampere (260 k) and Kuopio (population 126 k). In each city, we aimed to select sites representing both managed and natural-like forests. Managed sites had been actively managed according to typical urban forestry practices (Gundersen et al., 2005), whereas natural-like sites had been left unmanaged in recent decades and were mostly located in protected forests. All sites had a mature canopy tree layer dominated by Norway spruce (*Picea abies*) with variable proportions of admixed tree species (mostly *Pinus sylvestris*, *Betula pendula*, *B. pubescens*, *Populus tremula* and *Sorbus aucuparia*). We chose to focus on this forest type, because it is common throughout southern Finland and,

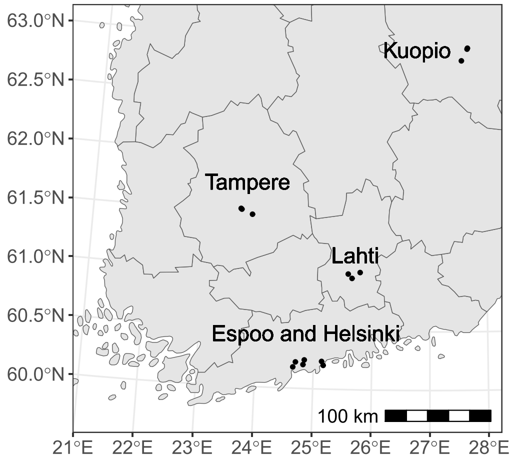

Fig. 1. Locations of study sites in southern Finland.

moreover, older stands are generally preferred for recreation (Gundersen and Frivold, 2008). Basal area of the living tree stand was on average 31.6 m^2/ha (sd=4.8). All sites had natural forest ground vegetation dominated by bilberry (*Vaccinium myrtillus*) alongside herbs and mosses. There were only naturally worn trails and paths within the forest sites and no artificially constructed walkways. Sites in Helsinki, Espoo, Lahti and Tampere were selected from an urban forest sample plot network established in 2022 (Korhonen et al., 2023) by choosing sites situated closest to residential areas or a walking trails allowing easy access. In Kuopio, we selected new forest sites with similar criteria. None of the forest sites were experimentally manipulated. Specific information about site locations and forest characteristics is provided in Supplementary material S1.

2.2. Questionnaires

The main objective of the questionnaires was (1) to survey people's perceptions of the forests and (2) to measure psychological well-being effects as changes in felt restoration and energy levels before and after visiting a forest. All questionnaires were done in Finnish language.

The first objective was addressed with a set of 10 semantic adjective pairs representing opposite poles of attributes related to forest qualities (Osgood, 1952). Each pair was presented as a seven-point scale between the opposites, and participants were asked to choose the most appropriate rating based on their impression at the end of the forest visit. We used partly the same adjective pairs as Simkin et al., (2021), which were derived from several previous studies: 'Pleasant–Unpleasant', 'Beautiful–Ugly', 'Safe–Scary', 'Restorative–Stressful', 'Rich in biodiversity–Poor in biodiversity', 'Natural–Artificial' and 'Interesting–Boring'. Because our measures of psychological well-being (see below) addressed vitality, we further added 'Empowering–Dispiriting' as a point of comparison. In addition, we included 'Vigorous–Weakened' relating to perceived forest and tree health status, and 'Easy to pass through–Difficult to pass through' relating to perceived physical obstruction in the forest.

The second objective was addressed with before-after measures based on two psychological rating scales: Restoration Outcome Scale (ROS; Korpela et al., 2008, cf. Hartig et al., 1998) and Subjective Vitality Scale (SVS; Ryan and Frederick, 1997; Bostic et al., 2000). ROS consists of six items that include three items related to relaxation and calmness ('I feel restored and relaxed', 'I feel calm', 'I have enthusiasm and energy for my everyday routines'), one related to attention restoration ('I feel focused and alert') and two related to clearing one's thoughts ('I can forget everyday worries', 'My thoughts are clear'). A four-item shortened version of SVS included statements: 'I feel alive and vital', 'I don't feel very energetic', 'I have energy and spirit' and 'I look forward to each new day'.

To be able to control for the effects of demographic variability in data analyses, we also asked participants to indicate background information such as gender identity (man, woman, other) and age group. We also asked how stressful their day had been on a scale of 1–5 (1 = not at all, 5 = very stressful) and their subjective connectedness with nature. Nature connectedness was self-assessed using the Inclusion of Nature in Self scale (INS, Schultz, 2002) which has a graphically presented seven-point scale.

2.3. Recruitment of volunteer participants

During the spring and summer 2023, we recruited adult (18 yrs or older) volunteer participants opportunistically through public announcements targeted to the neighborhoods and city districts close to the study sites. Announcements were distributed online through cities' web pages, city district social media groups, and as leaflets into mailboxes within walking distance (ca. 500 m) from the study sites. In the announcements, it was stated that we were investigating how neighborhood forests contribute to urban residents' well-being, and that participation involves a visit to one of the study forests with a researcher. It was also stated that the questionnaires are anonymous. Interested volunteers were instructed to contact the researcher to schedule a suitable time for participation in their preferred site. Participants were not given prior information about how the study sites compared with each other in terms of biodiversity or which aspects of biodiversity the study focused on. There was no reward to incentivize participation.

2.4. Experimental procedure

Most of the forest visits (n = 64) were organized between mid-May and end of June 2023 when deciduous vegetation had come fully into leaf, but berries and mushrooms were not yet available for picking. In one site, two visits were organized later in the summer in mid-August. Visits took place during daylight hours starting between 11:00 and 19:00. Up to five volunteers could participate in the same visit. Volunteers were instructed to arrive to a pre-determined meeting point that was located outside of the forest but always within less than 300 m distance from the site. Visits were conducted according to the procedure summarized in Fig. 2. Participants were asked to avoid all communication with other people. At the forest site, participants were instructed to spend 15 min freely observing the surroundings. Participants were allowed to roam around or stay put according to their own choosing. However, they were instructed to keep within the perimeter of the study plot (ca. 0.2 ha) which was delineated with 1.5 m tall orange plastic sticks stuck on the ground along the borders. As the study plots were rather small, 15 min was enough for the participants to wander through the whole plot with no hurry and with time to spare. Small portable stools, sit mats and mosquito repellent spray were available for the participants. Use of appliances such as phones, cameras or binoculars was not allowed.

Field measurements of air temperature and noise level, estimation of mosquito abundance, and notes about weather conditions, general soundscape and potential unexpected disturbance factors were done by the researcher during the 15-min observation period. Noise level was measured three times during the observation period with a sound level meter (DEM201, Velleman, Gavere, BE). Abundance of mosquitos was estimated on a scale of 0–3 by a researcher wearing no mosquito repellent (0 = no mosquitos; 1 = some mosquitos, minor nuisance; 2 = mosquitos moderately abundant, disturbing; 3 = mosquitos very abundant).

2.5. Biodiversity indicators

Tree admixture was measured as the proportion of non-dominant tree species, i.e. other than Norway spruce in the basal area of the living tree stand (mean=19 %, min=2 %, max=48 %). Calculations were based on field-based measurements of all living trees with diameter at breast height (1.3 m; DBH) $\geq$ 5 cm within a 0.16 ha sample plot. Tree measurements were done in 2023 in Kuopio. For other cities, we used data from 2022 (Korhonen et al., 2023).

Dead wood abundance was measured based on visual observation of dead standing and lying trees (DBH $\geq$ 15 cm) viewed from the center point of the study site. First, we scored abundances separately for standing and lying dead trees: 0 = no dead wood, 1 = 1–3 dead trees, 2 = 4 or more dead trees. Then, we summed the scores of standing and lying dead tree abundances to yield a total dead wood abundance score ranging from 0 to 4 (mean=2). Dead wood assessments were done in the summer 2024.

Ground vegetation heterogeneity was assessed by calculating average Bray-Curtis dissimilarity (Oksanen et al., 2022) between 16 vegetation sample plots within a 0.16 ha forest plot (mean=0.57, min=0.39, max=0.77). Vegetation sample plots were placed in a regular grid within the forest plot and cover percentages of all plant species (< 50 cm tall) were visually estimated within each 1 m^2 sample plot square

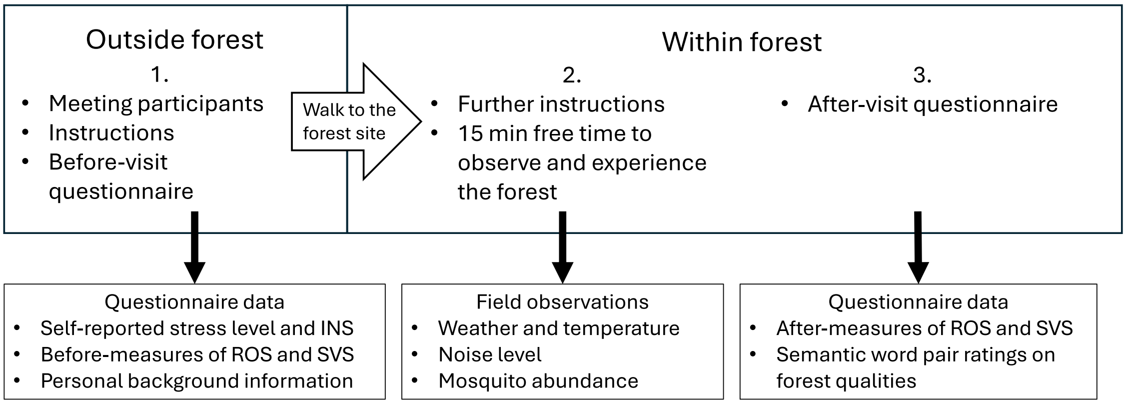

Fig. 2. Experimental procedure. INS = Inclusion of Nature in Self scale, ROS = Restoration Outcome Scale, SVS = Subjective Vitality Scale.

in the summer 2023. Vegetation data were collected in all but one of the study sites.

To investigate late-successional ectomycorrhizal (ECM) fungal richness, we collected soil samples from study sites. Soil sampling in Kuopio was done in the summer 2023. For other cities, we used data from 2022 (Korhonen et al., 2024). Fungi were analyzed directly from environmental DNA extracted from soil by metabarcoding of ITS2 nuclear ribosomal gene region. The DNA-based method reveals fungi that are present in the soil samples as vegetative and/or dormant forms irrespective of whether they produce visible structures above ground. Late-successional ECM fungal richness was calculated as the number of DNA-detected operational taxonomic units (OTUs) identified to unique species (or species hypotheses, see Kõljalg et al., 2013) of *Amanita*, *Cortinarius*, *Lactarius* and *Russula* (mean=14, min=8, max=24). These ECM fungal genera have been identified as associated with mature forest vegetation (Vlk et al., 2020). We counted OTUs present if they represented at least one promille of the total sequence read count in a sample. Further details of the soil sampling protocol and DNA analyses are described in Korhonen et al., (2024). None of the four biodiversity indicators were significantly correlated ($p > 0.10$) with each other (Table 2).

2.6. Associations of biodiversity indicators with perceived forest qualities

Associations between biodiversity indicators and semantic pair ratings related to perceived forest qualities were tested with cumulative link mixed models (CLMMs) that accommodate ordinal response variables. To avoid excessively complex model structure in relation to our data size, we simplified the seven-point scales of semantic pair ratings to three ordinal categories or to a binary variable (Fig. 3). We merged the original rating categories primarily at the thin end of the distribution to yield roughly balanced simplified categories. The simplified ordinal rating categories were used as the response variables in the CLMMs. For each semantic pair, we estimated separate CLMMs with each of the four biodiversity indicators as an explanatory variable together with a set of controlling variables.

Controlling variables included gender identity, INS, and abundance of mosquitos. Furthermore, we screened for potential effects related to the age of the participant, the number of participants attending the same forest visit, noise level (average of three measurements during visit), temperature and region (4 regions: Helsinki-Espoo, Lahti, Tampere, Kuopio). Examination of these effects was done by likelihood ratio tests comparing CLMMs with and without the tested variable included. Based on significance of the effect ($p < 0.05$), we included participant age in the model of ‘Easy to pass through–Difficult to pass through’ and temperature in the model of ‘Calming–Stressful’. To account for non-independence of ratings given by participants visiting the same forest sites, the forest site (15 sites) was included as a random effect in all CLMMs. CLMMs were estimated with the *clmm2* function in the R package *ordinal* (v12-4.1, Christensen, 2023).

CLMMs assume that the effect of predictors on the odds of the ordinal response is consistent across all levels of the variable. To check if this proportional odds assumption was met, we fit separate alternative models for each explanatory variable in each CLMM, so that the assumption was relaxed with a nominal effect (O’Connell & Liu, 2011). Thus, the effect of each variable was allowed to vary between different thresholds of the response. We then compared the CLMMs with and without the nominal effect by performing a likelihood ratio test to check if model performance was significantly improved by relaxing the proportional odds assumption. We interpreted a significant likelihood ratio test result ($p < 0.05$) as an indication that the assumption was not met. Based on the checks, we relaxed the proportional odds assumption for gender identity in CLMMs of ‘Natural–Modified’. If the assumption was not met for biodiversity indicator variables, we checked if the direction of the slopes across thresholds was the same or opposite. If slopes were in the same direction, we estimated a mean effect with a proportional odds model. If slopes were opposite, we concluded that there was no consistent directional response.

2.7. Associations of biodiversity indicators with felt restoration and energy levels

Associations of biodiversity indicators with changes in felt restoration (ROS) and energy levels (SVS) were tested with linear mixed models (LMMs). Summary scores of ROS and SVS before and after forest visit were calculated as means of individual item scores. The scale of the SVS item ‘I don’t feel very energetic’ was reversed before the calculation. We used the change in ROS and SVS summary scores (before-score

Table 2
Pairwise correlations of biodiversity indicators among forest sites. Coefficients (Coeff.) shown above diagonal represent Kendall’s rank correlations. Associated p-values are reported below diagonal (significant if $p < 0.05$).

	Tree admixture	Dead wood	Ground vegetation heterogeneity	Late-successional ECM fungal richness
Tree admixture	-	Coeff.= 0.06	Coeff.= 0.25	Coeff.= -0.02
Dead wood	p = 0.84	-	Coeff.= 0.11	Coeff.= 0.42
Ground vegetation heterogeneity	p = 0.38	p = 0.71	-	Coeff.= 0.00
Late-successional ECM fungal richness	p = 0.94	p = 0.14	p = 1.00	-

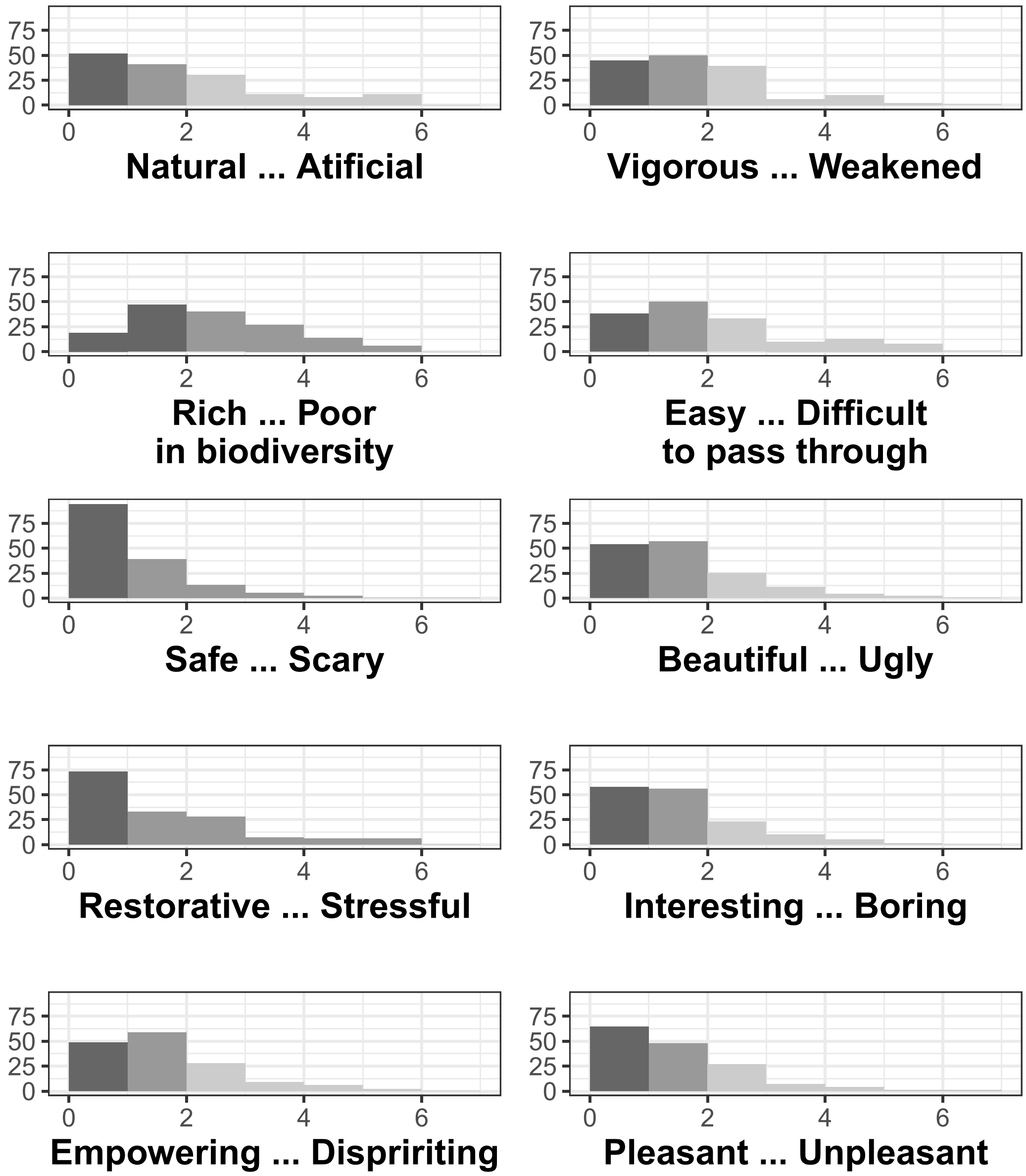

Fig. 3. Distribution of semantic pair ratings from all forest sites and study participants along a seven-point scale and their divisions into simplified ordinal or binary categories (indicated by shade). Y axis represents counts of ratings.

subtracted from after-score) as the response variables and estimated separate LMMs with each of the four biodiversity indicators as an explanatory variable together with a set of controlling variables. Controlling variables in all LMMs included gender identity, INS, abundance of mosquitos, self-reported stress level and the before-score of the response measure. The before-measure was included as a baseline covariate as it affects the possible range of the response (change). When the participant reported a high level of felt restoration or energy level at the start, the possibility for improvement was less as the result of the forest visit and the possible for deterioration was greater, and vice versa if the starting level was low. Furthermore, we screened for potential effects related to other personal traits, environmental conditions and region in the same way as we did with the analyses of semantic pair ratings (see above) but found them non-significant ($p > 0.05$). LMMs were estimated with the *lmer* function in the R package *lme4* (v1.1-35.3, Bates et al., 2015). Assumptions of the LMMs were checked by examining homoscedasticity and residual dispersion with the R package *DHARMa* (v0.4.6, Hartig, 2022). All analyses were performed in R software (v4.3.3, R Core Team, 2024).

3. Results

3.1. Participants and environmental conditions

The total number of recruited participants was 153. The number of participants per forest site varied between 5 and 19. The number of participants per visit was most commonly two (33 %) or one (30 %), and less often three (12 %), four (19 %) or five (6 %). Participants were mostly local inhabitants, 83 % reporting that they live within 3 km of the forest site they visited. Gender identity was reported as woman by 67 % and as man by 33 % of the participants. Overall, the personal trait profiles of participants were similar between cities (Fig. 4).

Temperature during forest visits varied between 9 and 26 °C with a mean (±sd) of 19.6 (±4.4). Measured noise levels varied between 26 and 65 dB with a mean (±sd) of 45.5 (±4.5). Rainy weather occurred on four visits (6 %). Detailed information about the environmental conditions during forest visits is provided in Supplementary material S1.

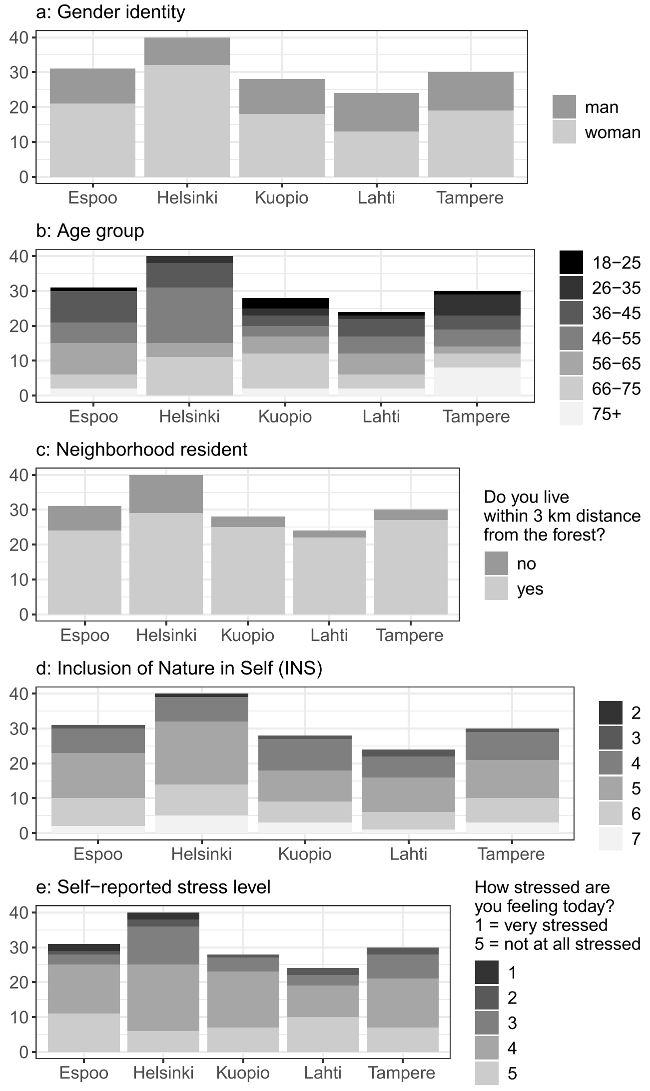

Fig. 4. Participant profiles across cities. Bar plots show the number of participants from each city and their distributions according to (a) self-reported gender identity, (b) age group, (c) whether they live close to the forest site that they visited, (d) connectedness with nature (7 = highest connectedness), (e) and feeling of stress.

3.2. Perceived forest qualities

Forest sites with higher levels of tree admixture were rated as significantly more beautiful and empowering than sites with higher dominance of Norway spruce ($p < 0.05$, Fig. 5a). Furthermore, forests with more admixture tended to be rated as more vigorous, richer in biodiversity and safer ($0.05 < p < 0.10$).

Forest sites with more dead wood were rated as significantly more natural, interesting, empowering and pleasant ($p < 0.05$). They also tended to be rated as richer in biodiversity, more calming and more difficult to pass through ($0.05 < p < 0.10$, Fig. 5b).

Ground vegetation heterogeneity had no statistically significant associations with the semantic pair ratings. However, the estimated effects indicated a general trend of higher vegetation heterogeneity resulting in more favorable ratings (toward the left side, Fig. 5c).

Species richness of late-successional ECM fungi had only marginally significant associations with the semantic pair ratings ($0.05 < p < 0.10$), but sites with higher richness tended to be rated as more natural, interesting and empowering as well as more difficult to pass through (Fig. 5d).

The relationship of tree admixture to 'Natural–Artificial' and the relationship of ground vegetation heterogeneity to 'Vigorous–Weakened' did not comply with the assumption of constant directional effect. In both cases, forest sites at the higher end of the biodiversity indicator tended to get more intermediate ratings. Detailed CLMM outputs and likelihood ratio test results are provided in Supplementary material S1.

3.3. Changes in felt restoration and energy levels

Overall, the changes in felt restoration (ROS) and energy levels (SVS) were significantly positive (Fig. 6), indicating improvement of psychological well-being during forest visits. However, the outcomes did not vary significantly with biodiversity indicators ($p > 0.10$), except for marginally significant negative association between ground vegetation heterogeneity and ROS ($p = 0.075$, Fig. 6e). The result indicates tentatively lower improvement in felt restoration in forests sites with higher vegetation heterogeneity. Detailed LMM outputs and likelihood ratio tests are provided in Supplementary material S1.

4. Discussion

Our results confirm the hypothesis (H1) that forest biodiversity correlates with people's perceptions of the forest environment. For the most part, sites with higher levels of tree admixture, dead wood and late-successional ECM fungal richness were favorably perceived by people. However, we found no significant support for the effects of biodiversity on felt restoration and energy levels (H2).

Associations of biodiversity indicators with perceived forest qualities were strongest for tree species admixture and dead wood abundance, which are among the most clearly visible structural features of the forest environment. Heterogeneity of ground vegetation was reflected in people's evaluations less clearly, possibly because differences in species composition of small understory plants are difficult to perceive (Balas and Momsen, 2014; Breitschopf and Bråthen, 2023).

Although ground vegetation heterogeneity elicited more favorable than disagreeable ratings, even if non-significantly, it was also the only biodiversity indicator that had a trend-like negative association with felt restoration. Improvement in feelings of relaxation and clarity of mind (ROS) was slightly weaker in sites with more heterogeneous vegetation. Further research would be needed to verify this result. Overall, the role of forest understory structures has been little explored in terms of preferences and well-being effects (but see Nielsen et al., 2018; Tomao et al., 2018).

In terms of appreciations, potential conflicts with biodiversity were limited to people's experience of sites with abundant dead wood being more difficult to pass through. Our finding that dead wood was otherwise agreeably perceived can be considered unexpected, because many earlier forest preference studies based on photographic visualizations have indicated opposite attitudes (Tyrväinen et al., 2003; Gundersen and Frivold, 2011; Gundersen et al., 2017; Ebenberger and Arnberger, 2019; Paletto et al., 2022). On the other hand, our results are in line with other field-based studies by Hauru et al. (2014) and Simkin et al. (2021) where dead wood was generally well accepted by participants observing forest environments on site.

Surprisingly, late-successional ECM fungal richness showed marginally significant associations with people's ratings of forest qualities, even though the study subjects had no way of observing soil-dwelling fungi directly. These effects were probably mediated by visible forest structures related to forest age, such as the amount of large old trees or abundance of accumulated needle-litter, which may also predict habitat quality and diversity for late-successional ECM fungi (Last et al., 1987). Across our study sites, late-successional ECM fungal richness was moderately correlated with dead wood abundance (Table 2), and evaluations related to both biodiversity indicators mirrored each other.

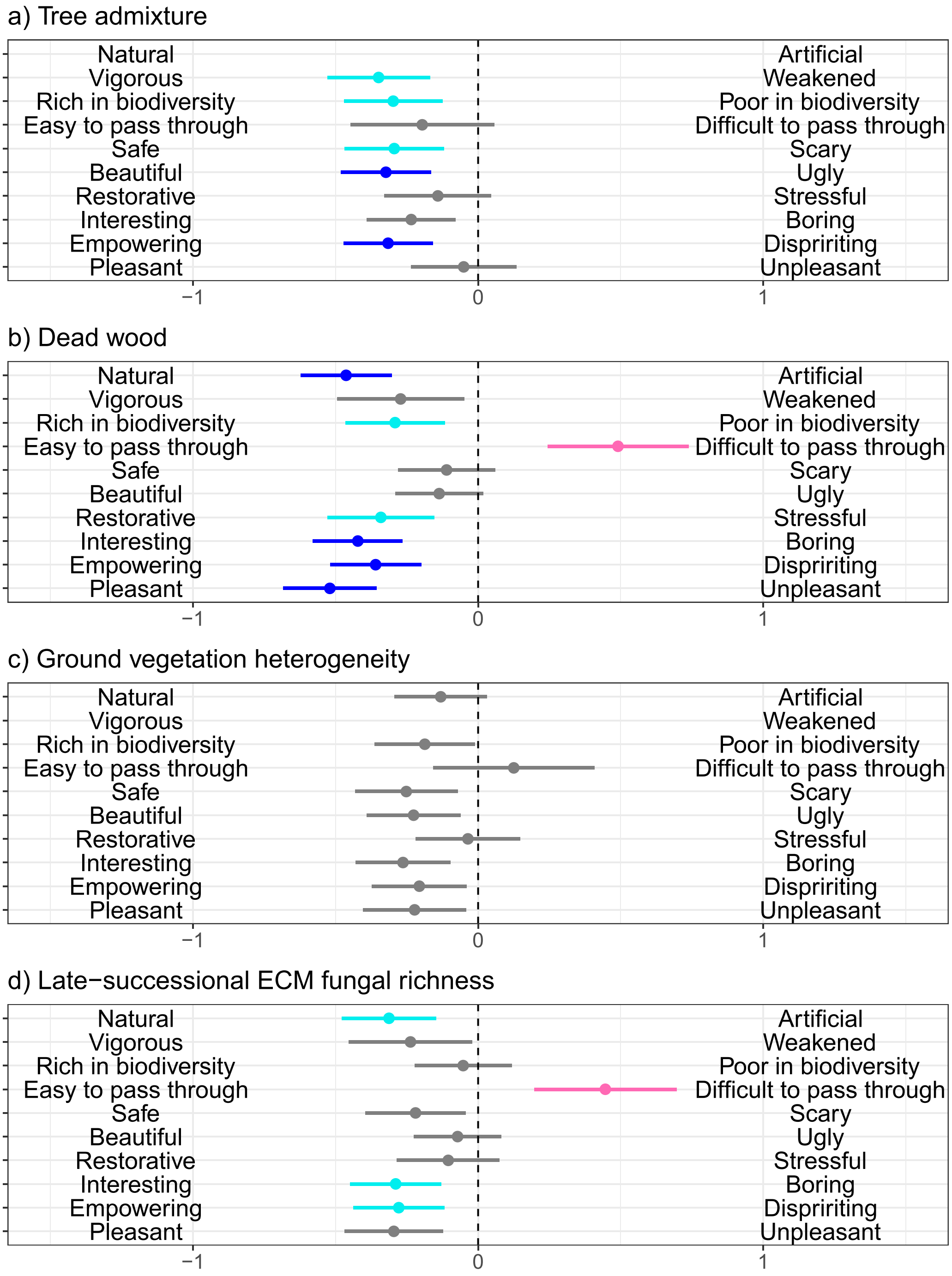

Fig. 5. Associations between forest biodiversity indicators (a-d) and perceived forest qualities based on CLMMs. Points represent coefficient estimates (±se shown by line range) of biodiversity indicators. Negative coefficient values indicate that forests with larger biodiversity indicator value received ratings towards the word on the left side, and positive coefficient values indicate respective effect toward the right side. Significance level of the coefficient value is indicated by color: dark blue if negative and $p < 0.05$, light blue if negative and $0.05 < p < 0.10$, pink if positive and $0.05 < p < 0.10$, grey if $p > 0.10$.

The lack of a strong coupling between perceived forest qualities and psychological well-being effects (felt restoration and improvement of energy levels) is consistent with at least one earlier study whose design compared ‘wild’ and ‘tended’ forests (Martens et al., 2011). As noted by Martens et al., (2011), individuals’ appreciations of the natural environment are probably only one of many factors that modulate the feelings of well-being. In our study, most participants were residents living close to the study sites, and they may have previously formed personal bonds to the forest areas they volunteered to visit (see Korpela et al., 2008). Therefore, positive feelings elicited by the familiarity of the site could have overpowered the effects of biodiversity. It is also possible that the visiting time was too short to elicit differences in feelings of restoration and vitality between forests representing contrasting levels of biodiversity. For example, in a field-experiment by Simkin et al., (2020) differences in ROS and SVS between forest sites were negligible after 15 min exposure but became clearer after additional 30 min spent walking. As previously noted, urban forests in Finland have been managed for several decades with an emphasis on recreational values, enabling their structural development to proceed in a relatively natural way. If the study would have included forests managed for timber production, which are typically managed as even-aged monocultural stands with lower structural diversity, more pronounced differences might

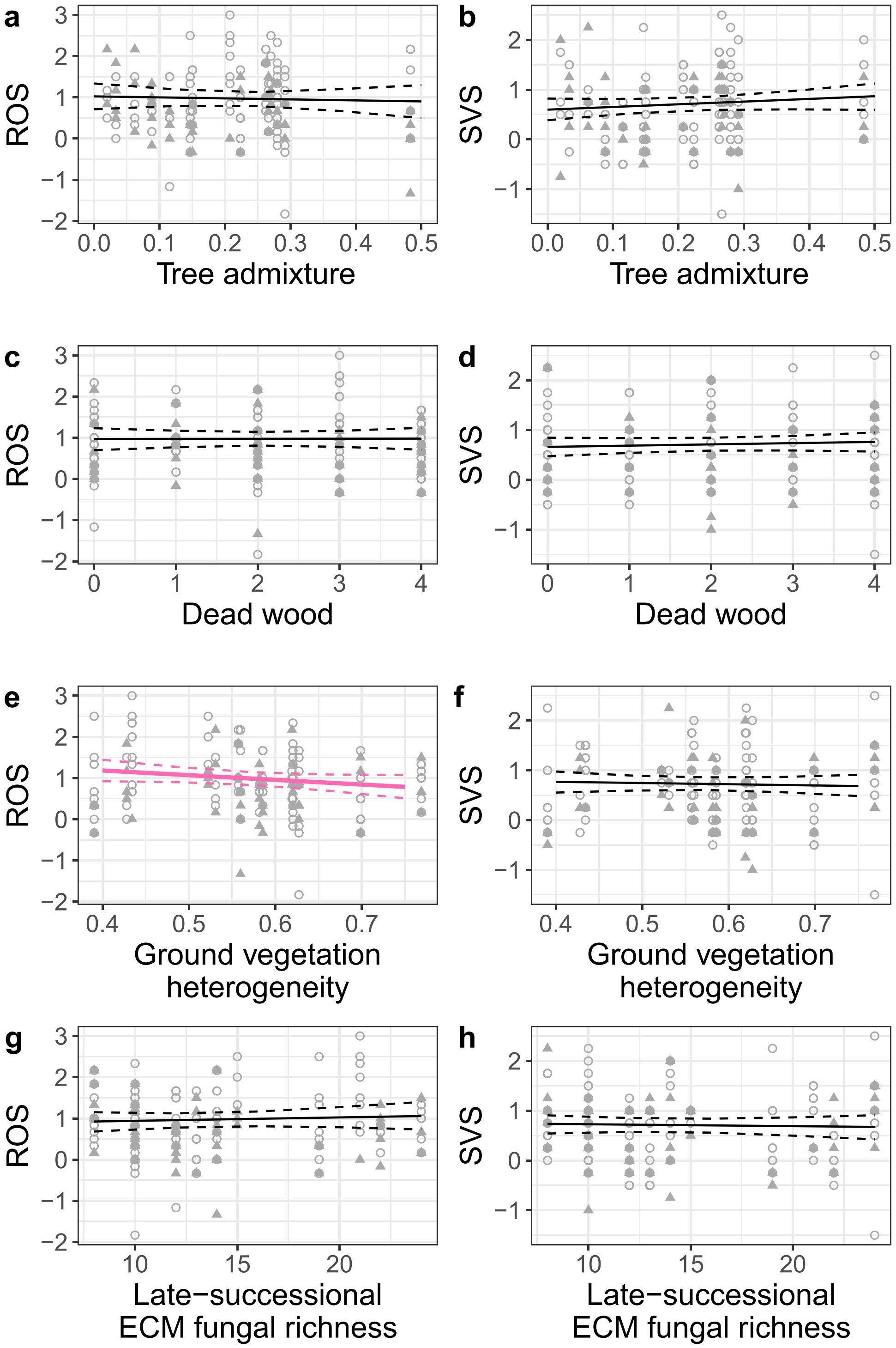

Fig. 6. Changes in felt restoration (ROS) and energy levels (SVS) during forest visits across biodiversity indicator gradients. Points represent ROS and SVS change of individual participants (before-score subtracted from after-score). Circular points represent women and triangles men. Solid lines represent predicted changes in ROS and SVS based on LMMs. Dashed lines represent 95 % confidence intervals based on 1000 bootstrap iterations. Pink color indicates statistically indicative ($0.05 < p \leq 0.10$) effect. For the predictions, other numeric explanatory variables were set to mean or median values and gender identity to woman.

have been observed between urban near-natural and managed forest conditions.

5. Conclusions

Our results contribute to the growing understanding on human well-being effects and perceptions of biodiversity in natural environments. Specifically, we demonstrate significant consistency between people's perceptions of forest qualities and measured biodiversity indicators at a relatively small spatial scale (< 0.5 ha) and within a narrow range of ecological variation. Compared to previous studies, this study focused on a carefully controlled set of sample sites representing a specific forest habitat type and developmental stage. This way, we were able to minimize potential confounding environmental variability that is inevitable when comparing biodiversity between natural and constructed green areas or between heterogeneous mosaics of contrasting habitat types. Our work highlights the utility of on-site study approaches to investigating human-nature relations and the importance of considering multiple dimensions of biodiversity.

Considering the relative similarity of our study sites, it is notable that correlations were found between measured biodiversity indicators and people's perceptions even when participants were not able to compare the site that they visited to other sites in the study. For example, sites with more admixed tree composition tended to be rated as more 'rich in biodiversity' and more dead-wood rich sites as more 'natural', consistent with ecological reasoning. Thus, our study population appears to have had a shared reference for typical ecological variability in the habitat type.

In practice, our results suggest that biodiversity-oriented forest management that favors tree species admixture, dead wood and old-forest continuity in urban neighborhood forests is well aligned with urban residents' preferences. However, as the walkability in dead-wood rich sites was found to be difficult, the areas with a high amount of dead wood require ongoing maintenance by keeping the pathways clear and ensuring safety of outdooring people by managing potentially hazardous trees. Because all of the habitat features, that are important for biodiversity, are unlikely to be well represented in a single forest area simultaneously, it is also important to assess which features hold the most significant biodiversity potential in a particular setting when planning management practices. For example, active management interventions that increase tree species admixture are usually better suited for younger managed stands than for forests with already developed old-growth characteristics. Lastly, there are several known preferences and needs for outdoor visitors besides the walkable pathways that were beyond the scope of this study, but which should be taken into account when planning and maintaining forest areas intended for recreational use.

CRediT authorship contribution statement

Mathilda Kauppila: Investigation. **Marjo Neuvonen:** Writing – review & editing, Writing – original draft, Methodology. **Ann Ojala:** Writing – review & editing, Writing – original draft, Methodology. **Jenni Simkin:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Aku Korhonen:** Writing – original draft, Project administration, Investigation, Formal analysis, Conceptualization. **Leena Hamberg:** Writing – review & editing, Supervision, Investigation, Conceptualization.

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Declaration of Competing Interest

The authors declare that they have no conflicts of interest to disclose.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2025.129219.

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