Forest Condition in Europe

The 2020 Assessment

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

6 TREE CROWN CONDITION IN 2019

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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 the 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 2019, as well as long-term trends for the main species and species groups.

Methods of the 2019 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. (2016, see also Eichhorn and Roskams 2013). Regular national calibration trainings of the survey teams and international cross-comparison courses (ICCs) ensure the quality of the data and comparability across the participating countries (Eickenscheidt 2015, Dănescu 2019, Meining et al. 2019).

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 6-1). In the maps presenting the mean plot defoliation and in Table 6-4, class 2 is subdivided into class 2-1 (> 25–40%) and class 2-2 (> 40–60% defoliation).

Table 6-1: 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 6-2 shows countries and the number of plots assessed for crown condition parameters from 2010 to 2019, and the total number of sample trees submitted in 2019. 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.

Damage cause assessments

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

Table 6-2: Number of plots assessed for crown condition parameters from 2010 to 2019 in countries with at least one Level I crown condition survey since 2010, and total number of sample trees submitted in 2019

Country	Plots 2010	2011	2012	2013	2014	2015	2016	2017	2018	Plots 2019	Trees 2019
Andorra	3	3	3	11	11	12					
Austria	135										
Belarus	410	416		373		377					
Belgium	9	9	8	8	8	8	53	53	52	52	551
Bulgaria	159	159	159	159	159	159	159	160	160	160	5 591
Croatia	83	92	100	105	103	95	99	99	99	97	2 328
Cyprus	15	15	15	15	15	15			15	15	365
Czechia	132	136	135		138	136	136	135	132	132	5 026
Denmark	17	18	18	18	18	18	17	17	17	17	406
Estonia	97	98	97	96	96	97	98	98	98	98	2 383
Finland	932	717	785								
France	532	544	553	550	545	542	533	527	521	515	10 399
Germany	411	404	415	417	422	424	421	416	410	421	10 094
Greece	98				57	47	23	36	40	45	1 055
Hungary	71	72	74	68	68	67	67	66	68	68	1 530
Ireland	29		20							28	589
Italy	253	253	245	247	244	234	246	247	249	237	4 593
Latvia	207	203	203	115	116	116	115	115	115	115	1 740
Lithuania	75	77	77	79	81	81	82	82	81	81	1 957
Luxembourg				4	4	4	4	3	3	4	96
Montenegro	49	49	49	49			49	49	49	49	1 176
Netherlands	11										
Norway	491	496	496	618	687	554	629	630	623	687	5 651
Poland	374	367	369	364	365	361	353	352	348	346	6 893
Rep. of Moldova								9	9		
Romania	239	242	241	236	241	242	243	246	246	247	6 036
Russian Fed.	288	295									
Serbia	121	119	121	121	128	127	127	126	126	127	2 984
Slovakia	108	109	108	108	107	106	103	103	101	100	4 499
Slovenia	44	44	44	44	44	44	44	44	44	44	1 065
Spain	620	620	620	620	620		620	620	620	620	14 880
Sweden	830	640	609	740	842	839	701	618	760	849	2 913
Switzerland	48	47	47	47	47	47	47	47	47	47	1 022
Turkey	554	563	578	583	531	591	586	598	601	597	13 837
United Kingdom	76										
TOTAL	7 521	6 807	6 189	5 795	5 697	5 343	5 555	5 496	5 634	**5 798**	**109 659**

- 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. (2016). 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 analysed 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 assessed for crown condition on the Level I network in 2019, *Pinus sylvestris* was the most abundant tree species (16.7% of all trees), followed by *Picea abies* (11.8%), *Fagus sylvatica* (11.4%), *Pinus nigra* (4.9%), *Quercus petraea* (4.2%), *Quercus robur* (4.1%), *Quercus ilex* (3.6%), *Pinus brutia* (3.2%), *Quercus cerris* (3.1%), *Betula pubescens* (2.4%), *Pinus halepensis* (2.4%), *Quercus pubescens* (2.1%), *Betula pendula* (2.1%), *Abies alba* (2.0%) and *Pinus pinaster* (1.8%). Most Level I plots with crown condition assessments contained one (49.5%) or two to three (38.1%) tree species per plot. On 10.2% of plots four to five tree species were assessed, and only 2.2% of the plots featured more than five tree species. In 2019, 49.9% of the assessed trees were broadleaves and 50.1% 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 6-4 and 6-5). For the calculation of the mean plot defoliation of all species, only plots with a minimum number of three trees were analysed. 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 partly explain the discrepancy between the number of trees in Table 6-3 and 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 & Drápelová 2011, Curtis & 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 & 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 (Marchetto 2015) was used.

Figures 6-2a-j show (1) the annual mean defoliation per plot, (2) the mean across plots and (3) the trend of defoliation based on the regional Sen's slope calculations for the period 2000–2019. 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 2011–2019 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 period of interest. All queries and statistical analyses were conducted in R/RStudio software environment (R Core Team 2016).

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 (Table 6-3). 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.

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

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Table 6-3: Information on the monitoring design for the national crown condition surveys in the participating countries in 2019

Country	Total area (1000 ha)	Forest area (1000 ha)	Grid size (km x km)	No. of sample plots	No. of sample trees
Albania	No information available for 2019				
Andorra	No information available for 2019				
Austria	No information available for 2019				
Belarus	No information available for 2019				
Belgium-Flanders	1351	146	4x4	71	1474
Belgium-Wallonia	1684	555	varying	47	372
Bulgaria	11100	4257	4x4/16x16	160	5591
Croatia	5659	2795	16x16	97	2328
Cyprus	925	298	16x16	15	365
Czechia	7887	2673	16x16	125	4538
Denmark	4293	627	varying	377	2376
Estonia	4534	2331	16x16	98	2286
Finland	No information available for 2019				
France	54883	16814	16x16	524	10668
Germany	35721		16x16	421	10128
Greece	13205	6513	16x16	46	1055
Hungary	9300	1939	16x16	78	1869
Ireland	No information available for 2019				
Italy	30128	10345	16x16	237	4166
Latvia	6459	3223	16x16	115	1732
Lithuania	6529	2197	4x4/16x16	992	5956
Luxembourg	259	91	4x4	49	1176
North Macedonia	No information available for 2019				
Rep. of Moldova	3385	374	3x3	618	16676
Montenegro	1381	827	16x16	49	1176
Netherlands	No information available for 2019				
Norway	32381	12210	3x3	1863	10563
Poland	31268	9255	8x8	2042	40840
Portugal	No information available for 2019				
Romania	23839	6565	16x16	249	
Russian Fed.	No information available for 2019				
Serbia	8836	2360	4x4/16x16	130	2990
Slovakia	4904	2014	16x16	100	3712
Slovenia	2027	1238	16x16	44	1056
Spain	49880	18289	16x16	620	14880
Sweden	47496	27881	varying	4857	7795
Switzerland	4129	1279	16x16	47	1004
Turkey	77846	22300	16x16	599	13738
Ukraine	No information available for 2019				
United Kingdom	No information available for 2019				
Total				14 670	170 510

EVALUATIONS

Results of the transnational crown condition survey

Defoliation

The transnational crown condition survey in 2019 was conducted on 109 659 trees on 5 798 plots in 27 countries (Table 6-2). Out of those, 103 831 trees were assessed in the field for defoliation (Table 6-4).

The overall mean defoliation for all species was 23.3% in 2019; there was a slight increase in defoliation for both conifers and broadleaves in comparison with 2018 (Table 6-4). Broadleaved trees showed a higher mean defoliation than coniferous trees (23.2% vs. 22.2%). Correspondingly, conifers had a higher frequency of trees in the defoliation classes 'none' and 'slight' (73.4% combined) than broadleaves (69.7%) and a lower frequency of trees with more than 60% defoliation (2.9% vs. 3.7%).

Among the main tree species and tree species groups, evergreen oaks and deciduous temperate oaks displayed the highest mean defoliation (28.6% and 26.9%, respectively). Common beech had the lowest mean defoliation (21.0%) followed by deciduous (sub-) Mediterranean oaks (21.2%) and Norway spruce with 22.0%. Mediterranean lowland pines had the highest percentage (75.8%) of trees with ≤ 25% defoliation, while deciduous temperate oaks had the lowest (58.3%). The strongest increase occurred in evergreen oaks (2.5%) and Mediterranean lowland pines (1.5%).

Mean defoliation of all species at plot level in 2019 is shown in Figure 6-1. More than two thirds (68.4%) of all plots had a mean defoliation up to 25%, and only 0.8% of the plots showed severe defoliation (more than 60%). Plots with mean defoliation over 40% were primarily located from the Pyrenees through southeast (Mediterranean) France to northwest Italy, but also from central and northern France through Germany and into Czechia, Slovakia and Hungary, and in western Bulgaria. Plots with low mean defoliation were found across Europe, but mainly in Norway, Sweden, Estonia, Romania, central Serbia, Greece and Turkey.

The following sections describe the species-specific mean plot defoliation in 2019 and the over-all trend and yearly mean plot defoliation from 2000 to 2019. For maps on defoliation of individual tree species in 2019, please refer to the online supplementary material[1].

Table 6-4: Percentage of trees assessed in 2019 according to defoliation classes 0-4 (class 2 subdivided), mean defoliation for the main species or species groups (change from 2018 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	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*)	22.4	52.0	15.7	6.2	3.0	0.6	22.8 (+0.7)	17 936
Norway spruce (*Picea abies*)	31.9	37.2	20.2	6.6	2.8	1.4	22.0 (+0.9)	12 495
Austrian pine (*Pinus nigra*)	29.1	43.8	15.0	7.1	4.8	0.3	22.9 (+0.8)	5 302
Mediterranean lowland pines	14.7	61.1	16.3	5.1	1.9	0.8	22.8 (+1.5)	8 382
Other conifers	35.0	41.0	15.5	5.9	2.3	0.2	20.2 (+0.7)	7 931
Common beech (*Fagus sylvatica*)	34.7	38.4	17.4	6.7	2.7	0.2	21.0 (+0.2)	12 599
Deciduous temperate oaks	19.1	39.2	27.7	9.7	3.9	0.4	26.9 (+1.0)	8 912
Dec. (sub-) Mediterranean oaks	30.6	43.6	16.5	6.5	2.4	0.4	21.2 (+/-0)	8 093
Evergreen oaks	7.0	52.8	25.7	9.1	5.3	0.2	28.6 (+2.5)	4 602
Other broadleaves	30.2	43.3	14.6	5.9	4.4	1.5	22.4 (-0.4)	17 579
TOTAL								
Conifers	26.0	47.4	16.8	6.2	2.9	0.7	22.2 (+0.9)	52 046
Broadleaves	27.4	42.3	18.8	7.1	3.7	0.7	23.2 (+0.3)	51 785
All species	26.7	44.9	17.8	6.6	3.3	0.7	23.3 (+0.7)	103 831

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

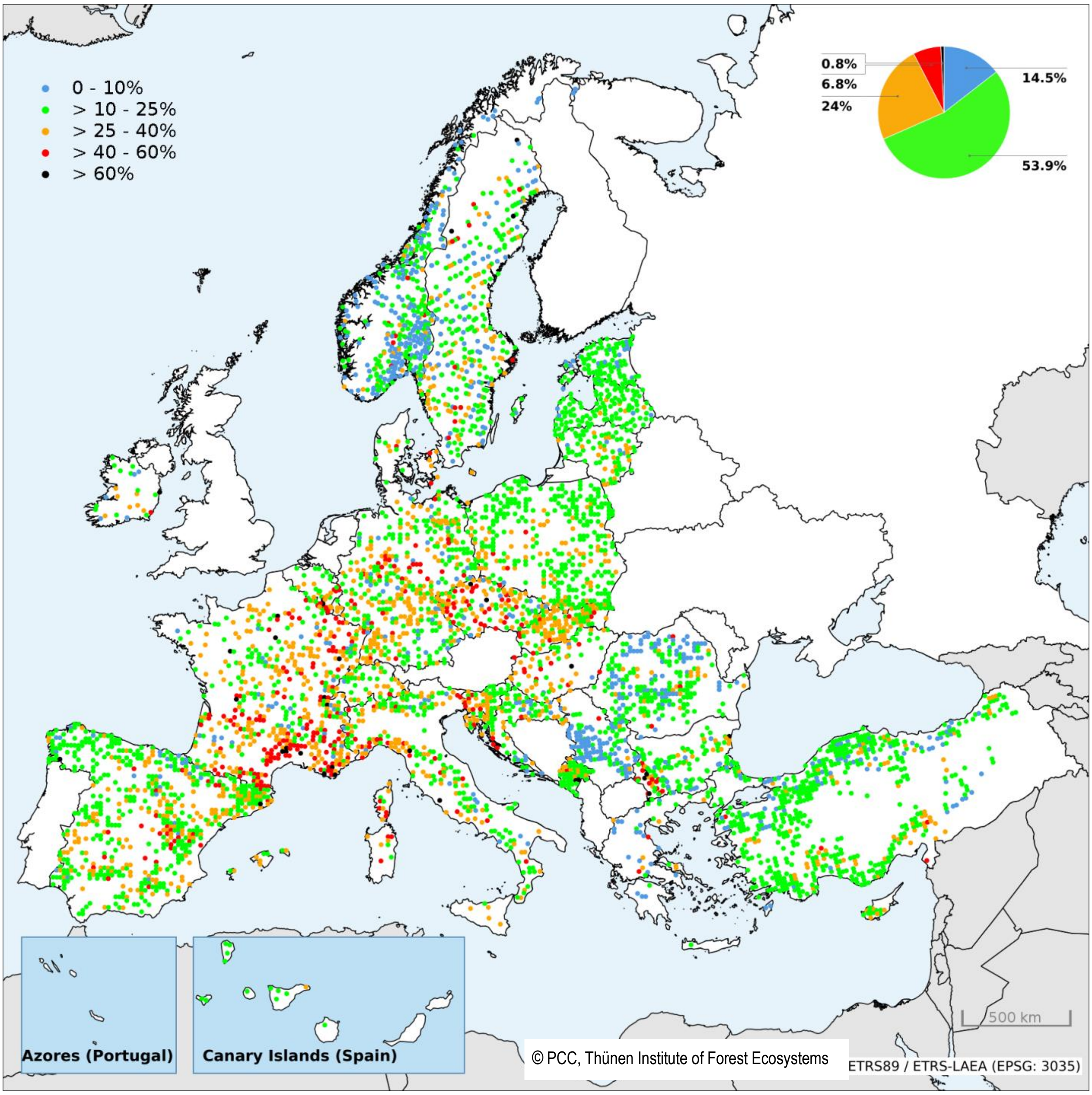
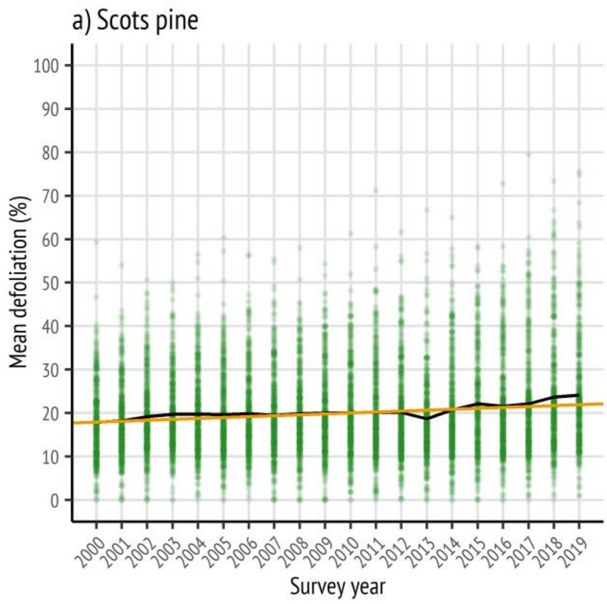
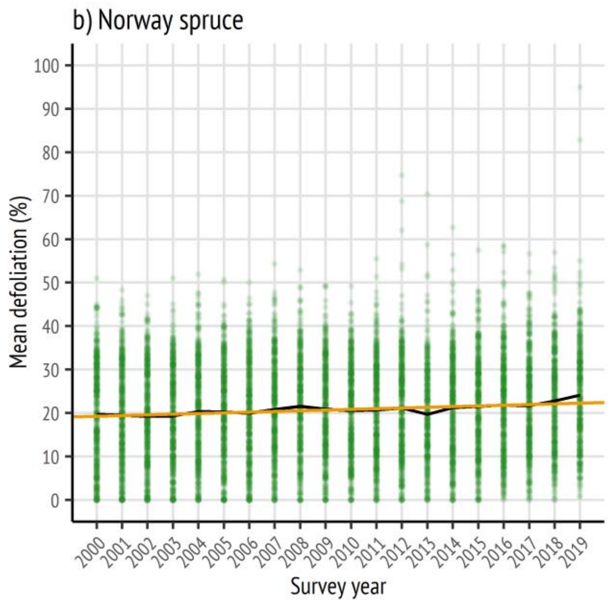
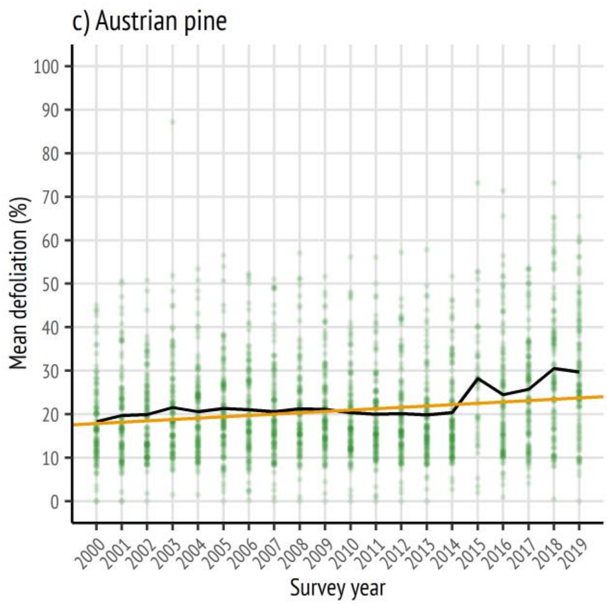
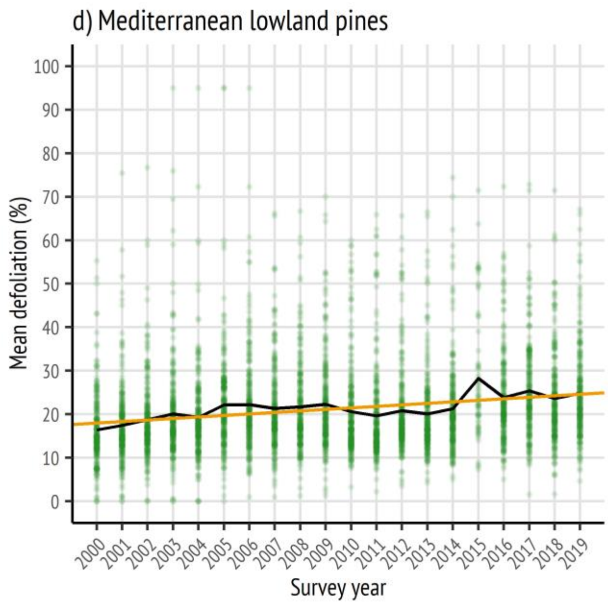


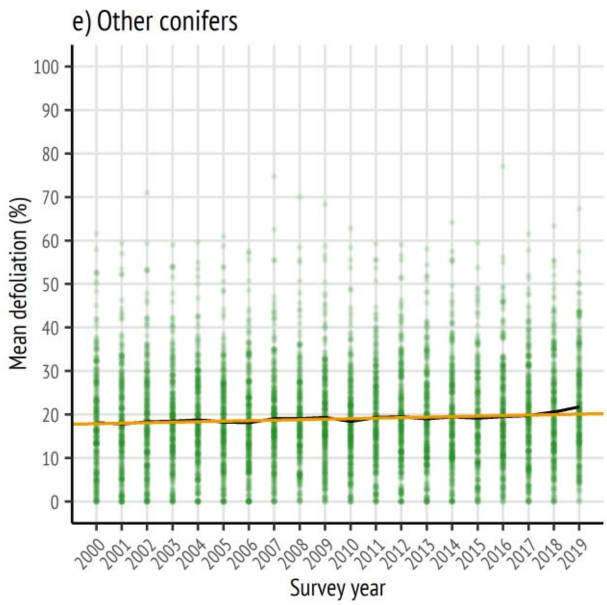
Figure 6-1: Mean plot defoliation of all species in 2019, shown as defoliation classes. The legend (top left) shows defoliation classes ranging from none (blue), slight (green), moderate (orange and red), to severe (black). The percentages refer to the needle/leaf loss in the crown compared to a reference tree. The pie chart (top right) shows the percentage of plots per defoliation class. Dead trees are not included.



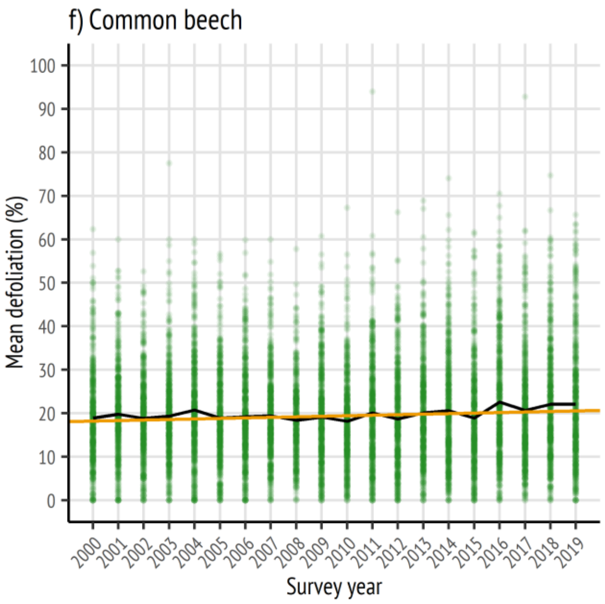


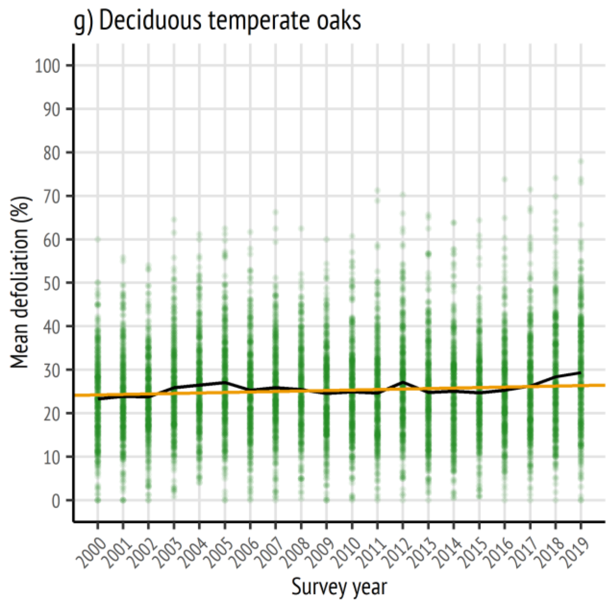


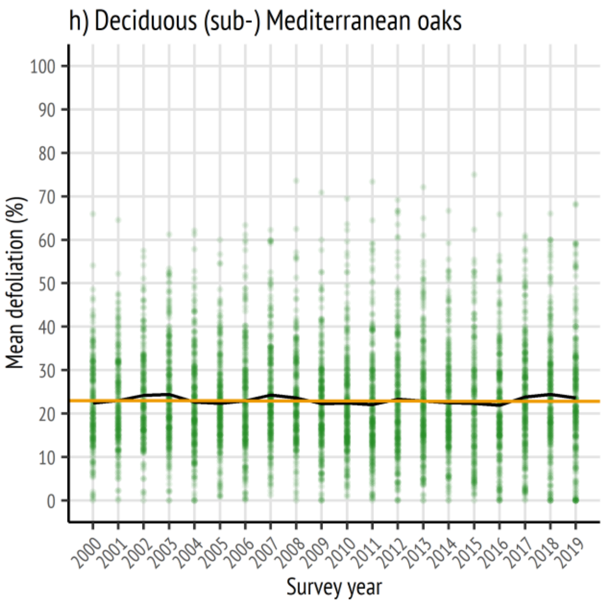


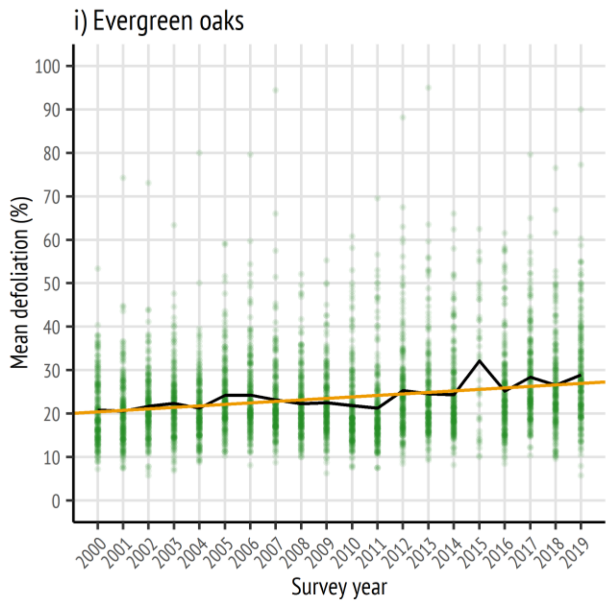


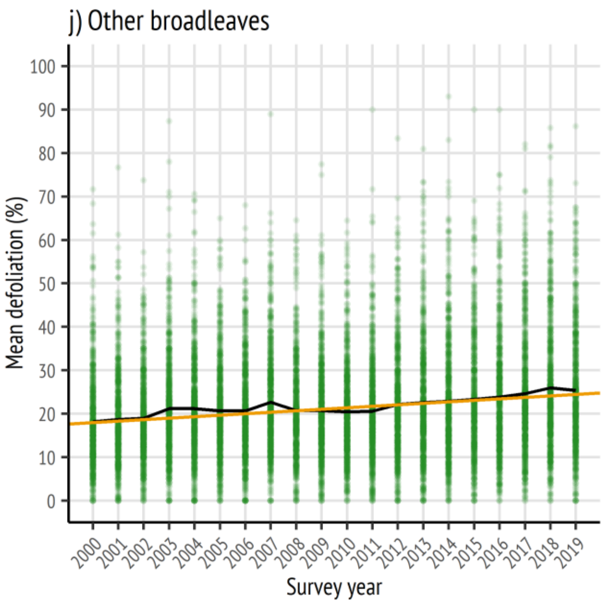
Figures 6-2 a-e: Over-all trend (orange line) and annual mean defoliation across plots (black line) at Level I plots from 2000–2019; points represent annual plot mean values: (a) Scots pine (regional Sen's slope = 0.2114, p < 0.001) (b) Norway spruce (regional Sen's slope = 0.1596, p < 0.001) (c) Austrian pine (regional Sen's slope = 0.3102, p = 0.0150) (d) Mediterranean lowland pines (regional Sen's slope = 0.3464, p < 0.001) (e) Other conifers (regional Sen's slope = 0.1160, p < 0.001)











Figures 6-2 f-j: Over-all trend (orange line) and annual mean defoliation across plots (black line) at Level I plots from 2000–2019; points represent annual plot mean values: (f) Common beech (regional Sen's slope = 0.1223, $p < 0.0350$) (g) Deciduous temperate oaks (regional Sen's slope = 0.1146, $p = 0.0478$) (h) Deciduous (sub-) Mediterranean oaks (regional Sen's slope = -0.0116, $p = 0.6732$) (i) Evergreen oaks (regional Sen's slope = 0.3435, $p < 0.001$) (j) Other broadleaves (regional Sen's slope = 0.3425, $p < 0.001$)

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Scots pine

Scots pine (*Pinus sylvestris*) was the most frequent tree species in the Level I network in 2019. 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 Turkey (and is also distributed considerably beyond the UNECE region).

On most of the plots with Scots pine, pine trees showed no (≤10%) or only slight mean defoliation (≤25%) in 2019; 15.3% and 63.1%, respectively, and 78.4% combined for defoliation classes 0 and 1 (please refer to the online supplementary material[1], Figure S1-1). Defoliation of Scots pine trees on 20.9% of the plots was moderate (>25–60% defoliation, class 2) and on 0.7% of the plots severe (>60% defoliation, class 3). Plots with the lowest mean defoliation were primarily found in southern Norway, eastern Germany, Estonia and northern Turkey, 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 (an increase of 4.2%, Figure 6-2a). 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.

Norway spruce

Norway spruce (*Picea abies*) is the second most frequently assessed species on Level I plots in 2019. The area of its distribution within the participating countries ranges from Scandinavia to northern Italy and from north-eastern Spain to Romania. Favouring 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 2019, Norway spruce trees on one quarter (24%) of all Norway spruce plots had defoliation up to 10%, and 42.7% had slight defoliation. Taken together, one third of the spruce plots (66.7%) had mean defoliation between 0 and 25% (please refer to the online supplementary material[1], Figure S1-2). On 32.5% of the plots defoliation was moderate (>25–60% defoliation) and severe defoliation was recorded on only 0.7% of the plots. Plots with low mean defoliation were found mostly in southern Norway and Sweden, northern Italy, Romania, Latvia and Estonia. Plots with high mean defoliation values were scattered across Europe.

The 20-year trend in mean plot defoliation of Norway spruce shows an increase of 3.2% (Figure 6-2b). The annual mean values did not deviate much from the trend line except in 2013 and 2019.

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 Turkey 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 different environmental conditions.

Austrian pine had a mean defoliation of up to 10% on 11.9% of the plots containing this species, and mean defoliation of >10–25% on 60.4% of the plots, in total 72.3% for class 0 and 1 (please refer to the online supplementary material[1], Figure S1-3). Defoliation was moderate on 25.9% of the plots (>25-60% defoliation) and severe on 1.8% of the plots. Plots with less than 10% mean defoliation were mostly located in Turkey. Plots with higher defoliation were mostly located in parts of France, Spain and western Bulgaria.

The 20-year trend in mean plot defoliation of Austrian pine shows an increase of 6.2% (Figure 6-2c). 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 Turkey, 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.

In 2019, 71.4% of Mediterranean lowland pine plots had mean defoliation of up to 25% for trees in this group (please refer to the online supplementary material[1], Figure S1-4), but only 3.8% of plots had defoliation up to 10%. Defoliation was moderate on 27.7% of the plots, and severe on 0.9%. Most of plots with defoliation up to 25% were located in Turkey 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 6.9% over the past 20 years (highest increase of all assessed species or species groups), and this trend is highly significant like in all other conifer species or species groups (Figure 6-2d).

Common beech

Common beech (*Fagus sylvatica*) is the most frequently assessed deciduous tree species within the ICP Forests monitoring programme. 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 2019, common beech had up to 10% mean defoliation on 20.9% of the beech plots, a bettering from the year before. Most of these plots were located in Romania, Bulgaria and Serbia (please refer to the online supplementary material[1], Figure S1-5). On 44.9% of the monitored plots, beech trees were slightly defoliated (>10–25% defoliation). There were 33.1% of plots with moderate mean defoliation (>25–60%), and 1.1% with severe defoliation (>60%). Plots with low defoliation were found mostly in southeastern 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 a slight increase of 2.4% (Figure 6-2e). Annual mean values generally stay close to the trendline, but there were two larger deviations from this trend, in 2004 and 2016. In 2004, the annual over-all mean 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). The effect of the drought affecting some European regions in 2018 is not very prominent.

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 Turkey.

In 2019, mean defoliation of temperate oaks was up to 10% on 6.5% of the plots, and from >10 to 25% on 40.3%, giving less than half of the plots (46.8%) with none or slight mean defoliation. Moderate mean defoliation (>25–60% defoliation) was recorded on 52.3% of plots and severe defoliation (more than 60% defoliation) on 0.9% of the plots (please refer to the online supplementary material[1], Figure S1-6). Plots with severe defoliation were located mostly in France, Germany and Croatia. Plots with low and moderate mean defoliation were scattered throughout Europe, while plots with mean defoliation up to 10% were mainly found in Romania, Croatia and Serbia.

There has been an increase in mean plot defoliation (2.2%) for deciduous temperate oaks in the past 20 years. Generally, the changes in the defoliation status are not very fast for deciduous temperate oaks and it typically takes several years for their crown to recover. A good example is the increase of oak defoliation in the drought year 2003, followed by a delayed recovery (Figure 6-2f). 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).

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.

In 2019, Mediterranean oaks had mean defoliation up to 10% on 16.1% of the plots, and on 49% of the plots between 10 and 25%, yielding a total of 65.1% of plots with mean defoliation up to 25% for these oaks. A third (34.5%) of plots showed moderate mean defoliation for Mediterranean oaks, and only 0.4% severe (please refer to the online supplementary material[1], Figure S1-7). Plots with lower mean defoliation were located predominantly in Serbia, Greece and Turkey, 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 6-2g). Mean plot defoliation values generally stay close to the trendline.

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.

On only 1.6% of the plots mean defoliation of evergreen oaks was up to 10%, and on 46.1% of the plots from >10 to 25% defoliation. When combining class 0 and 1, less than half of the plots had mean defoliation of up to 25% (47.7%, please refer to the online supplementary material[1], Figure S1-8). Moderate defoliation was recorded on 50.6% of plots, and severe on 1.6%. The majority of plots with defoliation of evergreen oaks over 40% were located in southern France including Corsica, and in Spain.

Based on the trend analysis, evergreen oaks have the second highest increase in defoliation over the last 20 years (6.9%, Figure 6-2h). The defoliation development pattern for evergreen oaks is characterized by several larger deviations from the trendline (however the mean plot value in 2015 results from the lack of assessments on Spanish plots).

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

Damage causes

In 2019, damage cause assessments were carried out on 103 297 trees in 5 654 plots and 26 countries. On 50 446 trees (48.8%) at least one symptom of damage was found. In total, 72 511 observations of damage were recorded with potentially multiple damage symptoms per tree. Both fresh and old damage is reported. On 1 153 plots no damage was found on any tree.

The number of damage symptoms on any individual tree can be more than one, therefore the number of cases analysed varies depending on the parameter. The number of recorded damage symptoms per assessed tree (ratio, Table 6-5) was higher for the broadleaved tree species and species groups than for the conifers. It was highest for evergreen oaks with 1.17 and lowest for Norway spruce with 0.41 symptoms per tree. Compared to 2018, both the numbers of recorded damage symptoms and the ratios have been increasing for all species and species groups, except for Scots pine.

Table 6-5: Number of damage symptoms, assessed trees and their ratio for the main tree species and species groups in 2019. 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*)	9 428	17 626	0.53
Norway spruce (*Picea abies*)	4 790	11 794	0.41
Austrian pine (*Pinus nigra*)	3 162	5 305	0.60
Mediterranean lowland pines	5 422	8 382	0.65
Other conifers	4 139	7 817	0.53
Common beech (*Fagus sylvatica*)	9 423	11 212	0.84
Deciduous temperate oaks	8 723	8 434	1.03
Dec. (sub-) Mediterranean oaks	7 212	8 087	0.89
Evergreen oaks	5 396	4 604	1.17
Other broadleaves	14 816	20 036	0.74
Total			
Conifers	26 941	50 924	0.53
Broadleaves	45 570	52 373	0.87
All species	72 511	103 297	0.70

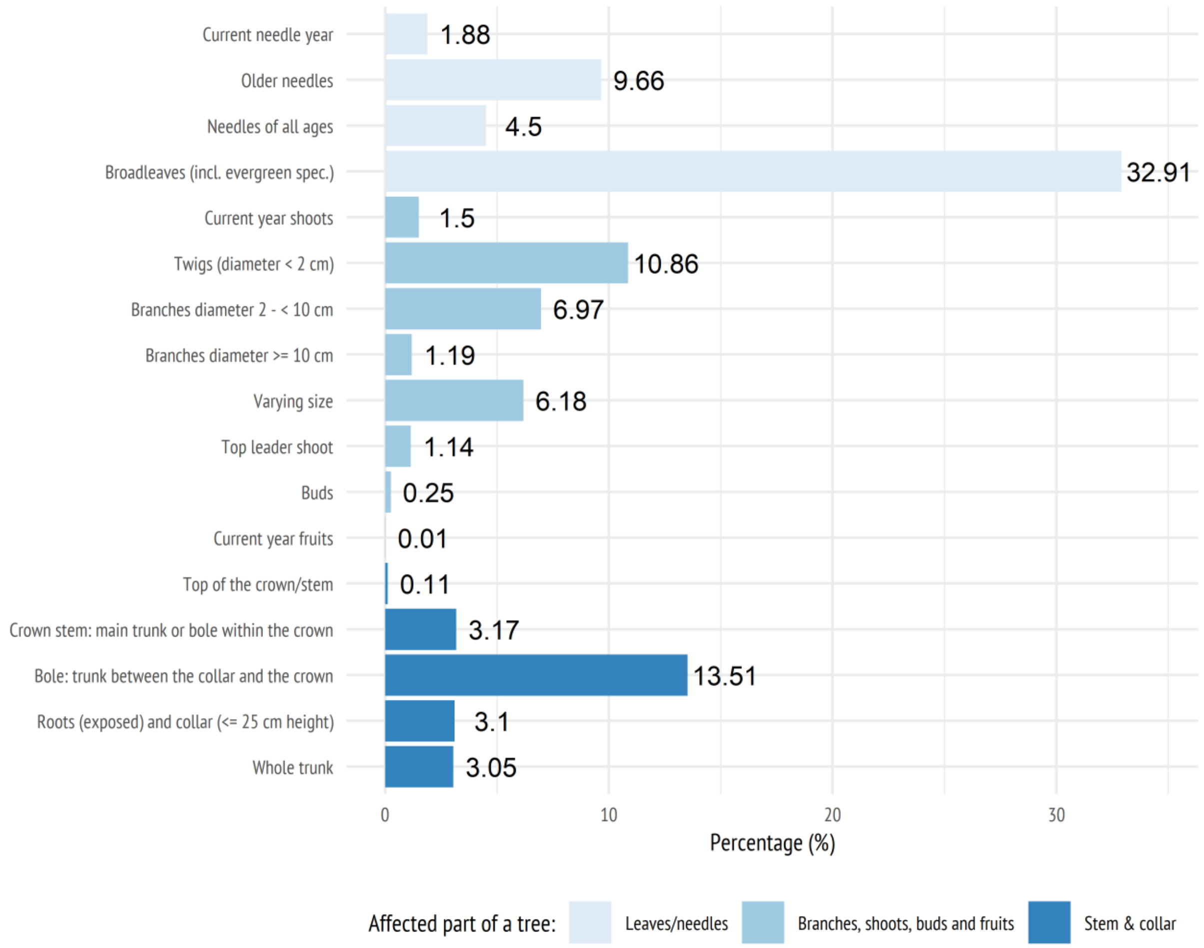

Figure 6-3: Percentage of recorded damage symptoms in 2019 (n=71 600), affecting different parts of a tree. Multiple affected parts per tree were possible. Dead trees are not included.

Symptom description and damage extent

Most of the reported damage symptoms were observed on the leaves of broadleaved trees (32.9%), followed by twigs and branches (25.2%), and stems (19.7%; Figure 6-3). Needles were also often affected (16.0%), while roots, collar, shoots, buds and fruits were less frequently affected.

More than half (52.9%) of all recorded damage symptoms had an extent of up to 10%, 38.5% had an extent between 10% and 40%, and 8.6% 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 26.4% of all recorded damage symptoms (Figure 6-4). Almost half of the symptoms caused by insects were attributed to defoliators (48.1%), the most frequent of all specified damage causes. Wood borers were responsible for 15.6%, leaf miners for 12.1%, and gallmakers for 6.7% of the damage caused by insects.

Abiotic agents were the second major causal agent group responsible for 17.6% of all damage symptoms. Within this agent group, more than half of the symptoms (53.4%) were attributed to drought, while snow and ice caused 8.9%, wind 7.2%, and frost 3.8% of the symptoms.

The third major identified cause of tree damage were fungi with 10.7% of all damage symptoms. Of those, 22.5% showed signs of decay and root rot fungi, followed by dieback and canker fungi (15.9%), needle cast and needle rust fungi (12.2%), powdery mildew (11.5%) and blight (9.8%).

Direct action of man refers mainly to impacts of silvicultural operations, mechanical/vehicle damage, forest harvesting or resin tapping. This agent group accounted for 4.2% of all recorded damage symptoms. The damaging agent group 'Game and grazing' was of minor importance (1.2%). Fire caused 0.6% of all damage symptoms. The agent group 'Atmospheric pollutants' refers here only to incidents caused by local pollution sources. Visible symptoms of direct atmospheric pollution impact, however, were very rare (0.1% of all damage symptoms). Other causal agents were responsible for 9.4% of all reported damage symptoms. Apart from these identifiable causes of damage symptoms, a considerable number of symptoms (29.9%) could not be identified in the field.

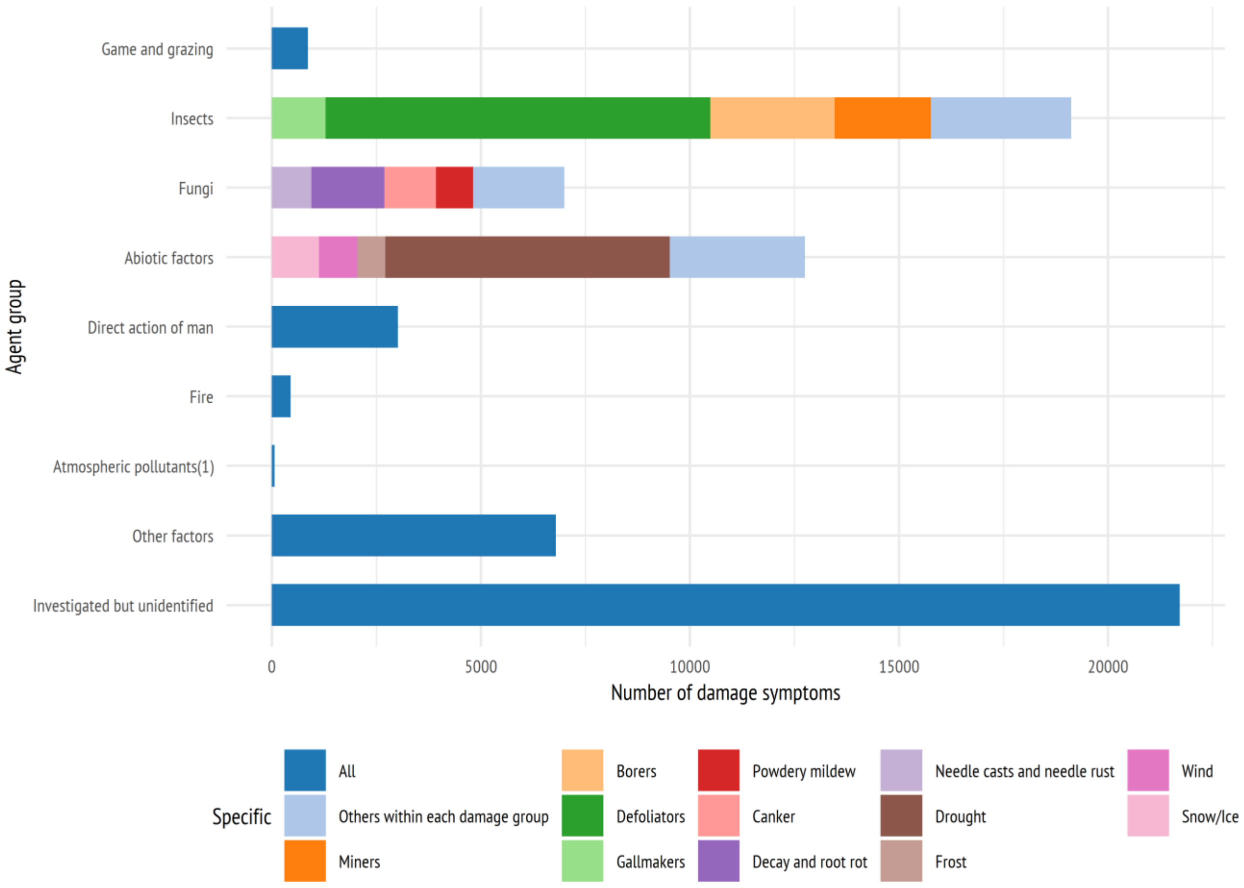

Figure 6-4: Number of damage symptoms (n=72 511) according to agent groups and specific agents/factors in 2019. Multiple damage symptoms per tree were possible, and dead trees are included. (1) Visible symptoms of direct atmospheric pollution impact only

The occurrence of damaging agent groups differed between major species or species groups (Figure 6-5). Insects were the most important damaging agent group for deciduous temperate oaks (causing 38.9% of all damage), common beech (37.5%), deciduous (sub-) Mediterranean oaks (34.4%), and Austrian pine (26.8%), while insect damage was not so common in Scots pine (11.4%) and Norway spruce (8.6%). Abiotic factors caused by far the most damage in evergreen oaks (44.8%) and Mediterranean lowland pines (43.8%). Fungi were important damaging agents for Austrian pine (19.4%), deciduous temperate oaks (14.9%), evergreen oaks (13.8%) and Scots pine (12.9%). Direct action of man was of little importance in general; it had the highest impact on Norway spruce (13.7%) and Scots pine (8.3%). Damage from game and grazing played a minor role for all species and species groups except for Norway spruce (10.4%). Fire affected mostly Mediterranean conifer species – 1.1% of Austrian pine and 1.2% of Mediterranean lowland pine trees were affected. The percentage of recorded but unidentified damage symptoms was quite low in evergreen oaks (9.2%) but large for Norway spruce (43.0%), deciduous (sub-) Mediterranean oaks (34.7%), common beech (33.3%), and Scots pine (32.6%).

The most important specific damaging agents for common beech were mining insects (causing 19.6% of the damage symptoms), followed by defoliators (11.3%) and drought (3.7%). Defoliators were also frequently causing damage on deciduous temperate oaks (19.3%), while powdery mildew (8.6%), borers (5.7%), and drought (4.1%) also were significant. For deciduous (sub-) Mediterranean oaks, defoliators (14.1%) were the most common damaging agents, followed by borers (8.2%), gallmakers (6.6%) and drought (5.3%). Drought was by far the most important damaging agent for evergreen oaks (41.5%), but also borers (12.0%), decay and root rot fungi (9.4%) and defoliators (7.8%) had a large impact on these oak species.

Most damage symptoms in Scots pine were caused by various effects of competition (13.0%), followed by *Viscum album* (7.5%) and defoliators (5.9%). For Norway spruce, borers (5.9%), red deer (5.6%) and mechanical/vehicle damage (5.0%) were most important. Defoliators were causing most damage (23.2 %) on Austrian pine trees, but *V. album* (12.7%), needle cast/needle rust fungi (10.9%), blight (6.9%) and drought (5.8%) also caused considerable damage. Mediterranean lowland pines were mostly affected by drought (35.4%) and defoliators (8.9%).

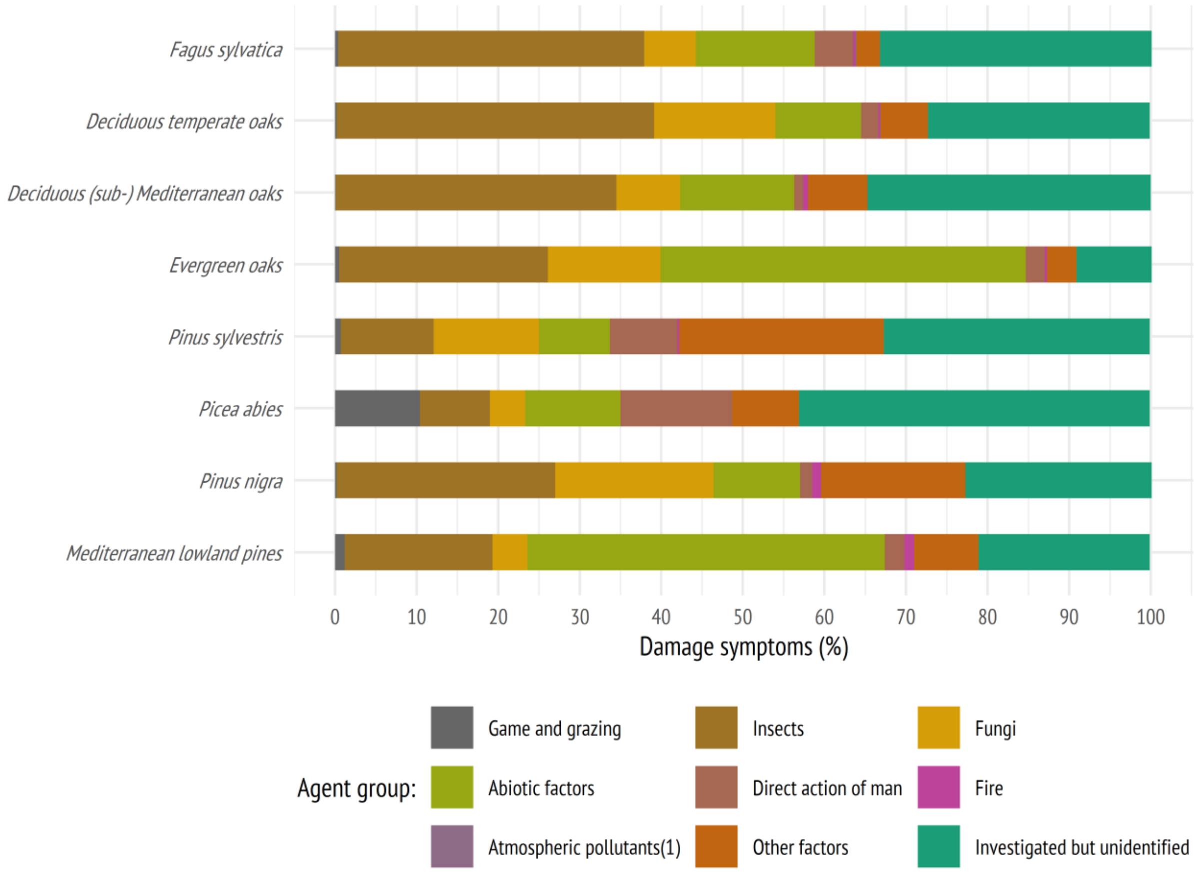

Figure 6-5: Percentage of damage symptoms by agent group for each main tree species and species group in 2019. (1) Visible symptoms of direct atmospheric pollution impact only

Regional importance of the different agent groups

Damage caused by insects in 2019 was observed on 1 960 European Level I plots, which corresponds to 3.5% of all plots with damage assessments. With some exceptions (Scandinavia, northern Germany and the Baltic countries), a high proportion of plots was affected by insects throughout Europe.

Damage caused by abiotic agents was reported from 1 941 Level I plots (34%) throughout Europe. Countries most affected by abiotic agents were Spain, Slovenia, and Montenegro.

The agent group 'Fungi' was responsible for damage on 1 347 European Level I plots (24%) in 2019, and was frequently occurring in many countries, most notably in Estonia, Slovenia, Montenegro, parts of Serbia, Poland, Bulgaria and Spain. Very low occurrence of damage by fungi was observed in Turkey, Romania, Switzerland and Greece.

The damaging agent group 'Direct action of man' impacted trees on 1 024 plots (18%), and was most frequently occurring in southern Sweden, parts of eastern Europe and southern Germany.

Damage caused by game and grazing in 2019 was most frequently observed in the Baltic countries, Hungary and Spain, and in parts of Poland and Germany. In total, 288 Level I plots (5%) had trees damaged by this agent group.

There were only 51 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 911 (0.9%) dead trees in the damage assessment 2019 (456 broadleaves and 455 conifers), an increase compared to 2018 (711 trees, 0.7%). The main cause of mortality to both conifer and broadleaved trees were abiotic factors (Figure 6-6). For the broadleaves, fungi and insects were also major causes of mortality, while for conifers, insects, fungi and fire were also of importance. A large part of the damaging agents causing tree mortality could not be identified with certainty.

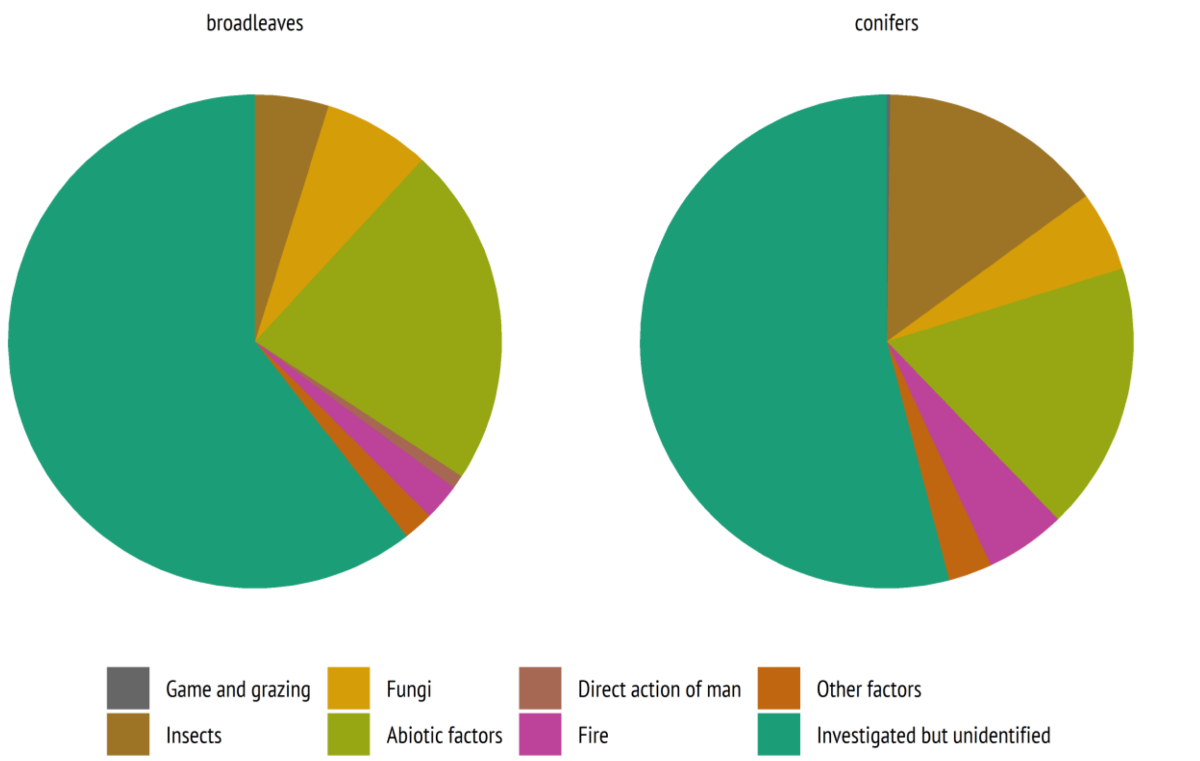

Figure 6-6: Percentage of damaging agent groups causing mortality of broadleaved and coniferous trees in 2019 (n = 911)

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

Conclusions

In 2019, the mean defoliation was somewhat higher than in 2018, increasing by 0.3% to 23.2% for broadleaved and by 0.9% to 22.2% for coniferous species. Out of all species and species groups, Mediterranean lowland pines and evergreen oaks had the largest increase in defoliation from 2018.

Based on the data of the past 20 years, the trends show a considerable increase in defoliation of Austrian pine, Mediterranean lowland pines and evergreen oaks (6.2%, 6.9% and 6.9%, respectively). On the other hand, the increase in defoliation for common beech (2.4%) and deciduous temperate oaks (2.2%) has been relatively low. The trends for Norway spruce and Scots pine show a moderate increase in defoliation of 3.2% and 4.2%, respectively. No trend was detected for deciduous (sub-) Mediterranean oaks.

As in previous years, the number of recorded damage symptoms per assessed tree was substantially higher for broadleaves than for conifers. Insects, abiotic causes and fungi were the most common damage agent groups for all species, comprising altogether more than half of all damage records. There was an increase in the number of observed damage symptoms compared to 2018, especially from drought. Also, tree mortality increased substantially in 2019, mainly caused by abiotic factors.

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