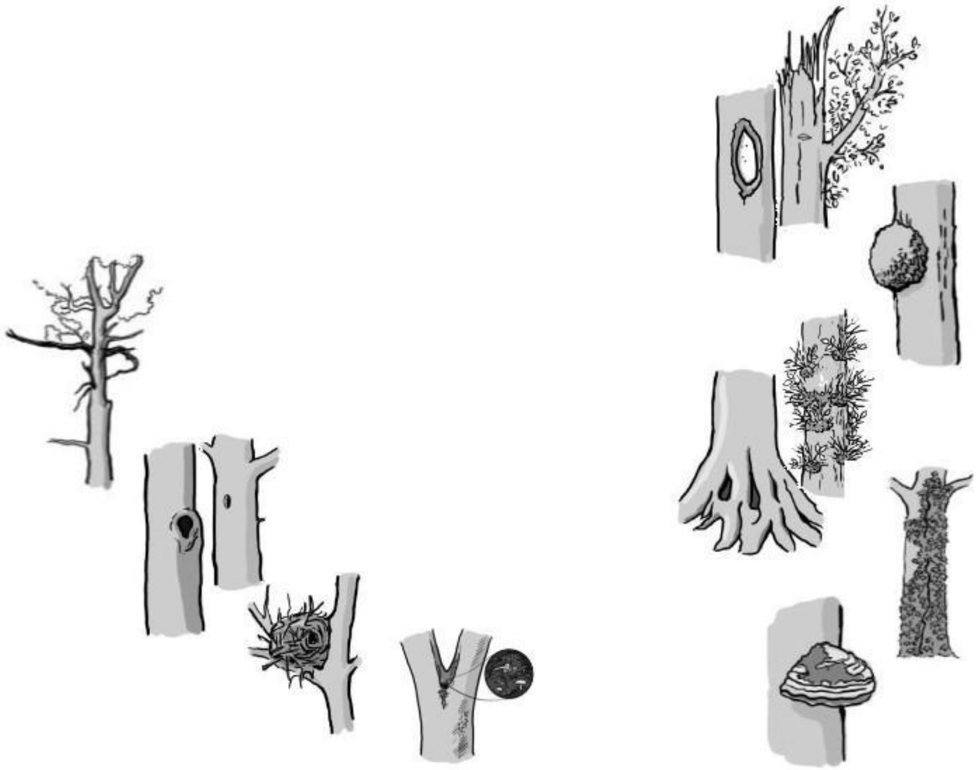
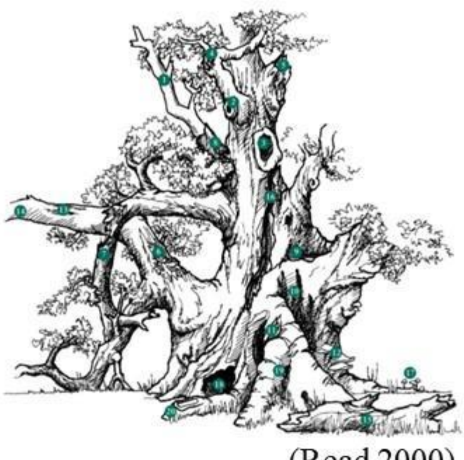
Description of tree microhabitats in the BOTTOMS-UP database



(Kraus et al. 2016, Larrieu et al. 2018)

(de Groot et al. 2016)



(Read 2000)

Authors and Affiliations:

Inken Doerfler: Institute of Biology and Environmental Science, Vegetation Science & Nature Conservation, University of Oldenburg, Oldenburg, Germany.

Yoan Paillet, Université Grenoble Alpes, INRAE, Lessem, Saint MArtin d'Heres, France

Michał Ciach, Department of Forest Biodiversity, Faculty of Forestry, University of Agriculture in Kraków, Kraków, Poland

Anders Mårell, INRAE, UR EFNO, F-45290 Nogent-sur-Vernisson, France

Sabina Burrascano Sapienza University of Rome, 00185, Rome, Italy and National Biodiversity Future Center, Palermo, Italy

Data custodians:

Archaux, Frederic
Asbeck, Thomas
Avtzis, Dimitrios
Azalos, Reka
Basile, Marco
Bergamini, Ariel
Bisikirskienė, Loreta
Blaser, Stefan
Boloni, Janos
Boscardin, Yves
Bouget, Christophe
Brazaitis, Gediminas
Bruun, Hans Henrik
Budrys, Eduardas
Doerfler, Inken
Dumas, Yann
Emrich, Dina
Fotakis, Dimitrios
Frank, Tamas
Frey, Julian
Fritz, Örjan
Fuhr, Marc
Goldberg, Irina
Gosselin, Frederic
Gosselin, Marion Vinot
Gossner, Martin M.
Haeler, Elena
Heidrich, Lea
Heilmann-Clausen, Jacob
Helbach, Jan
Hofmeister, Jeňýk
Hošek, Jan
Janssen, Philippe
Knuff, Anna Katharina
Korboulewsky, Nathalie
Kozák, Daniel
Lachat, Thibault
Læssøe, Thomas
Landivar, Carlos Miguel
Marell, Anders
Marozas, Vitas
Mikoláš, Martin
Müller, Jörg
Nemeth, Csaba
Nemeth, Tamas
Onodi, Gabor
Paillet, Yoan
Perot, Thomas
Perret, Sandrine
Preikša, Žydrūnas
Rahbek, Carsten
Rappa, Nolan
Riis-Hansen, Rasmus
Roth, Nicolas
Scheidegger, Christoph
Schwegmann, Sebastian
Šimkevičius, Kastytis
Spinu, Andrea
Spyroglou, Gavriil
Stillhard, Jonas
Svoboda, Miroslav
Tamutis, Vytautas
Topalidou, Eleni
Tøttrup, Anders
Veres, Katalin
Weisser, Wolfgang W.
Winiger, Nathalie
Wohlwend, Michael
Xystrakis, Fotios

Introduction

Biodiversity is decreasing globally, notably due to increasing human pressures on the environment (Butchart et al., 2010). Within forests, reduction, fragmentation but also habitat impoverishment by human interventions has a strong influence on forest biodiversity (e.g. Bähner et al., 2020; Müller et al., 2007). Especially within the temperate forests of Europe, which are under long-lasting and strong influence by human interventions (Hannah et al., 1995), only a few primary forests are left (Sabatini et al., 2021). Forest use history and current human interventions result often in a reduced habitat quality or diversity compared to forests without management (Stiers et al., 2018) due to, e.g., the alteration of tree species, growth cycles of trees or the removal of biomass management (e.g. Debeljak, 2006; Drössler et al., 2016). This has a major impact on forest biodiversity, threatening many species of habitat specialists that are dependent on traits of primary forest, e.g. continuous tree dieback or presence of large diameter deadwood (Lachat & Müller, 2018).

Therefore, sustainable forestry aims to increase the habitat quality and diversity of forests harvested for timber by retaining habitats important for biodiversity (Kraus & Krumm, 2013). The quality of habitats significantly relies on presence of tree related microhabitats (TreMs), which include mainly modification of bark or wood, interactions with species, or necrotic parts of the tree (Larrieu et al., 2018). Many TreMs develop mainly on deciduous trees with a large diameter (Larrieu & Cabanettes, 2012; Paillet et al., 2019) and are positively related to tree species richness and living status as snags bear more TreMs than living trees (Kozák et al., 2018; Paillet et al., 2017). TreMs provide a large variety of habitats for some taxonomic or ecological groups such as birds, bats or saproxylic beetles, thus promoting biodiversity in forests (Basile et al., 2020; Müller et al., 2014; Paillet et al., 2018; Regnery et al., 2013; Schauer et al., 2018; Schauer et al., 2017). However, the high number of different TreMs and difficulties within the assessments (Paillet et al., 2015) hamper their thorough inclusion into public inventories and their consideration by sustainable forestry. Additionally, the use of TreMs as indicator is still limited. Despite recent local efforts (Zeller et al., 2022), the research on the connection of forest-dwelling species from different taxonomic groups with the different categories of TreMs are not yet verified (Asbeck et al., 2021).

Due to the creation of the Bottoms-Up platform, which includes the collection of multi-taxon data from local scientific projects and information on TreMs (https://www.bottoms-up.eu/), new kinds of analyses on the relationships between TreMs and biodiversity are possible, thus allowing to make more informative recommendations for sustainable forestry.

The merging of existing data highlighted the great variety of TreMs sampling protocols and typologies and created momentum for the harmonization of the existing data. Here, we aim to harmonize and standardize the definition used across previous multi-taxon studies in to comply with the most commonly used TreM-handbooks (Larrieu et al., 2018). We also performed an overview of the structural and taxonomic data associated with TreM information across the Bottoms-Up datasets in order to map the potential for analyses on the relationship between multi-taxon biodiversity, stand structure and TreM data.

Methods

The Bottoms-Up core platform consists of four tables referred to the sampling unit scale, one containing sampling unit metadata; and the others containing the raw data separately for: standing trees; lying deadwood; multi-taxon species composition. The platform structure was designed to allow for effective relationships across tables at different spatial scales: sites, stands, and plots. In addition to the core structure, three ancillary tables refer to the dataset level and include protocol parameters separated for standing trees, lying deadwood, and biodiversity data (Burrascano et al., 2021).

From the database, we selected the datasets which reported tree microhabitats in their protocols. The original coding of tree microhabitats of each dataset was translated into the coding of (Larrieu et al., 2018) using the descriptions from the original publications reported by the data custodians (Table 1) and were confirmed by personal communication. Critical cases were discussed in a round of experts.

Table 1: Basic information on datasets with tree microhabitats. 1) only parts of biodiversity were sampled in the first survey and two datasets on TreMs exist, one with information on stand volume where TreM records are based on the protocol of the Bavarian state forestry (reported here) and one with information on stand composition where TreM records are based on Kraus et al. (2016).

	Dataset	**Country**	**Original catalogue**	**Repeated survey**
1	CH_TL	Switzerland	Catalogue reported in Tinner et al. (2013)	No
2	CZ_JH1	Czechia	-	No
3	DE_ID	Germany	Mixed, translated to Kraus et al. (2016)	Yes [1)]
4	DE_JP	Germany	Kraus et al. (2016)	No
5	DK_JC1	Denmark	Lelli et al. (2019)	Yes
6	DK_JC3	Denmark	Lelli et al. (2019)	Yes
7	FR_AM	France	Kraus et al. (2016)	No
8	FR_JP	France	Bruciamacchie et al. (2007)	No
9	FR_YP	France	Vuidot et al. (2011) based on Winter et al. (2008)	No
10	GR_FX	Greece	Kraus et al. (2016)	No
11	HU_RA	Hungary	-	No
12	IT_EA	Italy	Stokland et al. (2012)	No
13	LT_GB	Lithuania	Kraus et al. (2016)	No
14	SK_DK	Slovakia	Vuidot et al. (2011)	No
15	SK_MM	Slovakia	Vuidot et al. (2011)	No
16	SK_MS	Slovakia	Vuidot et al. (2011)	No

Results

Comparison of catalogues

The database includes 16 datasets with a total of 1,535 plots from ten countries with TreMs (Fig. 1). The single datasets had 5 – 422 plots. The most commonly used catalogues were the one from Kraus et al. (2016) and Vuidot et al. (2011) (Fig. 1). Data custodians recorded 5-150 types of tree microhabitats in their original coding.

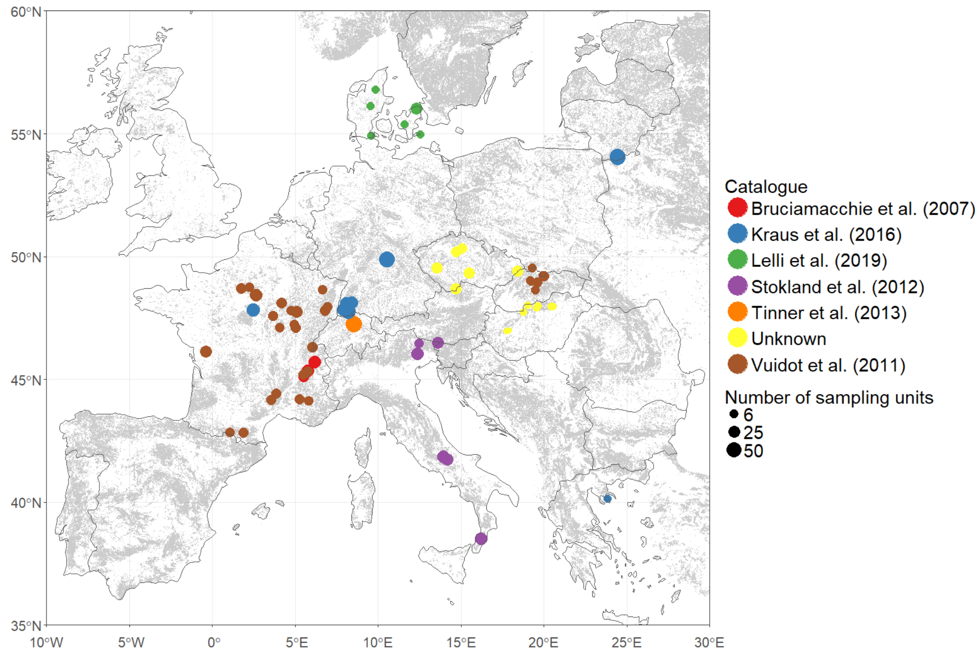


Figure 1. Figure 1: Distribution of the sites across which TreM information is available together with multi-taxon biodiversity data. The size of the dots refers to the number of sampling units in each site, the color of the dots indicate the TreM catalogue used.

Within the 16 analysed data sets, the original catalogues contained 5 to 149 TreM categories (Tab. 1), compared to 48 categories in the catalogue by Larrieu et al. (2018). 245 out of 438 categories from the 16 data sets could not be translated into the 3rd, i.e. the most detailed, level of Larrieu et al. (2018), but no datasets' coding could be translated completely into Larrieu *et al.* (2018) (Table A1). In 28 cases (within 8 of 16 data sets) 2 or more original categories were translated into one category from Larrieu et al. (2018), resulting into a differentiation between 1 to 44 TreM categories at the 3rd level per data set.

Within the 3rd level of translation, trees with *ephiphytic bryophytes*, *bark loss*, *epiphytic lichen*, *root buttress concavities* and *heavy resinosis* were the most common TreMs (Fig. 2). In general, *cavities s.l.*, *tree injuries and exposed sapwood*, *epiphytic and epixylic structures* were the most common TreM categories on the 1st level (Fig. 2).

Certain TreM categories, especially those which were mainly recorded on coniferous trees, such as *root buttress concavities*, *epiphytic lichen* or *heavy resinosis* were more or less restricted to one data set from Germany (DE_JP). Other TreM categories, such as *bark loss*, *cracks*, *dead branches* or *epiphytic bryophytes* were mainly restricted to a data set from France (FR_YP) (Appendix, Fig. A1).

The average percentage of trees with TreMs ranged from 0% (DE_ID) up to 100% (DE_JP, FR_YP), but seemed to be independent from the number of TreMs recorded (Fig. 2).

Cavities (Larrieu: 101 to 104; Kraus: CV1 to CV5)

Cavities include woodpecker breeding cavities, rot-holes, insect galleries and bore holes and concavities. Within this category buttress-root concavities, trunk rot-holes, woodpecker foraging excavations and dendrotelms are the most common 3rd level categories of the cavities (Figure 2, Table A2).

Woodpecker cavities (Woodpecker foraging)

Woodpecker cavities are mostly represented as general woodpecker cavities without a size specification (101: 5 datasets, 124 plots) and woodpecker flutes (1014: 7 datasets, 82 plots). The size specifications and woodpecker foraging excavations are relatively seldomly specified (1011: 1 dataset, 10 plots; 1012: 3 datasets, 34 plots; 1013: 3 datasets, 27 plots; 1042: 3 datasets, 46 plots).

Rot holes, trunk and mould cavities

Categories of rot holes where the position at the trunk or within the tree are specified are rarely present in the datasets (1021: 3 datasets, 20 plots; 1023: 4 datasets, 89 plots, 1026: 1 dataset, 1 plot), as well as trunk and large branch cavities (1022: 4 datasets, 39 plots) However, all categories combined, this TreM is the third most recorded TreM (in total 14 datasets).

Insect galleries and bore holes & Concavities (Dendrotelms, Root buttress)

Records of insect galleries and small bore holes are not very common in the database (1031: 2 datasets, 13 plots). Dendrotelms (1041) were not recorded in the database. Root buttress concavities were recorded in only a few datasets but many plots (1044: 2 datasets, 100 plots).

Tree injuries and exposed wood

Tree injuries include: exposed sapwood only and exposed sapwood and heartwood. All categories combined, tree injuries, wounds and exposed wood are the second TreMs being present in most catalogues (in total 15 datasets).

Exposed sapwood

Patches of bark loss with freshly decayed sapwood was recorded in about a quarter of the datasets (1051: 4 datasets, 344 plots). Fire scars were recorded in only one dataset (1052: 28 plots). TreMs where the bark is detached forming shelters and pockets were recorded in many datasets but occurred on a little number of plots (1053: 10 datasets, 87 plots; 1054: 6 datasets, plots 77). Bark loss is the second most common TreM (Figure 2, Table A2).

Exposed sapwood and heartwood

TreMs where not only sap- but also heartwood is exposed were recorded in about a quarter of the datasets. Stem breakage and limb breakage were the most common TreMs (1061: 6 datasets, 120; 1062: 6 datasets, 62 plots). Cracks and lightning scars were either recorded in a smaller number of datasets or in a smaller number of plots (1063: 4 datasets, 183 plots; 1064: 6 datasets, 58 plots). Dead branches are the most common TreM within this category (Figure 2, Table A2).

Crown deadwood

Crown deadwood

Deadwood within the crown as part of the tree, which was not specified into it extend, was recorded in 6 datasets (107: 80 plots). Also, dead branches were recorded less often (1071: 4 datasets, 212 plots) but are still the most common TreM of this category (Figure 2, Table A2). TreMs where the top of the tree is dead (1072: 1 dataset, 13 plots) or limbs are broken (1073: 5 datasets, 42 plots) are even more rarely recorded.

Excrescences

Excrescences and witches brooms & Deformation / growth form and Burrs and cankers

Excrescences without specifications are rarely recorded (108: 1 dataset, 88 plots) and witches’ brooms even less (1081: 2 datasets, 2 plots).

Deformations without specification are recorded in about a quarter of the datasets (109: 6 datasets, 106 plots) but the specifications burrs (1091: 3 datasets, 16 plots) or cankers (1092: 2 datasets, 3 plots) are rarely sampled and found (Figure 2, Table A2).

Fruiting bodies of saproxylic fungi and slime moulds

All categories combined; fruiting bodies of fungi are the TreM most recorded (16 out of 17 datasets). However, the separation of perennial and ephemeral fruiting bodies on the 2nd hierarchical level within (Larrieu et al., 2018) reduces the number of original codes that can be translated. Also, fruiting bodies of fungi were rarely found (Figure 2, Table A2).

Perennial fungal fruiting bodies and Ephemeral fungal fruiting bodies and slime moulds

Perennial fruiting bodies of fungi were recorded in 8 datasets (1101: 91 plots).

Ephemeral fruiting bodies of fungi were recoded less compared to perennial fruiting bodies (1111: 2 dataset, 5 plots; 1112: 2 datasets, 2 plots), whereas ascomycetes or myxomycetes are not recorded in the TreM surveys.

Epiphytic and parasitic crypto- and phanerogam

Epiphytic and epixylic structures

Epiphytes without specifications (112) were recorded only on one plot. Specified epiphytic categories were more common, with bryophytes being recorded most often (1121: 6 datasets, 256 plots), followed by lichen (1122: 3 datasets, 59 plots). Whereas ivy was recorded only in one dataset (9 plots) and ferns or mistletoes were not recorded in the database. Bryophytes and lichen were the TreMs most commonly found in the data base (Figure 2, Table A2).

Nests & Microsoils

Vertebrate nests were recorded in one dataset (1131: 6 plots). Accumulations of soils in the crowns of trees (1142) were recorded on one plot.

Exudates

Fresh exudates

Exudates without a specification were recorded in about a quarter of the datasets (115: 5 datasets, 113 plots). The specification of sap run was less common (1151: 3 datasets, 21 plots) and resin flow even less (1152: 1 dataset, 31 plots), but more often found (Figure 2, Table A2)

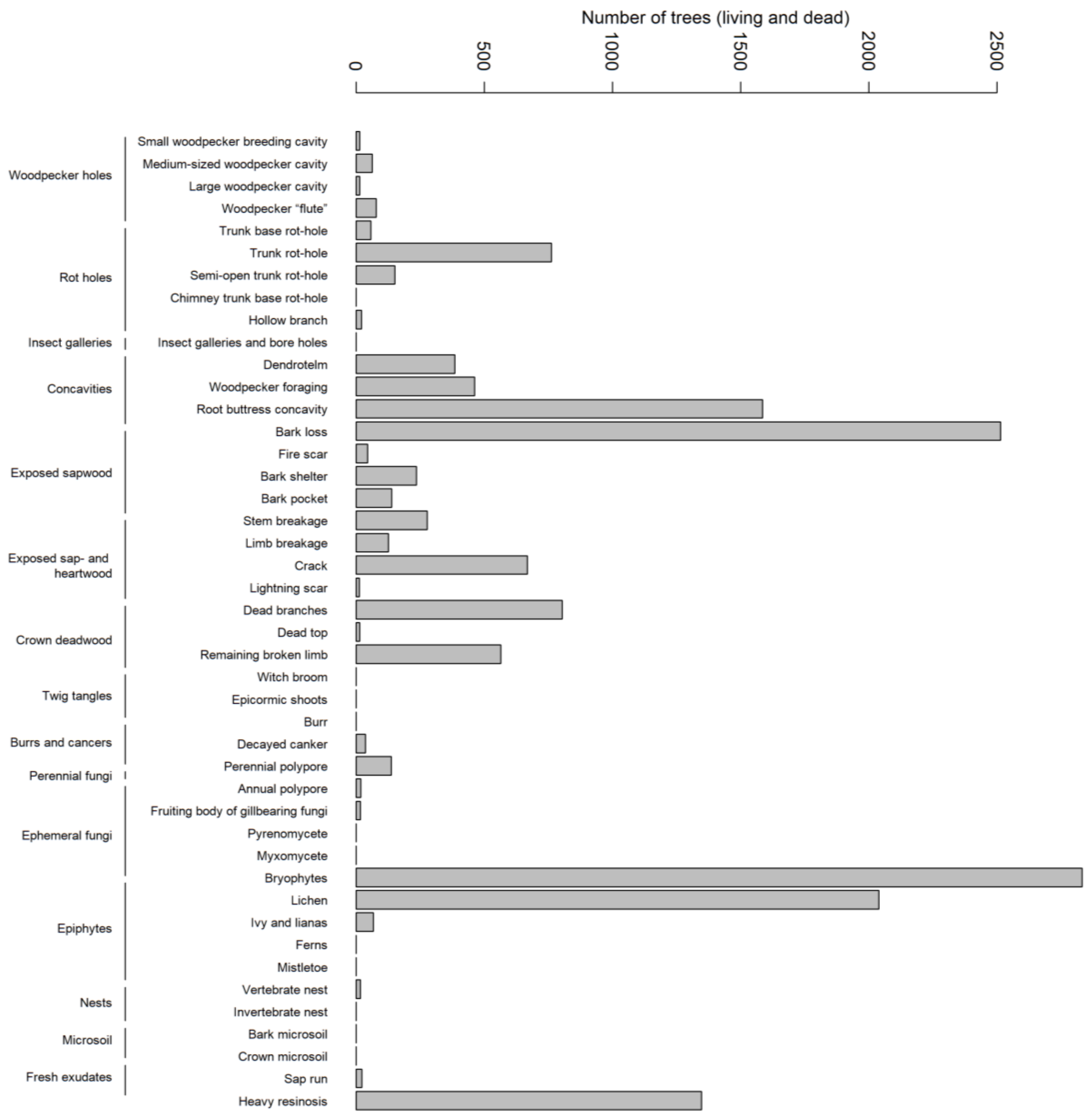


Figure 2: Number of trees (living and dead) bearing different types of TreMs. The x-axis indentify the 3rd level from (Larrieu et al., 2018), the lower x-axis and the lines show the 2nd level from (Larrieu et al., 2018).The arrangement of the figure corresponds to the order of TreMs presented in (Larrieu et al., 2018).

Description of live stand and deadwood within the datasets

Datasets with TreMs represented all EEA-forest types from category 1 (Boreal forests) to category 8 (Thermophilous deciduous forests), as well as category 10 (Coniferous forests of the Mediterranean, Anatolian and Macaronesian regions) and category 14 (Plantations and self-sown exotic forest) (Table 3, Table A2). 20 Natura 2000 habitat types are represented in the database, including beech and oak (9010, 9150, 9170) or spruce forests (9410). Alluvial forests are not represented by the datasets but are rarely sampled in the whole database (Burrascano *et al.* 2021) (Table 3, Table A2).

Table 3: Forest categories and types according to EEA 2006 and Natura2000 habitat type according to CE/42/93.

dataID	Forest category	Forest type	Natura2000 Habitat type
CH_TL	7	7.3	NA
CZ_JH1	5,6,7,14	5.2, 5.9, 6.4, 7.2, 14	9010, 9130, 9110, 9170
DE_ID	6	6.4	9110
DE_JP	7	7.2	
DK_JC1	6	6.1	9110, 9130, 9150
DK_JC3	6	6.1	9110, 9130
FR_AM	6	6.2	9160
FR_JP	3	3.2	9130
FR_YP	3-7	3.2, 4.1, 5.1, 5.4, 6.1, 6.2, 7.1, 7.2	91A0, 91I0, 91P0, 9150, 9180, 91Q0, 91C0, 91H0'
GR_FX	10	10.1.2	9540
HU_RA	8	8.2	91M0, 91H0
IT_EA	3,6,7,8	3.1, 8.1, 3.2, 6.3, 7.3, 7.4,	9110, 9130, 9210, 9410, 91L0
LT_GB	1,2	1.2, 2.2	9010, 91T0
SK_DK	3	3.2	9410
SK_MM	3	3.2	9410
SK_MS	3	3.2	9410

Out of the 16 datasets that included TreMs in their surveys, 3 did not contain measurements of deadwood and 2 no measurements of the living stand volume. Within two datasets (DE_ID and IT_EA1 & 3) measurements of the living stand and measurements of microhabitats were not combined (Table 4). The single datasets include in total 1142 plots where compositional data are available, 1112 plots where volumetric data are available and 690 plots where the spatial arrangement of trees was recorded.

34% of all trees recorded (dead and alive) bore TreMs. The recorded number of living trees is much higher than of dead trees, thus the number of living trees with TreMs is also distinctly higher than of dead trees with TreMs. However, within dead trees the percentage of trees with TreMs (48 %) is higher than in living trees (33 %) (Fig. 3, left). Within living trees TreMs occur in all vitality classes but most in class 2 and 3, which are combined the most common classes (Fig. 3, top right). Within dead trees the share of trees with TreMs is more or less independent of the decay class and follows the general pattern with decay class 1 and 2 being the most common (Fig. 3, lower right).

In total, 70 tree species were recorded in the analysed data sets (including ‘unknown’, deciduos, coniferous and 6 species determined to genus level) (Fig. 4). 17 of these species had no trees with TreMs (including ‘deciduous’ and ‘Salix spec.’), which were mostly rarely present in the data set (e.g. *Pyrus pyraster* or *Juglans regia*) or unlikely to develop TreMs (e.g. *Corylus avellana* or *Ilex aquifolium*) (Fig. 4). Non of the recorded tree species was exclusively represented in one data set. However, the Quercus species, were mainly recorded in two data sets from Hungary or France (HU_RA, FR_YP). *Fagus sylvatica* was, by far, the most common recorded tree species, followed by *Picea abies*, various Quercus species and *Abies alba* (Fig. 4). However, only about 30% of *Fagus sylvatica* and *Abies alba* trees bore TreMs, whereas about half of the *Picea abies* trees bore TreMs. Although the Quercus trees determined to species level (either Q. cerris, Q. petraea, Q. pubescens, or Q. robur) included only a few trees with TreMs, 96 % of Quercus trees not determined to species level bore TreMs. In total the number of broadleaved trees with TreMs was higher compared to coniferous. However, the percentage of trees with TreMs is smaller in broadleaved trees (29%) than in coniferous (45%) (Fig. 4, inset).

Living trees with TreMs had a higher diameter compared to living trees without TreMs or dead trees (with or without TreMs). The same pattern was found for the height and volume of trees, which is again highest for living trees and therein for Trees with TreMs (Appendix, Fig. A2-A5).

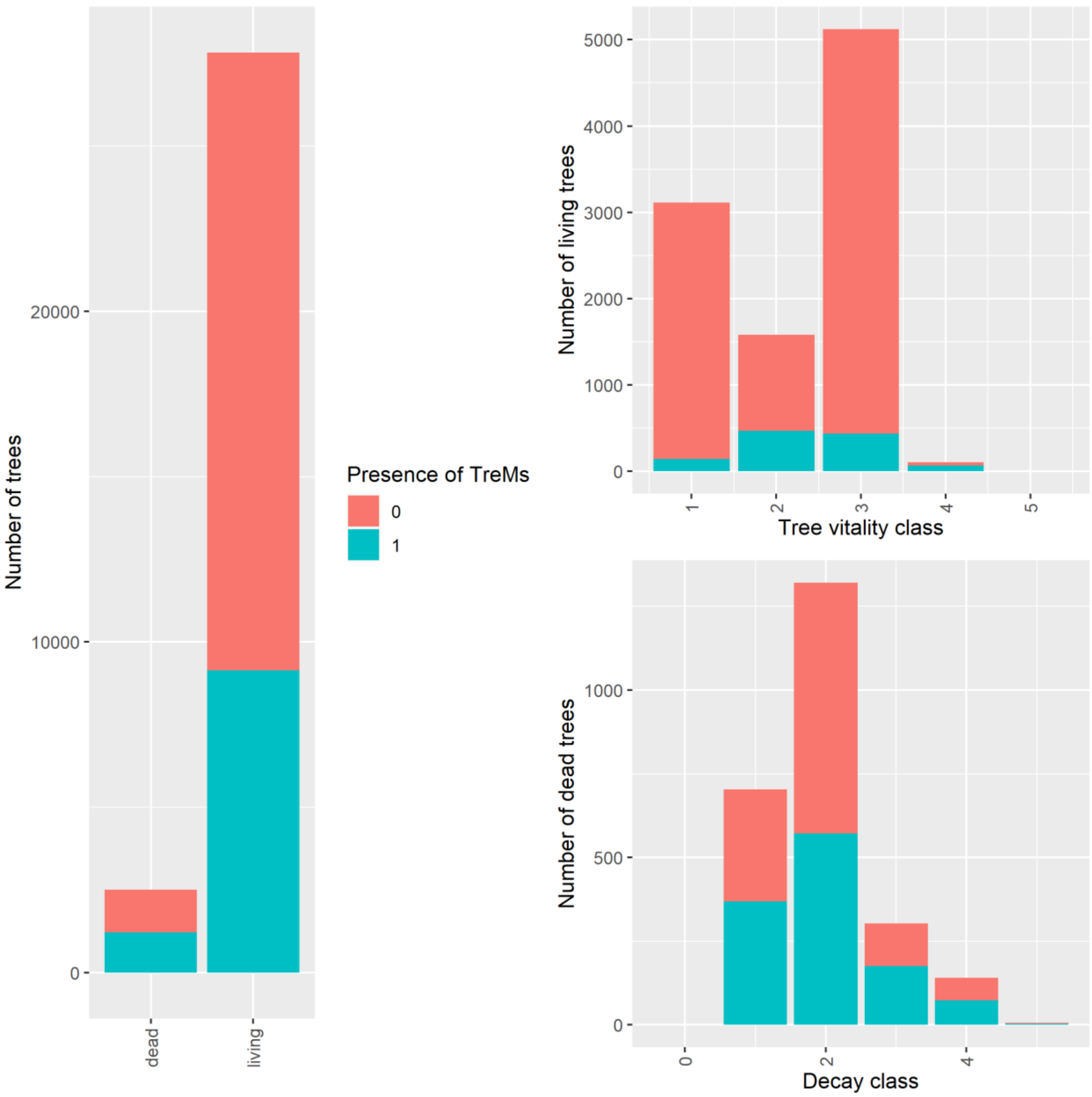


Figure 3: Number of trees which were recorded as living trees (living) or snags (dead). The colours indicate whether trees bore TreMs (1 = blue) or not (0 = red). Inset top right: Number of living trees, classified into vitality classes (1: healthy – continuing numbers descending health). Inset lower right: Number of dead trees classified into decay classes (0: living, 5: heavily decayed). Please note, that the vitality and decay classes were not given for all living or dead trees, wherefor the total numbers within this graph diverge from each other.

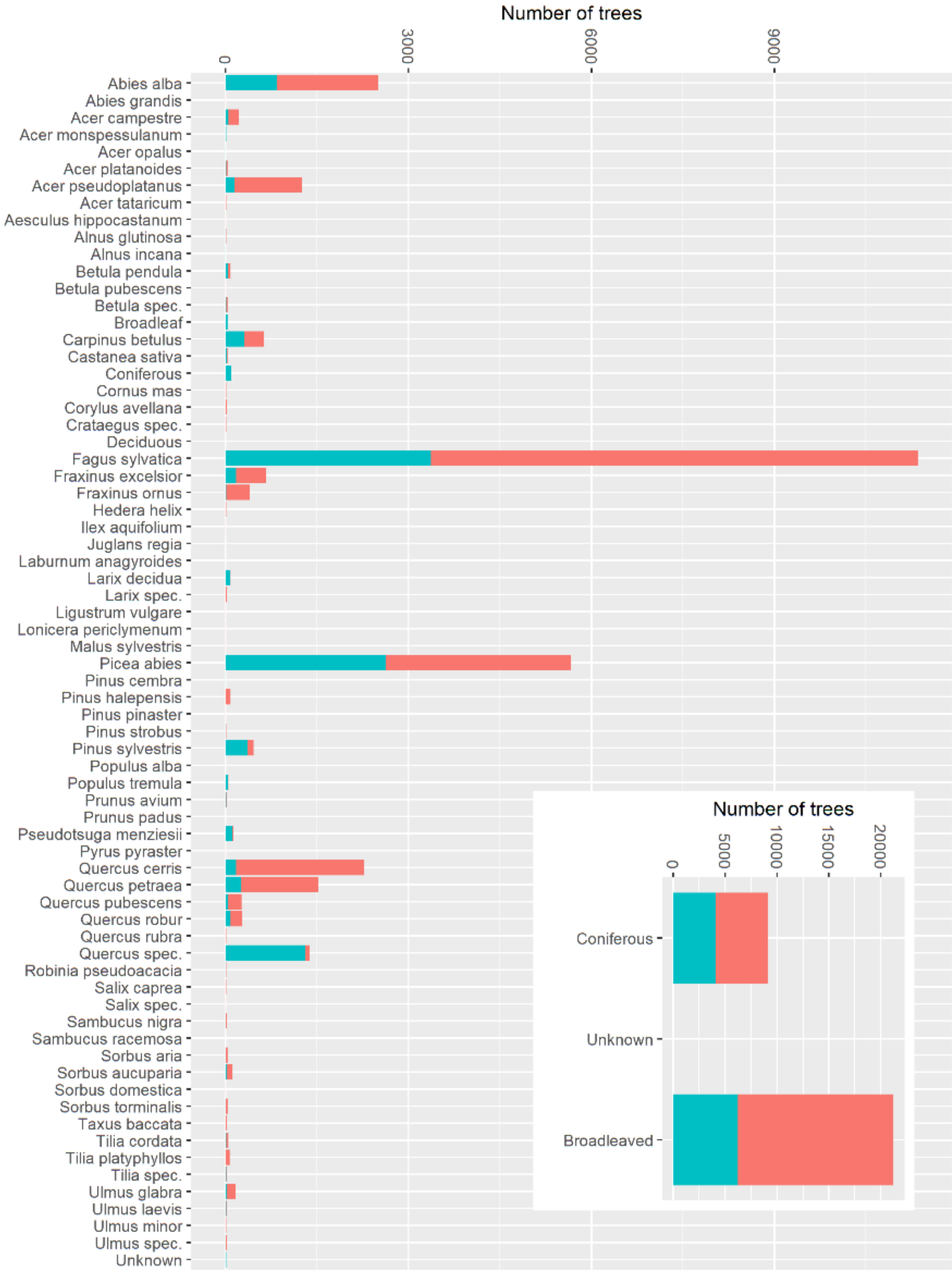


Figure 4: Number of trees from different tree species according to their live status. The colours indicate whether trees bore TreMs (1 = blue) or not (0 = red). Inset top right: Number of trees from coniferous or broadleaved trees species with (1 = blue) and without (0 = red) the presence of TreMs.

Table 4: information on stand and deadwood data reported for the single datasets. C: Circular, S: Square, R: Rectangle, ll: lowland, mt: mountain

0	Data ID	CH_TL	CZ_JH1	DE_ID	DE_JP	DK_JC3	FR_AM	FR_JP	FR_YP	GR_FX	HU_RA	IT_EA1	IT_EA2	IT_EA3	LT_GB	SK_DK	SK_MM	SK_MS
Volumetric data	Number of plots	69	106	45	135	25	33	70	237		22	54	78	6	174	18	22	18
0	Shape	C	S	C	S	C	R	C	C		S	C	C	C	C	C	C	C
0	Plot size	500	2500	500	10000	1000	5000	1257	1256 (ll), 2827 (mt)		6400	1256	530	2827	500	1000	1000	1000
0	Minimum diameter	36	5	30	7	1	7.5	30	20 (lls), 30 (mts)		10	5	5	5	6	6	6	6
0	Nested	YES	NO	YES	NO	YES	NO	YES	YES		NO	NO	NO	NO	NO	NO	NO	NO
Tree positions	Number of plots	69	106	45	0	0	33	0	237		22	54	60	6	0	18	22	18
0	Shape	C	S	C	NA	NA	R	NA	C		S	C	C	C	NA	C	C	C
0	Plot size	500	2500	500	NA	NA	5000	NA	1256 (ll), 2827 (mt)		6500	1256	530	2827	NA	1000	1000	1000
0	Minimum diameter	36	5	30	NA	NA	7.5	NA	20 (lls), 30 (mts)		10	5	5	5	NA	6	6	6
0 Compositiona l data	Nested	YES	NO	YES	NA	NA	NO	NA	YES		NO	NO	NO	NO	NA	NO	NO	NO
0	Number of plots	69	106	69	135	25	33	70	237		28	54	78	6	174	18	22	18
0	Shape	C	S	C	S	C	R	C	C		S	C	C	C	C	C	C	C
0	Plot size	500	2500	500	10000	1000	5000	1257	1256 (ll), 2827 (mt)		10000	1256	530	2827	500	1000	1000	1000
0	Minimum diameter	36	5	30	NA	0	7.5	30	20 (lls), 30 (mts)		10	5	5	5	6	6	6	6
0 0	Nested	YES	NO	YES	NO	NO	NO	YES	YES		NO	NO	NO	NO	YES	NO	NO	NO
dead trees and snags	Number of plots	69	106	69	135	400	25	70	237		22	54	78	3	174	18	22	18
lying deadwood and stumps	Number of plots	69	106	69	135	400	25	70	237		22	54	78	3	174	18	22	18
0	Shape	Lt	S	C	S	Lt	C	C	C		S	C	C	C	C	C	C	C
0	Size	NA	2500.0	500.0	10000.0	NA	1000.0	1257.0	1257.0		6400.0	1256.0	530.0	2827.0	500.0	1000.0	1000.0	1000.0

0	Minimum diameter	7.0	5.0	12.0	no diameter survey	10.0	10.0	30.0	30.0		10.0	5.0	5.0	5.0	14	6.0	6.0	6.0
0	Nested	NO	NO	NO	NO	YES	YES	YES	YES		NO	NO	NO	NO	NO	NO	NO	NO
0	2. Shape	NA	NA	NA	NA	Lt	S	C	Lt		NA	NA	NA	NA	NA	NA	NA	NA
0	2. Size	NA	NA	NA	NA	NA	100.0	314.0	NA		NA	NA	NA	NA	NA	NA	NA	NA
0	2. Minimum diameter	NA	NA	NA	NA	5.0	5.0	7.5	5.0		NA	NA	NA	NA	NA	NA	NA	NA

Description of taxonomic data within the datasets

All datasets included at least 3 taxa, except HU_RA were only Tracheophyta and Coleoptera were reported so far. Out of the 16 datasets birds (Aves) were, with records in 15 of 16 datasets, the most represented group (Table 6). Single datasets contained 3 to 8 taxonomic groups (Table 5 and A2).

Table 5: representation of taxonomic groups within the 17 datasets that contain TreMs.

Taxonomic group	Number of plots	Number of datasets
Tracheophyta	1603	13
Aves	1016	15
Basidiomycota	902	9
Coleoptera	874	13
Bryophyta	872	9
Lichens	800	12

Discussion

The BOTTOMS-UP platform includes 16 datasets with TreMs and multi-taxon data. This provides a good basis for analysing the relationship between TreMs and biodiversity. Some TreMs such as fungal fruiting bodies or cavities are evident for analyses due to their large representation. At least six taxonomic groups can be included in biodiversity measures covering auto- and heterotrophic groups as well as different levels in the food chain. Differences in forest management or biogeographic region can be included using stand data on living and dead trees

The catalogue by Larrieu et al. (2018) represent a comprehensive variety of TreMs, with detailed descriptions and pictures. The TreMs represented in this catalogue cover TreM categories described in earlier catalogues (e.g. Johann & Schaich, 2016; Read, 2000; Winter & Möller, 2008) with a few exceptions of e.g. root plates or man-made TreMs such as pollarded trees. Within the single datasets not all original TreM coding can be translated mostly because the detail within their description allows no translation into the catalogue of Larrieu et al. (2018), e.g. polypores_P3 (dataset: CH_TL) (110 or 111) since perennial an annual polypores are not separated in the data. Therefore, one needs to consider analyzing these categories as 'conks of fungi as proposed in (Courbaud et al., 2022). However, due to the specific habitat single TreMs provide, the selection of TreMs included and new categories need to be made by ecological reasoning. However, one need to consider co-occurrences of TreMs when using the data since e.g. cracks, burr-canker and crown deadwood are often co-occurring on deciduous trees (Jackson & Jackson, 2004; Larrieu et al., 2021).

Fungal fruiting bodies are represented in most of the datasets. Fruiting bodies harbor a large community of insects, with many monophagous ones (Jonsell & Nordlander, 2002; Komonen, 2003; Larrieu & Cabanettes, 2012). Fungi brackets can be quite rare in managed forests (Bütler et al., 2020) possibly because fungal richness depends on tree age and deadwood continuity (Heilmannclausen & Christensen, 2005) as well as snags (Paillet et al., 2019).

Injuries where the sapwood is exposed were recorded by 15 datasets, whereas injuries where the heartwood is exposed were less often recorded, probably because they are only relevant in tree species possessing true heart wood. Both types of injuries are quite common, also in managed forests since they are initiated during logging activities (Larrieu & Cabanettes, 2012). Fungi and insects can colonize these TreMs and develop them into mould filled cavities (Bütler et al., 2020).

Trunk and mould cavities are represented in 14 out of 17 datasets. These are relatively rare structures (Bütler et al., 2020) which provide a habitat for a high share of red list species (Schauer et al., 2017). Although management does not necessarily reduce cavities in general their presence is strongly determined by the share of deciduous trees and snags (Larrieu & Cabanettes, 2012; Paillet et al., 2017).

Woodpecker cavities are represented in 11 out of 17 datasets. Woodpecker holes, especially large ones build by the black woodpecker, provide a habitat for a large number of bird species but also mammals and insect (Johnsson et al., 1993). Their presence often goes alongside a colonization of fungi and depends on certain site conditions and tree species (Jackson & Jackson, 2004). Other TreMs such as dendrotelms or insect galleries are rarely recorded, but nests were the least common TreM recoded in the database.

The database therefore allows a meaningful analysis of relationships between TreMs and biodiversity since the recorded taxa contain species dependent on the specific TreMs such as birds, fungi or beetles which have species dependent on e.g. cavities, exposed wood or fungal fruiting bodies. The inclusion of epiphytic bryophytes and lichen as well as soil living bryophytes and plants represent species which are less dependent, but positively correlate with TreMs as it can be substantially influenced by microclimate or forest use history and current management. However, there is an underrepresentation of many taxonomic groups. Thus, Amphibia and Reptilia although they are shown to depend on e.g. Root buttress concavity different groups of Endopterygota, with the exception of beetles, mammals and soil living organisms.

Literature

Asbeck, T., Großmann, J., Paillet, Y., Winiger, N., & Bauhus, J. (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

Bähner, K. W., Tabarelli, M., Büdel, B., & Wirth, R. (2020). Habitat fragmentation and forest management alter woody plant communities in a Central European beech forest landscape. Biodiversity and Conservation, 29(8), 2729-2747. https://doi.org/10.1007/s10531-020-01996-6

Basile, M., Asbeck, T., Jonker, M., Knuff, A. K., Bauhus, J., Braunisch, V., Mikusinski, G., & Storch, I. (2020). What do tree-related microhabitats tell us about the abundance of forest-dwelling bats, birds, and insects? J Environ Manage, 264, 110401. https://doi.org/10.1016/j.jenvman.2020.110401

Bruciamacchie, M., Gilg, O., & Despert, Y. (2007). Un nouveau protocole pour le suivi des forêts - dans les espaces naturels protégés. Espaces Naturels.

Burrascano, S., Trentanovi, G., Paillet, Y., Heilmann-Clausen, J., Giordani, P., Bagella, S., Bravo-Oviedo, A., Campagnaro, T., Campanaro, A., Chianucci, F., De Smedt, P., García-Mijangos, I., Matošević, D., Sitzia, T., Aszalós, R., Brazaitis, G., Cutini, A., D'Andrea, E., Doerfler, I., . . . Ódor, P. (2021). Handbook of field sampling for multi-taxon biodiversity studies in European forests. Ecological Indicators, 132. https://doi.org/10.1016/j.ecolind.2021.108266

Butchart, S. H., Walpole, M., Collen, B., van Strien, A., Scharlemann, J. P., Almond, R. E., Baillie, J. E., Bomhard, B., Brown, C., Bruno, J., Carpenter, K. E., Carr, G. M., Chanson, J., Chenery, A. M., Csirke, J., Davidson, N. C., Dentener, F., Foster, M., Galli, A., . . . Watson, R. (2010). Global biodiversity: indicators of recent declines. Science, 328(5982), 1164-1168. https://doi.org/10.1126/science.1187512

Bütler, R., Lachat, T., Krumm, F., Kraus, D., & Larrieu, L. (2020). Field guide to tree-related microhabitats. Descriptions and size limits for their inventory.

Courbaud, B., Larrieu, L., Kozak, D., Kraus, D., Lachat, T., Ladet, S., Müller, J., Paillet, Y., Sagheb-Talebi, K., Schuck, A., Stillhard, J., Svoboda, M., & Zudin, S. (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/https://doi.org/10.1111/1365-2664.14068

Debeljak, M. (2006). Coarse woody debris in virgin and managed forest. Ecological Indicators, 6(4), 733-742. https://doi.org/10.1016/j.ecolind.2005.08.031

Drössler, L., Feldmann, E., Glatthorn, J., Annighöfer, P., Kucbel, S., & Tabaku, V. (2016). What Happens after the Gap?— Size Distributions of Patches with Homogeneously Sized Trees in Natural and Managed Beech Forests in Europe. Open Journal of Forestry, 06(03), 177-190. https://doi.org/10.4236/ojf.2016.63015

Hannah, L., Carr, J. L., & Landerani, A. (1995). Human Disturbance and Natural Habitat - a Biome Level Analysis of a Global Data Set. Biodiversity and Conservation, 4(2), 128-155. https://doi.org/Doi 10.1007/Bf00137781

Heilmann-Clausen, J., & Christensen, M. (2005). Wood-inhabiting macrofungi in Danish beech-forests ? conflicting diversity patterns and their implications in a conservation perspective. Biological Conservation, 122(4), 633-642. https://doi.org/10.1016/j.biocon.2004.10.001

Hofmeister J., Hošek J., Brabec M., Hermy M., Dvořák D., Fellner R., Malíček J., Palice Z., Tenčík A., Holá E., Novozámská E., Kuras T., Trnka F., Zedek M., Kašák J., Gabriš R., Sedláček O., Tajovský K., Kadlec T. (2019) Shared affinity of various forest-dwelling taxa point to the continuity of temperate forests. Ecological Indicators 101, 904-912 DOI: 10.1016/j.ecolind.2019.01.018
Jackson, J. A., & Jackson, B. J. S. (2004). Ecological Relationships between Fungi and Woodpecker Cavity Sites. The Condor, 106(1). https://doi.org/10.1093/condor/106.1.37

Johann, F., & Schaich, H. (2016). Land ownership affects diversity and abundance of tree microhabitats in deciduous temperate forests. Forest Ecology and Management, 380, 70-81. https://doi.org/10.1016/j.foreco.2016.08.037

Johnsson, K., Nilsson, S. G., & Tjernberg, M. (1993). Characteristics and utilization of old Black Woodpecker Dryocopus martius holes by hole-nesting species. Ibis, 235(4), 410-416.

Jonsell, M., & Nordlander, G. (2002). Insects in polypore fungi as indicator species: a comparison between forest sites differing in amounts and continuity of dead wood. Forest Ecology and Management, 157(1), 101-118. https://doi.org/https://doi.org/10.1016/S0378-1127(00)00662-9

Komlós, M., Botta-Dukát, Z., Bölöni, J. et al. Tall, large-diameter trees and dense shrub layer as key determinants of the abundance and composition of bird communities in oak-dominated forests. J. For. Res. 35, 62 (2024). https://doi.org/10.1007/s11676-024-01714-w

Komonen, A. (2003). Hotspots of Insect Diversity in Boreal Forests. Conservation biology, 17(4), 976-981. https://doi.org/10.1046/j.1523-1739.2003.02076.x

Kozák, D., Mikoláš, M., Svitok, M., Bače, R., Paillet, Y., Larrieu, L., Nagel, T. A., Begovič, K., Čada, V., Diku, A., Frankovič, M., Janda, P., Kameniar, O., Keren, S., Kjučukov, P., Lábusová, J., Langbehn, T., Málek, J., Mikac, S., . . . Svoboda, M. (2018). Profile of tree-related microhabitats in European primary beech-dominated forests. Forest Ecology and Management, 429, 363-374. https://doi.org/10.1016/j.foreco.2018.07.021

Kraus, D., Bütler, R., Krumm, F., Lachat, T., Larrieu, L., Mergner, U., Paillet, Y., Schuck, A., & Winter, S. (2016). Catalogue of tree microhabitats: Reference field list.

Kraus, D., & Krumm, F. (2013). Integrative approaches as an opportunity for the conservation of forest biodiversity

284.

Lachat, T., & Müller, J. (2018). Importance of Primary Forests for the Conservation of Saproxylic Insects. In M. D. Ulyshen (Ed.), Saproxylic Insects: Diversity, Ecology and Conservation (pp. 581-605). Springer International Publishing. https://doi.org/10.1007/978-3-319-75937-1_17

Larrieu, L., & Cabanettes, A. (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(8), 1433-1445. https://doi.org/10.1139/x2012-077

Larrieu, L., Cabanettes, A., Courbaud, B., Goulard, M., Heintz, W., Kozák, D., Kraus, D., Lachat, T., Ladet, S., Müller, J., Paillet, Y., Schuck, A., Stillhard, J., & Svoboda, M. (2021). Co-occurrence patterns of tree-related microhabitats: A method to simplify routine monitoring. Ecological Indicators, 127, 107757. https://doi.org/https://doi.org/10.1016/j.ecolind.2021.107757

Larrieu, L., Paillet, Y., Winter, S., Bütler, R., Kraus, D., Krumm, F., Lachat, T., Michel, A. K., Regnery, B., & Vandekerkhove, K. (2018). Tree related microhabitats in temperate and Mediterranean European forests: A hierarchical typology for inventory standardization. Ecological Indicators, 84, 194-207.

Lelli, C., Bruun, H. H., Chiarucci, A., Donati, D., Frascaroli, F., Fritz, Ö., Goldberg, I., Nascimbene, J., Tøttrup, A. P., Rahbek, C., & Heilmann-Clausen, J. (2019). Biodiversity response to forest structure and management: Comparing species richness, conservation relevant species and functional diversity as metrics in forest conservation. Forest Ecology and Management, 432, 707-717. https://doi.org/10.1016/j.foreco.2018.09.057

Müller, J., Bußler, H., & Blaschke, M. (2007). Assemblages of wood-inhabiting fungi related to silvicultural management intensity in beech forests in southern Germany. European Journal of Forest Research, 126(4), 513-527. https://doi.org/DOI 10.1007/s10342-007-0173-7

Müller, J., Jarzabek-Müller, A., Bussler, H., & Gossner, M. M. (2014). Hollow beech trees identified as keystone structures for saproxylic beetles by analyses of functional and phylogenetic diversity. Animal Conservation, 17(2), 154-162. https://doi.org/10.1111/acv.12075

Muukkonen, P. (2007). Generalized allometric volume and biomass equations for some tree species in Europe. European Journal of Forest Research, 126(2), 157-166. https://doi.org/10.1007/s10342-007-0168-4

Paillet, Y., Archaux, F., Boulanger, V., Debaive, N., Fuhr, M., Gilg, O., Gosselin, F., & Guilbert, E. (2017). Snags and large trees drive higher tree microhabitat densities in strict forest reserves. Forest Ecology and Management, 389, 176-186. https://doi.org/10.1016/j.foreco.2016.12.014

Paillet, Y., Archaux, F., du Puy, S., Bouget, C., Boulanger, V., Debaive, N., Gilg, O., Gosselin, F., Guilbert, E., & Firn, J. (2018). The indicator side of tree microhabitats: A multi-taxon approach based on bats, birds and saproxylic beetles. Journal of Applied Ecology, 55(5), 2147-2159. https://doi.org/10.1111/1365-2664.13181

Paillet, Y., Coutadeur, P., Vuidot, A., Archaux, F., & Gosselin, F. (2015). Strong observer effect on tree microhabitats inventories: A case study in a French lowland forest. Ecological Indicators, 49, 14-23. https://doi.org/10.1016/j.ecolind.2014.08.023

Paillet, Y., Debaive, N., Archaux, F., Cateau, E., Gilg, O., & Guilbert, E. (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

Read, H. (2000). Veteran trees - A guide to good management. Veteran Trees Initiative. https://ancienttreeforum.co.uk/wp-content/uploads/2015/03/Veteran-Trees-A-Guide-to-Good-Management-almost-complete.pdf

Regnery, B., Couvet, D., Kubarek, L., Julien, J.-F., & Kerbiriou, C. (2013). Tree microhabitats as indicators of bird and bat communities in Mediterranean forests. Ecological Indicators, 34, 221-230. https://doi.org/10.1016/j.ecolind.2013.05.003

Sabatini, F. M., Bluhm, H., Kun, Z., Aksenov, D., Atauri, J. A., Buchwald, E., Burrascano, S., Cateau, E., Diku, A., Duarte, I. M., Fernández López, Á. B., Garbarino, M., Grigoriadis, N., Horváth, F., Keren, S., Kitenberga, M., Kiš, A., Kraut, A., Ibisch, P. L., . . . Kuemmerle, T. (2021). European primary forest database v2.0. Scientific Data, 8(1), 220. https://doi.org/10.1038/s41597-021-00988-7

Schauer, B., Bong, J., Popp, C., Obermaier, E., & Feldhaar, H. (2018). Dispersal limitation of saproxylic insects in a managed forest? A population genetics approach. Basic and Applied Ecology, 32, 26-38. https://doi.org/10.1016/j.baae.2018.01.005

Schauer, B., Steinbauer, M. J., Vailshery, L. S., Müller, J., Feldhaar, H., & Obermaier, E. (2017). Influence of tree hollow characteristics on saproxylic beetle diversity in a managed forest. Biodiversity and Conservation. https://doi.org/10.1007/s10531-017-1467-9

Stiers, M., Willim, K., Seidel, D., Ehbrecht, M., Kabal, M., Ammer, C., & Annighöfer, P. (2018). A quantitative comparison of the structural complexity of managed, lately unmanaged and primary European beech (Fagus sylvatica L.) forests. Forest Ecology and Management, 430, 357-365. https://doi.org/https://doi.org/10.1016/j.foreco.2018.08.039

Stokland, J. N., Siitonen, J., & Jonsson, B. G. (2012). Biodiversity in dead wood. Cambridge University Press.

Tinner, R., Streit, K., Brigitte Commarmot, B., & Brang, P. (2013). Stichprobeninventur in Schweizer Naturwaldreservaten – Anleitung zu Feldaufnahmen.

van Buuren, S., Groothuis-Oudshoorn, K., Robitzsch, A., Vink, G., Doove, L., & Jolani, S. (2015). Package ‘mice’. Computer software.

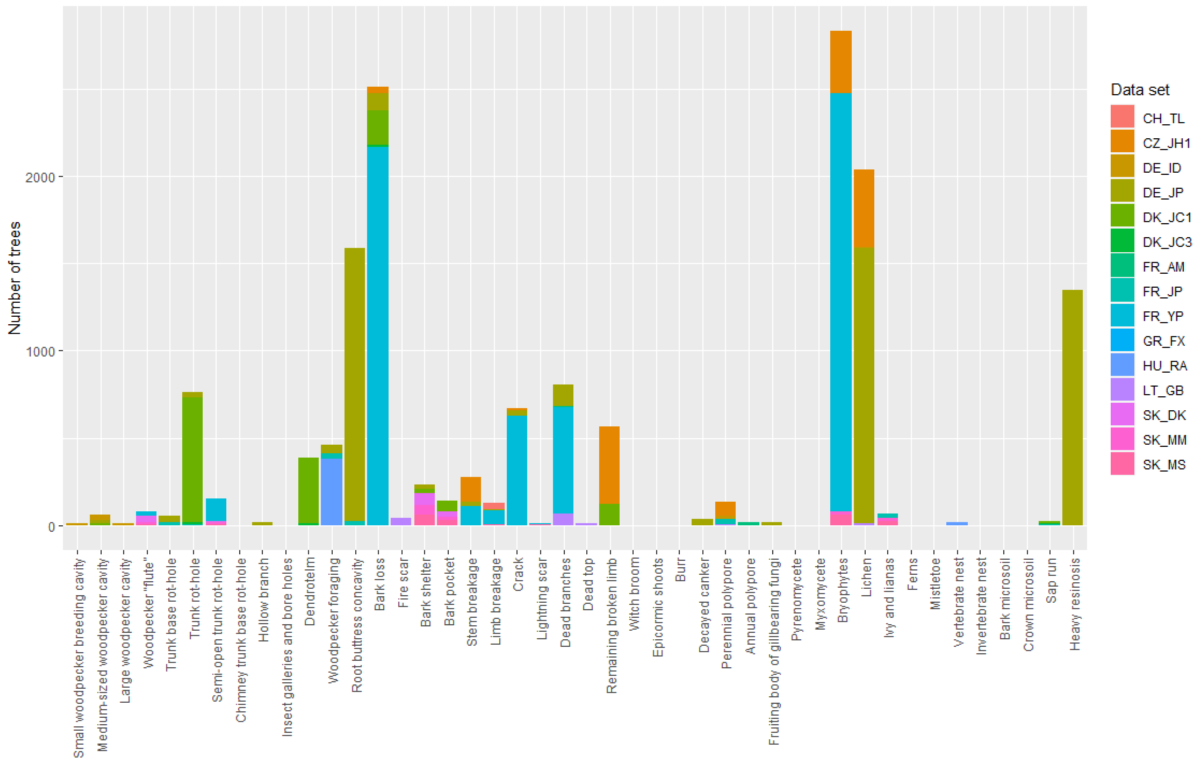
Vuidot, A., Paillet, Y., Archaux, F., & Gosselin, F. (2011). Influence of tree characteristics and forest management on tree microhabitats. Biological Conservation, 144(1), 441-450. https://doi.org/10.1016/j.biocon.2010.09.030

Winter, S., & Möller, G. C. (2008). Microhabitats in lowland beech forests as monitoring tool for nature conservation. Forest Ecology and Management, 255(3-4), 1251-1261. https://doi.org/10.1016/j.foreco.2007.10.029

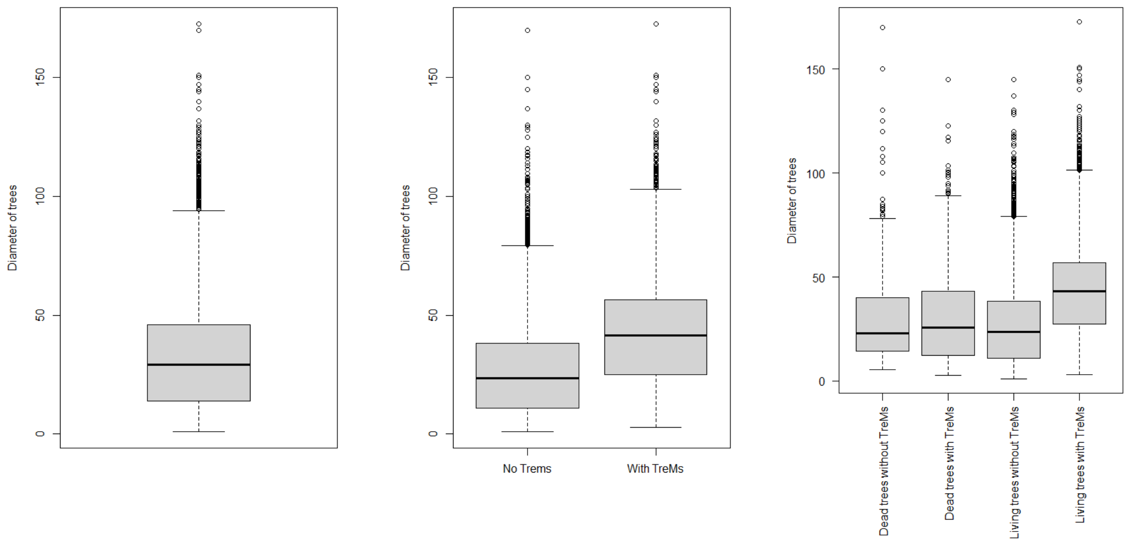
Zeller, L., Baumann, C., Gonin, P., Heidrich, L., Keye, C., Konrad, F., Larrieu, L., Meyer, P., Sennhenn-Reulen, H., Müller, J., Schall, P., & Ammer, C. (2022). Index of biodiversity potential (IBP) versus direct species monitoring in temperate forests. Ecological Indicators, 136. https://doi.org/10.1016/j.ecolind.2022.108692

Appendix

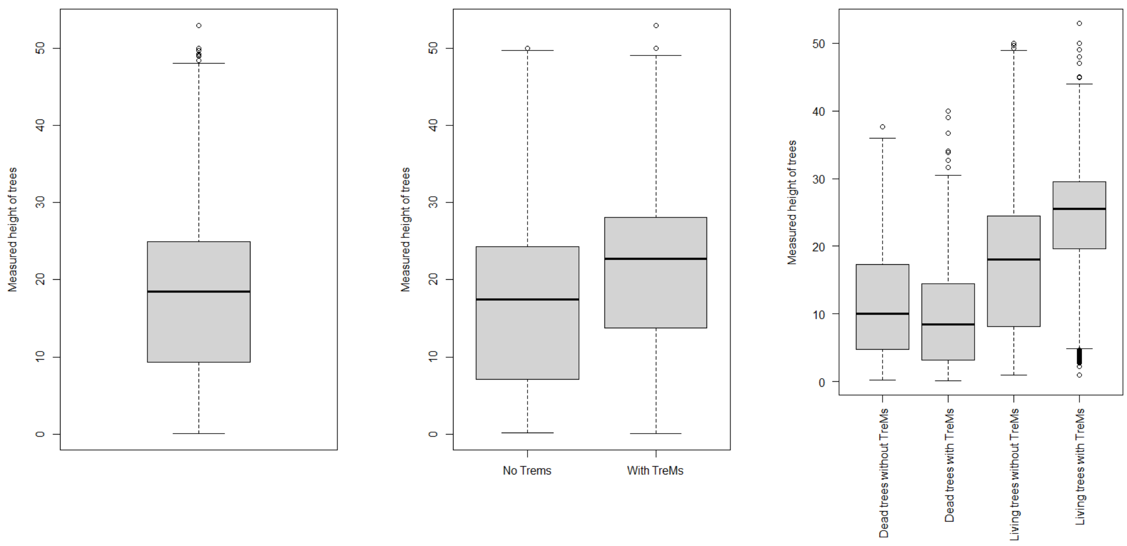
Figures



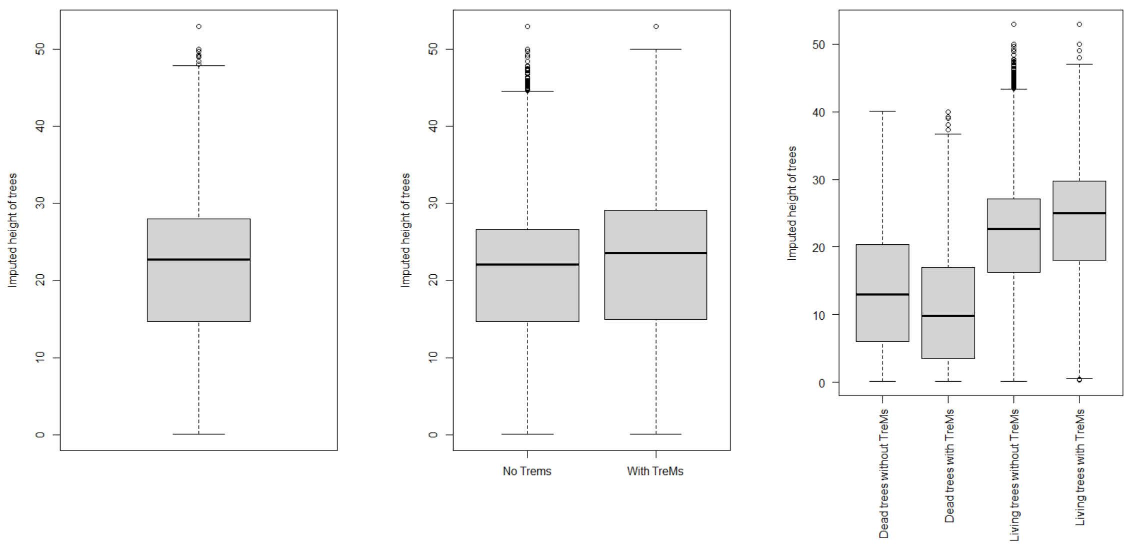
Appendix, Figure A1: Number of trees with different TreM types within the 16 data sets. The colours indicate in which data sets the trees were found.



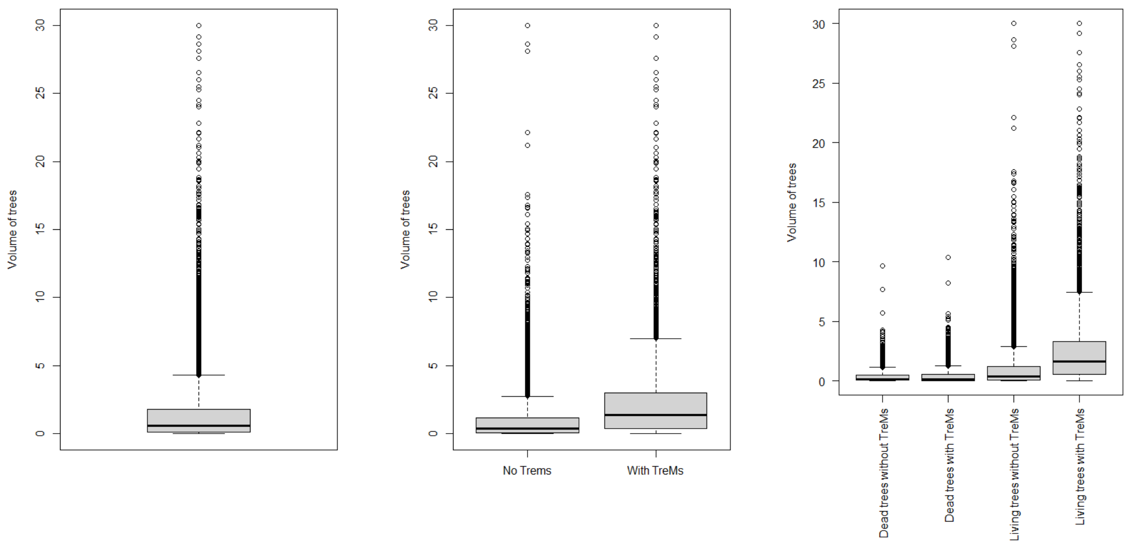
Appendix, Figure A2: Diameter of trees. Left panel: all trees, central panel: trees separated into trees without and with TreMs, right panel: trees separated into trees without and with TreMs and their live status (dead = snags, living = living trees).



Appendix, Figure A3: Height of trees. Left panel: all trees, central panel: trees separated into trees without and with TreMs, right panel: trees separated into trees without and with TreMs and their live status (dead = snags, living = living trees).



Appendix, Figure A4: Imputed height of trees, using the method of (van Buuren et al., 2015). Left panel: all trees, central panel: trees separated into trees without and with TreMs, right panel: trees separated into trees without and with TreMs and their live status (dead = snags, living = living trees).



Appendix, Figure A5: Volume of trees, calculated using an imputed height, calculated with the method of Muukkonen (2007). Left panel: all trees, central panel: trees separated into trees without and with TreMs, right panel: trees separated into trees without and with TreMs and their live status (dead = snags, living = living trees).

Tables

A1: Datasets from the COST Bottoms-Up database containing records of TreMs, their original coding and the respective translations into the catalogue of Larrieu *et al.* (2018).

Dataset	Original.Code	Larrieu et al 2018
CH_TL	hole_in_stem_P4	102
CH_TL	mould_cavity_H1	102
CH_TL	insect_galeries_P9	103
CH_TL	deadwood_in_crown_G5	107
CH_TL	polypores_P3	NA
CH_TL	bark_lesion	NA
CH_TL	crown_breakage_G2	NA
CH_TL	crown_breakage_G2	NA
CH_TL	stem_breakage_G1	NA
CH_TL	stem_breakage_G1	NA
CH_TL	type_stem_breakage_G1	NA
CH_TL	type_stem_breakage_G1	NA
CH_TL	cracks_and_fissures_F5	NA
CH_TL	cracks_and_fissures_F5	NA
CH_TL	sap_resin_flow_S4	115
CZ_JH1	Large cavity	102
CZ_JH1	Small cavity	102
CZ_JH1	Bark loss	NA
CZ_JH1	Large bark loss	1051
CZ_JH1	Stem breakage	1061
CZ_JH1	Limb breakage	1073
CZ_JH1	Crack	NA
CZ_JH1	Crack	NA
CZ_JH1	Rot holes	NA
CZ_JH1	Rot holes	NA
DE_ID	CV11	1011
DE_ID	CV12	1012
DE_ID	CV13	1013
DE_ID	CV21_22	102
DE_ID	CV23_24	102
DE_ID	CV31_32	102
DE_ID	EP12	1101
DE_ID	EP31	1121
DE_ID	EP32	1122
DE_ID	EP33	1123
DE_ID	IN11_12	NA
DE_JP	Microhabitats.Bark.BA11	1053
DE_JP	Microhabitats.Bark.BA12	1054
DE_JP	Microhabitats.Bark.BA21	NA
DE_JP	Microhabitats.Cavities.Woodpeckercavities.CV11	1011
DE_JP	Microhabitats.Cavities.Woodpeckercavities.CV12	1012

DE_JP	Microhabitats.Cavities.Woodpeckercavities.CV13	1013
DE_JP	Microhabitats.Cavities.Woodpeckercavities.CV14	1042
DE_JP	Microhabitats.Cavities.Woodpeckercavities.CV15	1014
DE_JP	Microhabitats.Cavities.Trunkmouldcavities.CV21	1021
DE_JP	Microhabitats.Cavities.Trunkmouldcavities.CV22	1021
DE_JP	Microhabitats.Cavities.Trunkmouldcavities.CV23	1022
DE_JP	Microhabitats.Cavities.Trunkmouldcavities.CV24	1022
DE_JP	Microhabitats.Cavities.Trunkmouldcavities.CV25	1023
DE_JP	Microhabitats.Branchholes.CV31	NA
DE_JP	Microhabitats.Branchholes.CV32	1022
DE_JP	Microhabitats.Branchholes.CV33	1026
DE_JP	Microhabitats.Dendrotelms.CV41	NA
DE_JP	Microhabitats.Dendrotelms.CV42	1041
DE_JP	Microhabitats.Dendrotelms.CV43	NA
DE_JP	Microhabitats.Dendrotelms.CV44	1041
DE_JP	Microhabitats.Insectgalleries.CV51	1031
DE_JP	Microhabitats.Insectgalleries.CV52	1031
DE_JP	Microhabitats.Deadbranchescrowndeadwood.DE11	1071
DE_JP	Microhabitats.Deadbranchescrowndeadwood.DE12	1071
DE_JP	Microhabitats.Deadbranchescrowndeadwood.DE13	1071
DE_JP	Microhabitats.Deadbranchescrowndeadwood.DE14	1071
DE_JP	Microhabitats.Deadbranchescrowndeadwood.DE15	1072
DE_JP	Microhabitats.fruitingbodiesfungi.EP11	1111
DE_JP	Microhabitats.fruitingbodiesfungi.EP12	1101
DE_JP	Microhabitats.fruitingbodiesfungi.EP13	1112
DE_JP	Microhabitats.fruitingbodiesfungi.EP14	1113
DE_JP	Microhabitats.EP21	1114
DE_JP	Microhabitats.epiphyticcryptophanerogmas.EP31	1121
DE_JP	Microhabitats.epiphyticcryptophanerogmas.EP32	1122
DE_JP	Microhabitats.epiphyticcryptophanerogmas.EP33	1123
DE_JP	Microhabitats.epiphyticcryptophanerogmas.EP34	1124
DE_JP	Microhabitats.epiphyticcryptophanerogmas.EP35	1125
DE_JP	Microhabitats.rootbuttresscavities.GR11	NA
DE_JP	Microhabitats.rootbuttresscavities.GR12	1044
DE_JP	Microhabitats.rootbuttresscavities.GR13	NA
DE_JP	Microhabitats.Witchesbroom.GR21	1081
DE_JP	Microhabitats.Witchesbroom.GR22	1082
DE_JP	Microhabitats.Cankersandburrs.GR31	1091
DE_JP	Microhabitats.Cankersandburrs.GR32	1092
DE_JP	Microhabitats.barkloss.IN11	NA
DE_JP	Microhabitats.barkloss.IN12	1051
DE_JP	Microhabitats.barkloss.IN13	NA
DE_JP	Microhabitats.barkloss.IN14	NA
DE_JP	Microhabitats.Exposedheartwood.IN21	1061
DE_JP	Microhabitats.Exposedheartwood.IN22	1062
DE_JP	Microhabitats.Exposedheartwood.IN23	1073

DE_JP	Microhabitats.Exposedheartwood.IN24	NA
DE_JP	Microhabitats.cracksandscars.IN31	1063
DE_JP	Microhabitats.cracksandscars.IN32	1063
DE_JP	Microhabitats.cracksandscars.IN33	1064
DE_JP	Microhabitats.cracksandscars.IN34	1052
DE_JP	Microhabitats.nests.NE11	1131
DE_JP	Microhabitats.nests.NE12	1131
DE_JP	Microhabitats.nests.NE21	1132
DE_JP	Microhabitats.sapandresinrun.OT11	1151
DE_JP	Microhabitats.sapandresinrun.OT12	1152
DE_JP	Microhabitats.microsoil.OT21	1142
DE_JP	Microhabitats.microsoil.OT22	1141
DK_JC1	JHC_C2	1053
DK_JC1	JHC_C1	1054
DK_JC1	JHC_I	1012
DK_JC1	JHC_D1	102
DK_JC1	JHC_D2	102
DK_JC1	JHC_F1	NA
DK_JC1	JHC_G	NA
DK_JC1	JHC_K	109
DK_JC1	JHC_B1	NA
DK_JC1	JHC_B2	NA
DK_JC1	JHC_A1	1073
DK_JC1	JHC_A2	1073
DK_JC1	JHC_J	1151
DK_JC3	JHC_C2	1053
DK_JC3	JHC_C1	1054
DK_JC3	JHC_I	1012
DK_JC3	JHC_D1	102
DK_JC3	JHC_D2	102
DK_JC3	JHC_F1	NA
DK_JC3	JHC_G	NA
DK_JC3	JHC_K	109
DK_JC3	JHC_B1	NA
DK_JC3	JHC_B2	NA
DK_JC3	JHC_A1	1073
DK_JC3	JHC_A2	1073
DK_JC3	JHC_J	1151
FR_AM	1tDW11	1071
FR_AM	tDW11	1071
FR_AM	tFU24	NA
FR_AM	pEP11	1111
FR_AM	tEP11	1111
FR_AM	pEP12	1101
FR_AM	pEP13	1112
FR_AM	tEP13	1112

FR_AM	tEP362	112
FR_AM	10tIN11	NA
FR_AM	11tIN11	NA
FR_AM	2tIN11	NA
FR_AM	3tIN11	NA
FR_AM	4tIN11	NA
FR_AM	6tIN11	NA
FR_AM	7tIN11	NA
FR_AM	8tIN11	NA
FR_AM	9tIN11	NA
FR_AM	pIN11	NA
FR_AM	tIN11	NA
FR_AM	pIN13	NA
FR_JP	7	NA
FR_JP	1	1042
FR_JP	5	1021
FR_JP	4	1022
FR_JP	6	NA
FR_JP	8	1101
FR_JP	12	1123
FR_JP	12	1123
FR_JP	2	1044
FR_JP	3	NA
FR_JP	9	1151
FR_YP	621	101
FR_YP	h621	101
FR_YP	p621	101
FR_YP	t621	101
FR_YP	623	1014
FR_YP	h623	1014
FR_YP	p623	1014
FR_YP	t623	1014
FR_YP	624	1023
FR_YP	625	1023
FR_YP	p624	1023
FR_YP	p625	1023
FR_YP	t624	1023
FR_YP	t625	1023
FR_YP	622	102
FR_YP	622P	102
FR_YP	h622	102
FR_YP	p622	102
FR_YP	pt622	102
FR_YP	t622	102
FR_YP	tp622	102
FR_YP	531	1071

FR_YP	532	1071
FR_YP	533	1071
FR_YP	611	NA
FR_YP	612	NA
FR_YP	613	NA
FR_YP	611P	NA
FR_YP	611T	NA
FR_YP	h611	NA
FR_YP	h612	NA
FR_YP	h613	NA
FR_YP	p611	NA
FR_YP	p612	NA
FR_YP	p613	NA
FR_YP	pt612	NA
FR_YP	t611	NA
FR_YP	t612	NA
FR_YP	t613	NA
FR_YP	671	1121
FR_YP	671P	1121
FR_YP	h671	1121
FR_YP	p6671	1121
FR_YP	p671	1121
FR_YP	pt671	1121
FR_YP	pth671	1121
FR_YP	t671	1121
FR_YP	t6716	1121
FR_YP	t671h671	1121
FR_YP	653	108
FR_YP	h653	108
FR_YP	ht653	108
FR_YP	p653	108
FR_YP	t653	108
FR_YP	643	1051
FR_YP	643h	1051
FR_YP	643p	1051
FR_YP	643T	1051
FR_YP	h643	1051
FR_YP	h643h	1051
FR_YP	p643	1051
FR_YP	pt651	1051
FR_YP	t643	1051
FR_YP	540	1061
FR_YP	h540	1061
FR_YP	551	1062
FR_YP	561	NA
FR_YP	632	1063

FR_YP	h632	1063
FR_YP	p632	1063
FR_YP	t632	1063
FR_YP	631	1064
FR_YP	h631	1064
FR_YP	t631	1064
FR_YP	661	115
FR_YP	662	115
FR_YP	h661	115
FR_YP	h662	115
FR_YP	p661	115
FR_YP	p662	115
FR_YP	t661	115
FR_YP	t662	115
GR_FX	TreMn5 (cavities - insect galleries)	103
GR_FX	TreMn1 (crown deadwood)	107
GR_FX	TreMn3 (fruiting bodies-perennail fungal fruiting)	1101
GR_FX	TreMn2 (tree injuries - exposed sapwood only)	NA
GR_FX	TreMn4 (epiphytic structure-nests)	NA
HU_RA	BA1	NA
HU_RA	CV11.13 CV21.22	NA
HU_RA	CV11.13	101
HU_RA	CV11-13	101
HU_RA	CV14	1042
HU_RA	CV14	1042
HU_RA	CV21.22	102
HU_RA	CV21-22	102
HU_RA	CV23.24	102
HU_RA	CV23.24	102
HU_RA	CV23-24	102
HU_RA	CV3	102
HU_RA	CV3	102
HU_RA	CV4	NA
HU_RA	CV4	NA
HU_RA	DE1	107
HU_RA	DE1	107
HU_RA	EP1	NA
HU_RA	EP1	NA
HU_RA	GR3	109
HU_RA	GR3	109
HU_RA	GR3	109
HU_RA	IN1	NA
HU_RA	IN1	NA
HU_RA	IN2	NA
HU_RA	IN2	NA
HU_RA	IN2	NA

HU_RA	IN2	NA
HU_RA	NE12	1131
HU_RA	NE12	1131
IT_EA	M12	1053
IT_EA	M11	1054
IT_EA	M18	1013
IT_EA	M21	1014
IT_EA	M8	1022
IT_EA	M19	1022
IT_EA	M23	NA
IT_EA	M3	NA
IT_EA	M6	1031
IT_EA	M15	1111
IT_EA	M22	1101
IT_EA	M7	1091
IT_EA	M13	NA
IT_EA	M16	1061
IT_EA	M5	1062
IT_EA	M1	1073
IT_EA	M17	NA
IT_EA	M10	1063
IT_EA	M4	1064
LT_GB	BA11	1053
LT_GB	BA21	NA
LT_GB	CV21	1021
LT_GB	CV31	NA
LT_GB	DE11	1071
LT_GB	DE12	1071
LT_GB	DE15	1072
LT_GB	EP12	1101
LT_GB	EP32	1122
LT_GB	GR31	1091
LT_GB	GR32	1092
LT_GB	IN11	NA
LT_GB	IN12	1051
LT_GB	IN23	1073
LT_GB	IN34	1052
SK_DK	64	1053
SK_DK	65	1054
SK_DK	11	101
SK_DK	13	1014
SK_DK	15	1023
SK_DK	12	102
SK_DK	71	107
SK_DK	72	107
SK_DK	73	107

SK_DK	41	NA
SK_DK	83	1121
SK_DK	81	109
SK_DK	51	NA
SK_DK	61	NA
SK_DK	63	NA
SK_DK	63	NA
SK_DK	31	115
SK_DK	32	115
SK_MM	64	1053
SK_MM	65	1054
SK_MM	11	101
SK_MM	13	1014
SK_MM	16	102
SK_MM	17	102
SK_MM	15	1023
SK_MM	12	102
SK_MM	71	107
SK_MM	72	107
SK_MM	73	107
SK_MM	41	NA
SK_MM	83	1121
SK_MM	82	1081
SK_MM	81	109
SK_MM	51	NA
SK_MM	74	1061
SK_MM	75	1062
SK_MM	61	NA
SK_MM	63	NA
SK_MM	63	NA
SK_MM	62	1064
SK_MM	31	115
SK_MM	32	115
SK_MS	64	1053
SK_MS	65	1054
SK_MS	11	101
SK_MS	13	1014
SK_MS	16	102
SK_MS	20	102
SK_MS	15	1023
SK_MS	12	102
SK_MS	71	107
SK_MS	72	107
SK_MS	73	107
SK_MS	41	NA
SK_MS	83	1121

SK_MS	81	109
SK_MS	51	NA
SK_MS	75	1062
SK_MS	61	NA
SK_MS	63	NA
SK_MS	63	NA
SK_MS	62	1064
SK_MS	31	115
SK_MS	32	115

Table A2: Number of plots with TreMs encoded in Larrieu *et al.* (2018) as well as basic stand data and presence of taxonomic data

1st		2nd	3rd	Code	CH_ TL	CZ_ JH1	DE_ ID	DE_ JP	DK_ JC1	DK_ JC3	FR_ AM	FR_ JP	FR_ YP	GR_ FX	HU_ RA	IT_ EA1	IT_ EA2	IT_ EA3	LT_ GB	SK_ DK	SK_ MM	SK_ MS
Cavities		Woodpecker cavities		101									78		13					6	14	13
			Small	1011			10															
			Medium-sized	1012			21	2	11													
			Large	1013			12									6	9					
			Flute	1014									17			17	27	1		11	5	4
		Rot-holes		102	10	35	26		156	7			162		16					1	11	11
			Trunk base	1021				2				17							1			
			Trunk	1022				2				6				8	23					
			Semi-open	1023									75							4	5	5
			Hollow branch	1026				1														
		Insect galleries,	bore holes	1031												3	10					
		Concavities	Dendrotelm	1041																		
			Woodpecker foraging excavation	1042				4				26			16							
			Root buttress	1044				85				15										
Tree injuries and exposed w		Expo-sed sapwood only	Bark loss	1051		70		5					241						6			
			Fire scar	1052															28			
			Bark shelter	1053				1	19	1						17	4	1	1	15	15	13
			Bark pocket	1054					46							1	2			10	9	9
		Exposed sapwood and	Stem breakage	1061		46		1					55			2	15				1	
			Limb breakage	1062				3					48			1	5				2	3
			Crack	1063				3					166			3	11					

ood		heart wood	Lightning scar	1064									8			20	26			1	1	2
Crown deadwood		Crown deadwood		107	29									1	16					12	10	12
			Dead branches	1071				6			3		158						45			
			Dead top	1072															13			
			Remaining broken limb	1073		36		1	102	1							3		1			
Excrescences				108									88									
		Twig tangles	Witch broom	1081				1													1	
			Epicormic shoots	1082																		
		Burrs and cankers		109					65	3					15					4	9	10
			Burr	1091													6	6	4			
			Decayed canker	1092				2											1			
Fruiting bodies of saproxylic fungi and slim		Perenial fungal fruiting bodies	Perennial polypore	1101			14				1	19		1		23	25	2	6			
		Ephemeral fungal fruiting bodies and slime	Annual polypore	1111							2					3						
			Pulpy agaric	1112				1			1											
			Pyrenomycete	1113																		
			Myxomycete	1114																		

emoulds																						
Epiphytic and epixylic structure		Epiphytic and epixylic structures		112							1											
			Bryophytes	1121			6	2					226							3	9	10
			Lichen	1122			2	49											8			
			Ivy and lianas	1123								9										
			Ferns	1124																		
			Mistletoe	1125																		
		Nests	Vertebrate nest	1131											6							
			Invertebrate nest	1132																		
		Micro soils	Bark microsoil	1141																		
			Crown microsoil	1142				1														
Exudates		Fresh exudates		115	6								56							18	17	16
			Sap run	1151					11	4		6										
			Heavy resinosis	1152				31														
				Dataset	CH_TL	CZ_JH1	DE_ID	DE_JP	DK_JC1	DK_JC3	FR_AM	FR_JP	FR_YP	GR_FX	HU_RA	IT_EA1	IT_EA2	IT_EA3	LT_GB	SK_DK	SK_MM	SK_MS
	Deadwood volume				0,0	6,8	80,1	0,0	15,6	0,9	NA	1,9	18,4	0,6	8,6	1,8	8,6	16,0	0,9	14,3	13,3	13,6
	Standing volume				29,1	132,6	19,8	0,0	NA	41,3	109,8	72,2	41,8	6,4	265,6	110,3	99,7	451,5	16,6	49,2	59,9	57,8
	Amphibia															1	1	1				
	Aphelinidae							1														
	Apidae							1														
	Aves					1	1		1		1		1			1	1	1	1	1	1	1
	Basidiomycota				1	1	1	1	1	1			1	1						1	1	1
	Bethylidae							1														
	Birds							1														
	Blattodea													1								
	Braconidae							1														

	Bryophyta	1	1		1	1	1	1		1						1			
	Carabidae							1		1			1		1				
	Ceraphronidae				1														
	Chiroptera			1									1	1	1				
	Chrysididae				1														
	Cimbicidae				1														
	Coleoptera	1	1	1		1	1		1	1	1	1	1	1		1	1	1	1
	Collembola							1											
	Cynipidae				1														
	Diapriidae				1														
	Diplopoda		1																
	Diprionidae				1														
	Diptera												1	1					
	Dryinidae				1														
	Encyrtidae				1														
	Eucoilidae				1														
	Eulophidae				1														
	Eupelmidae				1														
	Eurytomidae				1														
	Evaniidae				1														
	Figitidae				1														
	Formicidae				1														
	Gamasida							1											
	Heloridae				1														
	Hemiptera										1								
	Heteroptera			1															
	Hymenoptera															1			
	Ichneumonidae				1														
	Lepidoptera		1																
	Lichens		1																
	Lichinales	1		1		1		1	1							1	1	1	1
	Mammalia				1			1		1									
	Megaspilidae				1														
	Mymammromatidae				1														
	Mymaridae				1														
	Oniscidea		1																
	Oribatida							1											
	Pamphiliidae				1														
	Platygastridae				1														
	Pompilidae				1														
	Proctotrupidae				1														

	Pteromalidae				1														
	Reptilia												1	1					
	Rodentia							1											
	Scelionidae				1														
	Signiphoridae				1														
	Siricidae				1														
	Sphecidae..incl...crabronidae..				1														
	Tenthredinidae				1														
	Tiphiidae				1														
	Torymidae				1														
	Tracheophyta		1	1	1	1	1	1	1	1	1	1				1			
	Trichogrammatidae				1														
	Vespidae				1														
	Xyelidae				1														

Table A3: Adaption of coding and description of tree microhabitats as reported in the catalogues of Kraus *et al.* (2016) and Larrieu *et al.* (2018). Microhabitats reported in the same row have comparable structures, i.e. the codes can be translated into each other. Empty cells indicate that there is no match between the reported categories of the two catalogues.

Larrieu *et al.* (2018)				Kraus *et al.* (2016)			
Code	1st	2nd	3rd	Code	1st	2nd	3rd
1011	Cavities	Woodpecker Cavities	ø < 4 cm	CV11	Cavities	Woodpecker Cavities	ø 4 cm
1012			ø =4–7 cm	CV12			ø 5-6 cm
1013			ø > 10 cm	CV13			ø > 10 cm
1014			Woodpecker "flute"/ cavity string ø > 3 cm	CV15			Woodpecker "flute"/ cavity string
1021		Rot-holes	Trunk base; > 10 cm	CV21		Trunk and mould cavities	ø ≥ 10 cm (ground contact)
1021				CV22			ø ≥ 30 cm (ground contact
1022			Trunk rot-hole; > 10 cm	CV23			ø ≥ 10 cm
1022				CV24			ø ≥ 30 cm

1022				CV32		Branch holes	Hollow branch, ø ≥ 10 cm
1023			Semi-open trunk ø >30 cm	CV25		Trunk and mould cavities	ø ≥ 30 cm / semi-open
1024			Chimney trunk base ø > 30 cm	CV26			ø ≥ 30 cm / open top
1025			Chimney trunk ø > 30 cm	CV26			ø ≥ 30 cm / open top
1026			Hollow branch ø > 10 cm	CV33		Branch holes	Hollow branch, ø ≥ 10 cm
1031		Insect galleries and bore holes	ø > 2 cm or many small	CV51		Insect galleries and bore holes	Gallery with single small bore holes
1031				CV52			Large bore hole ø ≥ 2 cm
1041		Concavities	Dendrotelm ø > 15 cm ø > 15 cm	CV42		Dendrotelms and water-filled holes	ø ≥ 5cm / crown
1041				CV44			ø ≥ 15 cm / crown
1042			Woodpecker foraging excavation ø > 10 cm	CV14		Woodpecker Cavities	ø > 10 cm, feeding hole
1043			Bark-lined trunk concavity	/			
1044			Root buttress concavity Entrance ø > 10 cm	GR12	Deformation / growth form	Root buttress cavities	Trunk cleavage, length ≥ 30 cm
1051	Tree injuries and exposed wood	Exposed sapwood only	Bark loss >300 cm2	IN12	Injuries and wounds	Bark loss / exposed sapwood	> 600 cm2, decay stage < 3
1051				IN14			> 600 cm2, decay stage = 3
1052			Fire scar >600 cm2	IN34		Cracks and scars	Fire scar, ≥ 600 cm²
1053			Bark shelter opening at the bottom	BA11	Bark	Bark pockets	Bark shelter, width > 1 cm; depth > 10 cm; height > 10 cm

1054			Bark pocket opening at the top	BA12			Bark pocket, width > 1 cm; depth > 10 cm; height > 10 cm
1061		Exposed sapwood and heartwood	Stem breakage ø > 20 cm at the broken point	IN21	Injuries and wounds	Exposed heartwood / trunk and crown breakage	Broken trunk, ø ≥ 20 cm at the broken end
1062			Limb breakage (heartwood exposed) > 300 cm2	IN22			Broken tree crown / fork Exposed wood ≥ 300 cm²
1063			Crack; Length>30 cm; width>1 cm; depth>10 cm	IN31		Cracks and scars	Length ≥ 30 cm;
1063				IN32			Length ≥ 100 cm;
1064			Lightning scar; Length>30 cm; width>1 cm; depth>10 cm Biological Bat size	IN33			Lightning scar
1071	Crown deadwood	Crown deadwood	Dead branches; Branch ø > 10 cm or Branch ø > 3 cm and > 10% of the crown is dead	DE11	Dead wood	Dead branches and limbs / crown deadwood	ø 10 - 20 cm, ≥ 50 cm, sun exposed
1071			Branch ø > 10 cm or Branch ø > 3 cm and > 10% of the crown is dead	DE12			ø > 20 cm, ≥ 50 cm, sun exposed
1071			Branch ø > 10 cm or Branch ø > 3 cm and > 10% of the crown is dead	DE13			ø 10 - 20 cm, ≥ 50 cm, not sun exposed
1071			Branch ø > 10 cm or Branch ø > 3 cm and > 10% of the crown is dead	DE14			ø > 20 cm, ≥ 50 cm, not sun exposed
1072			Dead top; ø > 10 cm at the lower part of the piece of deadwood	DE15			Dead top
1073			Remaining broken limb ø >20 cm at the broken end; length of the remaining piece >0,5 m	IN23	Injuries and wounds	Cracks and scars	Broken limb, ø ≥ 20 cm at the broken end
1081	Excrescences	Twig tangles	Witch broom; Largest ø >50 cm	GR21	Deformation / growth form	Witches broom	Water sprout
1082			Epicormic shoots > 5 twig clusters	GR22		Cankers and burrs	NA
1091		Burrs and cankers	Burr, Largest ø >20 cm	GR31		Cankers and burrs	Decayed canker, ø > 20 cm
1092			Decayed canker Largest ø >20 cm or large part of the trunk covered	GR32		Injuries and wounds	

1101	Fruiting bodies of saproxylic fungi and slime moulds	Perennial fungal fruiting bodies	Perennial polypore Largest ø¸ >5 cm	EP12	Epiphytes	Fruiting bodies fungi	Perennial polypores, ø > 10 cm
1111		Ephemeral fungal fruiting bodies and slime moulds	Annual polypore	EP11			Annual polypores, ø > 5 cm
1112			Pulpy agaric	EP13			Pulpy agaric, ø > 5 cm
1113			Large Pyrenomycete	EP14			Large ascomycetes, ø > 5 cm
1114			Myxomycete	EP21		Myxomycetes	Myxomycetes, ø > 5 cm
1121	Epiphytic and parasitic crypto- and phanerogams	Epiphytic and epixylic structures	Bryophytes >10% of the trunk area covered	EP31		Epiphytic crypto- and phanerogams	Epiphytic bryophytes coverage > 25 %
1122			Lichen >10% of the trunk area covered	EP32			Epiphytic foliose and fruticose lichens, coverage > 25 %
1123			Ivy and lianas >10% of the trunk area covered	EP33			Lianas, coverage > 25 %
1124			Ferns >5 fronds	EP34			Epiphytic ferns, > 5 fronds
1125			Mistletoe Largest ø¸ > 20 cm for Viscum spp. and Loranthus europaeus, more than 10 clusters for Arceuthobium oxycedri	EP35			Mistletoe
1131		Nests	Vertebrate nest ø¸ > 10 cm Biological	NE11	Nests	Nests	Large vertebrate nest, ø > 80 cm
1131				NE12			Small vertebrate nest, ø > 10 cm
1132			Invertebrate nest. Presence (observation of nest or associated insects)	NE21			Invertebrate nest
1141		Microsoil	Bark microsoil Presence (direct observation or specific fungi)	OT22	Others	Microsoils	Bark microsoil
1142			Crown microsoil Presence	OT21			Crown microsoil
1151	Exu	Fresh	Sap run Length>10 cm	OT11		Sap and resin run	Sap flow, > 50 cm

115 2			Heavy resinosis Length>10 cm	OT1 2			Resin flow and pockets, > 50 cm
Not translatable				BA2 1	Bark	Bark structure	Coarse bark
				CV3 1	Cavities	Branch holes	ø ≥ 10 cm
				CV4 1		Dendrotelms and water-filled holes	ø ≥ 15 cm / trunk base
				CV4 3		Dendrotelms and water-filled holes	ø ≥ 15 cm / crown
				GR1 1	Deform-ation / growth form	Root buttress cavities	ø ≥ 10 cm
				GR1 3		Witches broom	NA
				IN1 1	Injuries and wounds	Bark loss / exposed sapwood	Bark loss > 600 cm2, decay stage < 3
				IN1 3		Bark loss / exposed sapwood	Bark loss > 600 cm2, decay stage = 3
				IN2 4		Cracks and scars	Length ≥ 30 cm; width > 1 cm; depth > 10 cm