2023

Forest Condition in Europe

The 2023 Assessment

ICP Forests Technical Report under the UNECE Convention on Long-range Transboundary Air Pollution (Air Convention)

LRTAP Long-range Transboundary Air Pollution

wge Working Group on Effects of the Convention on Long-range Transboundary Air Pollution

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ICP Forests Technical Report under the UNECE Convention on Long-range Transboundary Air Pollution (Air Convention)

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United Nations Economic Commission for Europe (UNECE)
Convention on Long-range Transboundary Air Pollution (Air Convention)
International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)
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7

TREE CROWN CONDITION IN 2022

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Highlights

In 2022, we witnessed a slight increase in mean defoliation as compared to year 2021, with a smaller change for conifers (0.6 percentage points, %p) than for broadleaves (1.4%p). While no change in mean defoliation was recorded for Scots pine and a very small increase for Norway spruce (0.2%p) and deciduous temperate oaks (0.3%p), larger increases were recorded for other main species and species groups, especially for Austrian pine (1.9%p) and evergreen oaks (2.0%p).

Trends show a considerable increase in defoliation of evergreen oaks over the past 20 years (7.3%p). On the other hand, the increase in defoliation for deciduous temperate oaks (3.2%p) and common beech (3.9%p) has been relatively low, while the increase of defoliation for Scots pine, Mediterranean lowland pines and Norway spruce was moderate. Trends were not significant for deciduous (sub-) Mediterranean oaks and Austrian pine.

This year a 2.6%p rise in the number of trees with damage symptoms was recorded, and the overall number of recorded damage symptoms was also higher than in 2021. As in previous years, the number of damage symptoms per assessed tree was substantially higher for broadleaves than for conifers (0.84 vs. 0.56, respectively). Insects, abiotic causes, and fungi were the most common damage agent groups for all species, comprising altogether more than half of all damage records. Tree mortality in 2022 was 0.9% (873 trees). Mortality rates for the main species and species groups ranged from 0.3 to 0.7% (except for Norway spruce with 1.9%), and the main causes of mortality were abiotic factors, followed by insects, fungi and fire.

Introduction and scientific background

Tree crown defoliation and occurrence of biotic and abiotic damage are important indicators of forest health. As such, they are considered within the Criterion 2, "Forest health and vitality", one of six criteria adopted by Forest Europe (formerly the Ministerial Conference on the Protection of Forests in Europe – MCPFE) to provide information for sustainable forest management in Europe.

Defoliation surveys are conducted in combination with detailed assessments of biotic and abiotic damage causes. Unlike assessments of tree damage, which can in some instances trace the tree damage to a single cause, defoliation is an unspecific parameter of tree vitality, which can be affected by a number of anthropogenic and natural factors. Combining the assessment of damage symptoms and their causes with observations of defoliation allows for a better insight into the condition of trees, and the interpretation of the state of European forests and its trends in time and space is made easier.

This chapter presents results from the crown condition assessments on the large-scale, representative, transnational monitoring network (Level I) of ICP Forests carried out in 2022, as well as long-term trends for the main species and species groups.

Methods of the 2022 survey

The assessment of tree condition in the transnational Level I network is conducted according to European-wide, harmonized methods described in the ICP Forests Manual by Eichhorn et al. (2020, see also Eichhorn and Roskams 2013).

Defoliation

Defoliation is the key parameter of tree condition within forest monitoring describing a loss of needles or leaves in the assessable crown compared to a local reference tree in the field or an absolute, fully foliated reference tree from a photo guide. Defoliation is estimated in 5% steps, ranging from 0% (no defoliation) to 100% (dead tree). Defoliation values are grouped into five classes (Table 7-1). In the maps presenting the mean plot defoliation and in Table 7-3, class 2 is subdivided into class 2-1 (> 25–40%) and class 2-2 (> 40–60% defoliation).

Table 7-1: Defoliation classes

Defoliation class	Needle/leaf loss	Degree of defoliation
0	up to 10%	None
1	> 10–25%	Slight (warning stage)
2	> 25–60%	Moderate
3	> 60–< 100%	Severe
4	100%	Dead (standing dead trees only)

Table 7-2 shows countries and the number of plots assessed for crown condition parameters from 2013 to 2022, and the total number of sample trees submitted in 2022. The number of trees used for analyses differs from the number of submitted trees due to the application of various data selection procedures. Both the number of plots and the number of trees vary in the course of time, for example due to mortality or changes in the sampling design.

Table 7-2: Number of plots assessed for crown condition parameters from 2013 to 2022 in countries with at least one Level I crown condition survey since 2013, and total number of sample trees submitted in 2022

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	Plots 2022	Trees 2022
Andorra	11	11	12								
Belarus	373		377								
Belgium	8	8	8	53	53	52	52	51	51	51	540
Bulgaria	159	159	159	159	160	160	160	160	159	160	5599
Croatia	105	103	95	99	99	99	97	98	95	97	2328
Cyprus	15	15	15			15	15	15	15	15	360
Czechia		138	136	136	135	132	132	127	121	117	4 176
Denmark	20	20	20	19	19	19	19	19	18	18	433
Estonia	96	96	97	98	98	98	98	95	95	93	2180
France	550	545	542	533	527	521	515	512	509	504	10 076
Germany	417	422	424	421	416	410	421	416	409	405	9 566
Greece		57	47	23	36	40	45	38	33	35	822
Hungary	68	68	67	67	66	68	68	68	69	71	1 546
Ireland							28	30	33	31	676
Italy	247	244	234	246	247	249	237	240	256	256	4 751
Latvia	115	116	116	115	115	115	115	115	115	115	1 753
Lithuania	79	81	81	82	82	81	81	81	81	81	1 965
Luxembourg	4	4	4	4	3	3	4	4	4	4	96
Moldova, Rep. of					9	9					
Montenegro	49			49	49	49	49	49	49	49	1 175
Norway	618	687	554	629	630	623	687	604	629	627	5 183
Poland	364	365	361	353	352	348	346	343	343	341	6 791
Romania	236	241	242	243	246	246	247	226	234	237	5 755
Serbia	121	128	127	127	126	126	127	126	126	126	2 857
Slovakia	108	107	106	103	103	101	100	99	97	99	4 418
Slovenia	44	44	44	44	44	44	44	44	44	44	1 088
Spain	620	620		620	620	620	620	620	620	620	14 880
Sweden	740	842	839	701	618	760	849	841	733	629	2 284
Switzerland	47	47	47	47	47	47	47	47	47	49	1 038
Türkiye	583	531	591	586	598	601	597	599	580	579	13 360
TOTAL	5 797	5 699	5 345	5 557	5 498	5 636	5 800	5 667	5 565	5 453	105 696

Damage cause assessments

The damage cause assessment of trees consists of three major parts. For a detailed description, please refer to Eichhorn et al. (2020) and Timmermann et al. (2016).

- Symptom description
  Three main categories indicate which parts of a tree are affected: (a) leaves/needles; (b) branches, shoots, buds, and fruits; and (c) stem and collar. A further specification of the affected part along with a symptom description is given.
- Determination of the damage cause (causal agents / factors)
  The main groups of causal agents are insects, fungi, abiotic factors, game and grazing, direct action of man, fire, and atmospheric pollutants. In each group, a more detailed description is possible through a hierarchical coding system.
- Quantification of symptoms (damage extent)
  The extent is the estimated damage to a tree, specifying the percentage of affected leaves/needles, branches or stem circumference due to the action of the causal agent or factor.

Additional parameters

Several other tree, stand, and site parameters are assessed, providing additional information for analysis of the crown condition data. For the full information, please refer to Eichhorn et al. (2020). Analysis of these parameters is not within the scope of this report.

Tree species

For the analyses in this report, the results for the four most abundant species are shown separately in figures and tables. *Fagus sylvatica* is analyzed together with *F. sylvatica* ssp. *moesiaca*. Some species belonging to the *Pinus* and *Quercus* genus were combined into species groups as follows:

- Mediterranean lowland pines (*Pinus brutia*, *P. halepensis*, *P. pinaster*, *P. pinea*)
- Deciduous temperate oaks (*Quercus petraea* and *Q. robur*)
- Deciduous (sub-) Mediterranean oaks (*Quercus cerris*, *Q. frainetto*, *Q. pubescens*, *Q. pyrenaica*)
- Evergreen oaks (*Quercus coccifera*, *Q. ilex*, *Q. rotundifolia*, *Q. suber*).

Of all trees submitted from the Level I network in 2022, *Pinus sylvestris* was the most abundant tree species (16.6% of all trees), followed by *Fagus sylvatica* (incl. ssp. *moesiaca*, 12.0%), *Picea abies* (11.1%), *Pinus nigra* (5.1%), *Quercus robur* (4.3%), *Quercus petraea* (4.3%), *Quercus ilex* (3.7%), *Quercus cerris* (3.2%), *Pinus brutia* (3.0%), *Betula pubescens* (2.4%), *Pinus halepensis* (2.4%), *Quercus pubescens* (2.2%), *Abies alba* (2.2%), *Betula pendula* (2.0%), *Pinus pinaster* (1.8%), and *Carpinus betulus* (1.8%).

Most Level I plots with crown condition assessments contained one (47.9%) or two to three (39.2%) tree species per plot. On 10.6% of plots, four to five tree species were assessed, and only 2.4% of plots featured more than five tree species. In 2022, 51.7% of all submitted trees were broadleaves and 48.3% conifers. The species percentages differ slightly for damage assessments, as selection of trees for assessments in participating countries varies.

Statistical analyses

For calculations, selection procedures were applied in order to include only correctly coded trees in the sample (Tables 7-4 and 7-5). For the calculation of the mean plot defoliation of all species, only plots with a minimum number of three trees were analyzed. For analyses at species level, three trees per species had to be present per plot. These criteria are consistent with earlier evaluations (e.g. Wellbrock et al. 2014, Becher et al. 2014) and explain the discrepancy in the distribution of trees in defoliation classes between Table 7-3 and Table S1-1 in the online supplementary material[1].

Trends in defoliation were calculated according to Sen (1968) and their significance tested by the non-parametric Mann-Kendall test (tau). These methods are appropriate for monotonous, single-direction trends without the need to assume any particular distribution of the data. Due to their focus on median values and corresponding robustness against outliers (Sen 1968, Drápela and Drápelová 2011, Curtis and Simpson 2014), the results are less affected by single trees or plots with unusually high or low defoliation. The regional Sen's slopes for Europe were calculated according to Helsel and Frans (2006). For both the calculation of Mann-Kendall's tau and the plot-related as well as the regional Sen's slopes, the rkt package in the R statistical software environment (Marchetto 2015) was used.

Figures 7-2a-j show (1) the annual mean defoliation per plot, (2) the change of mean defoliation across plots over the years, and (3) the trend of defoliation based on the regional Sen's slope calculations for the period 2003–2022. For the Mann-Kendall test, a significance level of $p \leq 0.05$ was applied. All Sen's slope calculations and yearly over-all mean defoliation values were based on consistent plot selections with a minimum of three trees per species and per plot. Maps of defoliation trends for the period 2013–2022 can be found in the online supplementary material[1]. For all trend calculations, plots were included if assessments were available for at least 80% of the years of interest. All queries and statistical analyses were conducted in the R/RStudio software environment (R Core Team 2016).

Quality assurance and control (QA/QC)

Since ICP Forests is a pan-European monitoring programme, stemming from various national initiatives that had already been

[1] http://icp-forests.net/page/icp-forests-technical-report

in place when the programme started operating, the methods of monitoring employed in ICP Forests partly reflect the initial differences of these systems. In line with that, initially no consistent, 'top-down' quality assurance (QA) approach was adopted and the emphasis was placed more on the quality control (QC) issues. A lot of effort has been invested into the development of the monitoring methodology in terms of harmonization and intercalibration of methods, and, where this was not possible, into the intercomparison of results obtained by different methods.

Quality assurance and control measures for crown condition assessments are organized at multiple levels: At national level, regular calibration trainings of the survey teams and control assessments in the field are conducted. Data submission to the ICP Forests collaborative database is regulated by protocols and check procedures. International cross-comparison courses (field and photo ICCs) ensure the possibility to compare data across participating countries (Eickenscheidt 2015, Dănescu 2019, Meining et al. 2019).

In recent years, the International Photo Cross-Comparison Course (Photo ICC), held every two years, has developed into an important and effective tool of the ICP Forests quality assurance program for the assessment of crown condition in Europe. Teams from 21 different European countries participated in the Photo ICC 2021 – more than ever before (Meining et al. 2021, internal report). As in the previous years, the survey comprised photos of tree species from three European regions: Northern (*Picea abies* and *Pinus sylvestris*), Central *(Picea abies*, *Pinus sylvestris*, *Fagus sylvatica*, *Quercus robur* and *Q. petraea*), and Mediterranean Europe (*Pinus pinaster*, *Pinus sylvestris* and *Quercus ilex*). Each team assessed a photo set of 30 pictures for each tree species. In total, 37 047 defoliation scores were included in the Photo ICC 2021.

The determination of the assessable crown naturally has a major influence on the assessment of trees, therefore participating teams were asked to assess defoliation using both their own national method and the widest span method, which was set as a reference standard for this survey. The results indicate noticeably larger differences between national teams when using the national method due to different assessable crown definitions. On the other hand, the use of standardized picture series can reduce assessment bias, with the additional advantage that crown condition survey standard remains fairly constant even in the case of personnel changes, and indeed, the consistency of the crown condition assessment in comparison with previous Photo ICCs could be confirmed for most species.

As observed in previous photo courses (Meining et al. 2019), the results for trees with higher defoliation levels presented a significantly higher deviation from the mean than the results for trees with lower defoliation levels. The differences in the assessment results between the field and reference teams may indicate a lack of harmonization for some countries, but the results of the Photo ICC 2021 show, in general, a good level of agreement in defoliation assessments between the participating countries.

National surveys

In addition to the transnational surveys, national surveys are conducted in many countries, relying on denser national grids and aiming at the documentation of forest condition and its development in the respective country. Since 1986, various densities of national grids (1x1 km to 32x32 km) have been used due to differences in the size of forest area, structure of forests, and forest policies. The results of defoliation assessments on national grids are presented in the online supplementary material[1]. Comparisons between the national surveys of different countries should be made with great care because of differences in species composition, site conditions, and methods applied.

Results of the transnational crown condition survey

Defoliation

The transnational crown condition survey in 2022 was conducted on 105 696 trees on 5 453 plots in 27 countries (Table 7-2). Out of those, 101 190 trees were assessed in the field for defoliation (Table 7-3).

The overall mean defoliation for all species was 23.8% in 2022; an increase in defoliation of 0.6%p for conifers and 1.4%p for broadleaves in comparison with 2021 (Table 7-3). Broadleaved trees showed a higher mean defoliation than coniferous trees (24.7% vs. 23.0%), as in previous years. Correspondingly, conifers had a higher frequency of trees in the defoliation classes 'none' and 'slight' (71.3% combined) than broadleaves (67.0%) and a lower frequency of trees with more than 60% defoliation (3.0% vs. 5.0%). Norway spruce had the highest share of standing dead trees (1.6%), common beech, Austrian pine and deciduous (sub-) Mediterranean oaks the lowest (0.2% each).

Among the main tree species and tree species groups, deciduous temperate oaks and evergreen oaks displayed the highest mean defoliation (27.7% and 28.6%, respectively). Common beech had the lowest mean defoliation (22.4%). The strongest increase in defoliation compared to 2021 occurred in evegreen oaks (+2.0%p) and in Austrian pine (+1.9%p), while there was no increase in Scots pine and only a small increase in Norway spruce (0.2%p) and deciduous temperate oaks (+0.3%p). Defoliation increased in all species and species groups compared to 2021, except in Scots pine.

Mean defoliation of all species at plot level in 2022 is shown in Figure 7-1. Two thirds (65.9%) of all plots had a mean defoliation up to 25%, and only 1.4% of the plots showed severe defoliation (more than 60%). While plots with defoliation up to 10% were located mainly in Norway, Serbia, Romania, and Türkiye, plots with slight mean defoliation (11-25%) were found across Europe. Clusters of plots with moderate to severe mean defoliation were found from the Pyrenees through southeast (Mediterranean) France to west Italy, but also from central and northern France

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through Germany and into Czechia, Slovakia and Hungary, as well as in western Bulgaria and central parts of Norway and Sweden.

The following sections describe the species-specific mean plot defoliation in 2022 and the over-all trend and yearly mean plot defoliation from 2003 to 2022. For maps on defoliation of individual tree species in 2022, and trends in mean plot defoliation from 2013 to 2022, please refer to the online supplementary material[1].

Table 7-3: Percentage of trees assessed in 2022 according to defoliation classes 0-4 (class 2 subdivided), mean defoliation for the main species or species groups (change from 2021 in parentheses), and the number of trees in each group. Class 4 contains standing dead trees only. Dead trees were not included when calculating mean defoliation.

Main species or species groups	Percentage of trees per defoliation class Class 0 (0-10%)	Class 1 (>10-25%)	Class 2-1 (>25-40%)	Class 2-2 (>40-60%)	Class 3 (>60-99%)	Class 4 (100%)	Mean defoliation	No. of trees
Scots pine (*Pinus sylvestris*)	21.6	52.6	15.8	6.8	2.7	0.5	22.9 (+/-0.0)	17 327
Norway spruce (*Picea abies*)	29.1	36.5	21.9	7.7	3.1	1.6	23.1 (+0.2)	11 388
Austrian pine (*Pinus nigra*)	27.2	43.3	16.2	8.4	4.8	0.2	24.1 (+1.9)	5 414
Mediterranean lowland pines	13.2	58.4	19.8	5.8	2.1	0.6	23.7 (+1.6)	7 977
Other conifers	31.1	42.5	16.6	6.6	2.8	0.4	21.5 (+0.7)	7 951
Common beech (*Fagus sylvatica*)	31.3	38.4	20.0	6.6	3.5	0.2	22.4 (+1.5)	12 435
Deciduous temperate oaks	17.7	40.8	25.5	10.0	5.5	0.4	27.6 (+0.3)	8 980
Dec. (sub-) Mediterranean oaks	26.2	43.5	18.1	8.3	3.8	0.2	23.4 (+1.4)	7 921
Evergreen oaks	6.7	52.4	26.5	9.1	5.0	0.3	28.6 (+2.0)	4 628
Other broadleaves	27.7	42.6	14.8	6.9	6.3	1.8	24.3 (+1.7)	17 169
TOTAL								
Conifers	24.1	47.2	18.0	7.0	3.0	0.7	23.0 (+0.6)	50 057
Broadleaves	24.7	42.3	19.5	7.8	5.0	0.8	24.7 (+1.4)	51 133
All species	**24.4**	**44.7**	**18.8**	**7.4**	**4.0**	**0.7**	**23.8 (+1.0)**	**101 190**

[1] http://icp-forests.net/page/icp-forests-technical-report

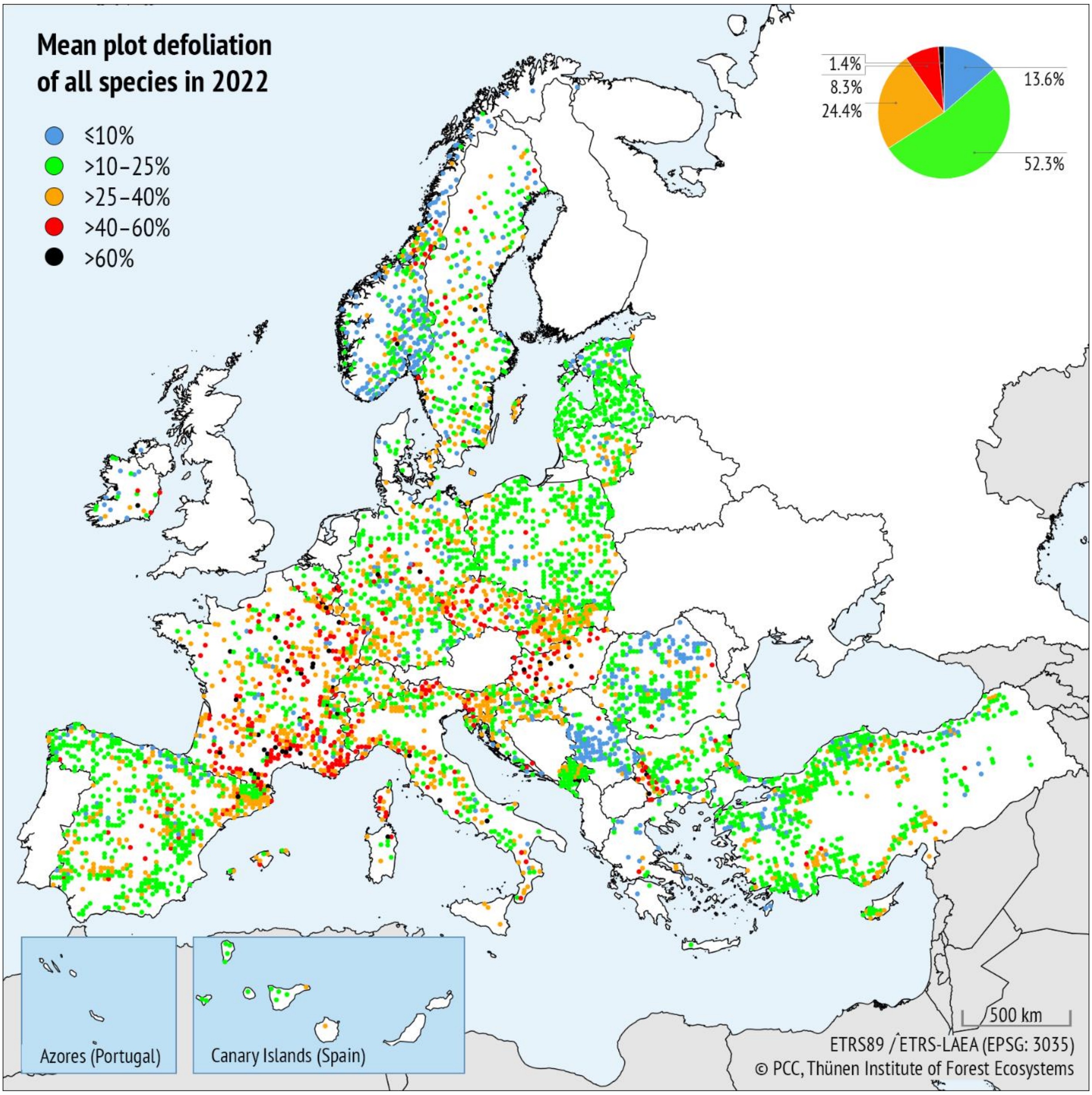
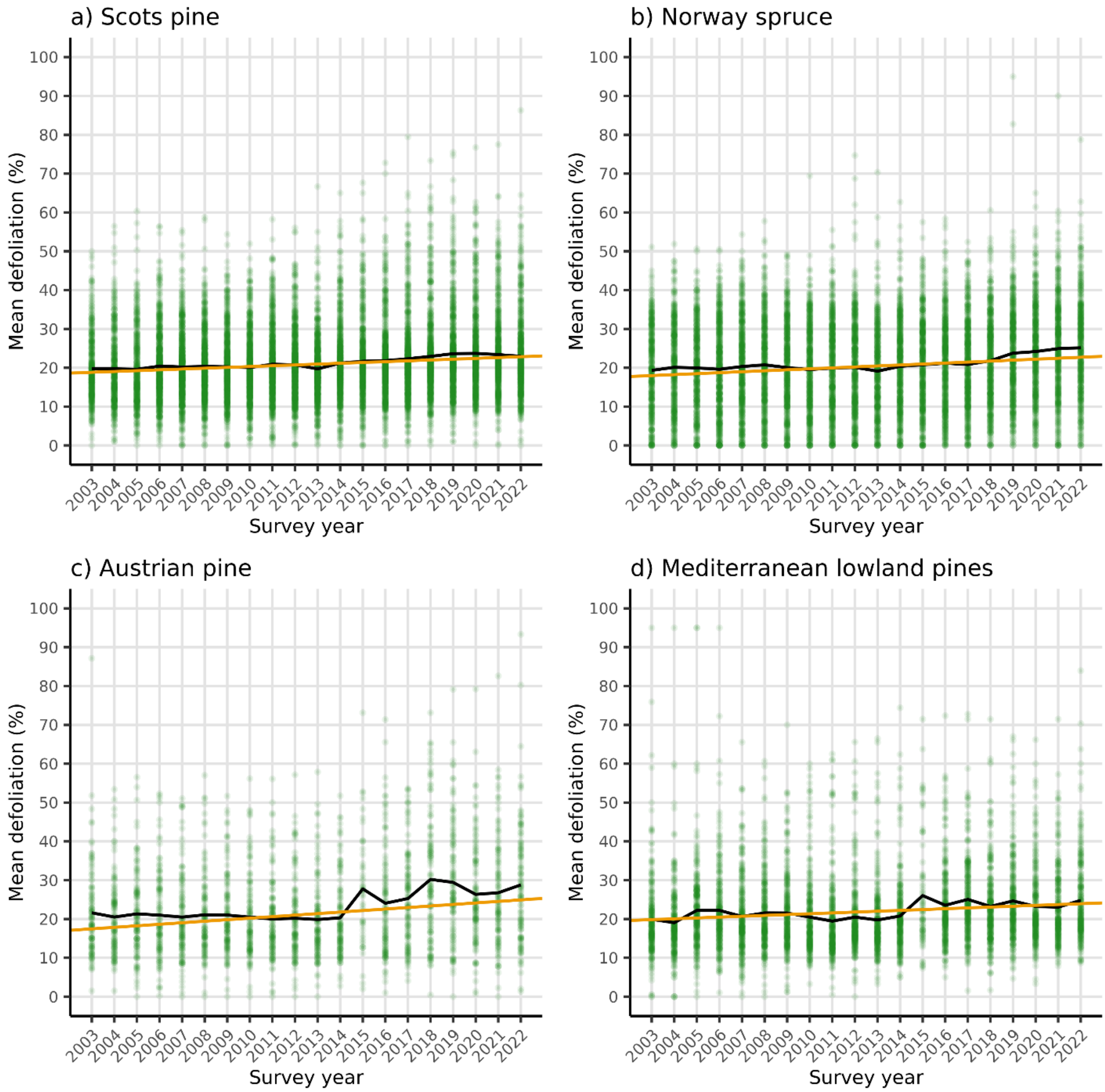
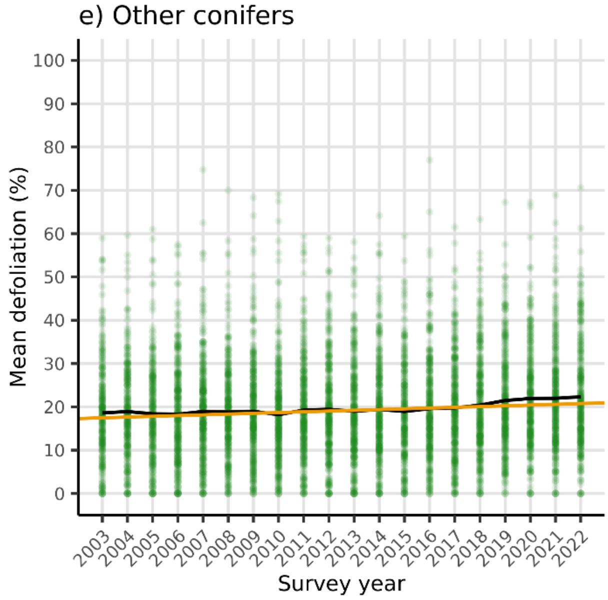


Figure 7-1: Mean plot defoliation of all species in 2022, shown as defoliation classes. The legend (top left) shows defoliation classes ranging from none (blue), slight (green), moderate (orange and red), to severe (black) defoliation. The percentages refer to the needle/leaf loss in the crown compared to a reference tree. The pie chart (top right) shows the percentage of plots per defoliation class. Dead trees are not included.

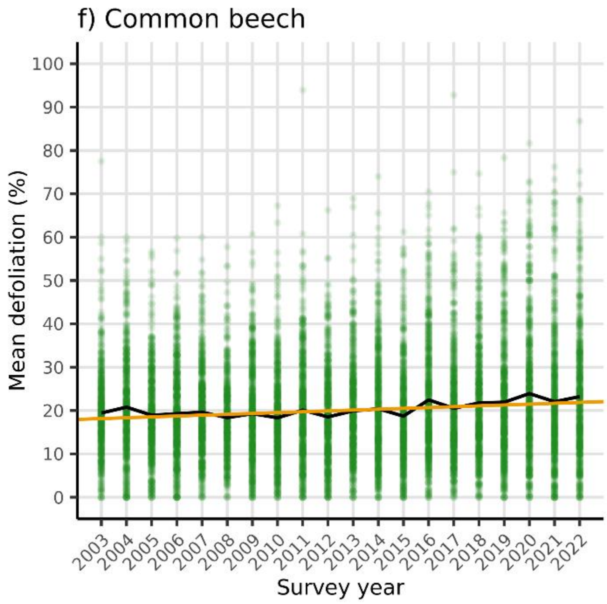


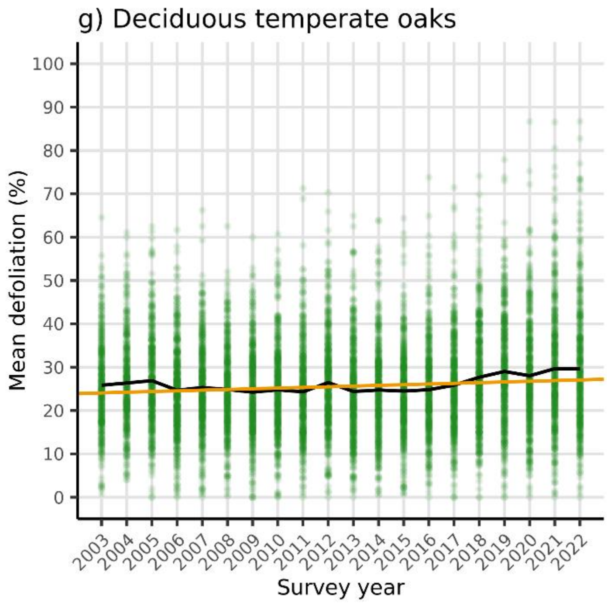


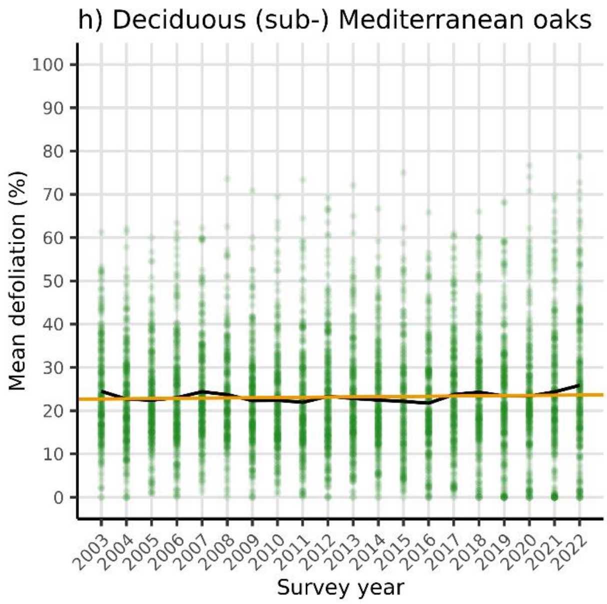
Figures 7-2 a-e: Over-all trend (orange line) and annual mean defoliation across plots (black line) at Level I plots from 2003–2022; points represent annual plot mean values:

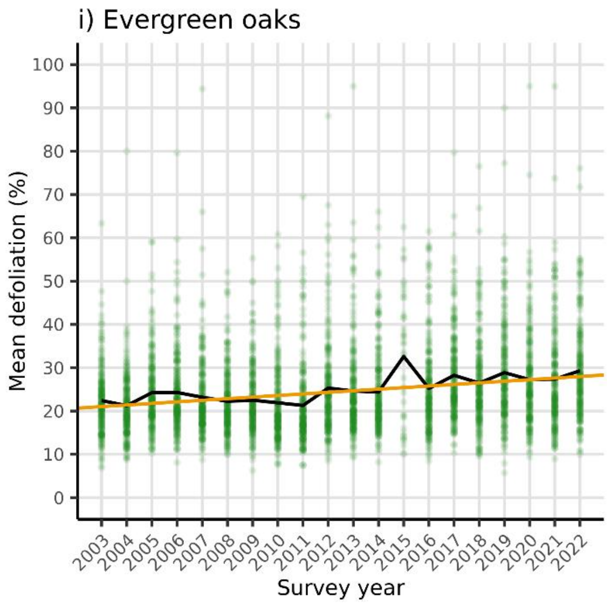
(a) Scots pine (regional Sen's slope = 0.2113, $p < 0.001$)
(b) Norway spruce (regional Sen's slope = 0.2481, $p < 0.001$)
(c) Austrian pine (regional Sen's slope = 0.3925, *n.s.*)
(d) Mediterranean lowland pines (regional Sen's slope = 0.2158, $p < 0.05$)
(e) Other conifers (regional Sen's slope = 0.1733, $p < 0.001$)

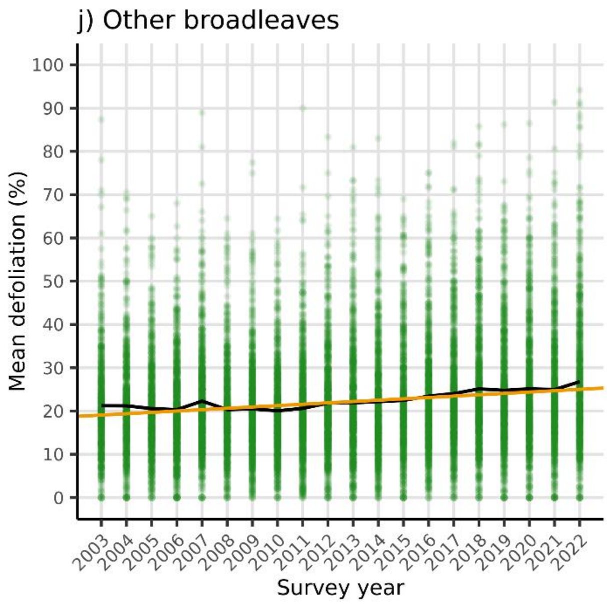
n.s. = not significant











Figures 7-2 f-j: Over-all trend (orange line) and annual mean defoliation across plots (black line) at Level I plots from 2003–2022; points represent annual plot mean values:

(f) Common beech (regional Sen's slope = 0.1963, $p < 0.01$)
(g) Deciduous temperate oaks (regional Sen's slope = 0.1577, $p < 0.05$)
(h) Deciduous (sub-) Mediterranean oaks (regional Sen's slope = 0.0476, *n.s.*)
(i) Evergreen oaks (regional Sen's slope = 0.3658, $p < 0.001$)
(j) Other broadleaves (regional Sen's slope = 0.3127, $p < 0.001$)

n.s. = not significant

Scots pine

Scots pine (*Pinus sylvestris*) is the most frequent tree species in the ICP Forests Level I network (Table 7-3). It has a wide ecological niche due to its ability to grow on dry and nutrient poor soils and has frequently been used for reforestation. Scots pine is found over large parts of Europe from northern Scandinavia to the Mediterranean region and from Spain to Türkiye (and is also distributed considerably beyond the UNECE region).

In 2022, Scots pine trees showed mean defoliation of up to 10% on 15.4% of plots and slight (>10–25%) mean defoliation on 61.6% of the plots (please refer to the online supplementary material[1], Figure S1-1). Defoliation of Scots pine trees on 22.2% of the plots was moderate (>25–60% defoliation, class 2) and only on 0.8% of the plots severe (>60% defoliation, class 3). Plots with the lowest mean defoliation were primarily found in southern Norway, Estonia, and parts of Spain and Türkiye, whereas plots with comparably high defoliation were located in Czechia, western Slovakia, south-eastern France, and western Bulgaria.

There has been a significant trend of mean plot defoliation of Scots pine over the course of the last 20 years with an increase of 4.2%p (Figure 7-2a). The mean defoliation across plots showed some fluctuation towards the end of the chosen reporting period, with mean defoliation values steadily above the trend line since 2015, and with the highest value in 2019.

Norway spruce

Norway spruce (*Picea abies*) is the second most frequently assessed conifer species within the ICP Forests monitoring programme. The area of its distribution within the participating countries ranges from Scandinavia to northern Italy and from north-eastern Spain to Romania. Favoring cold and humid climate, Norway spruce at the southern edge of its distribution area is found only at higher elevations. Norway spruce is very common in forest plantations effectively enlarging its natural distribution range.

In 2022, spruce trees on over one fifth (21.5%) of all Norway spruce plots had mean defoliation up to 10%, and further 40.3% had only slight defoliation (please refer to the online supplementary material[1], Figure S1-2). On 37.5% of the plots, spruce defoliation was moderate (>25–60% defoliation), while severe mean defoliation was recorded on 0.6% of the plots. Plots with low mean defoliation were found mostly in Scandinavia and the Balkan region. Plots with high mean defoliation values were mostly located in central Europe.

The 20-year trend in mean plot defoliation of Norway spruce shows an increase of almost 5%p (Figure 7-2b). The annual mean values have been on a steady rise and above the trend line since 2019, with the highest ever mean value recorded in 2022.

Austrian (Black) pine

Austrian pine (*Pinus nigra*) is one of the most important native conifers in southern Europe, growing predominantly in mountain areas from Spain in the west to Türkiye in the east, with scattered occurrences as far north as central France and northern Hungary. This species can grow in both dry and humid habitats with considerable tolerance for temperature fluctuations. Two subspecies are recognized, along with a number of varieties, adapted to various environmental conditions.

Austrian pine had a mean defoliation of up to 10% on 12.1% of the plots containing this species, and between 11 and 25% on 58.2% of plots (please refer to the online supplementary material[1], Figure S1-3). Defoliation was moderate on 27.6% of the plots (>25-60% defoliation) and severe on 2.1% of the plots. Plots with less than 10% mean defoliation were mostly located in Türkiye and northern Spain, while plots with higher defoliation were scattered throughout the region.

The 20-year trend in mean plot defoliation of Austrian pine shows large fluctuations since 2014 (Figure 7-2c). From 2010 to 2014 the annual mean plot defoliation was lower than the trend, but it has been above the trend line since then, reaching its absolute maximum in 2018.

Mediterranean lowland pines

Four pine species are included in the group of Mediterranean lowland pines: Aleppo pine (*Pinus halepensis*), maritime pine (*P. pinaster*), stone pine (*P. pinea*), and Turkish pine (*P. brutia*). Most plots dominated by Mediterranean lowland pines are located in Spain, France, and Türkiye, but they are also important species in other Mediterranean countries. Aleppo and maritime pine are more abundant in the western parts, and Turkish pine in the eastern parts of this area.

Mediterranean lowland pine plots had mean defoliation of up to 10% on 3.5% of plots and 65.1% of plots had defoliation between 11 and 25% (please refer to the online supplementary material[1], Figure S1-4). Defoliation was moderate on 30.4% of the plots, and severe on 1.0%. Most of plots with defoliation up to 25% were located in Türkiye and Spain. Plots with moderate to severe mean defoliation values (>40% defoliation) were mostly located in the proximity to the coastline of the western Mediterranean Sea.

For Mediterranean lowland pines, the trend shows an increase in defoliation of 4.3%p over the past 20 years (Figure 7-2d), with annual values staying mostly close to the trendline.

[1] http://icp-forests.net/page/icp-forests-technical-report

Common beech

Common beech (*Fagus sylvatica*) is the second most frequently assessed species on Level I plots in 2022 and by far the most frequently assessed deciduous tree species within the ICP Forests monitoring programme (Table 7-3). It is found on Level I plots from southern Scandinavia in the North to southernmost Italy, and from the Atlantic coast of northern Spain in the West to the Bulgarian Black Sea coast in the East.

In 2022, common beech had up to 10% mean defoliation on 20.6% of the beech plots (please refer to the online supplementary material[1], Figure S1-5). On 41.3% of plots, beech trees were slightly defoliated (>10–25% defoliation), moderate mean defoliation was recorded on 35.4%, and severe defoliation on 2.8% of plots. Most plots with lower mean defoliation were located in eastern Europe, while plots with severe defoliation were predominantly located in France and Germany.

The 20-year trend in mean plot defoliation of common beech shows an increase of 3.9%p (Figure 7-2f). Annual mean values generally stay close to the trend line, but there were three larger deviations from this trend, in 2004, 2016, and 2020 - the highest ever mean plot defoliation of 23.9% was recorded in 2020. In 2004, the annual mean plot defoliation was higher than the trend as a result of the drought in the preceding year which affected large parts of Europe (Ciais et al. 2005, Seidling 2007, Seletković et al. 2009).

Deciduous temperate oaks

Deciduous temperate oaks include pedunculate and sessile oak (*Quercus robur* and *Q. petraea*) and their hybrids. They cover a large geographical area in the UNECE region: from southern Scandinavia to southern Italy and from the northern coast of Spain to the eastern parts of Türkiye.

In 2022, mean defoliation of temperate oaks was up to 10% on 8.3% of the plots, and from >10 to 25% on 42.1%, therefore more than half of the plots had no or slight mean defoliation. Moderate mean defoliation (>25–60%) was recorded on 46.6% of plots and severe defoliation (more than 60% defoliation) on 3.1% of the plots (please refer to the online supplementary material[1], Figure S1-6). Plots with severe defoliation were located mostly in parts of central Europe and France, while plots with mean defoliation up to 25% were mainly found in the east of the continent.

A significant increase in mean plot defoliation (3.2%p) has been recorded for deciduous temperate oaks in the past 20 years. Generally, the changes in the defoliation status are not very fast for deciduous temperate oaks. A good example is the increase of oak defoliation in the drought year 2003, followed by a delayed recovery (Figure 7-2g). The largest deviation of the mean defoliation from the trend line happened in 2019, possibly due to the effects of drought events both in 2018 and 2019 (JRC 2019). The rise of defoliation continued in 2021, with no further change in 2022.

Deciduous (sub-) Mediterranean oaks

The group of deciduous (sub-) Mediterranean oaks includes Turkey oak (*Quercus cerris*), Hungarian or Italian oak (*Q. frainetto*), downy oak (*Q. pubescens*), and Pyrenean oak (*Q. pyrenaica*). The range of distribution of these oaks is confined to southern Europe, as indicated by their common names.

Mediterranean oaks had mean defoliation up to 10% on 12.6% of plots, and between 10 and 25% on 49.5% of plots, yielding a total of 65.3% of plots with mean defoliation up to 25% for these oaks in 2022. More than a third (35.5%) of plots showed moderate, and 2.4% severe mean defoliation for Mediterranean oaks (please refer to the online supplementary material[1], Figure S1-7). Plots with lower mean defoliation were located predominantly in Serbia, while plots with higher mean defoliation were found mostly in Hungary and southeastern France.

There has been no significant trend in mean plot defoliation for deciduous (sub-) Mediterranean oaks for the past 20 years (Figure 7-2h). Mean plot defoliation values generally stay very close to the trend line.

Evergreen oaks

The group of evergreen oaks consists of kermes oak (*Quercus coccifera*), holm oak (*Q. ilex*), *Q. rotundifolia* and cork oak (*Q. suber*). The occurrence of this species group as a typical element of the sclerophyllous woodlands is confined to the Mediterranean basin.

Only 2.0% of the evergreen oak plots had mean defoliation up to 10%, and there were 42.5% of the plots in the range >10 to 25% mean defoliation (please refer to the online supplementary material[1], Figure S1-8). Moderate defoliation was recorded on 54.2%, and severe defoliation on 1.2% of plots. The majority of plots with defoliation over 40% were located along the shoreline of the northwest Mediterranean.

Based on the trend analysis, evergreen oaks had the largest increase (+ 7.3%p) in defoliation of all analyzed species and species groups over the last 20 years (Figure 7-2i). The defoliation development pattern for evergreen oaks is characterized by larger deviations from the trend line, sometimes lasting for several years.

[1] http://icp-forests.net/page/icp-forests-technical-report

Damage causes

In 2022, damage cause assessments were carried out on 99 920 trees on 5 339 plots and in 26 countries. On 49 004 trees (49.0%) at least one symptom of damage was found, which is 2.6%p higher than in 2021 (46.4%). In total, 70 300 observations of damage were recorded (multiple damage symptoms per tree were possible). Both fresh and old damage was reported.

The average number of recorded damage symptoms per assessed tree (ratio, Table 7-4) was higher for the broadleaved tree species and species groups than for the conifers. It was highest for evergreen oaks with 1.09 symptoms per tree on average, and lowest for Norway spruce with 0.42 symptoms per tree. Compared to 2021, both the number of recorded damage symptoms and the ratios have been increasing for all species and species groups, except for deciduous temperate oaks, which had a decrease in number of observed damage symptoms.

Table 7-4: Number of damage symptoms and assessed trees, and their ratio for the main tree species and species groups in 2022. Multiple damage symptoms per tree and dead trees are included.

Main species or species groups	N damage symptoms	N trees	Ratio
Scots pine (*Pinus sylvestris*)	10 437	16 950	0.62
Norway spruce (*Picea abies*)	4 445	10 582	0.42
Austrian pine (*Pinus nigra*)	3 123	5 420	0.58
Mediterranean lowland pines	4 851	7 988	0.61
Other conifers	4 508	7 725	0.58
Common beech (*Fagus sylvatica*)	8 852	10 945	0.81
Deciduous temperate oaks	7 697	8 486	0.91
Dec. (sub-) Mediterranean oaks	6 997	7 929	0.88
Evergreen oaks	5 029	4 628	1.09
Other broadleaves	14 361	19 267	0.75
Total			
Conifers	27 364	48 665	0.56
Broadleaves	42 936	51 255	0.84
All species	**70 300**	**99 920**	**0.70**

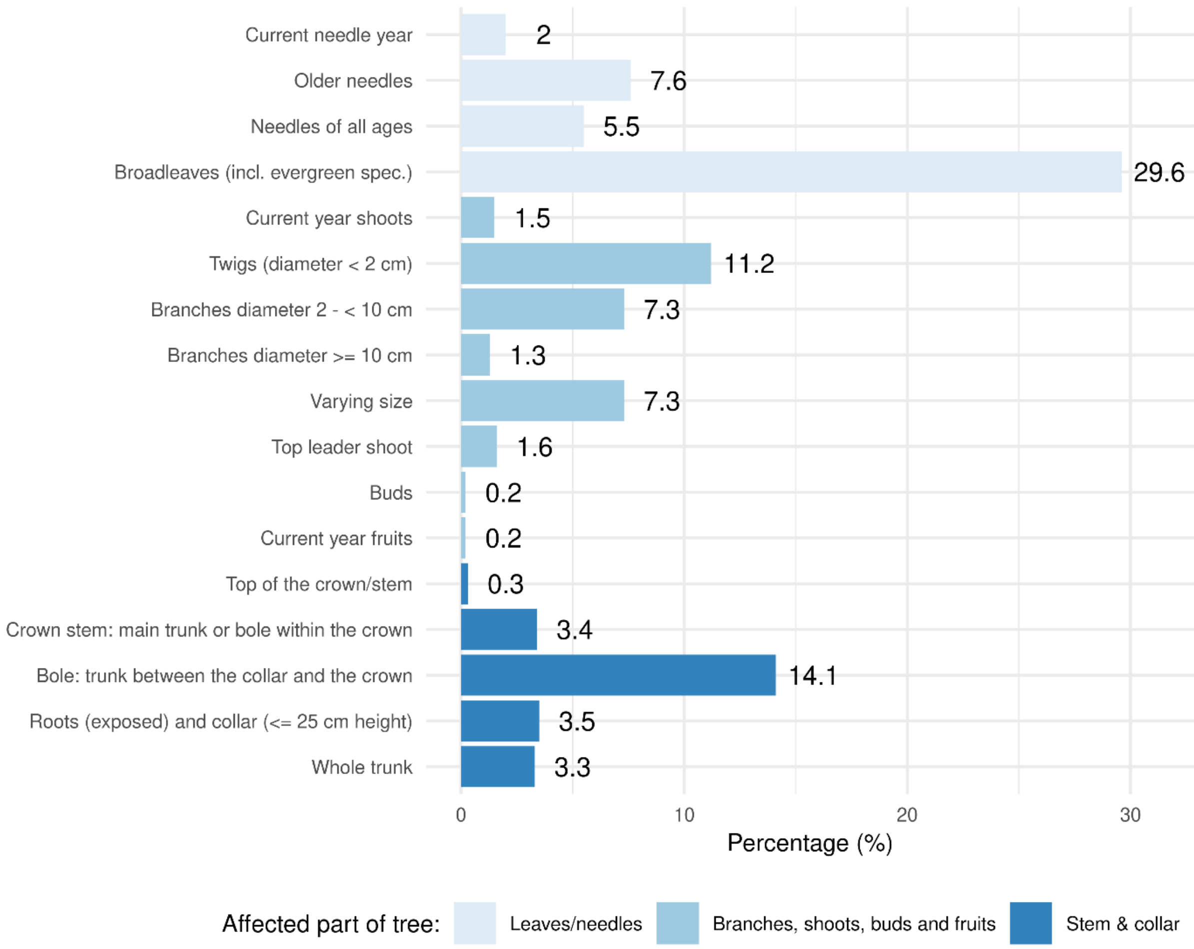


Figure 7-3: Percentage of recorded damage symptoms in 2022 (n=69 407), affecting different parts of a tree. Multiple affected parts per tree were possible. Dead trees are not included.

Symptom description and damage extent

Most of the reported damage symptoms were observed on the leaves of broadleaved trees (29.6%), followed by twigs and branches (27.1%), and stems (21.3%; Figure 7-3). Needles were also often affected (15.1%), while roots, collar, shoots, buds, and fruits of both broadleaves and conifers were less frequently affected.

More than half (54.9%) of all recorded damage symptoms had an extent of up to 10%, 35.6% had an extent between 10% and 40%, and 9.6% of the symptoms covered more than 40% of the affected part of a tree.

Causal agents and factors responsible for the observed damage symptoms

Insects were the predominant cause of damage and responsible for 23.4% of all recorded damage symptoms (Figure 7-4). Within the group of insects, 38.7% of damage symptoms were caused by defoliators. Wood borers were responsible for 18.8%, leaf miners for 13.2%, sucking insects for 11.7%, and gallmakers for 5.7% of the damage caused by insects.

Abiotic factors were the second major causal agent group responsible for 20.3% of all damage symptoms. Within this agent group, more than half of the symptoms (55.6%) were attributed to drought, while snow/ice and hail caused 11.2%, wind 7.5%, heat/sun scald 3.5% and frost 3.4% of the symptoms.

The third major identified cause of tree damage were fungi with 10.5% of all damage symptoms. Of those, 25% showed signs of decay and root rot fungi, followed by dieback and canker fungi and needle cast and needle rust fungi (15.2% each), blight (10.2%) and powdery mildew (6.1%).

Direct action of man refers mainly to impacts of silvicultural operations, mechanical/vehicle damage, forest harvesting, or resin tapping. This agent group accounted for 4.6% of all recorded damage symptoms. The damaging agent group 'Game and grazing' was of minor importance (1.2%). Fire caused 0.7% of all damage symptoms. The agent group 'Atmospheric pollutants' refers here only to damage caused by direct atmospheric pollution impact. Visible symptoms of direct atmospheric pollution impact, however, were very rare (0.03% of all damage symptoms). Other factors were responsible for 11.0% of all reported damage symptoms. Apart from these identifiable causes of damage symptoms, a considerable number of symptoms (28.4%) could not be identified in the field.

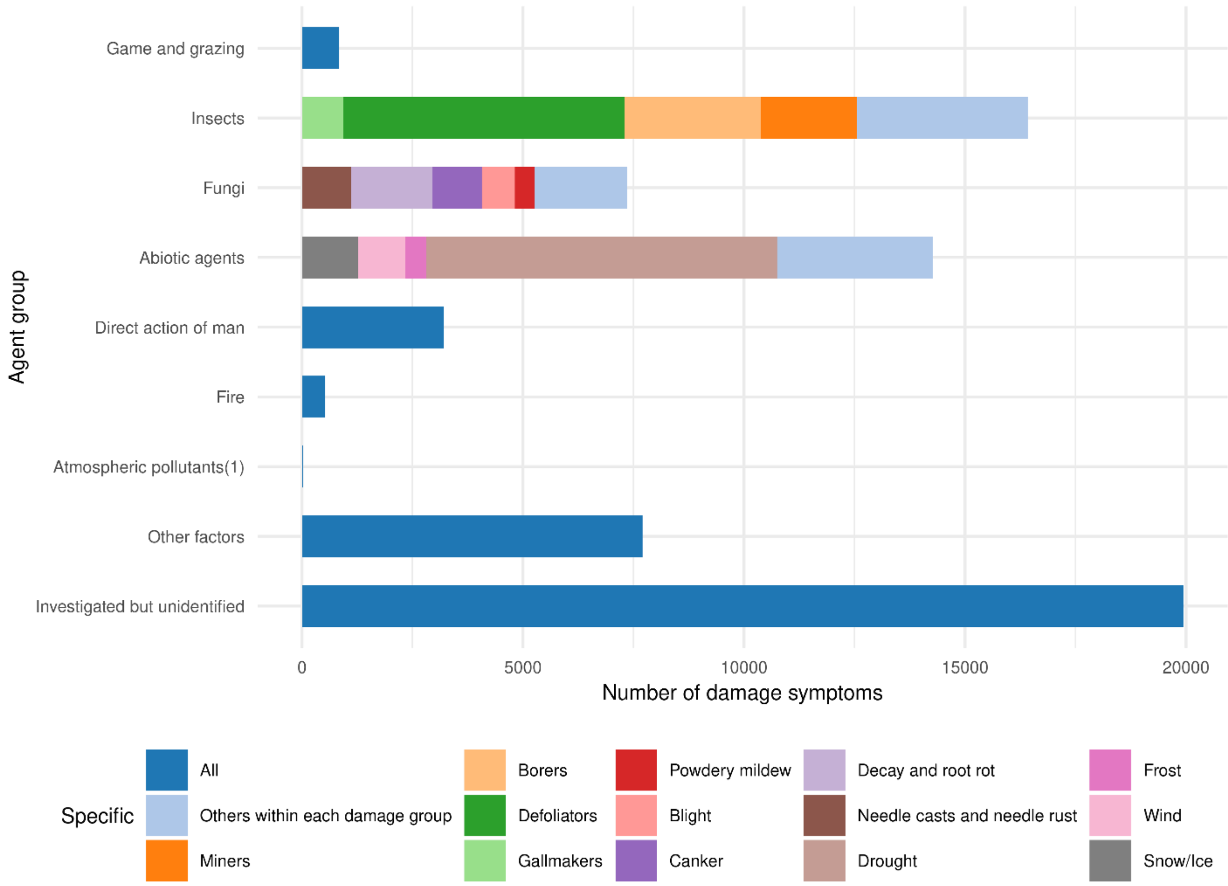


Figure 6-4: Number of damage symptoms (n=70 300) according to agent groups and specific agents/factors in 2022. Multiple damage symptoms per tree were possible, and dead trees are included. (1) Visible symptoms of direct atmospheric pollution impact only

The occurrence of damaging agent groups differed between major species or species groups (Figure 7-5). Insects were the most important damaging agent group for deciduous temperate oaks (causing 38.7% of all damage), common beech (36.1%) and deciduous (sub-) Mediterranean oaks (32.6%), while insect damage was not so common in Scots pine (8.2%) and Norway spruce (7.4%). Abiotic factors caused by far the most damage in evergreen oaks (46.8%) and Mediterranean lowland pines (40.9%), and the least in Austrian pine (12.4%) and Scots pine (11.5%). Fungi were important damaging agents for Austrian pine (19.4%), and evergreen oaks (15.6%). Direct action of man was of little importance for most species, apart from Norway spruce (15.5%) and Scots pine (7.9%). Damage from game and grazing played a minor role for all species and species groups except for Norway spruce (10%). Fire affected mostly Mediterranean species: 2.3% of Mediterranean lowland pine trees, 2.1% of Austrian pines and 0.8% of evergreen oaks were affected. Other identified factors, such as competition, European mistletoe (*Viscum album)* and European ivy (*Hedera helix*), were prominent in Scots pine (25.9%) and Austrian pine (20.7%). The percentage of recorded but unidentified damage symptoms was small in evergreen oaks (10.6%) but large for Norway spruce (40.3%), Scots pine (33.2%), and deciduous (sub-) Mediterranean oaks (31.3%).

The most important specific damaging agents for common beech were mining insects causing 20.3% of the damage symptoms, followed by defoliators (9%), drought (6.5%), and silvicultural operations (4.0%). Defoliators were also frequently causing damage on deciduous temperate oaks (11.7%), while sucking insects (9.1%), borers (8.6%), drought (6.3%), powdery mildew (4.9%), and competition (3.1%) were also significant. For deciduous (sub-) Mediterranean oaks, drought (11.4%) was the most common damaging agent, followed by defoliators (9.4%), sucking insects (8.8%), borers (8.4%), and European ivy (3.6%). Drought was by far the most important damaging agent for evergreen oaks (43.6%), but also borers (12.5%), decay and root rot fungi (11.1%), defoliators (4%), and blight (3.6%) had an impact on these oak species.

Most damage symptoms in Scots pine were caused by various effects of competition (14.2%), followed by *Viscum album* (7%), needle cast/needle rust fungi (5.4%), borers (4.9%), silvicultural operations (4.9%), wind and drought (3.6% each). For Norway spruce, silvicultural operations (10.2%), competition (7.2%), red deer (6.3%), borers (5.1%), mechanical/vehicle damage (4.8%), and snow/ice (4.5%) were most important. Defoliators were causing most damage (18.1%) on Austrian pine trees, but *Viscum album* (16.6%), needle cast/needle rust fungi (11.5%), drought (7.1%), and blight (5.4%) also caused considerable damage. Mediterranean lowland pines were mostly affected by drought (29.6%), defoliators (7.2%), sucking insects (6.6%), snow/ice (4.9%), and *Viscum album* (4.8%).

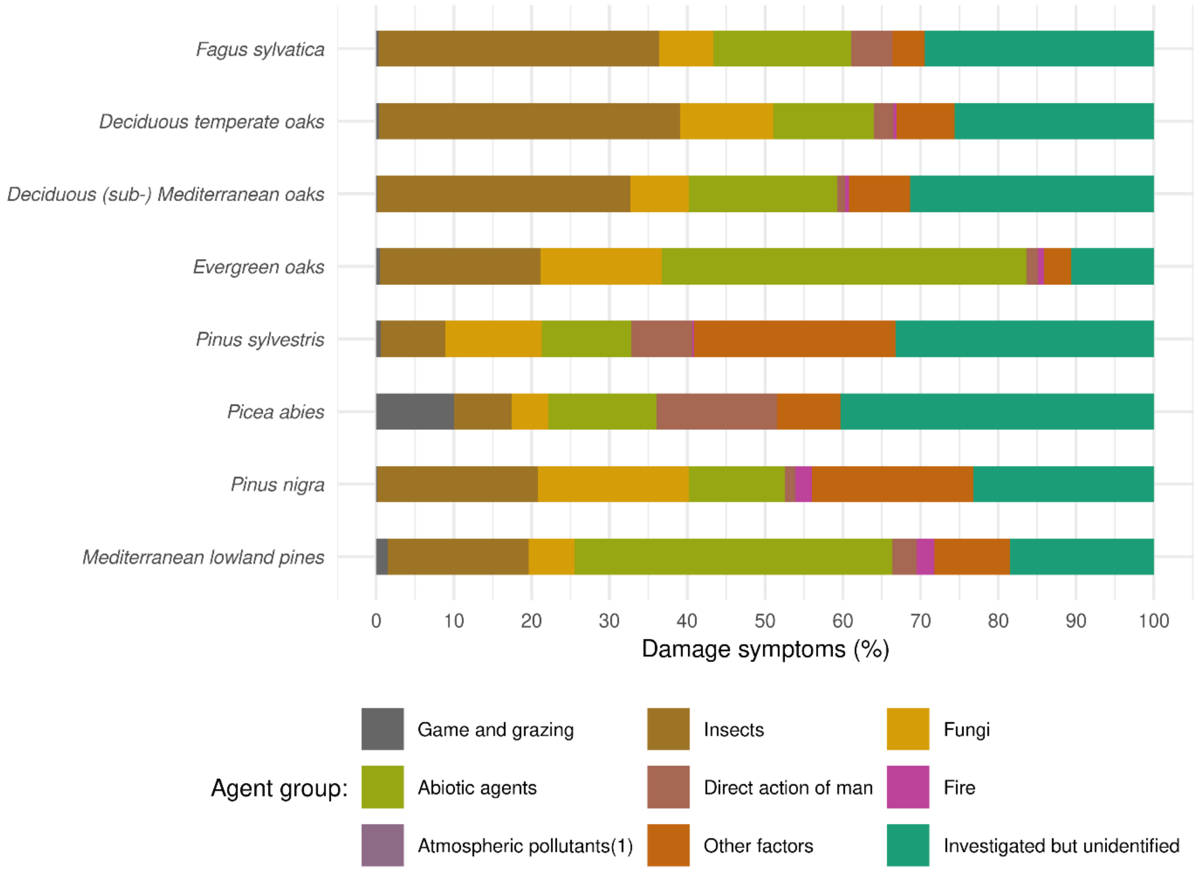


Figure 7-5: Percentage of damage symptoms by agent group for each main tree species and species group in 2022. (1) Visible symptoms of direct atmospheric pollution impact only

EVALUATIONS

Regional importance of the different agent groups

Damage caused by abiotic factors was reported from 2 008 Level I plots (38%), occurring frequently throughout Europe. Countries most affected by abiotic factors were Spain, Slovenia, Montenegro, and Cyprus.

Damage caused by insects was observed on 1 731 European Level I plots in 2022, which corresponds to 32% of all plots with damage assessments. With some exceptions (Scandinavia, Ireland, northern Germany, Czechia and the Baltic countries), a high proportion of plots was thus affected by insects throughout Europe.

The agent group 'Fungi' was responsible for damage on 1 321 European Level I plots (25%), and was frequently occurring in many countries, most notably in Estonia, Slovenia, Montenegro, parts of Serbia, Poland, Bulgaria, and Spain. Low occurrence of damage by fungi was observed in Norway, Sweden, Italy, Türkiye, and Greece.

The damaging agent group 'Direct action of man' impacted trees on 1 027 plots (19%) and was most frequently occurring in eastern parts of Europe and south-western Germany.

Damage caused by game and grazing was most frequently observed in the Baltic countries, Hungary, and Spain. In total, 280 Level I plots (5%) had trees damaged by this agent group.

There were 59 plots (1%) with damage inflicted by fire, most of them located in Spain.

For maps showing incidents of various agent groups, please refer to the online supplementary material[1].

Tree mortality and its causes

There were 873 (0.9%) new dead trees in the damage assessment 2022 (466 broadleaves and 407 conifers). The highest numbers of dead trees were found for Norway spruce (206 trees, corresponding to a mortality rate of 1.9%), downy birch (*Betula pubescens*, 134 trees, corresponding to 5.5%), and Scots pine (104 trees, corresponding to 0.6%). Mortality rates for the main species and species groups were in the range from 0.3 to 0.7% (with the exception of Norway spruce). Most dead trees were reported from Norway (201, mainly downy birch), Germany (121, mainly Norway spruce), Türkiye (90, mainly *Pinus brutia*), and Italy (71). The main cause of mortality to both coniferous and broadleaved trees were abiotic factors (Figure 7-6), followed by insects, fungi, and fire. The determination of the cause of tree mortality is often very difficult; it could not be identified for more than 60% of the dead trees in 2022.

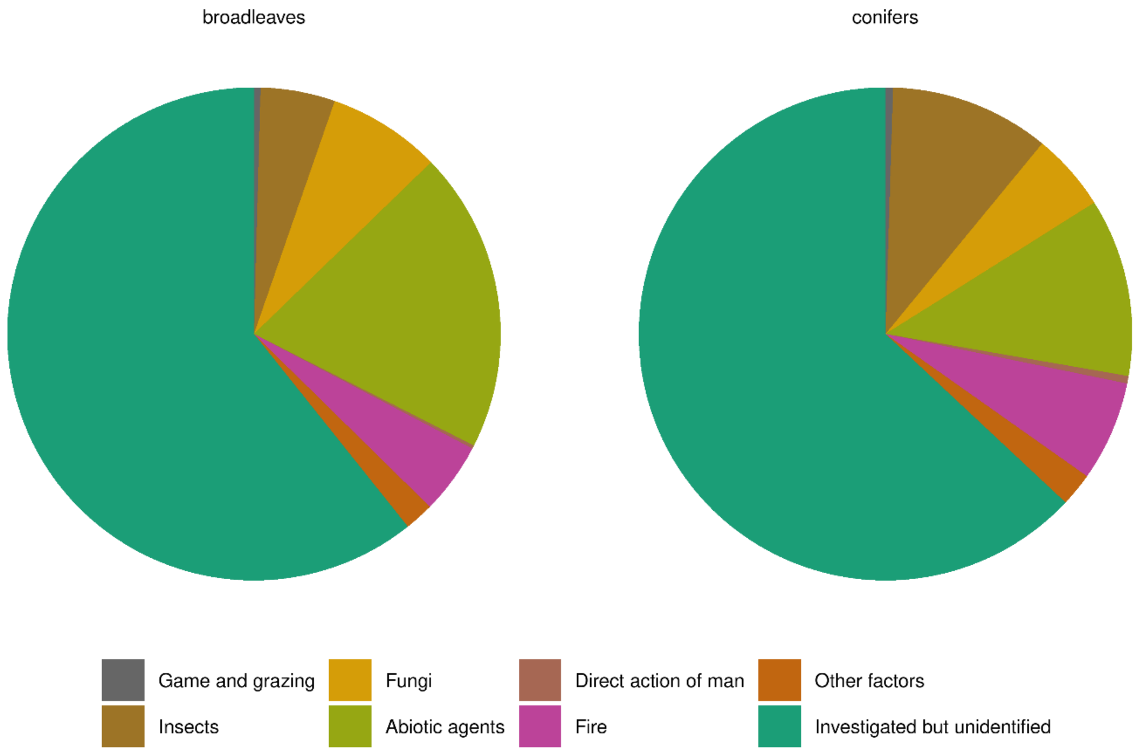


Figure 7-6: Percentage of damaging agent groups causing mortality of broadleaved and coniferous trees in 2022 (n = 873)

[1] http://icp-forests.net/page/icp-forests-technical-report

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