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Tree-related Microhabitats as Indicators of Anthropogenic Impact: Comparing Conservation and Recreation Areas in Yedigöller National Park (Türkiye)

Baummikrohabitate als Indikatoren anthropogener Einflüsse: Ein Vergleich von Schutz- und Erholungsgebieten im Nationalpark Yedigöller (Türkiye)

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Keywords: forest biodiversity, habitat tree, national park, recreation impact, tree-related microhabitats

Schlüsselbegriffe: Waldbiodiversität, Habitatbaum, Nationalpark, Erholungsnutzungseinfluss, Baummikrohabitate

Abstract

Tree-related microhabitats (TreMs) are distinct structures on living or dead trees that provide critical habitats for numerous species and serve as valuable indicators of forest biodiversity. This study represents the first assessment of TreMs in a national park in Türkiye, Yedigöller National Park, with the aim of comparing areas with different levels of human impact to evaluate effects on TreMs. Fieldwork was carried out in 10 study sites (5 conservation, 5 recreation) with one 625 m^2 square plot established at each site, where tree species, diameter, health status, and TreMs types were recorded. In total, 272 trees and 2020 TreMs were documented. Although recreational areas hosted a higher overall number of TreMs, conservation areas exhibited grea-

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ter average abundance and higher ecological value (EcoVal), reflecting the rarity and long formation time of many TreMs. Both living and standing dead wood (snags) were identified as essential for sustaining TreMs diversity, with dead wood harboring particularly rich and valuable TreMs assemblages. Habitat trees, regardless of being alive or dead, played a central role in supporting diverse and high-value microhabitats. These findings from Yedigöller National Park highlight the importance of TreMs for biodiversity conservation and underline the need to balance conservation priorities with recreational use in protected forests to ensure the long-term ecosystem integrity.

Zusammenfassung

Baummikrohabitate (TreMs) sind charakteristische Strukturen an lebenden oder toten Bäumen, die zahlreichen Arten essenzielle Lebensräume bieten und als wertvolle Indikatoren der Waldbiodiversität dienen. Die vorliegende Studie stellt die erste Untersuchung von TreMs in einem Nationalpark in der Türkei dar, Nationalpark Yedigöller, mit dem Ziel, Schutz- und Erholungsgebiete zu vergleichen, um die Auswirkungen menschlicher Aktivitäten auf TreMs zu bewerten. Die Feldarbeiten wurden in 10 Quadraten an 10 Untersuchungsflächen (5 Schutzgebiete, 5 Erholungsgebiete) mit jeweils einem 625 m^2 großen quadratischen Plot durchgeführt, wobei Baumarten, Durchmesser, Gesundheitszustand und TreMs-Typen erfasst wurden. Insgesamt wurden 272 Bäume und 2020 TreMs dokumentiert. Obwohl in den Erholungsgebieten eine höhere Gesamtzahl von TreMs festgestellt wurde, wiesen die Schutzgebiete eine größere durchschnittliche Häufigkeit und einen höheren ökologischen Wert (EcoVal) auf, was auf die Seltenheit und lange Entwicklungszeit vieler TreMs zurückzuführen ist. Es zeigte sich, dass sowohl lebendes als auch totes Holz für den Erhalt der TreMs-Diversität unerlässlich ist, wobei Totholz besonders artenreiche und wertvolle TreMs-Gemeinschaften beherbergt. Habitatbäume, unabhängig davon, ob lebend oder tot, spielten eine zentrale Rolle bei der Unterstützung vielfältiger und ökologisch hochwertiger Mikrohabitate. Diese Ergebnisse aus dem Yedigöller-Nationalpark unterstreichen die Bedeutung von TreMs für den Biodiversitätsschutz und heben die Notwendigkeit hervor, Naturschutzprioritäten mit Erholungsnutzung in Schutzwäldern in Einklang zu bringen, um die langfristige Integrität der Ökosysteme zu gewährleisten.

1 Introduction

Protected forests are essential for biodiversity conservation, yet many face mounting pressure from recreational activities and management interventions. National parks, which generally contain a considerable amount of forest cover, are keystones of the global protected area network (Arcese and Sinclair 1997; Nelson and Serafin 1997).

While there is still a need for effective tools to understand and monitor their ecological performance (Gaston *et al.* 2008), conflicts about land-use within and around the national parks persist more commonly in developing countries (Hough 1988) like Türkiye.

Tree-related microhabitats (TreMs)—including cavities, injuries, bark pockets, and fungal bodies—are distinct structures on living or dead trees that provide essential habitat for diverse taxonomic groups from invertebrates to vertebrates, fungi, and plants, during their life cycles (Grossmann *et al.* 2018; Larrieu *et al*., 2018; Bütler *et al.* 2020; Asbeck *et al.* 2021). Their diversity and abundance have emerged as powerful indicators of forest biodiversity (Larrieu and Cabanettes 2012; Michel and Winter 2009). Research demonstrates that TreMs abundance correlates strongly with tree size and vitality status: habitat trees (typically large, old trees) and dead wood harbor significantly more microhabitats than smaller, living trees (Paillet et al. 2019; Asbeck et al. 2020). The ecological value (EcoVal) of TreMs, based on their rarity and development time, provides a standardized metric for assessing habitat quality and conservation effectiveness (Kraus *et al.* 2018).

TreM-based assessments are increasingly operationalized through standardized field methodologies, including the Marteloscope approach, which enables systematic tree-level recording of microhabitat types and ecological values across permanent forest plots (Bütler *et al.* 2013; Kraus & Krumm 2013; Kraus *et al.* 2018). While TreMs research has been extensively conducted in temperate and boreal forests in Central Europe and North America, as well as in Western and Central Mediterranean forests (Dutta *et al.* 2025) -particularly Spain, France, and Italy (see Integrate+ Network; Kraus *et al.* 2022), studies in the Eastern Mediterranean, Anatolian, and Middle Eastern regions remain relatively scarce despite their ecological significance. Recent work in Iranian Oriental beech forests has highlighted the importance of tree species identity and DBH as key determinants of TreM occurrence (Khanalizadeh *et al.* 2020), while a broader investigation across Europe and Iran identified stand dynamics and tree aging as primary drivers of microhabitat formation rates, underscoring the need for predictive models to guide retention forestry decisions (Courbaud *et al.* 2022). Similarly, studies in Mediterranean oak and Italian mountain forests have confirmed that large trees and standing dead wood disproportionately support microhabitat diversity (Regnery *et al.* 2013; Marziliano *et al.* 2021). The Western Black Sea Region of Anatolia, part of the Euro-Siberian phytogeographical region and home to transitional forests where European temperate and Colchic elements converge, represents a particularly understudied system in this regard. These forests, dominated by tree taxa such as *Fagus orientalis*, *Carpinus betulus*, *Quercus* spp., *Abies* spp., and *Pinus* spp., face increasing recreational and management pressure that may affect TreM assemblages in ways not yet documented.

Yedigöller National Park in Türkiye provides an instructive example of protected areas with dual conservation-recreation functions while offering an ideal setting to investigate TreMs patterns in Black Sea region forests. The park's mixed deciduous-conife-

rous forests experience a stark gradient of human impact: recreational facilities are clustered around a few of the park's seven avalanche-formed lakes, concentrating visitor pressure into relatively small zones with measurable ecological impacts (Kırca and Altınçekiç 2018). In these areas, forest understory seedlings often fail to establish due to intensive trampling, while soil compaction from concentrated use leads to widespread exposure of tree roots at the surface (Kırca and Altınçekiç 2018). According to park management, additional interventions, including pruning to minimize branch-fall risks to visitors, are regularly applied in picnic and camping areas. Furthermore, dead branches and wood are frequently used in illegally lit fires, resulting in the near absence of dead wood in recreational sites. The park's rugged topography generates pronounced spatial heterogeneity in accessibility over short distances, allowing high-impact recreational zones to exist in close proximity to areas with minimal disturbance on less accessible terrain. Thus, although Yedigöller is legally designated as unmanaged forest within a national park, it remains subject to management interventions such as pruning for visitor safety as well as direct anthropogenic pressures (trampling, soil compaction, vandalism) and indirect impacts (dead wood removal for fires) (Kırca 2015; pers. comm. with park management; pers. obs.).

This study examines the TreMs distribution in Yedigöller National Park, comparing conservation and recreational areas, to assess anthropogenic impacts on biodiversity indicators. We test the hypothesis that recreational areas exhibit reduced TreMs abundance and ecological value compared to conservation areas, and investigate whether habitat trees and dead wood remain key determinants of microhabitat occurrence under varying human pressure. Additionally, we evaluate how specific anthropogenic activities affect different TreMs types, providing insights into the mechanisms of human impact on forest microhabitats. This study contributes to the limited knowledge of TreM patterns in Black Sea region forests while informing management strategies that balance biodiversity conservation with sustainable recreational use in protected forests where multiple functions coexist.

2 Materials and Methods

2.1 Study Area and Sample Sites

Our study was conducted in Yedigöller National Park, located in the Western Black Sea Region of Türkiye, within the province of Bolu (31.7333° E – 31.7833° E and 40.9167° N – 40.9667° N). Designated in 1965, the park spans 1,631 hectares of mixed deciduous and coniferous forests dominated by *Fagus orientalis*, *Carpinus betulus*, *Pinus nigra* subsp. *pallasiana*, *Quercus petraea*, and *Abies nordmanniana* subsp. *bornmuelleriana* (Kırca 2015, Tokcan 2015), creating diverse microhabitat conditions suitable for our study objectives. These intact ecosystems provide refuge for a variety of plant and animal species (Beşkardeş 2012), contributing to the park's conservation value

(Kırca 2015). Forest stands are predominantly uneven-aged (97%), with 74% exhibiting double or multiple canopy layers, creating structurally diverse conditions favorable for TreMs development. The park receives approximately 200,000 visitors annually between April and mid-November, with recreational activities concentrated around the seven avalanche-formed lakes (Figure 1).

To assess human impact on the national park's ecological integrity, we selected 10 study sites representing a gradient of anthropogenic influence previously characterized by Kırca (2015) and Kırca and Altınçekiç (2018). Sites were classified into two categories based on hemeroby levels from Kırca (2015): conservation areas (n=5; hemeroby levels 8-9, indicating minimal human modification) and recreation areas (n=5; hemeroby levels 4-6, indicating moderate modification from recreational activities). Site selection followed a purposive sampling approach based on three criteria:

(1) clear differentiation in hemeroby levels reflecting distinct human use intensities,
(2) representation of the park's dominant forest types and structural characteristics, and
(3) accessibility for comprehensive field surveys.

Within each site, a single 625 m^2 (25 × 25 m) quadrat was established in locations representing modal stand conditions. In conservation areas, quadrats were positioned ≥50 m from roads and recreational infrastructure to minimize edge effects; in recreation areas, quadrats were placed within 20 m of trails or facilities to capture maximum anthropogenic impact. All quadrats avoided immediate trail edges (>5 m) to ensure safety and minimize observer disturbance. Information on management practices was obtained through consultation with park management staff and direct field observations during site surveys (2023).

Welch's t-tests confirmed no significant differences between area types in key topographic and structural variables (Table 1): elevation (recreation: 815 ± 53 m; conservation: 885 ± 118 m; t=-1.26, p=0.273), tree density (recreation: 460.8 ± 86.5 trees/ha; conservation: 409.6 ± 151.2 trees/ha; t=0.64, p=0.554), mean DBH (recreation: 33.65 ± 11.46 cm; conservation: 41.09 ± 22.46 cm; t=-0.68, p=0.527), and basal area (recreation: 49.34 ± 23.19 m^2/ha; conservation: 65.68 ± 45.95 m^2/ha; t=-0.71, p=0.490).

Table 1: Topographic and structural characteristics of study sites in Yedigöller National Park. Sites are classified as recreation (Rec) or conservation (Con) based on hemeroby levels from Kırca (2015), which reflect the degree of human modification (scale 1-10; higher values indicate less human influence). Topographic variables (elevation, slope, aspect) and structural variables (tree density, mean DBH, basal area) were measured during field surveys in 2023. Statistical comparisons (Welch's t-tests) show no significant differences between area types.

Tabelle 1: Topographische und strukturelle Merkmale der Untersuchungsflächen im Yedigöller-Nationalpark. Die Flächen sind als Erholungsgebiete (Rec) oder Schutzgebiete (Con) klassifiziert, basierend auf Hemerobie-Stufen nach Kırca (2015), die den Grad der menschlichen Beeinflussung widerspiegeln (Skala 1–10; höhere Werte bedeuten geringere menschliche Beeinflussung). Topographische Variablen (Höhenlage, Hangneigung, Exposition) und Bestandesmerkmale (Baumdichte, mittlerer BHD, Grundfläche) wurden während der Felderhebungen im Jahr 2023 gemessen. Statistische Vergleiche (Welch-t-Tests) zeigen keine signifikanten Unterschiede zwischen den Gebietstypen.

Study site	**Elevation (m)**	**Slope (%)**	**Aspect**	**Hemeroby level**	**Tree Density (n/ha)**	**Mean DBH (cm)**	**Basal Area (m^2/ha)**
Rec-1	765	11-20	W	6	400	40.24	58.98
Rec -2	780	0-10	SW	6	512	37.16	62.04
Rec -3	780	0-10	NE	4	416	42.20	71.80
Rec -4	880	0-10	E	6	384	33.83	37.82
Rec -5	870	0-10	SW	6	592	14.81	16.07
Con-1	845	11-20	E	9	592	23.6	30.56
Con -2	790	11-20	NE	8	304	34.12	41.83
Con -3	810	11-20	E	9	368	39.20	59.13
Con -4	900	0-10	NE	8	224	79.48	142.57
Con -5	1080	11-20	NE	8	560	29.04	54.31
Mean ± SD (Rec)	**815 ± 53**				**460.8 ± 86.5**	**33.65 ± 11.46**	**49.34 ± 23.19**
Mean ± SD (Con)	**885 ± 118**				**409.6 ± 151.2**	**41.09 ± 22.46**	**65.68 ± 45.95**
t-test	**t=-1.26, p=0.273**				**t=0.64, p=0.554**	**t=-0.68, p=0.527**	**t=-0.71, p=0.490**

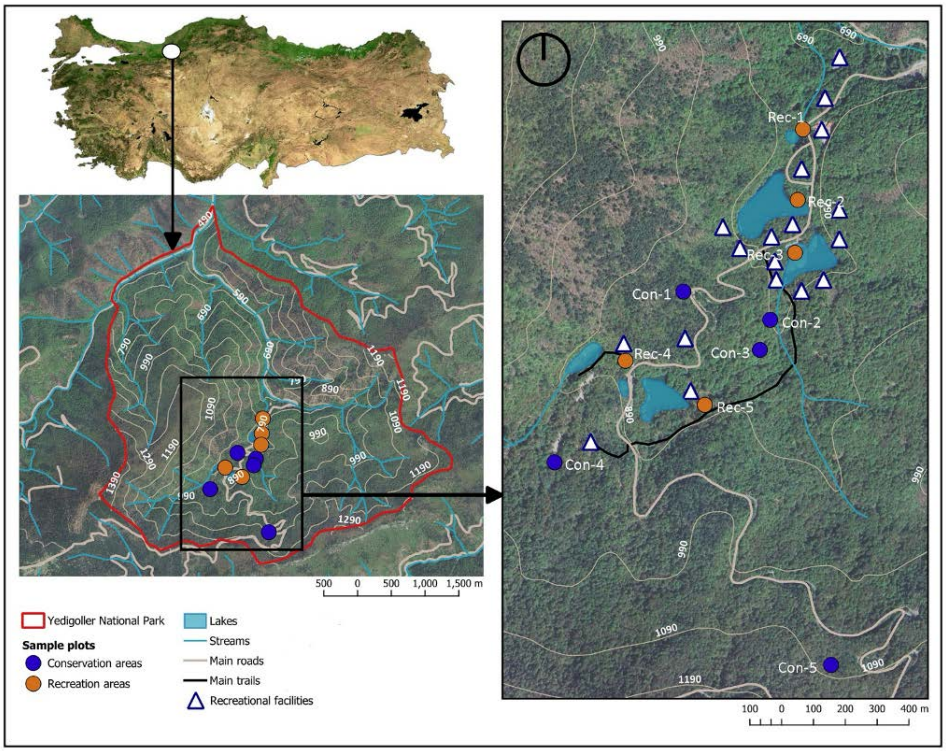


Figure 1: Study area in Yedigöller National Park and the distribution of sample plots and recreational facilities.

Abbildung 1: Untersuchungsgebiet im Yedigöller National Park sowie Verteilung der Probeflächen und Erholungseinrichtungen.

2.2 Tree Microhabitats, Habitat Trees and Vandalism

2.2.1 Tree inventory and Tree-Related Microhabitats

Within each 25 × 25 m (625 m^2) square plot, we recorded data for every tree with DBH ≥7.5 cm, following Schuck *et al.* (2015b) and the Marteloscope methodology standard (Larrieu *et al.* 2018; Kraus & Krumm 2013). Recorded parameters included species identification, DBH, and health status (classified as alive or standing dead: only snags were recorded among dead trees). Although shrub species (*e.g.*, *Rhododendron* spp.) were present in the study area, their stem diameters remained below the 7.5 cm DBH threshold and were therefore excluded from the analysis.

TreMs were assessed following the standardized catalogue of Kraus *et al.* (2016), which classifies microhabitats from broad categories (Level 1) to specific types (Level 3), and

remains actively applied in recent studies on forest management and conservation (Fröhlich *et al.* 2025; Przepióra *et al.* 2025; Visick *et al.* 2025). We applied the 2016 catalogue to maintain compatibility with the Integrate+ decision support system, which automates EcoVal scoring, and to ensure comparability with the broader European TreM literature; our fieldwork preceded publication of the revised catalogue (Bütler *et al.* 2024). All TreM types were recorded at Level 3 following best practices (Larrieu *et al.* 2018), but results are presented at Level 2 to facilitate interpretation and ensure comparability with forest inventories and conservation frameworks such as Natura 2000 (Supplementary Table 1). We also documented a site-specific anthropogenic impact termed vandalism, characterized by human-caused trunk injuries from scraping and nailing; these records are presented separately to illustrate human impact patterns in recreational areas, but were not included in statistical analyses.

2.2.2 Habitat Trees and Vandalism

Habitat trees were defined as individuals with DBH ≥ 40 cm, following the operational threshold used in European forest management and TreM assessments. This threshold is widely used as an operational indicator of ecological value in European forest management (Niedermann-Meier *et al.* 2010).

Tree vandalism was frequently observed in recreation areas and consisted mainly of carved inscriptions and trunk injuries caused by visitors. Following the TreM framework, vandalism traces were classified into two size classes analogous to bark loss/exposed sapwood categories (IN1): VA1 (25–600 cm^2) and VA2 (>600 cm^2). Trees exhibiting both types were classified as VA1+VA2 (Figure 2).

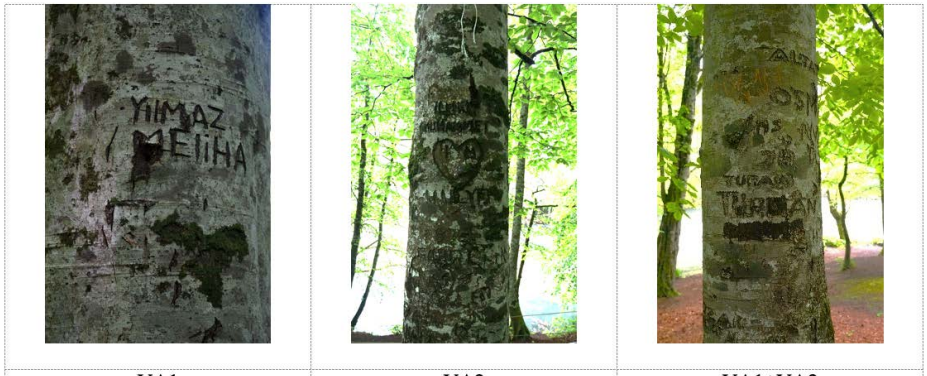


Figure 2: Examples of vandalism classes: VA1 (25–600 cm²), VA2 (>600 cm²), and VA1+VA2 (both types present on the same tree).

Abbildung 2: Beispiele für Vandalismusklassen: VA1 (25–600 cm²), VA2 (>600 cm²) und VA1+VA2 (beide Typen am selben Baum vorhanden).

2.2.3 TreM Categories Used to Assess Forestry Implementations and Anthropogenic Pressure

TreM types associated with cavity-related, direct and indirect anthropogenic effects were evaluated by comparing their frequencies between area types. We compared cavity-related TreMs including woodpecker cavities (CV12: ø 5-6 cm) and branch holes (CV31: ø ≥5 cm; CV32: ø ≥10 cm), which may develop following either branch pruning or natural branch fall (Figure 3-A). Since these structures form over 10-30+ years through progressive decay, we cannot determine whether any individual cavity originated from historical pruning, natural branch fall, storm damage, or other causes.

To identify direct anthropogenic effects, we examined direct injury-type TreMs that are more likely to reflect recent (<10 years) anthropogenic impacts, including fresh trunk injuries with limited decay progression. These included trunk and mould cavities with ground contact (CV23, ø ≥ 10 cm; CV24, ø ≥ 30 cm) and without ground contact (CV25, ø ≥ 30 cm/semi-open), together with bark loss (IN11, 25–600 cm², decay stage <3; IN12, >600 cm², decay stage <3) (Figure 3-B).

For indirect anthropogenic effects, discussions with foresters indicated that visitor activities such as walking, picnicking, or camping can cause soil compaction, exposing tree roots and eventually leading to the formation of trunk cavities with ground contact. Accordingly, we examined trunk and mould cavities with ground contact (CV21, ø ≥ 10 cm; CV22, ø ≥ 30 cm) and root buttress cavities (GR1) (Figure 3-C).

Figure 3 illustrates only the selected TreM categories used in the assessment of forestry implementations and anthropogenic pressure and does not represent the complete TreM typology of Kraus *et al.* (2016), which comprises 64 TreM types (Supplementary Table 1).

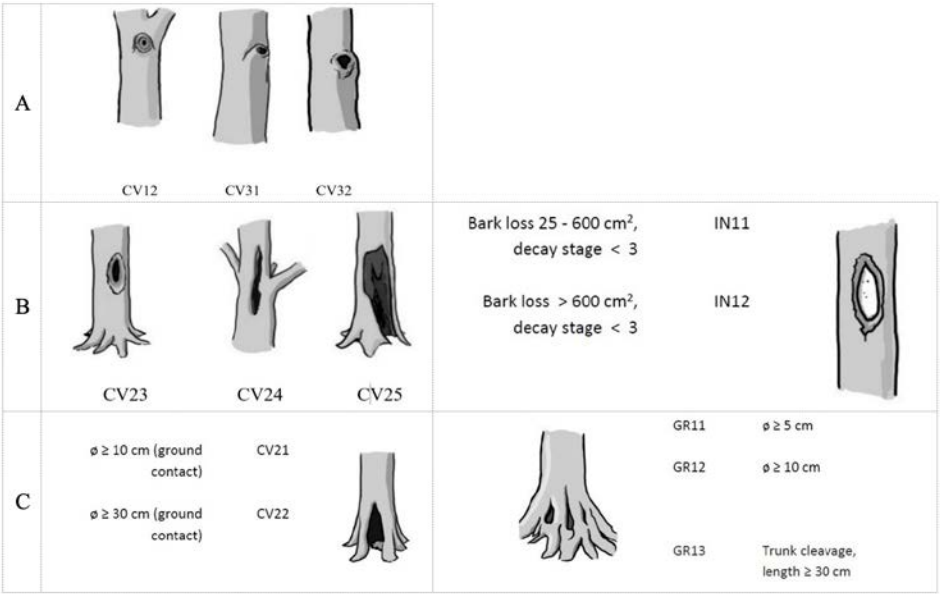


Figure 3: Selected TreM categories used to assess forestry implementations and anthropogenic pressure: (A) woodpecker cavities and branch holes, (B) direct anthropogenic injury types, and (C) indirect anthropogenic cavity types (Images from Kraus et al. 2016).

Abbildung 3: Ausgewählte TreM-Kategorien zur Bewertung forstlicher Maßnahmen und anthropogener Einflüsse: (A) Spechthöhlen und Astlöcher, (B) direkte anthropogene Verletzungstypen and (C) indirekte anthropogene Höhlentypen (Abbildungen nach Kraus *et al.* 2016).

2.3 Data Analysis

All statistical analyses were conducted in R (R Core Team, 2023). TreM data were analyzed at the individual tree level using non-aggregated observations to preserve variability within the dataset. Mean (± standard deviation, SD) values were calculated only for descriptive summaries and graphical visualization. Two response variables were considered:

(i) the number of TreMs per tree and
(ii) the ecological value of TreMs (EcoVal).

EcoVal was calculated following Kraus et al. (2018) by weighting TreMs according to their rarity (R), development time (D), and structural size (s), and was log-transformed (log10) where necessary to improve normality and reduce heteroscedasticity.

Differences in TreM abundance and EcoVal among area types (conservation vs. recreation), tree species, vitality classes (alive vs. standing dead wood), and habitat tree categories (DBH ≥ 40 cm vs. DBH < 40 cm) were evaluated using linear models (LM) or generalized linear models (GLM), depending on the distribution of the response variable. For count data, Poisson models were initially fitted and negative binomial models were applied when overdispersion was detected. Pairwise comparisons were performed using estimated marginal means (emmeans package).

Because *Abies nordmanniana* subsp. *bornmuelleriana* occurred only in conservation areas, species-level comparisons were restricted to *Fagus orientalis*, *Carpinus betulus*, and *Quercus petraea*, which were present in both area types. To account for potential confounding effects of tree size, additional models included DBH as a continuous predictor together with habitat tree classification, area type, and tree species. Interactions between DBH and habitat tree category were included in models testing EcoVal responses. Relationships between DBH and TreM abundance were further visualized using simple linear regression.

Multivariate differences in TreM composition between conservation and recreation areas were assessed using Principal Component Analysis (PCA) based on centered and scaled variables. TreM types with zero variance were excluded prior to analysis, and interpretation focused on the first two principal components (PC1 and PC2).

Vandalism categories (VA1, VA2, and VA1+VA2) and selected TreM types associated with cavity-related processes, forestry interventions, and anthropogenic impacts were evaluated descriptively by comparing occurrence frequencies between area types. These analyses were considered exploratory because the origin and timing of many TreMs could not be attributed with certainty to specific historical events.

Graphical outputs combined raw observations with mean ± SD values to visualize both variability and central tendency. EcoVal was displayed on a logarithmic (log10) scale where appropriate. Statistical significance was assessed at $\alpha = 0.05$. Analyses were conducted using the ggplot2 (Wickham, 2016), emmeans (Lenth, 2024), and vegan (Oksanen *et al.* 2019) packages.

3 Results

3.1 Effects of Management Context on Tree Microhabitat Abundance, Ecological Value and Composition

While the total number of TreMs (conservation area = 983; recreation area = 1,037) and their cumulative EcoVal scores (conservation area = 10,177; recreation area = 10,611) were higher in recreation areas (Supplementary Table 1), mean-based comparisons revealed a different pattern. The average number of TreMs per tree (7.7 ± 6.4 in conservation areas vs. 7.2 ± 4.7 in recreation areas) and mean EcoVal (79.5 ± 90.2 vs. 73.7 ± 85.8, respectively) were both higher in conservation areas (Figure 4; Supplementary Table 2). This indicates that, on a per-tree basis, trees in conservation areas support richer and more valuable microhabitat structures.

No significant difference was detected in TreM abundance between area types ($p = 0.478$), whereas EcoVal values were significantly higher in conservation areas ($p < 0.001$) (Figure 4; Supplementary Figure 1). The three most frequently recorded TreM types were identical in both area types: GR1 (root buttress cavities), IN1 (bark loss/exposed sapwood), and EP3 (epiphytic crypto- and phanerogams) (Figure 5; Supplementary Table 1).

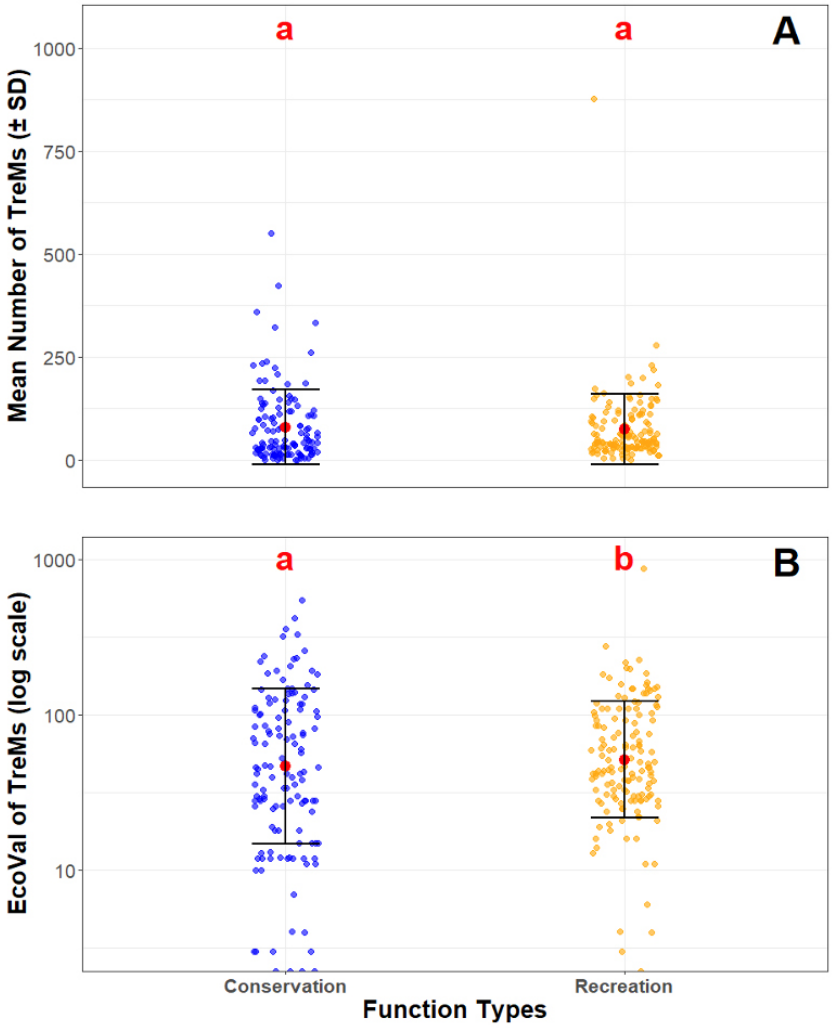


Figure 4: Hybrid visualization of tree-related microhabitats (TreMs) in conservation and recreation areas. Points represent individual tree-level observations, while red dots indicate mean values and error bars show ± standard deviation (SD). (A) Number of TreMs per tree and (B) EcoVal of TreMs per tree. EcoVal values are displayed on a logarithmic (log10) scale to better represent data variability. Different lowercase letters indicate statistically significant differences among groups ($p < 0.05$).

Abbildung 4: Hybriddarstellung der Baum-Mikrohabitate (TreMs) in Schutz- und Erholungsgebieten. Punkte stellen Einzelbeobachtungen auf Baumniveau dar, während rote Punkte die Mittelwerte und Fehlerbalken ± Standardabweichung (SD) anzeigen. (A) Anzahl der TreMs pro Baum und (B) EcoVal der TreMs pro Baum. Die EcoVal-Werte sind logarithmisch (log10) dargestellt, um die Variabilität besser abzubilden. Unterschiedliche Kleinbuchstaben kennzeichnen statistisch signifikante Unterschiede zwischen Gruppen ($p < 0,05$).



Figure 5: Examples of the most frequently recorded TreM types: GR1 (root buttress cavities), IN1 (bark loss/ exposed sapwood) and EP3 (epiphytic crypto- and phanerogams).

Abbildung 5: Beispiele der am häufigsten erfassten TreM-Typen: GR1 (Wurzelanlaufhöhlen), IN1 (Rindenverlust/freiliegendes Splintholz) und EP3 (epiphytische Kryptogamen und Phanerogamen).

Principal Component Analysis (PCA) revealed significant differences in microhabitat composition between conservation and recreation areas for both TreM abundance and EcoVal. The first two principal components explained 56.3% of the variation in TreM abundance data and 53.9% of the variation in EcoVal data (Figure 6). PC1 accounted for the largest share of variation in both analyses (36.6% and 36.8%, respectively) and was primarily associated with CV4 (dendrotelms and water-filled holes) and GR2 (witches' brooms), which showed the strongest loadings on this axis (Supplementary Table 3). Pairwise comparisons based on PCA scores confirmed significant differences between conservation and recreation areas for both TreM abundance ($R^2 = 0.592$, $p = 0.021$) and EcoVal ($R^2 = 0.527$, $p = 0.031$).

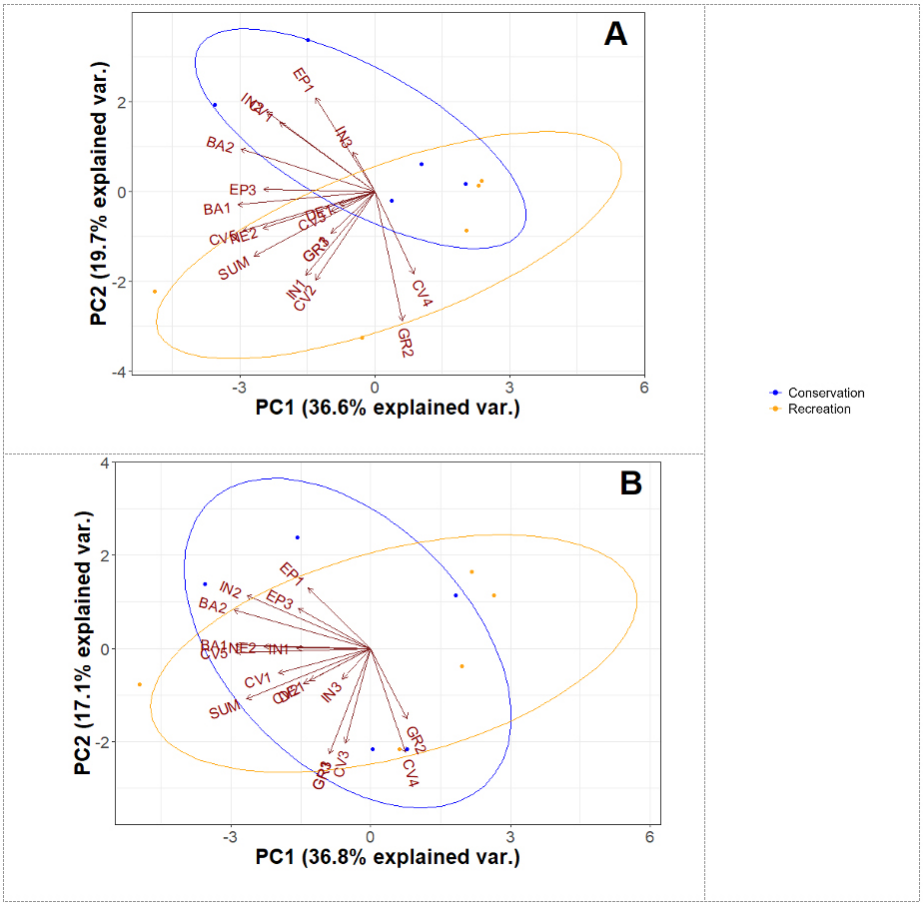


Figure 6: Principal component analysis (PCA) of (A) TreM number and (B) EcoVal in conservation and recreation areas. TreM codes (e.g., CV, IN, BA, GR, EP, NE, OT) follow the classification described in Supplementary Table 1.

Abbildung 6: Hauptkomponentenanalyse (PCA) von (A) der Anzahl der TreMs und (B) des EcoVal in Schutz- und Erholungsgebieten. TreM-Codes (z. B. CV, IN, BA, GR, EP, NE, OT) folgen der Klassifikation in Ergänzungstabelle 1.

3.2 Species-Specific Patterns of Tree Microhabitats

A total of eight tree species were recorded across the study area, with marked differences in species composition between conservation and recreation areas (Table 2; Supplementary Table 4). In general, trees in conservation areas tended to have larger diameters and higher TreM abundance and EcoVal values on a per-tree basis, despite often occurring at lower densities.

Table 2: Structural characteristics (mean DBH and height), number of individuals, and total values of tree-related microhabitats (TreMs) and their ecological value (EcoVal) for each tree species in conservation (Con.) and recreation (Rec.) areas.

Tabelle 2: Strukturelle Merkmale (mittlerer BHD und Höhe), Anzahl der Individuen sowie Gesamtwerte der Baum-Mikrohabitate (TreMs) und ihres ökologischen Wertes (EcoVal) für jede Baumart in Schutz- (Con.) und Erholungsgebieten (Rec.).

Species	**Number of individuals**		**Mean DBH (cm)**		**Mean Height (m)**		**Total Number of TreMs**		**Total Number of EcoVal**	
	Con.	**Rec.**	**Con.**	**Rec.**	**Con.**	**Rec.**	**Con.**	**Rec.**	**Con.**	**Rec.**
Abies nordmanniana subsp. *bornmuelleriana*	26	-	23.8	-	10.7	-	142	-	1583	-
Acacia sp.	-	1	-	30.0	-	22.1	-	3	-	43
Acer sp.	-	5	-	19.7	-	12.3	-	13	-	101
Carpinus betulus	6	31	51.0	38.1	23.5	16.7	85	301	1251	3913
Fagus orientalis	83	105	38.8	31.3	19.3	17.3	694	716	6709	6520
Pinus nigra	3	-	46.8	-	18.8	-	11	-	98	-
Quercus petraea	9	2	21.6	29.5	10.3	21.6	44	4	510	34
Ulmus sp.	1	-	72.6	-	31.0	-	7	-	26	-
TOTAL	**128**	**144**	-	-	-	-	**983**	**1037**	**10177**	**10611**

To ensure comparability between area types, species-level analyses were restricted to *Fagus orientalis*, *Carpinus betulus*, and *Quercus petraea*, which occurred in both conservation and recreation areas (Figure 7). For *F. orientalis* and *C. betulus*, total TreM numbers were generally higher in recreation areas because of greater tree abundance. However, mean TreM abundance and EcoVal per tree were significantly higher in conservation areas ($p < 0.01$), indicating that individual trees supported richer and more valuable microhabitat assemblages. This pattern was particularly pronounced for *C. betulus*.

A similar trend was observed for *Q. petraea*, for which both TreM abundance and EcoVal were higher in conservation areas, although differences were not statistically significant (TreM abundance: $p = 0.087$; Figure 7; Supplementary Table 4). Given the low number of *Q. petraea* individuals in recreation areas (n=2), these results should be interpreted with caution.

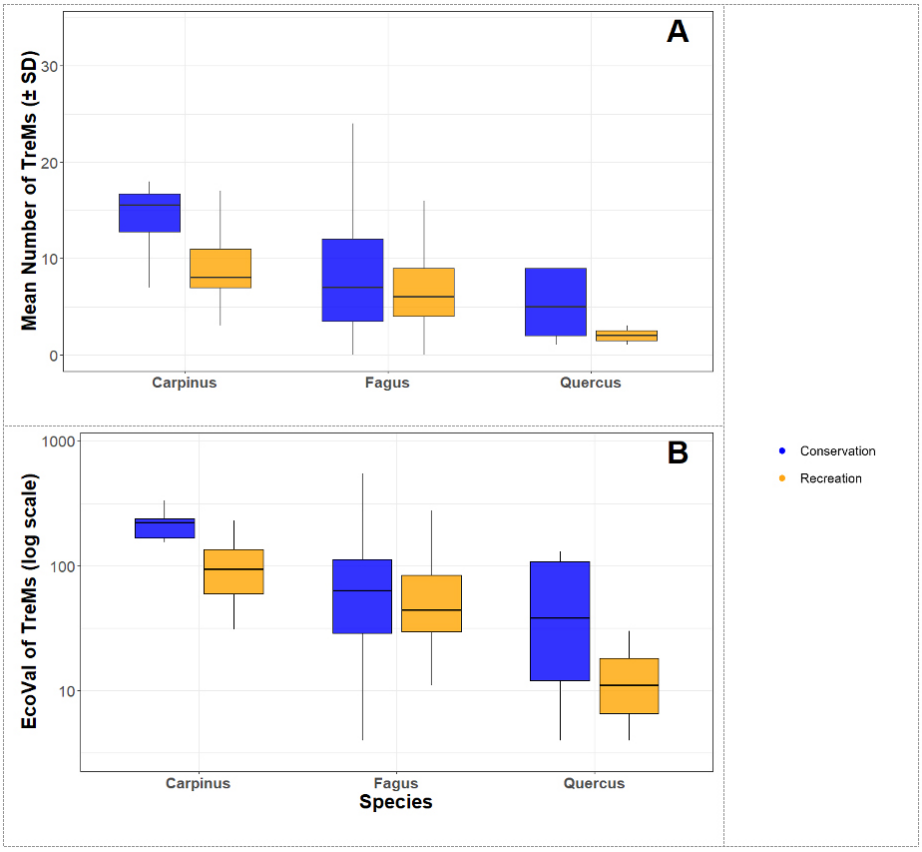


Figure 7: Hybrid visualization of tree-related microhabitats (TreMs) for selected tree species in conservation and recreation areas. (A) Number of TreMs per tree and (B) EcoVal of TreMs per tree (displayed on a logarithmic, log10 scale). Different lowercase letters indicate statistically significant differences among groups ($p < 0.05$). Species codes: Carpinus = Carpinus betulus, Fagus = Fagus orientalis, Quercus = Quercus petraea.

Abbildung 7: Hybriddarstellung der Baum-Mikrohabitate (TreMs) für ausgewählte Baumarten in Schutz- und Erholungsgebieten. Punkte stellen Einzelbeobachtungen auf Baumniveau dar, während rote Punkte die Mittelwerte und Fehlerbalken ± Standardabweichung (SD) anzeigen. (A) Anzahl der TreMs pro Baum und (B) EcoVal der TreMs pro Baum (logarithmisch, log10 skaliert). Unterschiedliche Kleinbuchstaben kennzeichnen statistisch signifikante Unterschiede zwischen Gruppen ($p < 0{,}05$). Artkürzel: Carpinus = *Carpinus betulus*, Fagus = *Fagus orientalis*, Quercus = *Quercus petraea*.

The distribution of TreM types also varied among species and area types (Supplementary Table 5; Figure 8). *Fagus orientalis* and *Carpinus betulus* supported the highest diversity and abundance of microhabitats, whereas Quercus petraea exhibited lower values. Conservation areas were characterized by higher frequencies of epiphy-

tic microhabitats (EP1–EP3) and cavity-related structures (CV2–CV5), while recreation areas showed a greater occurrence of injury-related microhabitats (IN1–IN3). These patterns suggest that both tree species and management context influence the abundance, ecological value, and composition of tree-related microhabitats.

To further assess whether these area-type differences could be explained by tree size alone, we conducted analyses including DBH as a continuous predictor alongside area type and habitat tree classification (see section 3.4).

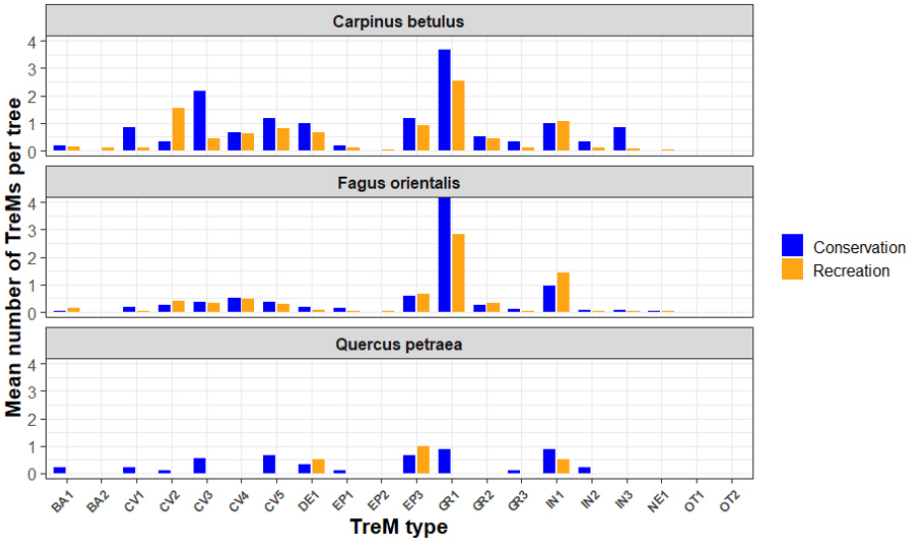


Figure 8: Distribution of tree-related microhabitat (TreM) types (Level 2) across selected tree species in conservation and recreation areas. Bars represent the mean number of TreMs per tree for each TreM type, with blue and orange bars indicating conservation and recreation areas, respectively. Species codes: CBE = Carpinus betulus, FOR = Fagus orientalis, QPE = Quercus petraea.

Abbildung 8: Verteilung der Baum-Mikrohabitat-Typen (TreM, Ebene 2) für ausgewählte Baumarten in Schutz- und Erholungsgebieten. Balken stellen die mittlere Anzahl der TreMs pro Baum für jeden TreM-Typ dar; blaue und orangefarbene Balken kennzeichnen Schutz- bzw. Erholungsgebiete. Die Artkürzel: CBE = *Carpinus betulus*, FOR = *Fagus orientalis*, QPE = *Quercus petraea*.

3.3 Effects of Tree Vitality on Tree Microhabitat Abundance and Ecological Value

Out of the 272 sampled trees, 259 were alive and 13 were standing dead wood (snags), with dead wood being considerably less frequent in recreation areas (2 individuals) than in conservation areas (11 individuals), likely reflecting both safety-related snag removal by park management and illegal harvesting for campfires in recreational zones. Mean-based comparisons showed that living trees exhibited similar TreM abundance and EcoVal values in conservation and recreation areas, with no significant differences between area types (Figure 9; Supplementary Table 6).

In contrast, standing dead wood supported substantially higher TreM abundance and EcoVal on a per-tree basis, particularly in conservation areas. Despite representing only a small proportion of the sampled trees, snags exhibited significantly higher TreM abundance and ecological value than living trees. These results highlight the disproportionate ecological importance of standing dead wood for the development and maintenance of tree-related microhabitats.

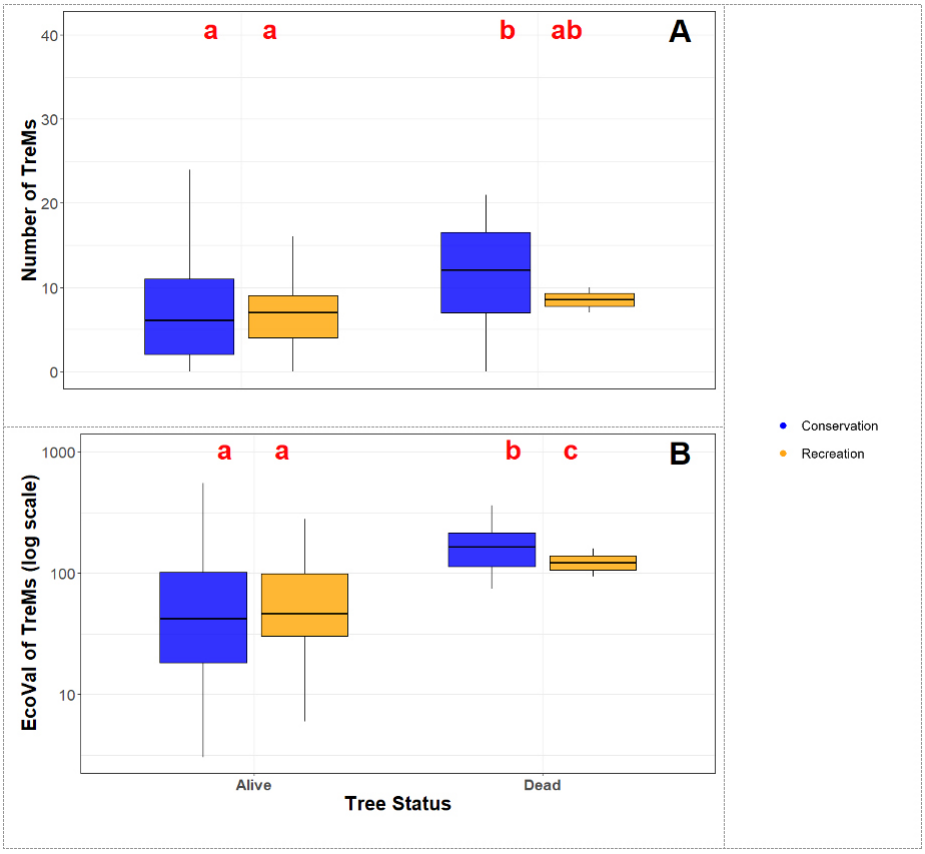


Figure 9: Boxplot visualization of tree-related microhabitats (TreMs) for alive trees and standing dead wood (snags) in conservation and recreation areas. (A) Number of TreMs and (B) ecological value of TreMs (EcoVal). Boxes represent the interquartile range (IQR), horizontal lines indicate median values, and whiskers represent data dispersion. EcoVal values are displayed on a logarithmic (log10) scale to better represent variability. Different lowercase letters indicate statistically significant differences among groups ($p < 0.05$).

Abbildung 9: Boxplot-Darstellung der Baum-Mikrohabitate (TreMs) für lebende Bäume und stehendes Totholz (Snags) in Schutz- und Erholungsgebieten. (A) Anzahl der TreMs und (B) ökologischer Wert der TreMs (EcoVal). Die Boxen stellen den Interquartilsabstand (IQR) dar, die horizontalen Linien zeigen die Medianwerte und die Whisker die Datenstreuung. Die EcoVal-Werte sind logarithmisch (log10) dargestellt, um die Variabilität besser abzubilden. Unterschiedliche Kleinbuchstaben kennzeichnen statistisch signifikante Unterschiede zwischen Gruppen ($p < 0,05$).

3.4 Habitat Trees, Tree Diameter and Ecological Value

Of the 272 sampled trees, 79 were classified as habitat trees (DBH ≥ 40 cm), including 38 individuals in conservation areas and 41 in recreation areas (Figure 10; Supplementary Table 9).

TreM abundance did not differ significantly between habitat trees and trees with DBH < 40 cm. In both area types, smaller trees exhibited slightly higher mean TreM numbers, although these differences were not consistently significant (Supplementary Table 9).

In contrast, habitat trees consistently exhibited higher EcoVal values than smaller trees despite having comparable or lower TreM abundance. This difference was particularly pronounced and statistically significant in conservation areas ($p < 0.001$; Supplementary Table 11), indicating that habitat trees support microhabitats of greater ecological importance even when overall TreM abundance is similar (Figure 10).

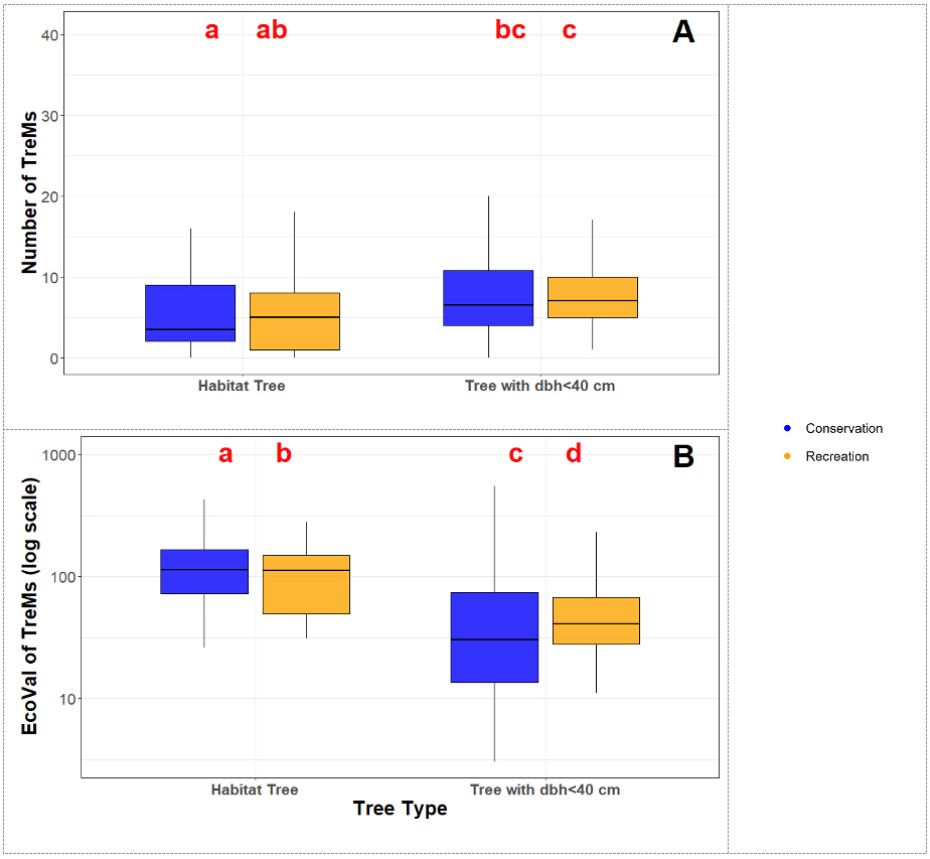


Figure 10: Hybrid visualization of tree-related microhabitats (TreMs) for habitat trees (DBH ≥ 40 cm) and trees with DBH < 40 cm in conservation and recreation areas. EcoVal values are displayed on a logarithmic (log10) scale to better represent variability. Different lowercase letters indicate statistically significant differences among groups (p < 0.05).

Abbildung 10: Hybriddarstellung der Baum-Mikrohabitate (TreMs) für Habitatbäume (BHD ≥ 40 cm) und Bäume mit BHD < 40 cm in Schutz- und Erholungsgebieten. Punkte stellen Einzelbeobachtungen auf Baumniveau dar, während rote Punkte die Mittelwerte und Fehlerbalken ± Standardabweichung (SD) anzeigen. Die EcoVal-Werte sind logarithmisch (log10) dargestellt, um die Variabilität besser abzubilden. Unterschiedliche Kleinbuchstaben kennzeichnen statistisch signifikante Unterschiede zwischen Gruppen (p < 0,05).

Regression analyses further showed that DBH was not significantly related to TreM abundance ($p = 0.103$), and neither habitat tree classification, area type, nor species identity significantly affected TreM abundance ($p > 0.29$). Pairwise comparisons likewise revealed no significant differences in TreM abundance between habitat trees and smaller trees within either area type ($p = 0.12$) (Figure 11A).

In contrast, EcoVal increased significantly with tree diameter ($p < 0.001$), following a significant positive relationship (Figure 11B; see caption for model parameters) . Although habitat tree classification itself was not a significant predictor ($p > 0.60$), area type and species identity remained significant after accounting for DBH ($p < 0.01$). A significant interaction between DBH and habitat tree classification ($p < 0.001$) further indicated that the relationship between tree size and ecological value differed between tree categories (Figure 11B).

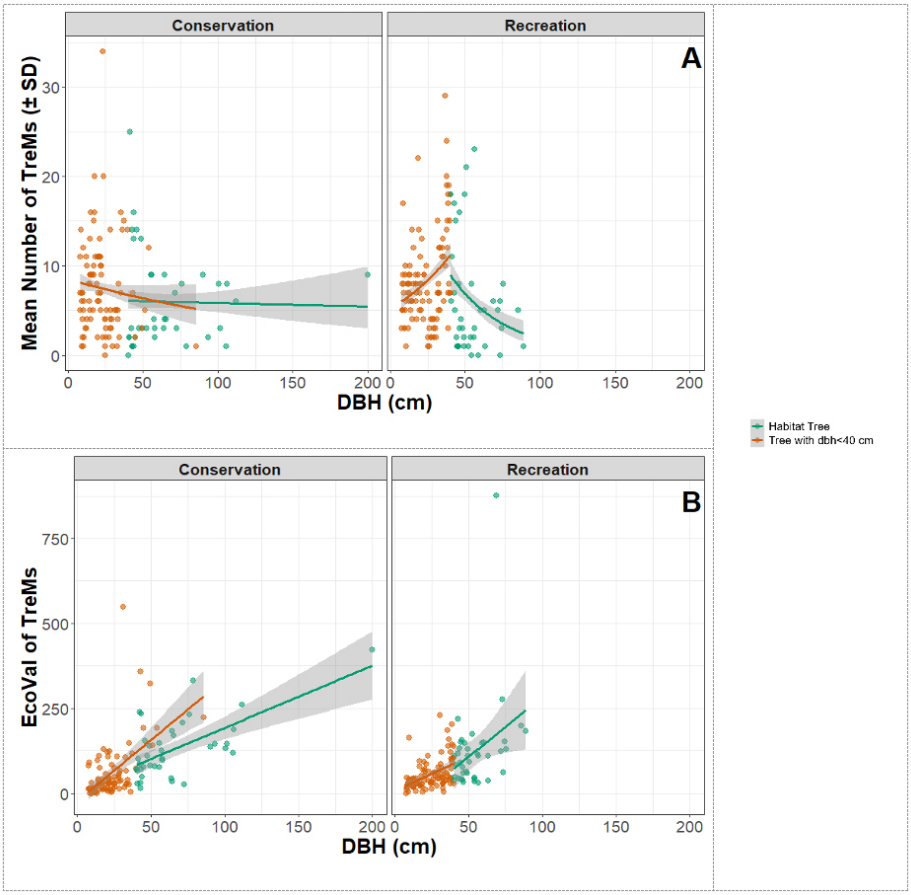


Figure 11: Relationship between (A) DBH and mean number of TreMs and (B) DBH and EcoVal across conservation and recreation areas. Points represent individual trees and lines show fitted model relationships. For panel (A), the relationship was described using a simple linear regression model ($NT = 8.23 - 0.024 \times DBH$, $R^2 = 0.01$), indicating a weak and non-significant relationship ($p = 0.103$). For panel (B), the relationship between DBH and EcoVal (log-transformed) was described using a simple linear regression model ($\log(EcoVal + 1) = 2.94 + 0.027 \times DBH$, $R^2 = 0.33$, $p < 0.001$), indicating a strong positive relationship. Colors denote DBH classification (habitat trees vs. trees with DBH < 40 cm). EcoVal is displayed on a logarithmic (log10) scale.

Abbildung 11: Beziehung zwischen (A) dem Brusthöhendurchmesser (DBH) und der mittleren Anzahl von Baum-Mikrohabitaten (TreMs) sowie (B) dem DBH und dem EcoVal in Schutz- und Erholungsgebieten. Die Punkte stellen einzelne Bäume dar, während die Linien die angepassten Modellbeziehungen zeigen. Für Panel (A) wurde die Beziehung mittels eines einfachen linearen Regressionsmodells beschrieben ($NT = 8.23 - 0.024 \times DBH$, $R^2 = 0.01$), was auf eine schwache und nicht signifikante Beziehung hinweist ($p = 0.103$). Für Panel (B) wurde die Beziehung zwischen DBH und EcoVal (log-transformiert) ebenfalls mit einem einfachen linearen Regressionsmodell beschrieben ($\log(EcoVal + 1) = 2.94 + 0.027 \times DBH$, $R^2 = 0.33$, $p < 0.001$), was auf eine starke positive Beziehung hinweist. Die Farben kennzeichnen die DBH-Klassifikation (Habitatbäume vs. Bäume mit DBH < 40 cm). Der EcoVal wird auf einer logarithmischen (log10) Skala dargestellt.

3.5 Vandalism Patterns in Conservation and Recreation Areas

In the protected areas, we recorded VA1 type on 1 tree and VA2 type on 4 trees. The recreational areas showed significantly higher incidence: 52 trees with VA1 damage and 58 with VA2 damage. Additionally, 43 trees (1 in the protected areas and 42 in the recreational areas) exhibited both VA1 and VA2 types (Figure 12). The concentration of vandalism in recreation areas, particularly the high prevalence of VA2 damage, suggests that large-scale bark injuries may progressively develop into more complex cavity structures, potentially altering long-term TreMs composition in these zones.

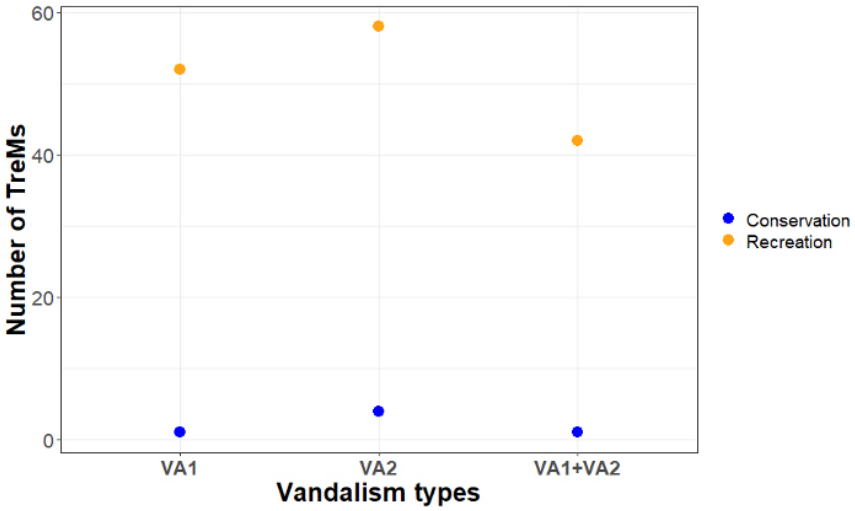


Figure 12: Number of vandalism-related TreMs (VA1, VA2, and VA1+VA2) recorded in conservation and recreation areas. Since each vandalism instance is recorded as one TreM per tree, values also reflect the number of affected trees per category.

Abbildung 12: Anzahl vandalismusbedingter TreMs (VA1, VA2 und VA1+VA2) in Schutz- und Erholungsgebieten. Da jede Vandalismusinstanz als ein TreM pro Baum erfasst wird, entsprechen die Werte zugleich der Anzahl betroffener Bäume je Kategorie.

3.6 Potential Effects of Forestry Implementations and Anthropogenic Pressure on Tree Microhabitats

Descriptive comparisons of selected TreM types associated with cavity formation, direct injury, and indirect anthropogenic effects revealed the following patterns. No significant differences were found in cavity-related TreMs between conservation and recreation areas (Figure 13-A; X-squared = 1.1965, df = 2, p-value = 0.5498; Supplementary Table 12). This result may reflect three possible explanations:

(1) pruning does not substantially alter long-term cavity formation rates,
(2) natural branch fall in conservation areas creates equivalent structures at similar frequencies, or
(3) current cavity distributions reflect historical conditions rather than recent management practices.

Given these causal ambiguities, we interpret this result cautiously as indicating no detectable difference in cavity-type TreM availability rather than as evidence regarding pruning impacts specifically.

Although not statistically significant (Figure 13-B; X-squared = 2.4747, df = 4, p-value = 0.6492), notable patterns emerged: CV23, IN11, and IN12 were approximately twice as common in recreation areas, while CV24 and CV25 occured at roughly four times the frequency (Supplementary Table 13). These patterns are suggestive of higher injury rates in recreation areas, though temporal ambiguity — even „fresh“ injuries may be 5-10 years old — limits causal interpretation. These structures could reflect visitor-caused damage, management interventions, or differential natural processes between area types.

Indirect anthropogenic effects showed the strongest and only statistically significant differences (Figure 13-C; X-squared = 26.893, df = 2, p-value = 1.446e-06). CV21 was significantly more prevalent in recreation areas, consistent with soil compaction from visitor pressure. GR1 was more common in conservation areas (Supplementary Table 14), a pattern that may reflect earlier-stage root exposure that progressively develops into ground-contact cavities (CV21, CV22) under sustained anthropogenic pressure.

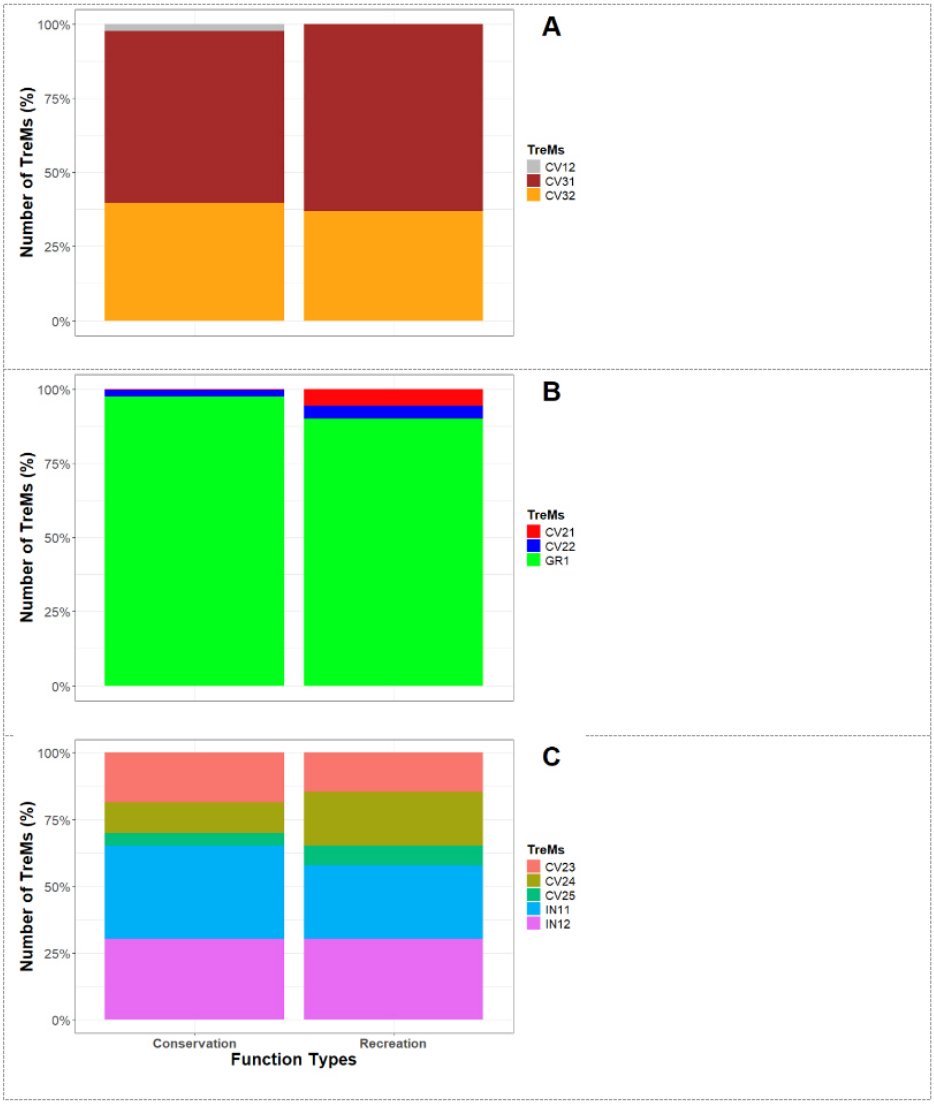


Figure 13: Comparison of (A) woodpecker cavities and branch holes, (B) direct anthropogenic effects and (C) indirect anthropogenic effects in conservation and recreation areas.

Abbildung 13: Vergleich von (A) Spechthöhlen und Astlöchern, (B) direkter anthropogener Einflüsse and (C) indirekter anthropogener Einflüsse zwischen Schutz- und Erholungsgebieten.

4 Discussion

4.1 Not All Microhabitats Are Equal: Higher Ecological Value in Conservation Areas

Our findings demonstrate that conservation and recreation areas in Yedigöller National Park differ not in the overall quantity of TreMs but in their ecological quality, with conservation areas supporting significantly higher EcoVal despite comparable or slightly lower total TreM counts. This distinction is ecologically meaningful: recreation areas accumulated higher frequencies of common, low-value microhabitat types such as bark loss and epiphytes, while conservation areas harbored structurally complex, slow-forming structures that contribute disproportionately to habitat value. This pattern is consistent with the broader literature showing that management disturbance reduces not only TreM abundance but preferentially suppresses rare, high-value microhabitat types that require long development times and structural complexity to form (Paillet *et al.* 2018; Asbeck *et al.* 2021). The mechanism likely involves multiple interacting pathways: safety-related pruning and tree removal reduce the structural substrate for complex cavity development, while soil compaction and trampling impair the decay processes that underlie many high-value TreM types. Conversely, the reduced disturbance in conservation areas allows trees to age, accumulate structural damage, and develop the morphological complexity that characterizes high-value microhabitat assemblages.

These findings are consistent with studies from Central European and Mediterranean forests demonstrating that reduced management intensity promotes the accumulation of structurally complex, high-value TreMs over time (Paillet *et al.* 2018; Regnery *et al.* 2013)). Importantly, our results extend this pattern to Black Sea region forests, where such comparisons have not previously been documented, suggesting that the relationship between disturbance regime and microhabitat quality may be broadly applicable across temperate forest types. The significant difference in EcoVal despite the absence of significant differences in raw TreM counts further underscores that abundance-based metrics alone are insufficient for assessing forest habitat quality—a finding with direct implications for biodiversity monitoring frameworks that currently rely on TreM counts rather than weighted ecological value scores.

An important methodological distinction emerges when comparing stand-level versus tree-level metrics. Although recreation areas contained marginally higher total TreM counts and slightly greater TreM density per hectare due to higher tree density, conservation areas exhibited higher per tree TreM abundance and substantially higher EcoVal per tree. This divergence illustrates why raw stand-level TreM counts can be misleading as biodiversity indicators: a forest with higher total microhabitat numbers may nonetheless support lower habitat quality if those microhabitats are predominantly common, low-value types associated with recent disturbance. For conservation purposes, tree-level metrics weighted by ecological value are more informative

because they capture habitat quality rather than quantity alone—a forest with fewer but structurally complex, high-value habitat trees may sustain more specialist species than one with many small-diameter trees bearing primarily recent wounds and common microhabitat types (Courbaud *et al.* 2022; Bianco *et al.* 2024). Our results suggest that areas with lower disturbance intensity are associated with the development of mature, ecologically valuable microhabitat assemblages (*e.g.*, trunk cavities, dendrotelms, and epiphytic lichens and mosses), rather than simply higher microhabitat numbers—a pattern with direct implications for how TreM-based assessments are designed and interpreted in forest monitoring programmes.

4.2 Species Abundance Does Not Reflect Microhabitat Quality

Species identity influenced TreM abundance and diversity, with Fagus orientalis and Carpinus betulus supporting richer microhabitat assemblages than Quercus petraea across both area types. This is broadly consistent with species-specific patterns documented in Hyrcanian Oriental beech forests, where hornbeam showed higher microhabitat occurrence probabilities than beech (Khanalizadeh *et al.* 2020), underlining that broadleaved mixtures generally support higher microhabitat density than monospecific stands (Asbeck *et al.* 2021; Spînu *et al.* 2024).

Notably, despite being more abundant in recreation areas, both Fagus orientalis and Carpinus betulus exhibited significantly higher per-tree TreM abundance and EcoVal in conservation areas. This indicates that the same tree species can support markedly different microhabitat assemblages depending on the disturbance regime to which they are subjected, and that anthropogenic pressure—rather than differences in tree size or stand structural conditions—is the primary driver of microhabitat quality variation in Yedigöller. Species composition alone is therefore an insufficient proxy for microhabitat quality, and direct assessment of TreM ecological value is necessary to capture management-related differences in habitat provision (Courbaud *et al.* 2022). Broadleaved mixtures may provide the structural substrate for diverse microhabitat assemblages, but realizing that potential appears to require conditions of low disturbance intensity.

4.3 Dead Wood and Habitat Trees as Ecological Keystones Under Anthropogenic Pressure

Standing dead wood emerged as a disproportionately important microhabitat substrate despite its low overall occurrence in the study area. Snags supported substantially higher per-tree TreM abundance and EcoVal than living trees (Figure 9), consistent with the well-established role of dead wood as a driver of microhabitat diversity

in temperate forests (Humphrey *et al.* 2005; Rondeux and Sanchez, 2010; Vuidot *et al.* 2011). This pattern reflects the progressive structural complexity that develops through decay: as wood deteriorates, it generates cavity types, fungal fruiting bodies, and saproxylic microhabitats that are largely absent from living trees (Siitonen 2012). The pronounced scarcity of snags in recreation areas (2 vs. 11 individuals in conservation areas) is likely attributable to two compounding anthropogenic factors: safety-related removal of potentially hazardous snags by park management near trails and facilities, and illegal harvesting of dead wood by visitors for campfires. The predominance of snags in conservation areas may partly reflect the presence of *Abies nordmanniana* subsp. *bornmuelleriana*, which occurred exclusively in those sites. Although aged living broadleaved trees generally host more TreMs in temperate forest ecosystems, dead conifer snags can contribute substantially to stand-level TreM richness through distinctive decay-related microhabitat types that differ in composition from those found on broadleaved species (Spînu 2023), potentially explaining the higher microhabitat values observed in conservation areas where *Abies nordmanniana* subsp. *bornmuelleriana* snags were present.

Beyond their ecological significance, dead wood structures at different decomposition stages may serve as tangible educational features that enhance visitor appreciation of natural forest processes (Rathmann *et al.* 2020; Sacher *et al.* 2022). Evidence suggests that when visitors are effectively informed about the ecological functions of dead wood, acceptance of its retention increases, potentially reducing illegal harvesting and supporting broader conservation goals (Gundersen and Frivold 2011). Integrating interpretive signage explaining the role of snags and decaying wood into visitor management strategies could therefore serve the dual purpose of habitat protection and environmental education—particularly relevant in Yedigöller where illegal firewood collection represents a direct and documented threat to this critical microhabitat substrate.

Habitat trees similarly supported microhabitats of substantially higher ecological value than smaller trees, with differences particularly pronounced in conservation areas (Figure 10). This finding is consistent with the well-documented positive relationship between tree diameter and microhabitat ecological value across European temperate forests, where large, old trees function as ecological keystones by accumulating rare, slow-forming structures over decades (Großmann and Pyttel 2019; Kozák *et al.* 2023; Spînu *et al.* 2024). The strong positive DBH-EcoVal relationship observed in our regression analysis (Figure 11B) confirms this pattern in Black Sea region forests, extending it to a system where such relationships had not previously been quantified. Critically, area type and species identity remained significant predictors of EcoVal even after accounting for DBH, indicating that the conservation-recreation contrast reflects genuine differences in microhabitat quality independent of tree size structure. This suggests that management regime shapes microhabitat quality through mechanisms beyond simply determining which tree sizes are present, likely including the preservation of structural complexity, decay processes, and long formation-time

microhabitat types that are disrupted by safety interventions and visitor pressure (Martynova *et al.* 2021). The retention of large trees and promotion of natural aging are therefore essential management priorities, particularly given that safety-related interventions in recreation areas most commonly target the largest, oldest individuals—precisely those with the highest microhabitat value (Ministerium für Landwirtschaft, Umweltschutz und Raumordnung 2004; Mölder *et al.* 2020; Müller *et al.* 2020).

These findings collectively underscore that dead wood retention and habitat tree safeguarding are ecologically essential priorities in protected forests where anthropogenic pressure operates through both direct removal and indirect disturbance pathways. The management implications of these findings are developed further in the recommendations section below.

4.4 Management Interventions, Anthropogenic Pressure, and Microhabitat Development

Many TreM types develop over decades through complex processes, making it impossible to retrospectively attribute current microhabitat presence to specific historical management actions versus natural processes; the patterns reported here should therefore be interpreted as reflecting cumulative long-term effects of divergent management regimes rather than direct causal links.

Our exploratory analyses comparing specific TreM types between area types revealed complex patterns that require careful interpretation. While pruning is regularly conducted in recreation areas for visitor safety (park management, pers. comm.), no significant difference in cavity-type microhabitats was detected between area types. This reflects a fundamental methodological challenge in retrospective TreM studies: cavities develop slowly over 10-30+ years through progressive decay following branch loss, making it impossible to determine whether a current cavity originated from historical pruning, natural branch fall, storm damage, or other causes (Remm and Lõhmus, 2011). Our results therefore neither confirm nor deny pruning impacts on cavity formation; rather, they indicate that any such effects are not detectable above background variation from natural processes. This could mean:

(1) pruning and natural branch fall create functionally equivalent structures at similar rates,
(2) pruning intensity is insufficient to create detectable differences, or
(3) current cavity distributions reflect historical conditions predating recent management regimes.

More direct evidence of anthropogenic impacts comes from fresh injury patterns and soil compaction effects. Recreation areas showed higher frequencies of recent trunk injuries (IN11, IN12)—though not statistically significant—and significantly higher

frequencies of ground-contact cavities potentially linked to soil compaction (CV21). Combined with the substantially higher vandalism rates documented in section 3.5, these patterns suggest ongoing anthropogenic alteration of microhabitat composition, even when long-term cavity development shows no clear signal. Our study can document current TreM composition differences but cannot definitively attribute specific slow-forming TreMs to particular historical causes, as a limitation inherent to cross-sectional assessments of microhabitat systems with multi-decadal formation timescales.

Importantly, these shifts in microhabitat frequency are not necessarily associated with higher ecological value. Frequently recorded types in recreation areas, such as IN1 and GR1, are characterized by relatively low EcoVal scores, whereas less frequent but structurally complex microhabitats such as CV2 contribute disproportionately higher ecological value. This indicates that anthropogenic pressures may increase the occurrence of certain microhabitats while simultaneously reducing overall habitat quality.

Taken together, these results demonstrate that forestry practices and anthropogenic pressures do not simply reduce microhabitat availability but instead modify the processes and pathways through which TreMs are formed. Differences between conservation and recreation areas should therefore be interpreted as shifts in microhabitat composition and development dynamics rather than irreversible degradation—a distinction with important implications for restoration potential. In Turkish national parks, where recreation is generally concentrated in a limited number of highly frequented sites—as in Yedigöller—adaptive management measures targeting the identified drivers of microhabitat quality loss may be particularly effective in helping recreation areas approximate the ecological functions observed in conservation zones.

4.5 Vandalism: A Visitor-Induced Disturbance

Our study documented vandalism as a novel anthropogenic TreM type concentrated almost exclusively in recreation areas, with 52 trees showing VA1 damage, 58 showing VA2 damage, and 42 exhibiting both types in recreation areas, compared to just 6 affected trees in conservation areas. The scale of this disturbance is ecologically significant: large-scale bark injuries of this kind may compromise the long-term microhabitat potential of affected trees by accelerating uncontrolled decay, facilitating pathogen entry, and interfering with the natural development of other TreM types. Previous research has highlighted how mechanical injuries caused by humans can disrupt tree health and reduce their habitat potential, and degrade the ecosystem services they provide (Cole and Marion 1988; Sánchez *et al.* 2021). Beyond its direct ecological effects, the prevalence of vandalism reflects insufficient visitor engagement with forest biodiversity values—a challenge that is not unique to Yedigöller but

is particularly acute in national parks where recreational concentration creates sustained pressure on ecologically sensitive zones. Addressing vandalism therefore requires both regulatory enforcement and proactive visitor education strategies, which we discuss further in the management recommendations below.

4.6 Conservation Implications and Management Recommendations

Our findings have direct implications for conservation planning in Yedigöller National Park and comparable protected areas where recreation and biodiversity conservation functions coexist. While recreational activities need not be incompatible with conservation goals, our results demonstrate that their concentration in ecologically sensitive zones (*e.g.*, areas around lakes) can substantially reduce microhabitat quality through multiple interacting pathways. Effective management therefore requires addressing both the structural drivers of microhabitat loss (dead wood removal, habitat tree loss, soil compaction) and the behavioral drivers (vandalism, illegal firewood collection) identified in this study.

Dead wood retention and habitat tree safeguarding should be treated as non-negotiable priorities in recreation area management. Where natural dead wood is scarce, supplementary measures such as selective girdling or on-site retention of material from necessary safety operations can help restore substrate availability (Çolak *et al.* 2011). Safety concerns regarding large or dead trees should be addressed through individual risk assessment rather than precautionary removal, as blanket removal disproportionately eliminates the highest-value microhabitat structures. Pruning practices should similarly be modified to retain cut material on site as habitat substrate where visitor safety permits.

Visitor education and engagement represent equally critical components of an effective management strategy. Evidence suggests that informed visitors show greater acceptance of dead wood retention and natural forest processes, reducing pressure on these critical substrates (Gundersen and Frivold 2011; Rathmann *et al.* 2020). More broadly, fostering meaningful engagement with forest biodiversity (*e.g.*, interpretive infrastructure, guided experiences, and citizen science opportunities) has been shown to increase conservation awareness and participation among park visitors (Cosquer *et al.* 2012; Loyau and Schmeller 2017; McKinley *et al.* 2017). In Yedigöller, where vandalism and illegal firewood collection represent documented and ongoing threats, such engagement strategies could complement regulatory enforcement in addressing visitor-induced disturbance.

Periodic TreM monitoring should be integrated into park management planning to track microhabitat recovery in response to management interventions and to provide an evidence base for adaptive management decisions. Given that TreMs develop over

decadal timescales, establishing baseline assessments and regular monitoring cycles is essential for detecting management-related change and informing long-term conservation strategies (Winter and Möller 2008). Our study provides such a baseline for Yedigöller, and the methodological framework that combines TreM abundance with EcoVal assessment offers a transferable approach for protected area monitoring across the broader Black Sea region and Eastern Mediterranean.

5 Conclusions

This study provides the first assessment of TreMs in a Turkish national park, demonstrating that conservation and recreation areas differ not in the overall quantity of microhabitats but in their ecological quality—a distinction that abundance-based metrics alone would fail to detect. Our findings confirm that anthropogenic pressure, operating through both direct disturbance and indirect management interventions, shapes microhabitat quality independently of tree species composition and size structure. Standing dead wood and habitat trees emerged as critical ecological keystones whose disproportionate contribution to microhabitat value is severely undermined by recreational pressure and safety-related management in Yedigöller. The novel documentation of vandalism as an anthropogenic TreM type further indicates the extent of visitor-induced impacts on forest microhabitat structure in heavily used protected areas.

Beyond their local significance, these findings contribute to the limited knowledge of TreM patterns in Black Sea region forests and demonstrate the applicability of EcoVal-weighted assessment as a sensitive tool for detecting management-related differences in habitat quality that raw TreM counts obscure. Future research should extend TreM assessments to species-level responses to examine whether the microhabitat quality differences documented here translate into detectable differences in the abundance and diversity of TreM-dependent species groups, including cavity-nesting birds, saproxylic invertebrates, and epiphytic cryptogams (Remacha *et al.* 2016; Asbeck *et al.* 2021). Long-term monitoring of TreM dynamics in both area types would further enable assessment of recovery trajectories under improved management and provide the temporal perspective necessary for understanding microhabitat formation and loss in these transitional forest ecosystems.

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Data availability statement

The data underlying this article will be shared on reasonable request to the corresponding author.

References

Arcese, P., and A. R. E. Sinclair. 1997. „The role of protected areas as ecological baselines." Journal of Wildlife Management 61: 587-602. https://doi.org/10.2307/3802167

Asbeck, T., J. Großmann, Y. Paillet, N. Winiger, and J. Bauhus. 2021. „The use of tree-related microhabitats as forest biodiversity indicators and to guide integrated forest management." Current Forestry Reports 7 (1): 59-68. https://doi.org/10.1007/s40725-020-00132-5

Asbeck, T., C. Messier, and J. Bauhus. 2020. „Retention of tree-related microhabitats is more dependent on selection of habitat trees than their spatial distribution." European Journal of Forest Research 139 (6): 1015-1028. https://doi.org/10.1007/s10342-020-01303-6

Beşkardeş, V. 2012. „Investigations on avifauna of Yedigöller and Yeşilöz Wildlife Reserves." Turkish Journal of Forestry 13: 28-34. https://doi.org/10.18182/tjf.84109

Bianco, G., Hemp, A., Schleuning, M., 2024. "Variation in the diversity and composition of tree-related microhabitats across climate and human impact gradients on a tropical mountain." Ecological Indicators 169, 112927. https://doi.org/10.1016/j.ecolind.2024.112927

Bütler, R., T. Lachat, L. Larrieu, and Y. Paillet. 2013. „Habitat trees: Key elements for forest biodiversity." Joensuu: European Forest Institute.

Bütler, R., T. Lachat, F. Krumm, D. Kraus, and L. Larrieu. 2020. Field guide to tree-related microhabitats: Descriptions and size limits for their inventory. Birmensdorf: Swiss Federal Institute for Forest, Snow and Landscape Research WSL.

Bütler, R., Lachat, T., Krumm, F., Kraus, D., Larrieu, L., 2024. Field guide to tree-related microhabitats. Descriptions and size limits for their inventory in temperate and Mediterranean forests. (2nd ed.). Birmensdorf: Swiss Federal Institute for Forest, Snow and Landscape Research WSL.

Cole, D.N., Marion, J.L., 1988. "Recreation impacts in some riparian forests of the Eastern United States." Environmental Management 12, 99–107. https://doi.org/10.1007/BF01867381

Cosquer, A., R. Raymond, and A.-C. Prevot-Julliard. 2012. "Observations of Everyday Biodiversity: A New Perspective for Conservation?" Ecology and Society 17 (4). https://www.jstor.org/stable/26269197.

Courbaud, B,, Larrieu, L., Kozak, D. *et al.* 2022. "Factors Influencing the Rate of Formation of Tree-Related Microhabitats and Implications for Biodiversity Conservation and Forest Management." Journal of Applied Ecology 59 (2): 492–503. https://doi.org/10.1111/1365-2664.14068.

Çolak, A. H., M. Tokcan, and S. Kırca. 2011. Ölü Ağaç – Yaşayan Ölüler. Batı Karadeniz Ormancılık Araştırma Müdürlüğü-Bolu, Çevre ve Orman Bakanlığı.

Dutta, T., Larrieu, L., and Schuck, A. 2025. "Who Is Using Tree-Related Microhabitats (TreMs)?" Biological Conservation 307 (July): 111180. https://doi.org/10.1016/j.biocon.2025.111180.

Fröhlich, A., Bidziński, K., Jankowska-Jarek, M., Swearer, S., Ciach, M., 2025. Noise, light pollution, and human presence predict forest habitat degradation: A key agent in biodiversity decline. Ecological Applications 35, e70131. https://doi.org/10.1002/eap.70131

Gaston, K. J., S. F. Jackson, L. Cantú-Salazar, and G. Cruz-Piñón. 2008. „The ecological performance of protected areas." Annual Review of Ecology, Evolution, and Systematics 39: 93-113. https://doi.org/10.1146/annurev.ecolsys.39.110707.173529

Grossmann, J., J. Schultze, J. Bauhus, and P. Pyttel. 2018. „Predictors of microhabitat frequency and diversity in mixed mountain forests in South-Western Germany." Forests 9 (3): 104. https://doi.org/10.3390/f9030104

Großmann, J., and P. Pyttel. 2019. "Mikrohabitate Und Baumdimension Als Grundlage Der Habitatbaum-Auswahl Im Bergmischwald." Natur Und Landschaft 12 (December). https://doi.org/10.17433/12.2019.50153759.531-541.

Gundersen, V. and L. H. Frivold. 2011. "Naturally Dead and Downed Wood in Norwegian Boreal Forests: Public Preferences and the Effect of Information." Scandinavian Journal of Forest Research 26 (2): 110–19. https://doi.org/10.1080/02827581.2010.536567.

Hebert, J., P. Lejeune, J. F. van Belle, and Y. Schenkel. 1996. „Indice du martelage sur l'exploitation mecanisee des premieres eclaircies resineuses." Silva Belgica 103: 9-14.

Hough, J. L. 1988. „Obstacles to effective management of conflicts between national parks and surrounding human communities in developing countries." Environmental Conservation 15: 129-136. https://doi.org/10.1017/S0376892900028939

Humphrey, J. W. 2005. „Benefits to biodiversity from developing old-growth conditions in British upland spruce plantations: A review and recommendations." Forestry 78: 33-53. https://doi.org/10.1093/forestry/cpi004

Humphrey, J., A.-L. Sippola, G. Lempériere, B. Dodelin, K.N.A. Alexander, and J. Butler. 2005. "Deadwood as an Indicator of Biodiversity in European Forests: From Theory to Operational Guidance." In Monitoring and Indicators of Forest Biodiversityin Europe – From Ideas to Operationality, edited by M. Marchetti, 193–206. Deadwood as an Indicator of Biodiversity in European Forests:From Theory to Operational Guidance 51. Finland: European Forest Institute. https://jukuri.luke.fi/handle/10024/512187.

Khanalizadeh, A., Eshaghi Rad, J., Zahedi Amiri, G., Zare, H. Werner Rammer, and Manfred J. Lexer. 2020. "Assessing Selected Microhabitat Types on Living Trees in Oriental Beech (Fagus Orientalis L.) Dominated Forests in Iran." Annals of Forest Science 77 (3): 1–13. https://doi.org/10.1007/s13595-020-00996-4

Kırca, S. 2015. „Determination of Nature Conservation and Restoration Priority Areas in Landscape Planning: Example of Yedigöller National Park (Bolu)." İstanbul Üniversitesi / Fen Bilimleri Enstitüsü / Peyzaj Mimarlığı Ana Bilim Dalı, Istanbul.

Kırca, S., and H. Altınçekiç. 2018. „Use of Ecological Value Analysis for Prioritizing Areas for Nature Conservation and Restoration." Journal of the Faculty of Forestry Istanbul University 68: 22–35.

Kozák, D., M. Svitok, V. Zemlerová, M. Mikoláš, T. Lachat, L. Larrieu, Y. Paillet, et al. 2023. "Importance of Conserving Large and Old Trees to Continuity of Tree-Related Microhabitats." Conservation Biology 37 (3): e14066. https://doi.org/10.1111/cobi.14066.

Kraus, D., R. Bütler, F. Krumm, T. Lachat, L. Larrieu, U. Mergner, Y. Paillet, T. Rydkvist, A. Schuck, and S. Winter. 2016. Catalogue of Tree Microhabitats – Reference Field List. Integrate+ Technical Paper. 16p.

Kraus, D., and F. Krumm. 2013. Integrative Approaches as an Opportunity for the Conservation of Forest Biodiversity. European Forest Institute. http://www.integrateplus.org.

Kraus, D., A. Schuck, F. Krumm, R. Bütler Sauvain, H. Cosyns, B. Courbaud, and G. Wilhelm. 2018. Seeing Is Building Better Understanding - The Integrate+ Marteloscopes. Integrate+ Technical Paper, European Forest Institute. https://informar.eu/marteloscope-sites.

Kraus, D., Schuck, A., Bebi, P., Blaschke, M., Bütler, R., Flade, M., Heintz, W., Krumm, F., Lachat, T., Larrieu, L., Lehnerova, L., Levin, M., Mergner, U., Pach, M., Paillet, Y., Pyttel, P., Rydkvist, T., Santopuoli, G., Sever, K., Sturm, K., Vandekerkhove, K., Winter, S., Witz, M., Winnock, M., Marcandella, M., Roth, I., Jakob, A., Dickele, R., Hofmann, G., Ruis-Eckhardt, D., Boschen, S., Schölmerich, U., Leder, B., Guericke, M., Merkel, H., Löffler, D., Schusser, S., Runkel, M., Steinmetz, A., Marx, K.H., Mongelluzzi, A., Wilshusen, F., Jean-Jacques Boutteaux, Loic Duchamp, Dericbourg, N., Rouyer, E., Csikos, V., Sweeny, K., Steichen, D., Leytem, M., Konczal, S., Stereńczak, K., Kazimirovic, M., Šebeň, V., Zapater, T.B., Van Der Maaten-Theunissen, M., Pommer, A., Nord-Larsen, T., Fuhr, M., Luc-Olivier Delebeque, Lidón Martínez Navarro, Lasala, D., S.M. Waez-Mousavi, Kiomars Sefidi, Abellanas, B., Heintz, W., 2022. Spatially explicit database of tree related microhabitats (TreMs). https://doi.org/10.15468/OCOF3V

Larrieu, L., A. Cabanettes, A. Brin, et al. 2014. „Tree Microhabitats at the Stand Scale in Montane Beech–Fir Forests: Practical Information for Taxa Conservation in Forestry." European Journal of Forest Research 133: 355–367. https://doi.org/10.1007/s10342-013-0767-1.

Larrieu, L., and A. Cabanettes. 2012. „Species, Live Status, and Diameter Are Important Tree Features for Diversity and Abundance of Tree Microhabitats in Subnatural Montane Beech–Fir Forests." Canadian Journal of Forest Research 42: 1433–1445. https://doi.org/10.1139/x2012-077.

Larrieu, L., Y. Paillet, S. Winter, R. Butler, D. Kraus, F. Krumm, T. Lachat, A. K. Michel, B. Regnery, and K. Vandekerkhove. 2018. „Tree Related Microhabitats in Temperate and Mediterranean European Forests: A Hierarchical Typology for Inventory Standardization." Ecological Indicators 84: 194–207. https://doi.org/10.1016/j.ecolind.2017.08.051.

Leclerc, D., and M. Millot. 1998. „Techniques pour une Gestion Multifonctionnelle Durable des Forêts de Montagne: Cas des Alpes en France et en Italie." Revue Forestière Française 50: 67–81. https://doi.org/10.4267/2042/5583

Lenth, R. 2024. emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.10.5, https://github.com/rvlenth/emmeans

Loyau, A., and D. S. Schmeller. 2017. "Positive Sentiment and Knowledge Increase Tolerance towards Conservation Actions." Biodiversity and Conservation 26 (2): 461–78. https://doi.org/10.1007/s10531-016-1253-0.

Martynova, M., R. Sultanova, D. Khanov, E. Talipov, and R. Sazgutdinova. 2021. "Forest Management Based on the Principles of Multifunctional Forest Use." Journal of Sustainable Forestry 40 (1): 32–46. https://doi.org/10.1080/10549811.2020.1734025.

Marziliano, P. A., Antonucci, S., Tognetti, R. *et al.* 2021. "Factors Affecting the Quantity and Type of Tree-Related Microhabitats in Mediterranean Mountain Forests of High Nature Value." Forest Ecology. iForest - Biogeosciences and Forestry 14 (3): 250. world. https://doi.org/10.3832/ifor3568-014.

McKinley, D. C., A. J. Miller-Rushing, H. L. Ballard, R. Bonney, H. Brown, S. C. Cook-Patton, D. M. Evans, *et al.* 2017. "Citizen Science Can Improve Conservation Science, Natural Resource Management, and Environmental Protection." Biological Conservation, The role of citizen science in biological conservation, 208 (April): 15–28. https://doi.org/10.1016/j.biocon.2016.05.015.

McMullin, R. T., and Y. F. Wiersma. 2019. "Out with OLD Growth, in with Ecological continNEWity: New Perspectives on Forest Conservation." Frontiers in Ecology and the Environment 17 (3): 176–81. https://doi.org/10.1002/fee.2016.

Michel, A. K., and S. Winter. 2009. „Tree Microhabitat Structures as Indicators of Biodiversity in Douglas-Fir Forests of Different Stand Ages and Management Histories in the Pacific Northwest, U.S.A." Forest Ecology and Management 257: 1453–1464. https://doi.org/10.1016/j.foreco.2008.11.027.

Ministerium für Landwirtschaft, Umweltschutz und Raumordnung. 2004. Waldbau-Richtlinie „Grüner Ordner" der Landesforstverwaltung Brandenburg. Ministerium für Landwirtschaft, Umweltschutz und Raumordnung (MLUR) des Landes Brandenburg, p. 143.

Mölder, A., M. Schmidt, T. Plieninger, and P. Meyer. 2020. „Habitat-Tree Protection Concepts Over 200 Years." Conservation Biology. https://doi.org/10.1111/cobi.13511.

Müller, J., J. Bauhus, M. Dieter, H. Spellmann, B. Möhring, S. Wagner, H. Wolf, et al. 2020. "Wege zu einem effizienten Waldnaturschutz in Deutschland: Stellungnahme Januar 2020." Berichte über Landwirtschaft – Zeitschrift für Agrarpolitik und Landwirtschaft, January. https://doi.org/10.12767/buel.vi228.284.

Nelson, J. G., and R. Serafin. 1997. „Keys to Life." In National Parks and Protected Areas, edited by J. G. Nelson and R. Serafin, 1–7. Berlin and Heidelberg: Springer. https://doi.org/10.1007/978-3-642-60907-7_1.

Ní Dhubháin, Á. 2010. An Evaluation of Continuous Cover Forestry in Ireland. COFORD, Department of Agriculture, Fisheries and Food, Dublin.

Niedermann-Meier, S., M. Mordini, R. Bütler, and P. Rotach. 2010. „Habitatbäume im Wirtschaftswald: Ökologisches Potenzial und finanzielle Folgen für den Betrieb." Schweizerische Zeitschrift für Forstwesen 161 (10): 391–400. https://doi.org/10.3188/szf.2010.0391.

Oksanen, J., F. G. Blanchet, R. Kindt, P. Legendre, P. R. Minchin, R. B. O'Hara, G. L. Simpson, P. Solymos, M. H. H. Stevens, H. Wagner, *et al.* 2019. vegan: Community Ecology Package. R Package Version 2.5-6. https://CRAN.R-project.org/package=vegan.

Paillet, Y., Archaux, F., Puy, S. du, Bouget, C., Boulanger, V., Debaive, N., Gilg, O., Gosselin, F., Guilbert, E., 2018. "The indicator side of tree microhabitats: A multi-taxon approach based on bats, birds and saproxylic beetles." Journal Applied Ecology 55, 2147–2159. https://doi.org/https://doi.org/10.1111/1365-2664.13181

Paillet, Y., N. Debaive, F. Archaux, E. Cateau, O. Gilg, and E. Guilbert. 2019. „Nothing Else Matters? Tree Diameter and Living Status Have More Effects than Biogeoclimatic Context on Microhabitat Number and Occurrence: An Analysis in French Forest Reserves." PLOS ONE 14 (5): e0216500. https://doi.org/10.1371/journal.pone.0216500.

Przepióra, F., Lewandowski, P., Ciach, M., 2025. Spatial distribution of tree-related microhabitats in a primeval mountain forest: From natural patterns to landscape planning and forest management recommendations. Science of the Total Environment 960, 178319. https://doi.org/10.1016/j.scitotenv.2024.178319

R Core Team 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Rathmann, J., P. Sacher, N. Volkmann, and M. Mayer. 2020. "Using the Visitor-Employed Photography Method to Analyse Deadwood Perceptions of Forest Visitors: A Case Study from Bavarian Forest National Park, Germany." European Journal of Forest Research 139 (3): 431–42. https://doi.org/10.1007/s10342-020-01260-0.

Regnery, B., Y. Paillet, D. Couvet, and C. Kerbiriou. 2013. „Which Factors Influence the Occurrence and Density of Tree Microhabitats in Mediterranean Oak Forests?" Forest Ecology and Management 295: 118–25. https://doi.org/10.1016/j.foreco.2013.01.009

Remm, J., Lõhmus, A., 2011. Tree cavities in forests – The broad distribution pattern of a keystone structure for biodiversity. Forest Ecology and Management 262, 579–585. https://doi.org/10.1016/j.foreco.2011.04.028

Remacha, C., J. A. Delgado, M. Bulaic, and J. Pérez-Tris. 2016. "Human Disturbance during Early Life Impairs Nestling Growth in Birds Inhabiting a Nature Recreation Area." PLOS ONE 11 (11): e0166748. https://doi.org/10.1371/journal.pone.0166748.

Rondeux, J., and C. Sanchez. 2010. „Review of Indicators and Field Methods for Monitoring Biodiversity within National Forest Inventories. Core Variable: Deadwood." Environmental Monitoring and Assessment 164: 617–30. https://doi.org/10.1007/s10661-009-0917-6.

Sacher, P., J. Meyerhoff, and M. Mayer. 2022. "Evidence of the Association between Deadwood and Forest Recreational Site Choices." Forest Policy and Economics 135 (February): 102638. https://doi.org/10.1016/j.forpol.2021.102638.

Sánchez, J.J., Marcos-Martinez, R., Srivastava, L., Soonsawad, N., 2021. Valuing the impacts of forest disturbances on ecosystem services: An examination of recreation and climate regulation services in U.S. national forests. Trees For. People 5, 100123. https://doi.org/10.1016/j.tfp.2021.100123

Schuck, A., D. Kraus, F. Krumm, and H. Schmitt. 2015a. Integrate+ Marteloscopes Calibrating Silvicultural Decision Making. Integrate+ Technical Paper No1. 12p.

Schuck, A., F. Krumm, and D. Kraus. 2015b. Integrate+ Marteloscopes - Description of Parameters and Assessment Procedures. Integrate+ Technical Paper No. 18. 16 p.

Siitonen, J., 2012. "Microhabitats" In Biodiversity in Dead Wood, Ecology, Biodiversity and Conservation, edited by Jogeir N. Stokland, Juha Siitonen, and Bengt Gunnar Jonsson, 150–182. Cambridge, Cambridge University Press. https://doi.org/10.1017/CBO9781139025843.008

Spînu, A.P., 2023. "Quality and temporal deveopment of habitat trees and their microhabitats in temperate European forests". University of Freiburg, Freiburg im Breisgau, Germany.

Spînu, A.P., Nicolaie, M.A., Asbeck, T., Kozak, D., Paillet, Y., Cateau, E., Mikoláš, M., Svoboda, M., Bauhus, J., 2024. "Temporal Development of Microhabitats on Living Habitat Trees in Temperate European Forests". Ecosystems 27, 690–709. https://doi.org/10.1007/s10021-024-00915-y

Thormann, J.-J., K. Allenspach-Schliessbach, H. Bugmann, M. Frehner, P. Junod, C. Rosset, and K. Kühne. 2019. „Bedeutung von Marteloskopen für Praxis und Lehre in der Schweiz." Schweizerische Zeitschrift für Forstwesen 170: 60–68. https://doi.org/10.3188/szf.2019.0060.

Tokcan, M. 2015. Yedigöller Milli Parkı ile Sarımustan Bölgesi'nin Hemerobi Dereceleri ve Bitki Toplumlarının Belirlenmesi, Doktora Tezi, İ.Ü. Fen Bilimleri Enstitüsü, Orman Botaniği Anabilim Dalı, 343 s.

Visick, O.D., Adams, I., Marzano, F.S., Ratnieks, F.L.W., 2025. Effect of bark harvest intensity on the formation of cavities and other microhabitats in cork oaks (Quercus suber). European Journal of Forest Research 144, 467–479. https://doi.org/10.1007/s10342-025-01770-9

Vuidot, A., Y. Paillet, F. Archaux, and F. Gosselin. 2011. „Influence of Tree Characteristics and Forest Management on Tree Microhabitats." Biological Conservation 144 (1): 441–50. https://doi.org/10.1016/j.biocon.2010.09.030

Wickham H. 2016. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York. ISBN 978-3-319-24277-4, https://ggplot2.tidyverse.org.

Winter, S., and G. C. Möller. 2008. „Microhabitats in Lowland Beech Forests as Monitoring Tools for Nature Conservation." Forest Ecology and Management 255: 1251–61. https://doi.org/10.1016/j.foreco.2007.10.029

Supplementary Material

Supplementary Table 1: Total number of tree microhabitat (TreM) types and their ecological values (EcoVal) in conservation and recreation areas.

Ergänzende Tabelle 1: Gesamtzahl der Baum-Mikrohabitat-Typen (TreMs) und deren ökologische Werte (EcoVal) in Schutz- und Erholungsgebieten.

Saproxylic Microhabitats						
Level 1	**Level 2 TreM codes**	**Level 2 TreM types**	**Number of TreMs**		**EcoVal of TreMs**	
			Conservation	**Recreation**	**Conservation**	**Recreation**
1. Cavities	1.1. CV1	Woodpecker cavities	34	5	1161	176
	1.2. CV2	Trunk and mould cavities	26	92	921	2860
	1.3. CV3	Branch holes	48	48	960	848
	1.4. CV4	Dendrotelms and water-filled holes	48	70	916	922
	1.5. CV5	Insect galleries and bore holes	59	56	556	336
2. Injures and wounds	2.1. IN1	Bark loss / exposed sapwood	106	156	1260	1656
	2.2. IN2	Exposed heartwood / trunk and crown breakage	15	6	274	118
	2.3. IN3	Cracks and scars	10	4	280	110

3. Bark structure	3.1. BA1	Bark pockets	19	20	370	420
	3.2. BA2	Bark structure	8	4	48	24
4. Dead wood	DE1	Dead branches and limbs / crown dead wood	31	30	242	230
Epixylic Microhabitats						
Level 1	**Level 2 TreM codes**	**Level 2 TreM types**	**Number of TreMs**		**EcoVal of TreMs**	
			Conservation	**Recreation**	**Conservation**	**Recreation**
1.Deformation / growth form	1.1. GR1	Root buttress cavities	436	383	1403	1239
	1.2. GR2	Witches broom	26	48	466	864
	1.3. GR3	Cankers and burrs	12	5	120	52
2. Epiphytes	2.1. EP1	Fruiting bodies fungi	14	2	504	72
	2.2. EP2	Myxomycetes	0	0	0	0
	2.3. EP3	Epiphytic crypto- and phanerogams	88	105	624	612
3. Nests	NE1	Nests	3	3	72	72
4. Other	4.1. OT1	Sap and resin run	0	0	0	0
	4.2. OT2	Microsoil	0	0	0	0
TOTAL			**983**	**1037**	**10177**	**10611**

Supplementary Table 2: Mean (±SD) number of TreMs and their EcoVal per tree in conservation and recreation areas.

Ergänzende Tabelle 2: Mittelwert (±SD) der Anzahl von TreMs und ihres EcoVal pro Baum in Schutz- und Erholungsgebieten.

	Number of TreMs	**EcoVal of TreMs**
Conservation	7.7 ± 6.4	79.5 ± 90.2
Recreation	7.2 ± 4.7	73.7 ± 85.8

Supplementary Table 3: Principal component analysis (PCA) loadings (PC1 and PC2) for TreM number and EcoVal in conservation and recreation areas.

Ergänzende Tabelle 3: Ladungen der Hauptkomponentenanalyse (PCA) (PC1 und PC2) für die Anzahl der TreMs und deren EcoVal in Schutz- und Erholungsgebieten.

Number of TreMs	**PC1**	**PC2**
CV1	-0.2574	0.2585
CV2	-0.1607	-0.3261
CV3	-0.1193	-0.0720
CV4	0.1075	-0.3034
CV5	-0.3576	-0.1434
IN1	-0.1865	-0.3094
IN2	-0.2928	0.2966
IN3	-0.0596	0.1493
BA1	-0.3711	-0.0473
BA2	-0.3640	0.1582
DE1	-0.0972	-0.0471
GR1	-0.1183	-0.1548
GR2	0.0765	-0.4780
GR3	-0.1183	-0.1548
EP1	-0.1608	0.3492
EP3	-0.3016	0.0095
NE2	-0.3028	-0.1344
SUM	-0.3289	-0.2390

EcoVal of TreMs	PC1	PC2
CV1	-0.2501	-0.0997
CV2	-0.1811	-0.1402
CV3	-0.0680	-0.3773
CV4	0.0943	-0.4146
CV5	-0.3667	-0.0154
IN1	-0.2008	0.0009
IN2	-0.3357	0.2108
IN3	-0.0765	-0.1213
BA1	-0.3659	0.0149
BA2	-0.3707	0.1517
DE1	-0.1648	-0.1275
GR1	-0.1117	-0.4207
GR2	0.0991	-0.2814
GR3	-0.1117	-0.4207
EP1	-0.1688	0.2408
EP3	-0.1970	0.1599
NE2	-0.2897	0.0067
SUM	-0.3367	-0.2014

Supplementary Table 4: Mean (±SD) number of TreMs and their EcoVal per tree for tree species in conservation and recreation areas.

Ergänzende Tabelle 4: Mittelwert (±SD) der Anzahl von TreMs und ihres EcoVal pro Baum nach Baumarten in Schutz- und Erholungsgebieten.

Species	**Number of TreMs**		**EcoVal of TreMs**	
	Conservation	**Recreation**	**Conservation**	**Recreation**
Abies nordmanniana subsp. *bornmuelleriana*	5.5 ± 6.4	-	60.1 ± 92.9	-
Acacia sp.	-	3.0 ± 0	-	43.0 ± 0
Acer sp.	-	2.6 ± 0.9	-	20.2 ± 8.8
Carpinus betulus	14.2 ± 4.1	9.7 ± 5.8	208.5 ± 83.9	126.2 ± 150.8
Fagus orientalis	8.4 ± 6.4	6.8 ± 4.1	80.8 ± 88.2	62.1 ± 48.9
Pinus nigra	3.7 ± 1.1	-	32.7 ± 9.1	-
Quercus petraea	4.9 ± 3.4	2.0 ± 1.4	56.7 ± 51.8	17.0 ± 18.4
Ulmus sp.	7.0 ± 0	-	26.0 ± 0	-

Supplementary Table 5: Total number of each tree microhabitat (TreM) type recorded for each tree species in conservation (C) and recreation (R) areas, as well as in total (T) (ACA=Acacia sp., ACE=Acer sp., ANO=Abies nordmanniana subsp. bornmuelleriana, CBE=Carpinus betulus, FOR=Fagus orientalis, PNI=Pinus nigra, QPE=Quercus petraea, ULM=Ulmus sp.).

Ergänzende Tabelle 5: Gesamtzahl der einzelnen TreM-Typen für jede Baumart in Schutzgebieten (C) und Erholungsgebieten (R) sowie insgesamt (T) (ACA=*Acacia* sp., ACE=*Acer* sp., ANO=*Abies nordmanniana* subsp. *bornmuelleriana*, CBE=*Carpinus betulus*, FOR=*Fagus orientalis*, PNI=*Pinus nigra*, QPE=*Quercus petraea*, ULM=*Ulmus* sp.).

Saproxylic Microhabitats																													
Level 1	**Level 2 TreM codes**	**Level 2 TreM types**	**ACA**			**ACE**			**ANO**			**CBE**			**FOR**			**PNI**			**QPE**			**ULM**		
			C	**R**	**T**	**C**	**R**	**T**	**C**	**R**	**T**	**C**	**R**	**T**	**C**	**R**	**T**	**C**	**R**	**T**	**C**	**R**	**T**	**C**	**R**	**T**
1. Cavities	1.1. CV1	Woodpecker cavities	0	0	**0**	0	0	**0**	11	0	**11**	5	3	**8**	16	2	**18**	0	0	**0**	2	0	**2**	0	0	**0**
	1.2. CV2	Trunk and mould cavities	0	0	**0**	0	0	**0**	1	0	**1**	2	48	**50**	22	44	**66**	0	0	**0**	1	0	**0**	0	0	**0**
	1.3. CV3	Branch holes	0	0	**0**	0	0	**0**	1	0	**1**	13	14	**27**	29	34	**63**	0	0	**0**	5	0	**5**	0	0	**0**
	1.4. CV4	Dendrotelms and water-filled holes	0	1	**1**	0	0	**0**	2	0	**2**	4	19	**23**	42	50	**92**	0	0	**0**	0	0	**0**	0	0	**0**
	1.5. CV5	Insect galleries and bore holes	0	0	**0**	0	0	**0**	13	0	**13**	7	25	**32**	31	31	**62**	2	0	**2**	6	0	**6**	0	0	**0**
2. Injures and wounds	2.1. IN1	Bark loss / exposed sapwood	0	1	**1**	0	2	**2**	18	0	**18**	6	33	**39**	80	152	**232**	2	0	**2**	8	1	**9**	1	0	**1**
	2.2. IN2	Exposed heartwood / trunk and crown breakage	0	0	**0**	0	0	**0**	4	0	**4**	2	3	**5**	7	3	**10**	0	0	**0**	2	0	**2**	0	0	**0**
	2.3. IN3	Cracks and scars	0	0	**0**	0	0	**0**	0	0	**0**	5	2	**7**	5	2	**7**	0	0	**0**	0	0	**0**	0	0	**0**
3. Bark structure	3.1. BA1	Bark pockets	0	0	**0**	0	0	**0**	11	0	**11**	1	5	**6**	4	15	**19**	1	0	**1**	2	0	**2**	0	0	**0**
	3.2. BA2	Bark structure	0	0	**0**	0	0	**0**	3	0	**3**	0	4	**4**	1	0	**1**	3	0	**3**	0	0	**0**	1	0	**1**
4. Dead wood	DE1	Dead branches and limbs / crown dead wood	0	0	**0**	0	0	**0**	6	0	**6**	6	20	**26**	15	9	**24**	1	0	**1**	3	1	**4**	0	0	**0**
Epixylic Microhabitats																													
Level 1	**Level 2 TreM codes**	**Level 2 TreM types**	**ACA**			**ACE**			**ANO**			**CBE**			**FOR**			**PNI**			**QPE**			**ULM**		
			C	**R**	**T**	**C**	**R**	**T**	**C**	**R**	**T**	**C**	**R**	**T**	**C**	**R**	**T**	**C**	**R**	**T**	**C**	**R**	**T**	**C**	**R**	**T**
1.Deformation / growth form	1.1. GR1	Root buttress cavities	0	1	**1**	0	7	**7**	43	0	**43**	22	79	**101**	358	296	**654**	1	0	**1**	8	0	**8**	4	0	**4**
	1.2. GR2	Witches broom	0	0	**0**	0	0	**0**	1	0	**1**	3	14	**17**	22	34	**56**	0	0	**0**	0	0	**0**	0	0	**0**
	1.3. GR3	Cankers and burrs	0	0	**0**	0	0	**0**	0	0	**0**	2	4	**6**	8	2	**10**	1	0	**1**	1	0	**1**	0	0	**0**
2. Epiphytes	2.1. EP1	Fruiting bodies fungi	0	0	**0**	0	0	**0**	2	0	**2**	1	4	**5**	12	3	**15**	0	0	**0**	1	0	**1**	0	0	**0**
	2.2. EP2	Myxomycetes	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	2	**2**	0	0	**0**	0	0	**0**	0	0	**0**
	2.3. EP3	Epiphytic crypto- and phanerogams	0	0	**0**	0	4	**4**	25	0	**25**	7	28	**35**	49	71	**120**	0	0	**0**	6	2	**8**	1	0	**1**
3. Nests	NE1	Nests	0	0	**0**	0	0	**0**	1	0	**1**	0	1	**1**	2	2	**4**	0	0	**0**	0	0	**0**	0	0	**0**
4. Other	4.1. OT1	Sap and resin run	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
	4.2. OT2	Microsoil	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**

Supplementary Table 6: Mean (±SD) number of TreMs and their EcoVal per tree for alive and dead individuals in conservation and recreation areas.

Ergänzende Tabelle 6: Mittelwert (±SD) der Anzahl von TreMs und ihres EcoVal pro Baum für lebende und tote Individuen in Schutz- und Erholungsgebieten.

	Number of TreMs		**EcoVal of TreMs**	
	Alive	**Dead**	**Alive**	**Dead**
Conservation	7.3 ± 6.3	11.4 ± 6.4	71.3 ± 84.6	166.5 ± 106.2
Recreation	7.2 ± 4.7	8.5 ± 2.1	73.0 ± 86.1	125.5 ± 46.0

Supplementary Table 7: Number of individuals, total number of TreMs, and total EcoVal for alive and dead trees in conservation and recreation areas.

Ergänzende Tabelle 7: Anzahl der Individuen, Gesamtzahl der TreMs sowie Gesamt-EcoVal für lebende und tote Bäume in Schutz- und Erholungsgebieten.

	Number of individuals		**Number of TreMs**		**EcoVal of TreMs**	
	Alive	**Dead**	**Alive**	**Dead**	**Alive**	**Dead**
Conservation	117	11	858	125	8345	1832
Recreation	142	2	1020	17	10360	251
TOTAL	**259**	**13**	**1878**	**142**	**18705**	**2083**

Supplementary Table 8: Pairwise comparisons (p-values) of TreM number and EcoVal between alive and dead individuals in conservation and recreation areas.

Ergänzende Tabelle 8: Paarweise Vergleiche (p-Werte) der TreM-Anzahl und des EcoVal zwischen lebenden und toten Individuen in Schutz- und Erholungsgebieten.

	p values for number of TreMs	**p values for EcoVal of TreMs**
Alive ind. in conservation vs. Dead ind. in conservation	<.0001	<.0001
Alive ind. in conservation vs. Alive ind. in recreation	0.9702	0.4141
Alive ind. in conservation vs. Dead ind. in recreation	0.9312	<.0001
Dead ind. in conservation vs. Alive ind. in recreation	<.0001	<.0001
Dead ind. in conservation vs. Dead ind. in recreation	0.6752	0.0002
Alive ind. in recreation vs. Dead ind. in recreation	0.9016	<.0001

Supplementary Table 9: Mean (±SD) number of TreMs and their EcoVal per tree for habitat trees (DBH ≥ 40 cm) and trees with DBH < 40 cm in conservation and recreation areas.

Ergänzende Tabelle 9: Mittelwert (±SD) der Anzahl von TreMs und ihres EcoVal pro Baum für Habitatbäume (BHD ≥ 40 cm) und Bäume mit BHD < 40 cm in Schutz- und Erholungsgebieten.

	Number of TreMs		**EcoVal of TreMs**	
	Habitat trees	**Trees with dbh < 40 cm**	**Habitat trees**	**Trees with dbh < 40 cm**
Conservation	6.0 ± 5.4	7.5 ± 5.4	130.3 ± 88.1	58.1 ± 82.7
Recreation	6.4 ± 6.5	8.3 ± 5.2	123.0 ± 133.9	54.1 ± 44.0

Supplementary Table 10: Number of individuals, total TreMs, and total EcoVal for habitat trees (DBH ≥40 cm) and trees with DBH < 40 cm in conservation and recreation areas.

Ergänzende Tabelle 10: Anzahl der Individuen, Gesamtzahl der TreMs sowie Gesamt-EcoVal für Habitatbäume (BHD ≥40 cm) und Bäume mit BHD < 40 cm in Schutz- und Erholungsgebieten.

	Number of individuals		**Number of TreMs**		**EcoVal of TreMs**	
	Hab. Trees	**Trees <40cm**	**Hab. Trees**	**Trees <40cm**	**Hab. Trees**	**Trees <40cm**
Conservation	38	90	228	674	4950	5227
Recreation	41	103	263	855	5042	5569
TOTAL	**79**	**193**	**491**	**1529**	**9992**	**10796**

Supplementary Table 11: Pairwise comparisons (p-values) of TreM number and EcoVal between habitat trees (DBH ≥40 cm) and trees with DBH < 40 cm in conservation and recreation areas.

Ergänzende Tabelle 11: Paarweise Vergleiche (p-Werte) der TreM-Anzahl und des EcoVal zwischen Habitatbäumen (BHD ≥40 cm) und Bäumen mit BHD < 40 cm in Schutz- und Erholungsgebieten.

	p values for number of TreMs	**p values for EcoVal of TreMs**
Habitat tree in conservation vs. Tree with <40 cm in conservation	0.0199	<.0001
Habitat tree in conservation vs. Habitat tree in recreation	0.8816	0.0209
Habitat tree in conservation vs. Tree with <40 cm in recreation	0.0001	<.0001
Tree with <40 cm in conservation vs. Habitat tree in recreation	0.1437	<.0001
Tree with <40 cm in conservation vs. Tree with <40 cm in recreation	0.1884	0.0012
Habitat tree in recreation vs. Tree with <40 cm in recreation	0.0015	<.0001

Supplementary Table 12: Total number of selected TreM types associated with pruning practices in conservation and recreation areas (CV12: woodpecker cavities ø=5-6 cm, CV31: branch holes ø>=5 cm, CV32: branch holes ø>=10 cm).

Ergänzende Tabelle 12: Gesamtzahl ausgewählter TreM-Typen im Zusammenhang mit Schnittmaßnahmen in Schutz- und Erholungsgebieten (CV12: Spechthöhlen ø=5–6 cm, CV31: Astlöcher ø≥5 cm, CV32: Astlöcher ø≥10 cm).

	CV12	**CV31**	**CV32**
Conservation	1	25	17
Recreation	0	29	17

Supplementary Table 13: Total number of selected TreM types associated with direct anthropogenic effects in conservation and recreation areas (CV23: trunk and mould cavities ø>=10 cm, CV24: trunk and mould cavities ø>=30 cm, CV25: trunk and mould cavities ø>=30 cm/semi-open, IN11: bark loss 25-600 cm² and decay stage <3, IN12: bark loss >25-600 cm² and decay stage <3).

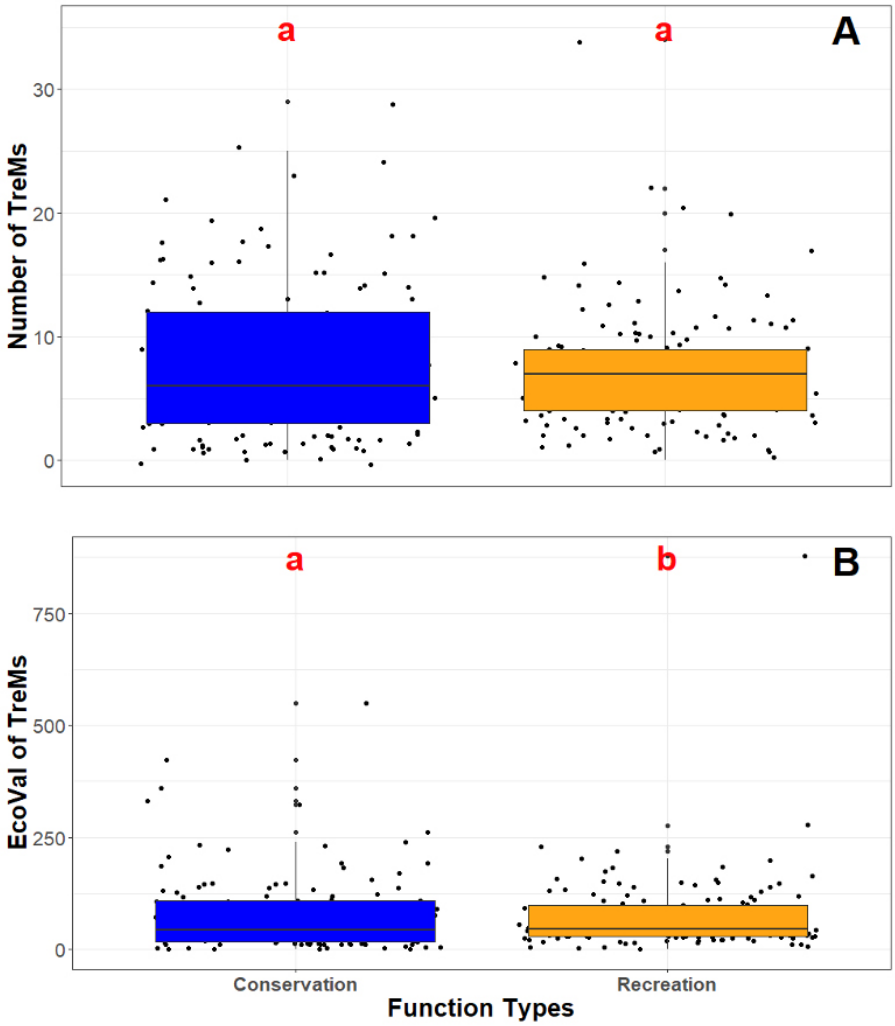
Ergänzende Tabelle 13: Gesamtzahl ausgewählter TreM-Typen im Zusammenhang mit direkten anthropogenen Einflüssen in Schutz- und Erholungsgebieten (CV23: Stamm- und Mulmhöhlen ø≥10 cm, CV24: Stamm- und Mulmhöhlen ø≥30 cm, CV25: Stamm- und Mulmhöhlen ø≥30 cm/halb-offen, IN11: Rindenverlust 25–600 cm² und Zersetzungsstadium <3, IN12: Rindenverlust >25–600 cm² und Zersetzungsstadium <3).

	CV23	CV24	CV25	IN11	IN12
Conservation	8	5	2	15	13
Recreation	16	22	8	30	33

Supplementary Table 14: Total number of selected TreM types associated with indirect anthropogenic effects in conservation and recreation areas (CV21: trunk and mould cavities ø>=10 cm with ground contact, CV22: trunk and mould cavities ø>=30 cm with ground contact, GR1: root buttress cavities).

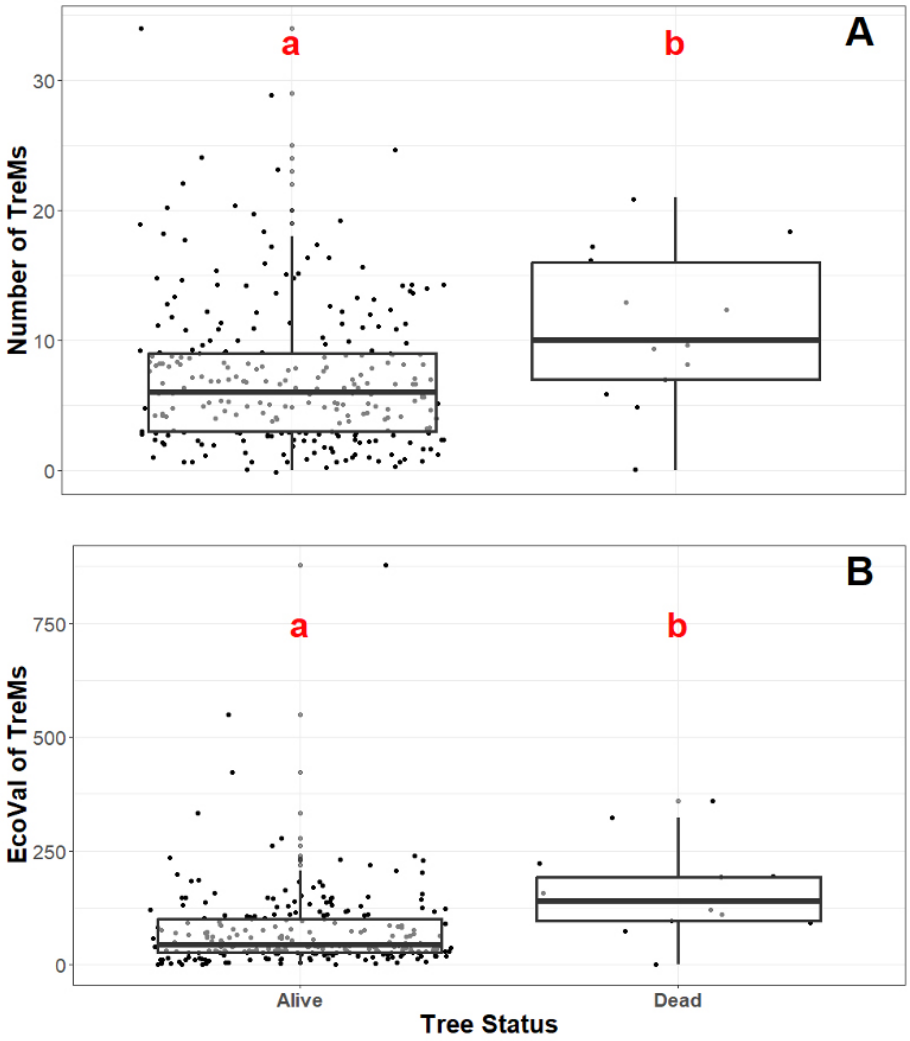
Ergänzende Tabelle 14: Gesamtzahl ausgewählter TreM-Typen im Zusammenhang mit indirekten anthropogenen Einflüssen in Schutz- und Erholungsgebieten (CV21: Stamm- und Mulmhöhlen ø≥10 cm mit Bodenkontakt, CV22: Stamm- und Mulmhöhlen ø≥30 cm mit Bodenkontakt, GR1: Wurzelanlaufhöhlen).

	CV21	CV22	GR1
Conservation	1	10	436
Recreation	24	19	383



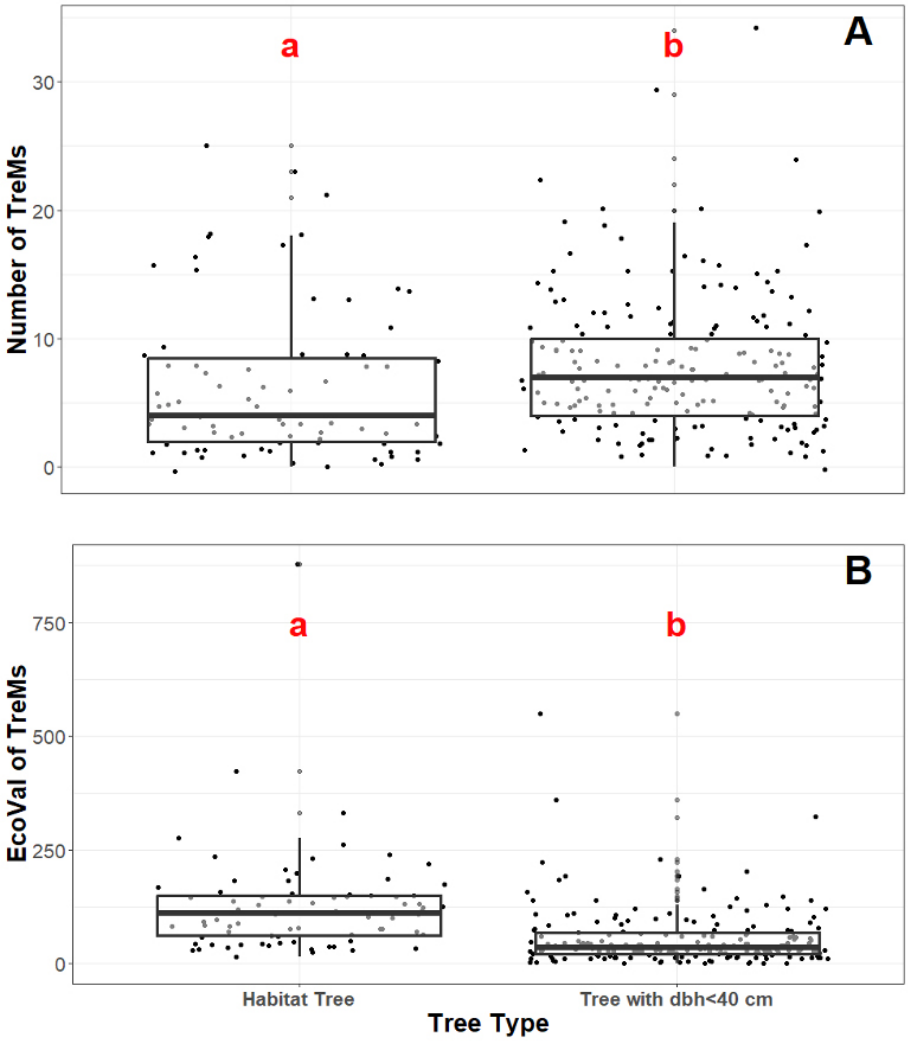
Supplementary Figure 1: Comparison of the number of tree microhabitats (TreMs) and their ecological values (EcoVal) in conservation and recreation areas.

Ergänzende Abbildung 1: Vergleich der Anzahl von Baum-Mikrohabitaten (TreMs) und ihres ökologischen Wertes (EcoVal) in Schutz- und Erholungsgebieten.



Supplementary Figure 2: Comparison dead and alive individuals in terms of TreMs number and their EcoVal.

Ergänzende Abbildung 2: Vergleich toter und lebender Individuen hinsichtlich der Anzahl von TreMs und ihres EcoVal.



Supplementary Figure 3: Comparison of habitat trees (DBH ≥ 40 cm) and trees with DBH < 40 cm in conservation and recreation areas in terms of TreM number and their EcoVal.

Ergänzende Abbildung 3: Vergleich von Habitatbäumen (BHD ≥ 40 cm) und Bäumen mit BHD < 40 cm in Schutz- und Erholungsgebieten hinsichtlich der Anzahl von TreMs und ihres EcoVal.