EFORWOOD
Tools for Sustainability Impact Assessment

Prevalence of biotic and abiotic hazards in European forests

Hervé Jactel and Floor Vodde

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Preface

This report is a deliverable from the EU FP6 Integrated Project EFORWOOD – Tools for Sustainability Impact Assessment of the Forestry-Wood Chain. The main objective of EFORWOOD was to develop a tool for Sustainability Impact Assessment (SIA) of Forestry-Wood Chains (FWC) at various scales of geographic area and time perspective. A FWC is determined by economic, ecological, technical, political and social factors, and consists of a number of interconnected processes, from forest regeneration to the end-of-life scenarios of wood-based products. EFORWOOD produced, as an output, a tool, which allows for analysis of sustainability impacts of existing and future FWCs.

The European Forest Institute (EFI) kindly offered the EFORWOOD project consortium to publish relevant deliverables from the project in EFI Technical Reports. The reports published here are project deliverables/results produced over time during the fifty-two months (2005–2010) project period. The reports have not always been subject to a thorough review process and many of them are in the process of, or will be reworked into journal articles, etc. for publication elsewhere. Some of them are just published as a "front-page", the reason being that they might contain restricted information. In case you are interested in one of these reports you may contact the corresponding organisation highlighted on the cover page.

Uppsala in November 2010

Kaj Rosén
EFORWOOD coordinator
The Forestry Research Institute of Sweden (Skogforsk)
Uppsala Science Park
SE-751 83 Uppsala
E-mail: firstname.lastname@skogforsk.se

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PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

PD 2.4.2: Prevalence of biotic and abiotic hazards in European forests

Hervé JACTEL, Floor VODDE
INRA – UMR BIOGECO – Laboratory of Forest Entomology & Biodiversity
69 Route d'Arcachon, 33612 Cestas, France

Manuela BRANCO, Jean-Michel CARNUS, José Ramón GONZALEZ, Wojciech GRODZKI, Bo LANGSTROM, Francisco MOREIRA, Sigrid NETHERER, Bruce NICOLL, Christophe ORAZIO, Dominique PIOU, Helena SANTOS, Mart-Jan SCHELHAAS, Karl TOJIC.

May beetles (*Melolontha melolontha*) feeding on oak trees in Zvolen
during the Eforwood week, May 7-11, 2007 (Photo by Véronique Cucchi).

Abstract:

In order to undertake a sanitary risk analysis, we first reviewed the prevalence of the main biotic, abiotic and anthropic hazards in European forests. We used the ICP Forests data on the causes of damage from the Level I monitoring network. We retained the relevant information from a total of 3391 plots, continuously monitored for the years 1994 to 2005, in 21 countries. The biotic hazards contributed the most to the sanitary damage (60% of the causes) then the abiotic hazards represented 20% and anthropic hazards 20% of the causes of damage. This partition of the relative importance of hazard types remained stable throughout the studied period. A large variation of damage frequency was observed among tree species. However overall, broadleaved tree species seemed to experience more frequent damage, or to accumulate more damage, than coniferous trees. Furthermore the analysis revealed a clear effect of climate on the prevalence of hazards, with both biotic and abiotic hazards causing more damage in biogeographical zones with harsher climates such as in Mountainous and Mediterranean areas. These results were used to draw exposure to hazards profiles, i.e. to cluster the main 10 European forest types and 5 European forest biomes according to the relative prevalence of the different causes of damage. It was concluded that the prevalence of biotic and abiotic hazards in European forests mainly depends on the tree taxa, the bioclimatic zones and the silviculture rotation.

Key words: risk analysis, hazards, biotic, abiotic, anthropic, damage, tree species, European forest types, forest biomes, cluster analysis.

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1. INTRODUCTION

Forests in good health are essential to sustain wood resources and ecosystem services. Yet forests are subject to a large number of threats that can cause tree mortality, tree growth loss and wood quality degradation or reduce amenity value of forest landscapes. Threats to forest may also reduce ecological functions of forest, such as soil protection against erosion, carbon stock, water retention, plant and animal diversity. Forest health and vitality has therefore been considered as one of the main criteria of sustainable forest management (e.g. MCPFE, 2002). Causes of negative impact on forest health include among others biotic agents like pest insects, pathogens, game and grazers, abiotic agents such as fire, wind or snow, frost or drought and anthropic causes like poor harvesting practices or air pollution.

Within the EFORWOOD Module 2, the main objective of Work Package 2.4 is to evaluate the effects of new forest management alternatives on sanitary risks in European forest. The concept of ***risk*** combines the probability of occurrence of a potentially damaging phenomenon, i.e. ***hazard*** prevalence, with the degree of loss resulting from the occurrence of the phenomenon, i.e. the ***vulnerability*** of the system to this hazard. In what concerns forest ecosystems, a sanitary risk assessment will therefore help to identify forests that are at risk of damage from climatic, human or natural hazards. This information is of interest to help determine the silvicultural operations that can make a forest stand more sensitive to sanitary hazards. This report represents the first step of a risk assessment analysis, collecting and interpreting the statistics on the occurrence of the main hazards.

Several efforts are made at different geographic scales to assess biotic, abiotic and anthropic damage in European forests. The most well-known global reporting is done in the frame of the Global Forest Resources Assessment under the FAO (FAO, 2006). The damaging factors are collected and analysed together, bearing in mind that the occurrence of one disturbance factor could predispose an area to other disturbance factors. For Europe the ICP Forests (International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests, www.icp-forests.org) database is mentioned as the most comprehensive overview of forest conditions. ICP Forests monitoring was launched in 1985; it is based on a systematic transnational grid of 16 x 16 km which comprises around 6000 observation plots distributed over 40 countries.

Because of its standardised protocol, the ICP Forests database represents a unique source of information to evaluate damage in European forest. However, to our knowledge no attempt has been made so far to use this information in order to highlight the main hazards in the main tree species and to provide an overview of the relative prevalence of different damaging agents. The objective of this report is to put the outcomes of such an ICP data analysis at the disposal of forest managers and end-users. Characteristics and limitations of the dataset as well as the potential for further risk analysis are discussed.

2. MATERIAL and METHODS

Available datasets

WP 2.4 has requested access to the ICP Forests data on crown conditions and eventually 25 countries have agreed upon data use: Andorra, Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Norway, Poland, Portugal, Serbia, Spain, Sweden, United Kingdom. This information allowed a representative coverage of European forests (Fig.1).

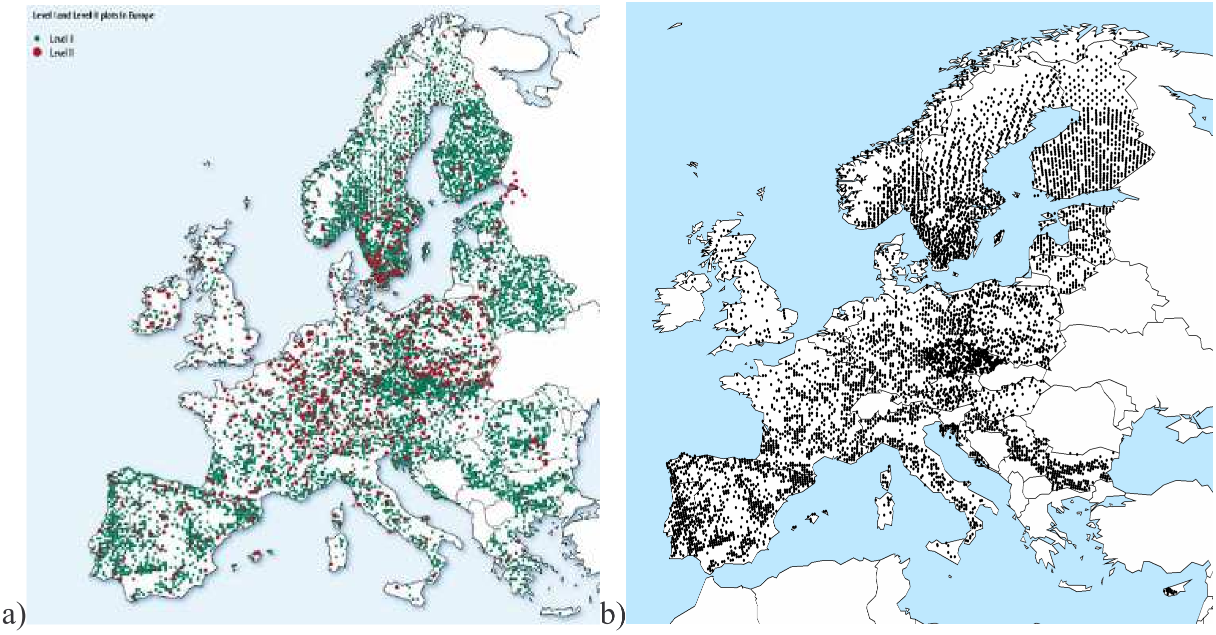


Figure 1: ICP Forests plots across Europe. *a)* All plots. *b)* Plots received.

The structure of the ICP Forests data on crown conditions is plot based. At Level I, for about 6000 plots on a systematic 16x16 km grid, tree species composition, several plot characteristics, the health situation (mainly defoliation and crown discoloration) as well as damage causes (agents) observed for individual trees have been reported annually since 1987 in some countries and 1990 in the rest of European countries. ICP plots usually comprise between 20 and 30 trees from the dominant, co-dominant and subdominant classes. In any case a minimum of 10 trees have to be assessed. The original ICP Forests dataset on crown conditions, as we received it, consisted of almost 800 separate data files on the plot and the tree level.

These files were merged into four linked Access tables:

1) <u>A plot level table, holding 6 538 unique records</u>
The plot level variables consist of the country, the plot number, the date of observation, latitude and longitude coordinates, water availability, humus type, aspect, the mean age of the predominant storey, soil type and climate region. Except for the variable describing stand age, these parameters showed little variation in time. The data received date back to 1987. However, the number of countries reporting was limited then, and increased with time. Some plots were not recorded throughout the whole period, owing to changed conditions, such as an increase or decrease of the forest cover and mortality of all trees due to gradual damage or extreme events. In France, for example, the storms of December 1999 led to a reduction of the number of plots in 2000.

2) A tree level table, holding 171 855 unique records

This table holds all individual trees registered during the monitoring period, regardless of the year. The country and plot numbers are linked to the plot level table, while the tree number and species code provide additional information on each tree registered.

3) An observations level table, holding 1 640 569 unique records

Observations of defoliation, discoloration, symptoms and part of the tree affected are linked with the plot level table by the country and plot codes and with the tree level table by the tree number. As this information varies annually, the number of records is considerably higher. All trees in the ICP plots are observed for damage but no dendrometric measurements are made. Each tree monitored – whether damaged or not - in each year represents one record.

4) A damage level table, holding 653 335 unique records

In this table only the damaged trees are reflected. Each record is linked with the plot level table by the country and plot codes, with the tree level table by the tree number and with the observations level table by the year of observation. Some individual trees hold several records in one year, due to different disturbance causes found in that year. The damage classes registered, consisted of the ICP codes 100-800. Code 100 represents game and grazing, 200 is insect damage, 300 is fungal disease, 400 is abiotic damage, 500 is direct action by man, 600 is fire, 700 is pollution and 800 is other factors. In the year 2005, some countries have used the new, more detailed assessment for damage (Table 1). This new method allows a damage specification for e.g. insects into groups ranging from defoliators, to wood borers and gall makers.

Table 1 List of detailed damage types documented in 2005

Game (100)	Insect (200)	Fungi (300)	Abiotic (400 and 600)	Anthropic (500 and 700)
Cervidae	Defoliators	Stem canker	Drought	Silvicultural operation
Suidae	Bark beetles	Root rot	Wind	Machine damage
Rodentia	Gall makers	Stem rusts	Snow	Pollution
Aves	Miners	Needle rusts	Others	Other
Domestic animals	Sucker	Leaf mildew	Fire	
Other vertebrates	Other insects	stem blight	Frost	
		Stem deformation	Lightning	
		Leaf necrosis	Hail	
		Other fungi		

For statistical analysis a representative database, holding sufficient replicates, is required. When chronological data are used, one must be careful about autocorrelations. For conducting a time series analysis about 50 observations (time periods) would be required, while in the present data we only have 15 years. Instead, a "repeated measures ANOVA" was used which is appropriate for longitudinal data. Furthermore we had to deal with prevalence data, i.e. percentages of damaged trees that require a sufficient number of individuals to be properly calculated. Therefore it was necessary to reorganise the ICP database. Plots had to comprise a minimum of 4 trees of one species that had been monitored continuously from 1994 to 2005 to be retained in the final dataset. Only those species represented in more than 20 plots in Europe were included in the analysis (with the exception of the Sitka spruce which represents an important resource for timber), summing up to 26 of originally 104 tree species. This resulted in a dataset holding 3 391 plots for in total 21 countries. The reduction of plots did not influence the geographic representation across Europe (Fig.2). Calculating percentage of damaged trees per plot irrespective of tree species is not relevant. We therefore split a plot record with several species in as many monospecific sub-plot records where tree species were represented by at least 4 individual trees. The final dataset had 4109 monospecific sub-plot records.

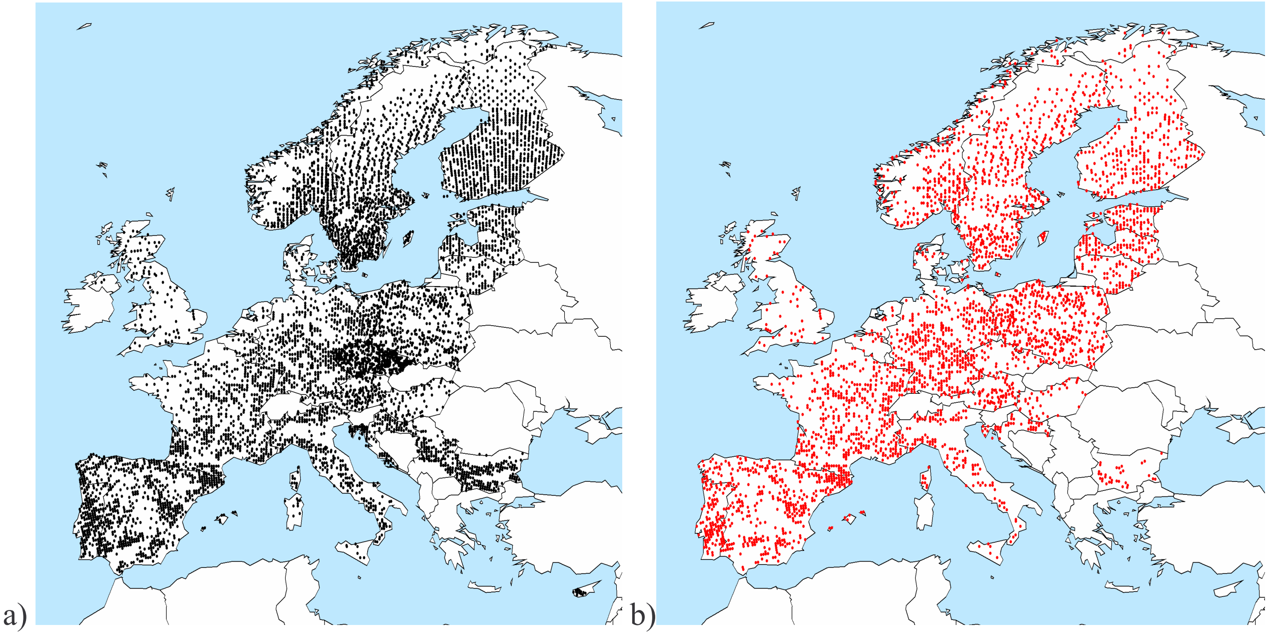


Figure 2: ICP Forests plots across Europe. *a)* Received plots. *b)* Selected plots.

In order to improve the MCPFE reporting on sustainable forest management in Europe, the European Environment Agency released a technical report (EEA Technical report N°9/2006) where a new classification of European Forest Types was proposed. Based on stand composition (tree species basal area) and level of anthropic modification, 14 main categories further subdivided in 75 types were presented. Because the classification was successfully applied to stratify ICP plots WP 2.4 has requested access to the EEA data on plot assignation to the 14 categories, further called "forest type" in this report. However the number of plots in our dataset was not balanced among the 14 types. To make proper statistical analyses we therefore only retained 10 European forest types with more than 150 replicates (Table 2).

Table 2 List of the 14 European Forest Types as defined by the European Environment Agency. In bold the 10 types retained in our analysis.

Forest types		Number of plots
1	**Boreal forest**	**948**
2	**Hemiboreal forest and nemoral coniferous and mixed broadleaved-coniferous forest**	**598**
3	**Alpine coniferous forest**	**297**
4	**Acidophylous oakwood and oak-birch forest**	**274**
5	Mesophytic deciduous forest	69
6	**Lowland to submontane beech forest**	**224**
7	**Montane beech forest**	**160**
8	**Thermophilous deciduous forest**	**277**
9	**Broadleaved evergreen forest**	**237**
10	**Coniferous forests of the Mediterranean, Anatolian and Macaronesian regions**	**220**
11	Mire and swamp forest	21
12	Floodplain forest	13
13	**Non-riverine alder, birch or aspen forest**	**704**
14	Plantations and self-sown exotic forest	67

Based on the biogeographical regions used by the European Environment Agency to categorize European Forest Types we refined a list of 5 forest biomes in Europe. Plots from the Atlantic, Mediterranean and Alpine regions were grouped in the Atlantic, Mediterranean and Mountainous biomes respectively, plots from the Arctic and Boreal regions were grouped in the Boreal biome and plots from the Black sea, Pannonian and Continental regions were grouped in the Continental biome. The number of plots for each biome in our final dataset is presented in Table 3 and their geographical coverage in Fig. 3.

Table 3 List of the 5 European Forest Biomes

Forest biomes	Number of plots
Boreal	1175
Atlantic	434
Continental	1415
Mountainous	404
Mediterranean	681

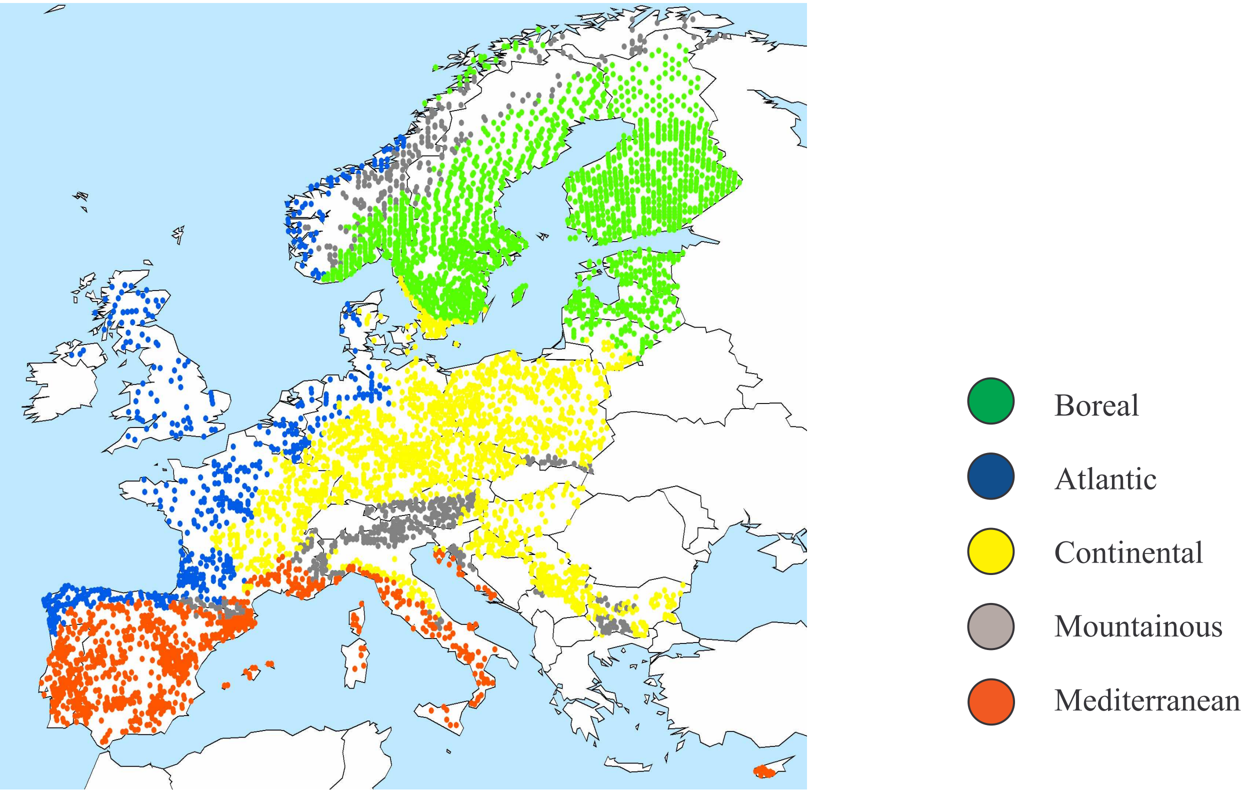


Figure 3: Distribution of the ICP Forests plots among the 5 European Forest Biomes.

Statistical analysis

The overall analysis compared between 26 main European tree species, 10 more abundant European Forest Types and 5 European forest biomes in a total of 4109 plot records.

The percentages of damaged trees per plot were calculated for each year from 1994 to 2005 as the percentage of individual trees with at least one damage of any cause. Then the mean percentage of damaged trees per monospecific sub-plot was calculated using years as replicates. Repeated measures analyses of variance were used to test for significant difference of percentage of damaged trees per sub-plot between species, after angular transformation of percentage values. Tukey's post hoc tests were used to test for significant differences between means. To test for any significant difference in the percentage of attacked trees between conifer and broadleaved species we made a nested analysis of variance with the taxon (conifer vs. broadleaved) and the tree species as independent variables, tree species being nested in the taxon.

We did not calculate the mean percent of defoliation per plot since we assumed that the defoliation estimate might have varied a lot between countries or between years according to the methodology used or the composition of the recording teams.

The mean percentage of trees per sub-plot was similarly calculated in the 26 tree species for each of the 7 main causes of damage (ICP codes from 100 to 700). The damage code 800 for the years 1994-2004 and the codes 800-999 for the year 2005 were not considered in the analysis, as these do not add to the clarification of the occurrence.

The relative percentages of damaged trees by the 7 causes were calculated for the whole dataset and for the year 2005 to rank their relative importance. We used the weighted arithmetic mean to calculate average values of the percentage of damaged trees by the different causes of damage across European forests, with the number of plots per tree species as weights. Paired Wilcoxon's test was used to compare the percentage values calculated for the whole period of 12 years and for the last year 2005. Then, using only 2005 data, we calculated the absolute and relative percentages of damaged trees for the main sub-categories of damaging agents for each of the 7 causes of damage.

Principal Components Analyses (PCA) were carried out using 8 variables (mean overall percentage of damaged trees and mean percentages of damaged trees by the 7 main causes) and correlation matrix (Pearson) in order to explore common response patterns of the 26 species to main sanitary hazards. We performed a rotation of the axes (Varimax method) to help the interpretation of the patterns. A similar approach was used to classify European Forest Types and biomes according to their overall level of damage and main causes of damage.

All statistical tests were made with Statistica (2005) or XLSTAT (2007) software.

3. RESULTS

3.1. Patterns of forest damage in Europe

The 26 most abundant European tree species significantly differed in level of damage during the 1994-2005 period (Table 4).

Table 4 Repeated measures analysis of variance to test for the effect of tree species on the percentage of damaged trees per plot (after angular transformation) during the 1994-2005 period of time.

Source	ddl	F	*Pr* > F
Intercept	12	2959.8	< 0.0001
Tree species	25	20.9	< 0.0001

The mean percentage of damaged trees per plot varied from 16% in the silver birch to 51% in the pedunculate and cork oak (Fig.4). The fourteen most damaged species only included broadleaved species with the exception of the Aleppo pine. By contrast, there was a majority of conifer species in the twelve least damaged species (Fig.4). The mean percentage of damaged trees per plot (Table 5) was significantly higher in broadleaved (38.7 ± 0.7%) than in conifer species (27.4 ± 0.4%).

Table 5 Nested analysis of variance to test for the effect of tree species and taxon on the percentage of damaged trees per plot.

Source	ddl	F	*Pr* > F
Intercept	1	4032. 4	< 0.0001
Tree taxon = conifer *vs*. broadleaved	1	48.4	< 0.0001
Tree species (nested in Tree taxon)	24	14.9	< 0.0001

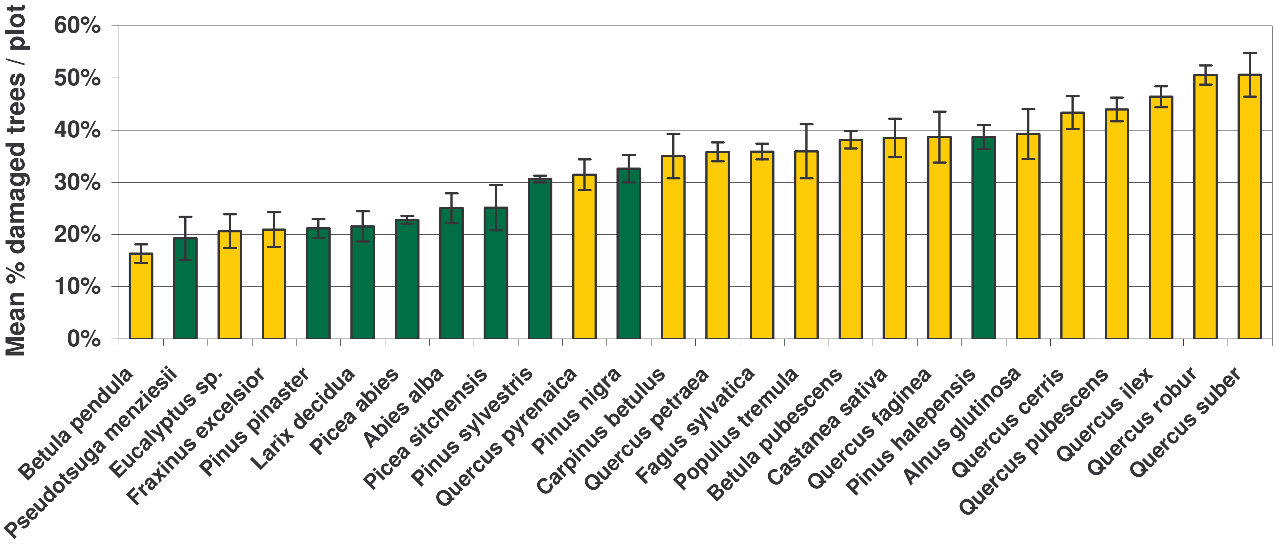


Figure 4. Mean percentage of damaged trees per plot in the 26 tree species during the 1994-2005 period of time.

Green bars for coniferous species and yellow bars for broadleaved species.

There was considerable variation in the absolute percentage of damaged tree by the different biotic, abiotic and anthropic agents among tree species (Table 6). The mean percentage of damaged trees by game and grazers varied from 0 to 3% with *Picea abies* and *Populus tremula* as the most damaged species. The level of damage by insects ranged from only 1% in *Picea abies* to more than 20% in several Fagaceae like *Carpinus betulus*, *Fagus sylvatica*, several *Quercus* and *Alnus species*. The least damaged tree species by pathogens was *Picea sitchensis* (0.2%) and the most damaged *Castanea sativa* (27%). The percentage of damaged trees by abiotic causes varied from almost 2% in *Pinus sylvestris* or *Fraxinus excelsior* to more than 17% in three Mediterranean species, *Betula pubescens, Pinus halepensis* and *Quercus ilex*. The highest level of fire damage was observed in *Pinus nigra* (2.5%) and *Quercus faginea* (4.3%), again two Mediterranean species. The percentage of trees damaged by anthropic causes remained low, below 5% of the trees per plot with the exception of *Quercus ilex* (10%) and *Quercus suber* (27%). Damage by pollutants was quite rare, often less than 1%, except in *Populus tremula, Quercus robur, Pinus sylvestris* and *Abies alba* (9%).

Table 6 Mean absolute percentage of trees damaged by the 7 main biotic, abiotic and anthropic causes of damage in the 26 most abundant European tree species during the 1994-2005 period of time.

		Mean % damaged trees / plot by						
Tree species	**Number of plots**	**game**	**insect**	**fungi**	**abiotic**	**anthropic**	**fire**	**pollution**
Abies alba	80	0.3	4.5	5.9	4.6	2.6	0.0	8.9
Alnus glutinosa	25	1.4	30.0	2.1	3.6	0.2	0.3	0.0
Betula pendula	92	0.1	5.9	0.8	2.6	0.9	0.0	0.0
Betula pubescens	164	0.1	7.6	4.6	15.7	1.6	0.0	1.2
Carpinus betulus	36	0.7	20.5	7.4	5.7	2.4	0.0	0.2
Castanea sativa	60	0.0	13.5	27.2	8.4	0.5	0.2	0.1
Eucalyptus sp.	34	1.0	8.1	1.3	3.6	5.1	0.0	0.0
Fagus sylvatica	285	1.2	20.8	2.7	5.3	4.7	0.2	0.8
Fraxinus excelsior	39	0.1	14.5	0.7	1.9	1.3	0.0	0.0
Larix decidua	44	0.2	6.1	1.7	9.7	1.6	0.4	0.0
Picea abies	849	2.0	1.1	1.7	3.3	3.2	0.1	1.0
Picea sitchensis	10	0.1	18.9	0.2	5.5	0.3	0.0	0.0
Pinus halepensis	73	1.0	3.7	11.0	18.0	0.9	1.5	0.0
Pinus nigra	88	0.5	16.3	4.5	6.9	1.3	2.5	0.0
Pinus pinaster	122	0.0	5.0	2.5	4.7	3.1	1.9	0.0
Pinus sylvestris	1283	0.8	2.9	5.1	1.6	2.3	0.2	4.5
Populus tremula	27	2.8	10.3	4.4	2.8	0.7	0.0	3.1
Pseudotsuga menziesii	23	0.0	2.1	12.2	2.0	1.2	0.0	0.0
Quercus cerris	41	0.6	23.8	11.4	12.9	1.3	0.0	0.0
Quercus faginea	25	0.0	13.5	4.8	11.9	1.0	4.3	0.0
Quercus ilex	172	0.3	10.6	2.7	22.7	10.4	0.3	0.0
Quercus petraea	159	0.4	22.7	7.2	3.9	1.8	0.1	0.6
Quercus pubescens	86	0.5	27.1	8.7	8.6	0.1	0.1	0.1
Quercus pyrenaica	38	1.6	13.3	7.3	5.5	0.9	1.1	0.0
Quercus robur	190	0.6	31.9	8.6	4.1	1.9	0.3	3.9
Quercus suber	64	0.5	15.5	5.2	11.0	27.3	1.9	0.0
Weighted Mean*		**0.9**	**8.7**	**4.7**	**5.2**	**3.1**	**0.3**	**2.1**

* The weighted mean *wm* is calculated as follows:

$$wm = \frac{\sum n_i p_i}{\sum n_i}$$

With n_i the number of sampled plots per species and p_i the mean percentage of damaged trees in this species

Considering the 26 European tree species all together, the relative contribution of the seven agents to tree damage were in order of increasing importance during the 1994-2005 period (Fig.5) the anthropic agents (total of 21%), the abiotic agents (22%) and the biotic agents (57%) with the insects representing the main cause of damage (34%).

Data from 2005 showed a similar pattern (Fig.6) as the percentage of damaged trees per agent type did not significantly differ between the two periods of time (Wilcoxon paired test, N = 7, Variance = 0.17, *P* = 0.87). More generally, the relative amount of damage caused by these three groups of agents remained quite stable throughout the 1994-2005 period of time (Fig.7).

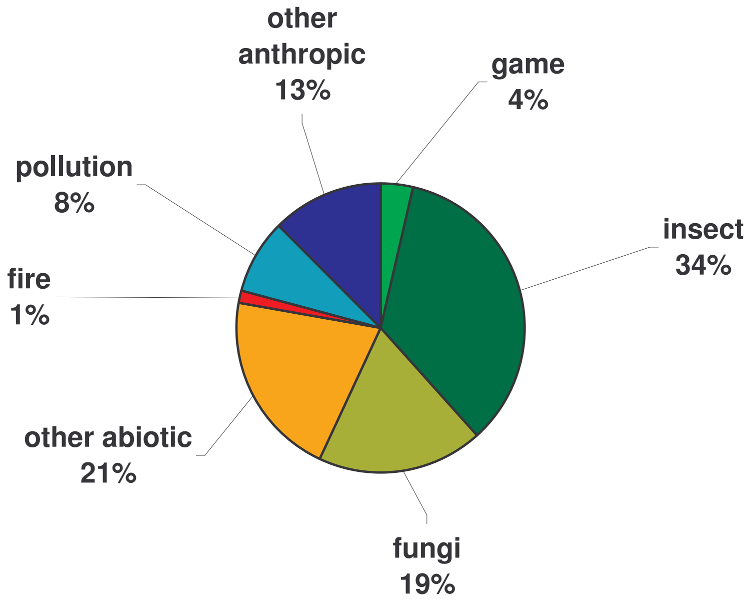


Figure 5 Proportion of damage causes (Σ % = 100) in the 26 tree species, in European forests during the 1994-2005 period of time. (In green the biotic causes, in orange the abiotic causes, in blue the anthropic causes of damage)

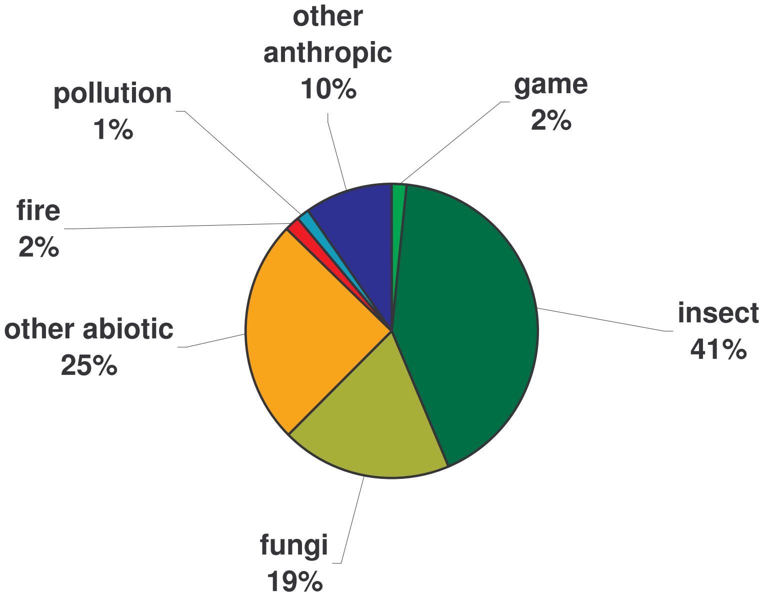


Figure 6 Proportion of damage causes (Σ % = 100) in the 26 tree species, in European forests in 2005. (In green the biotic causes, in orange the abiotic causes, in blue the anthropic causes of damage)

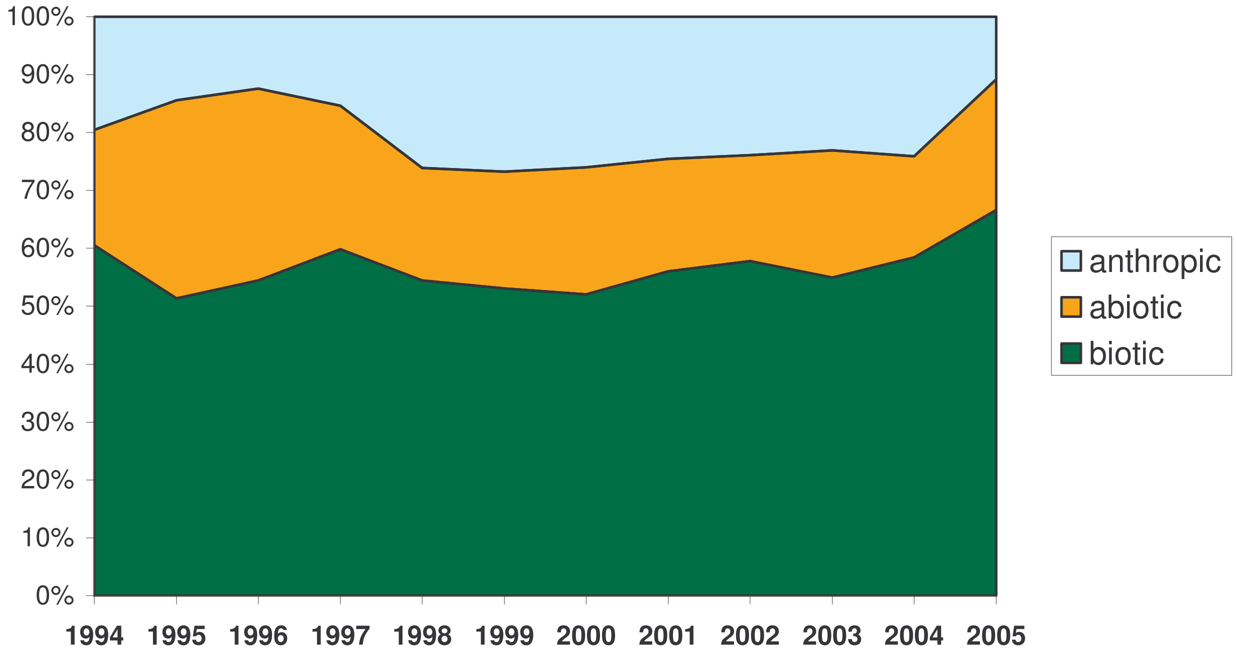


Figure 7 Evolution of the proportion of damage causes in the 26 tree species in European forests during the 1994 – 2005 period of time.
(In green the biotic causes, in orange the abiotic causes, in blue the anthropic causes of damage)

We therefore used the year 2005 to provide a more detailed overview of the prevalence of damaging agents for each of the main causes of damage in European forests.

As regards game and grazers, about half of the damages were caused by deer and a great proportion by birds (Fig.8).

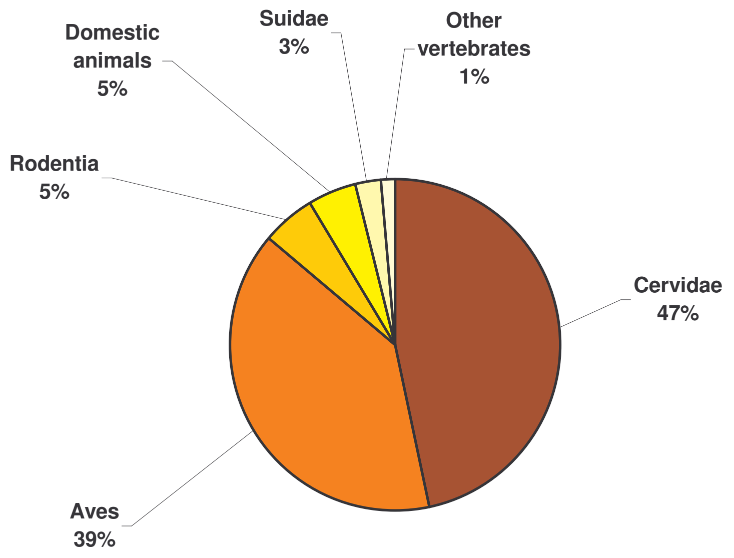


Figure 8 Proportion of damaged trees by different types of **game and grazers** in 2005

The two main categories of pest insects were classified as defoliators and bark beetles or wood borers (Fig.9).

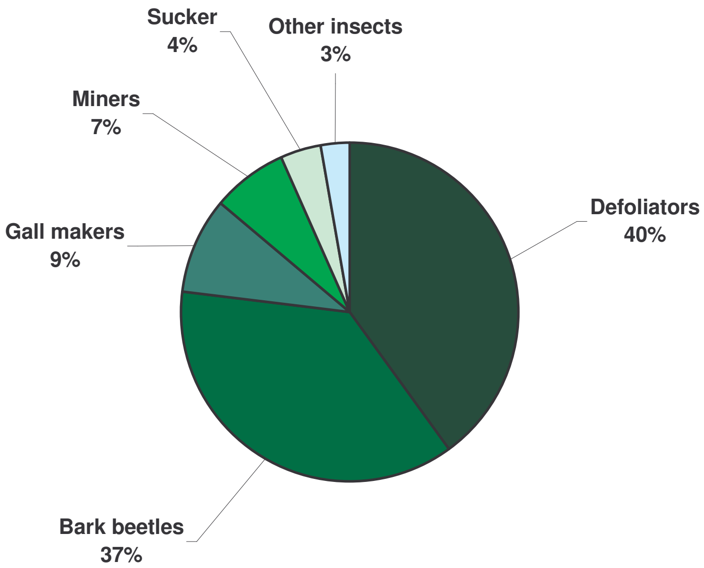


Figure 9 Proportion of damaged trees by different types of **insects** in 2005

Most of the damages caused by fungal pathogens (Fig.10) were observed in tree roots (20%) and stem (total of 56%).

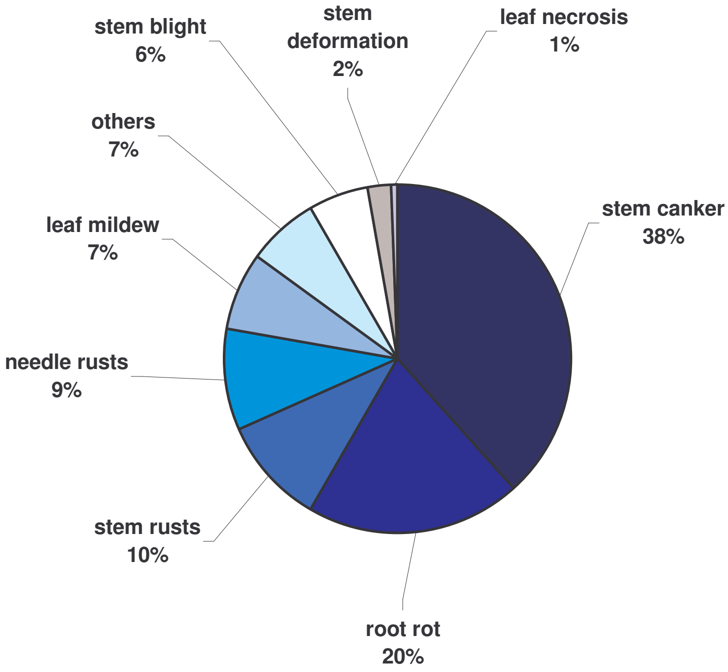


Figure 10 Proportion of damaged trees by different types of **fungi** in 2005

When pooling all abiotic damaging agents, it appears that drought, wind and snow account all together for about 80% of the damages (Fig.11). Fires only represented 5% of the damaged recorded in the dataset.

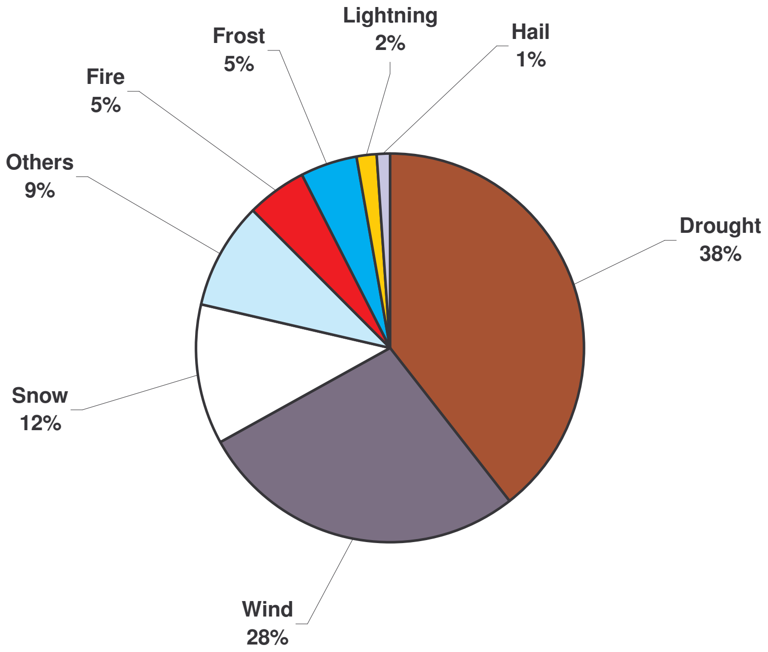


Figure 11 Proportion of damaged trees by different types of **abiotic causes** in 2005

In 2005, ca. 70% of anthropic damage was made during silvicultural or harvesting operations (Fig.12).

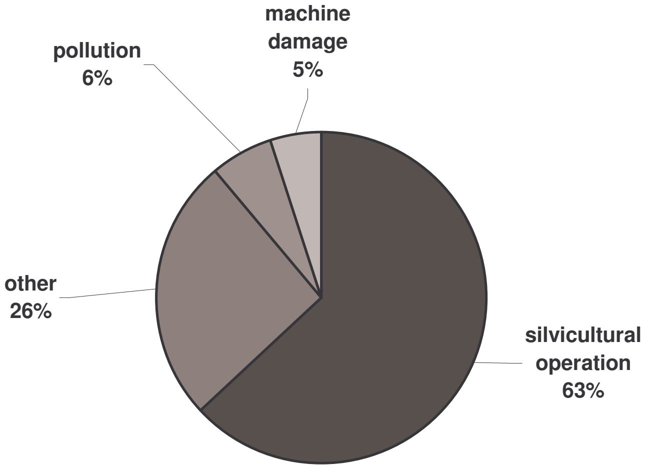
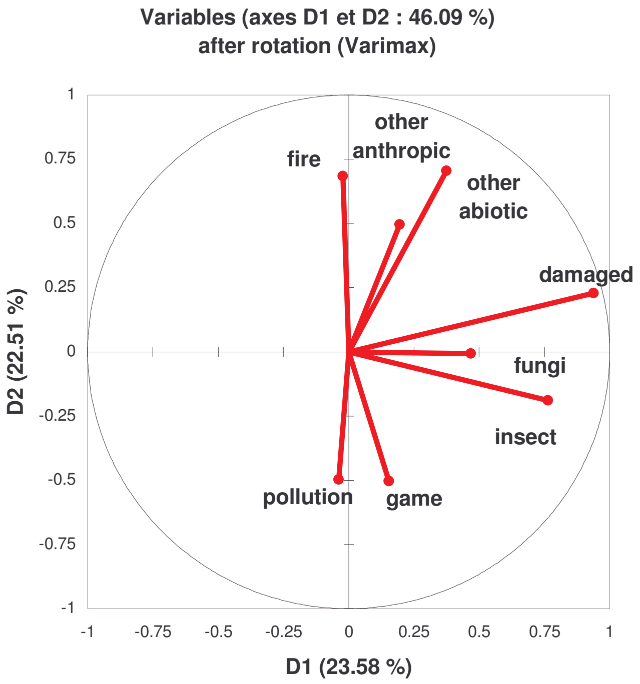


Figure 12 Proportion of damaged trees by different types of **anthropic causes** in 2005

3.2. . Profiles of hazards exposure

Although the 26 tree species seemed to display idiosyncratic response to hazards, we believed that some common properties may emerge from a more thorough analysis. We therefore performed Principal Components Analyses which are designed to reduce multivariate data to a smaller set of orthogonal, uncorrelated components that account for the maximum amount of variability. They are useful to detect structure in the relationships between variables and then to cluster observations with similar component values.

Principal component analysis (Fig.13a) described 46% of the total variance in the original data for the first two axes. The percentage of damaged trees per plot was the best correlated variable to axis 1 (D1) with a Pearson's r of 0.94. Percentages of trees damaged by insects and fungi were also positively correlated to D1 (0.76 and 0.47 respectively) a confirmation of the prominent place of biotic causes of damage in forest hazards. The percentages of damaged trees by fire and other abiotic causes of damage were positively correlated with the second axis (0.68 and 0.71 respectively) whereas game and pollution were negatively correlated to the same axis (-0.50 for both). When plotted on the same plane, the 26 tree species could be grouped in three distinct clusters (Fig13b). *Betula pubescens, Pinus nigra, Pinus halepensis*, and three Mediterranean oaks, *Quercus ilex, Q. faginea* and *Q. suber* were grouped together on the right hand side along axis 1 and on the upper side along axis 2, indicating that they shared common high levels of damage, mainly due to abiotic hazards. A second cluster comprised 10 broadleaved species, *Q. robur, Q. pubescens, Q. petraea, Q. cerris, Q. pyrenaica, Alnus glutinosa, Carpinus betulus, Fagus sylvatica, Castanea sativa*, these 9 being Fagaceae. They shared common high levels of damage, but in that case mainly due to biotic (insect and fungi) hazards. *Populus tremula* showed similar high level of biotic damage with the particularity of high game damage. A third cluster assembled the other 10 tree species that showed the lowest level of damage: *Betula pendula, Fraxinus excelsior and Eucalyptus sp, Pinus pinaster and P. sylvestris, Picea abies* and *P. sitchensis, Larix decidua, Abies alba* and *Pseudotsuga menziesii.* It is noteworthy that 8 species out of these 10 in the cluster are conifers.



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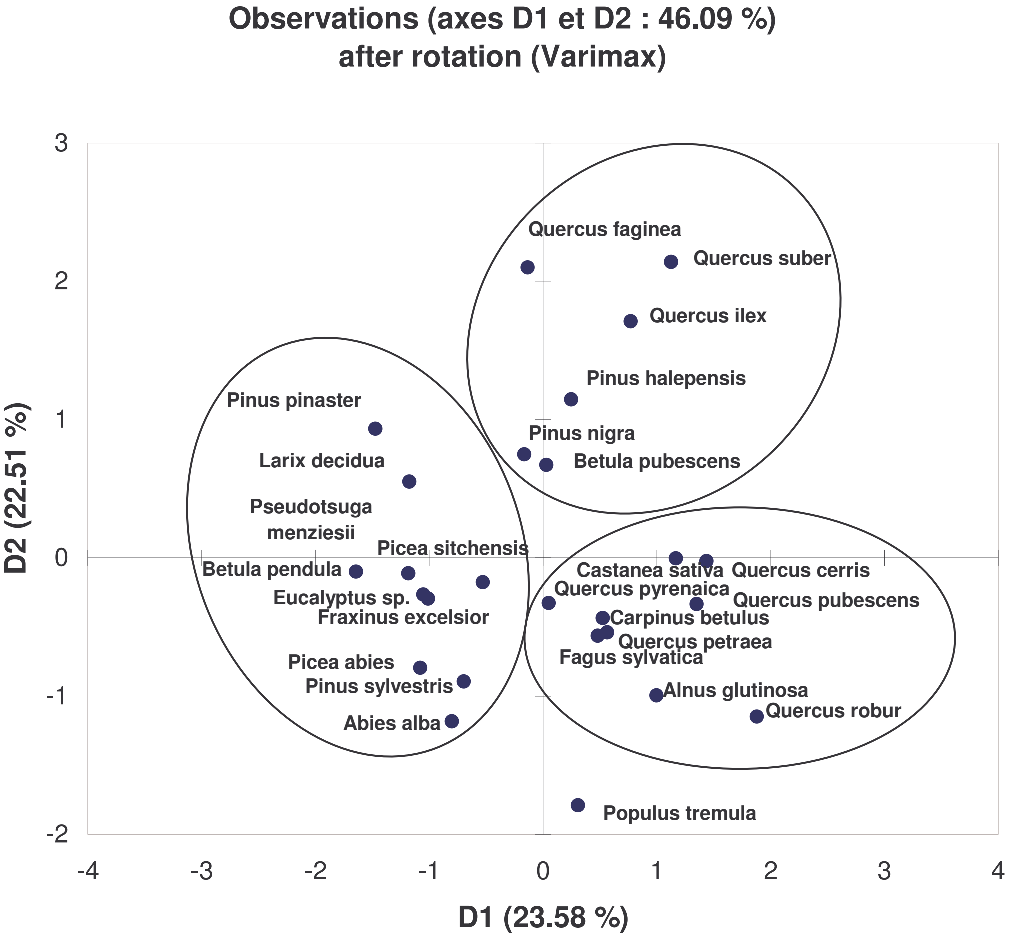


b

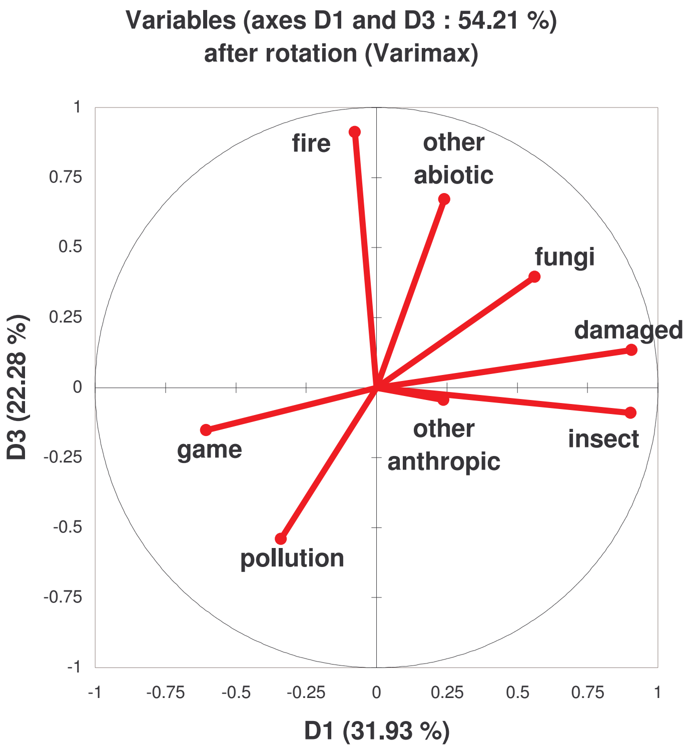
Figure 13 Principal Component Analysis (PCA, after rotation of the axes) of the 26 species (Fig.13b) using the 8 damage variables (Fig.13a).

A similar approach to cluster the 10 European Forest Types according to their profile of hazards exposure was used. We calculated the mean total percentage of damaged trees per plot in each of the ten types as well as the percentages of damaged trees by the seven types of damaging agents (Table 7).

Table 7 Mean absolute percentage of trees damaged by the 7 main biotic, abiotic and anthropic hazards in the 10 most abundant European Forest Types during the 1994-2005 period of time.

European Forest Types	**Mean % damaged trees**	**Mean % damaged trees / plot by**						
		game	**insect**	**fungi**	**abiotic**	**anthropic**	**fire**	**pollution**
Alpine coniferous forest	25	3	3	3	8	4	0	3
Boreal forest	27	1	2	3	4	2	0	0
Non-riverine alder, birch, aspen forest	28	1	7	4	3	2	0	5
Mediterranean Coniferous forests	30	0	5	6	11	2	2	0
Hemiboreal forest and nemoral forest	31	1	3	4	1	2	0	5
Lowland to submontane beech forest	35	1	18	3	3	7	0	1
Montane beech forest	36	0	20	3	7	4	0	3
Acidophylous oak and birch forest	39	1	22	6	3	4	0	0
Thermophilous deciduous forest	40	1	20	12	9	1	0	1
Broadleaved evergreen forest	46	0	16	5	19	8	1	2
Weighted Mean		**0.8**	**8.9**	**4.5**	**5.4**	**3.3**	**0.3**	**2.3**

We used these eight variables and ten observations to carry out a PCA analysis. When plotted in the same plane, the 10 forest types could be grouped in three distinct clusters (Fig14a). The first axis (D1) described 32% of the total variance in the original data and it was positively correlated with the total percentage of damaged trees (Pearson's r = 0.91) and the percentage of damaged trees by insects (0.90). The second axis (D2) explained 22% of the variation and was mainly correlated with the percentage of damaged trees by anthropic hazards (0.95). However we neglected this axis as anthropic hazards only represented 12% of the causes of damage. The third axis (D3) explained 22% of the variation; it was positively correlated with the percentage of damaged trees by fire and other abiotic hazards (0.91 and 0.67 respectively). When plotted on the plane defined by axes 1 and 3, the 10 forest types could be grouped in three distinct clusters (Fig14b). The Mediterranean conifers were separated from the other forest types and located in the upper left quarter of the plot, indicating similar high level of damages mainly caused by abiotic hazards. Five other forest types, comprising deciduous tree species from temperate to warm climates, were clustered in the right half of the plot. They shared common high levels of damage, but in that case mainly caused by biotic (insects and fungi) hazards, with broadleaved evergreen forests also showing significant abiotic damages. Finally the other 4 forest types, with coniferous and deciduous forests from cold climates, were grouped on the left bottom side of the plot as they showed similar low level of damage.



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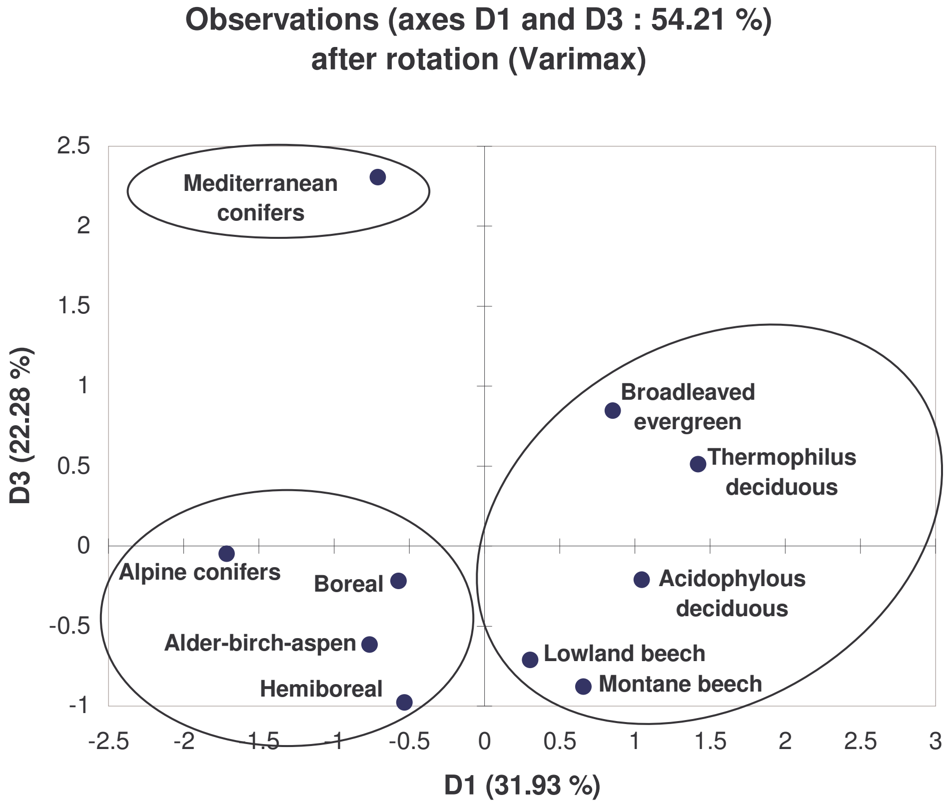


b

Figure 14 Principal Component Analysis (PCA after axes rotation) of the 10 forest types (Fig.14b) using the 8 damage variables (Fig.14a).

We further investigated the distribution of sanitary hazards prevalence in the five main European forest biomes (Table 8). The mean percentage of damaged trees per plot seemed to increase from oceanic and temperate climates (Boreal and Atlantic biomes) to more continental or dryer climates (Mountainous and Mediterranean biomes).

Table 8 Mean absolute percentage of trees damaged by the 7 main biotic, abiotic and anthropic hazards in the 5 European Forest Biomes during the 1994-2005 period of time.

		Mean % damaged trees / plot by						
European Forest Types	**Mean % damaged trees**	**game**	**insect**	**fungi**	**abiotic**	**anthropic**	**fire**	**pollution**
Boreal	26	1.2	3.3	8.2	4.3	3.1	0.1	0.1
Atlantic	28	0.6	16.3	4.1	3.6	1.4	0.0	0.0
Continental	33	1.2	10.2	4.9	3.3	3.3	0.1	5.5
Mountainous	35	1.8	9.0	5.2	12.3	4.8	0.5	1.9
Mediterranean	39	0.5	13.4	5.2	12.5	6.3	1.2	0.0
Weighted Mean		**0.9**	**9.1**	**4.7**	**5.4**	**3.2**	**0.3**	**2.3**

Because the number of observations (5) was lower than the number of variables (8) it was not possible to make a PCA with this table. Furthermore, the previous analyses indicated a difference of response to hazards between coniferous and broadleaved species. We therefore tested for the effect of forest biomes and tree taxa on the mean percentage of damaged trees per plot. The two categorical variables had highly significant effects, as well as their interaction (Table 9).

Table 9 Analysis of variance to test for the effects of Forest Biomes and Tree taxa on the percentage of damaged trees per plot.

Source	DDL	F	Pr > F
Forest Biomes	4	27.170	< 0.0001
Tree Taxa	1	122.595	< 0.0001
Biomes × Taxa	4	9.710	< 0.0001

The mean percentage of damaged trees per plot was consistently lower in coniferous than in broadleaved tree species, irrespective of the Forest Biomes, with the exception of the Boreal forests in which the two tree taxa were equally, but weakly, damaged (Fig.15). The Mountainous and Mediterranean Forest Biomes consistently showed the highest percentage of damaged trees, irrespective of the tree taxa. The Boreal and Atlantic Forests had the lowest levels of damage irrespective of the tree taxa.

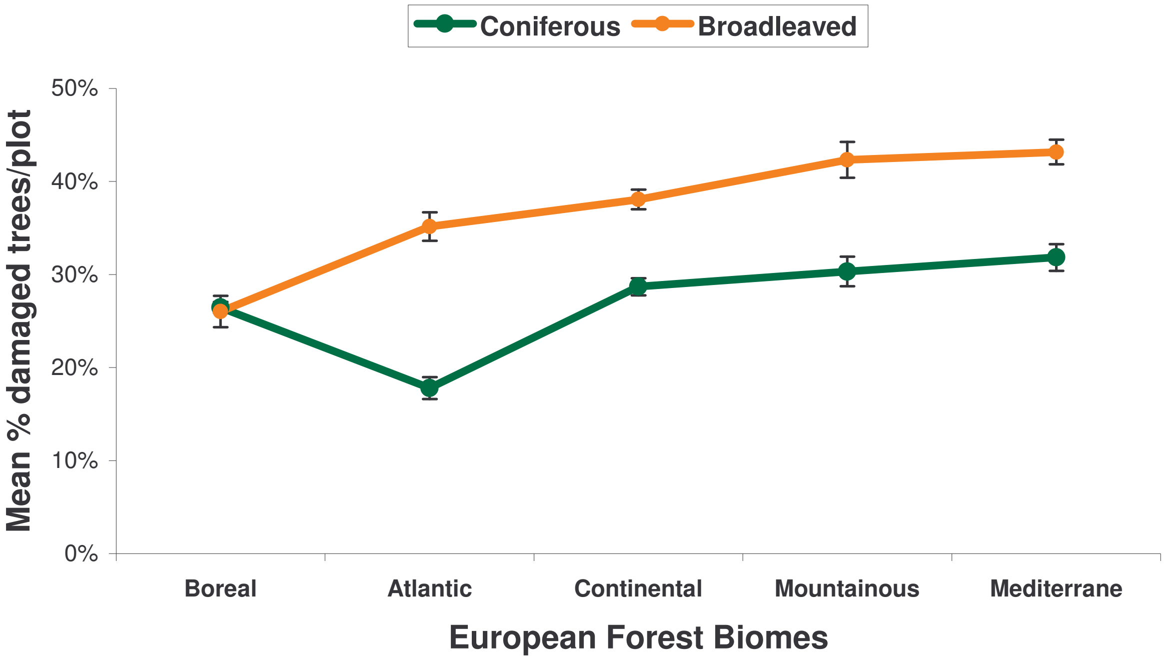
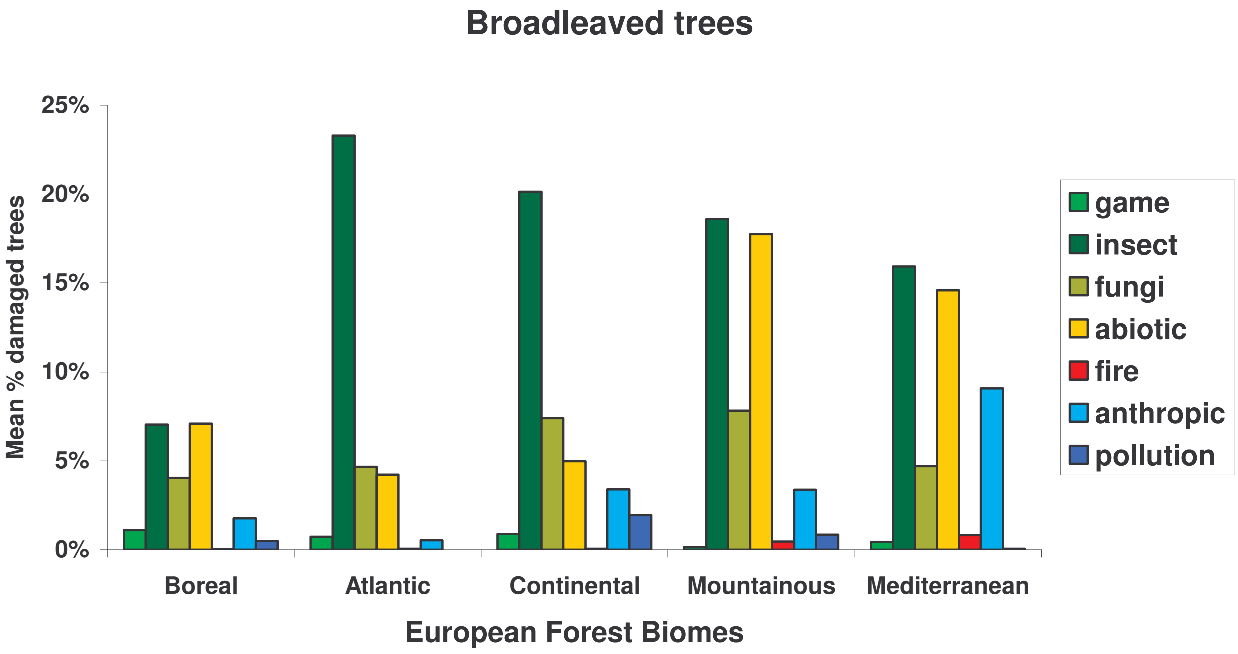


Figure 15 Mean percentage of damaged trees per ICP plot in the 5 European Forest Biomes according to the taxon of the tree species.

We further split the percentage of damaged trees into the seven types of damaging agents for the five Forest Biomes and the two tree taxa (Fig.16).

The ***broadleaved trees*** were consistently weakly damaged by game and grazers (ca. 1% of trees). By contrast they always showed high levels of damage by pest insects (ca. 20% of trees) with the exception of Boreal forests. A similar pattern was observed with damages by forest pathogens although at an overall lower prevalence (ca. 5%). The percentage of broadleaved trees damaged by abiotic hazards (but fire) was moderate in Boreal, Atlantic and Continental biomes (ca. 5%) and quite high in Mountainous and Mediterranean biomes (ca. 15%). The percentage of damaged trees by fire was negligible except for Mountainous and Mediterranean biomes. Damages of anthropic origin concerned 3-5% of trees but only 1% in the Boreal biome and almost 10% in Mediterranean forests.

The ***coniferous trees*** were also rarely damaged by game or grazers with the notable exception of ca. 3% of damaged trees in Mountainous forests. The percentage of trees damaged by pest insects ranged from 3% in Boreal forests to 6% in Atlantic and 9% in Mediterranean biomes. As for the broadleaved species the percentage of damaged conifers by fungi remained at a fairly constant level of 3-5% with the noticeable exception of the Boreal forest (9%). The percentage of coniferous trees damaged by abiotic hazards (but fire) was moderate in Boreal, Atlantic and Continental biomes (ca. 3%) and higher in Mountainous and Mediterranean biomes (ca. 9%). Again the percentage of damaged trees by fire was negligible except in Mountainous and Mediterranean biomes. Damages of anthropic origin showed more variability, notably in Mountainous and Continental forest that experienced the highest rates of damage by pollution (3% and 8% respectively).



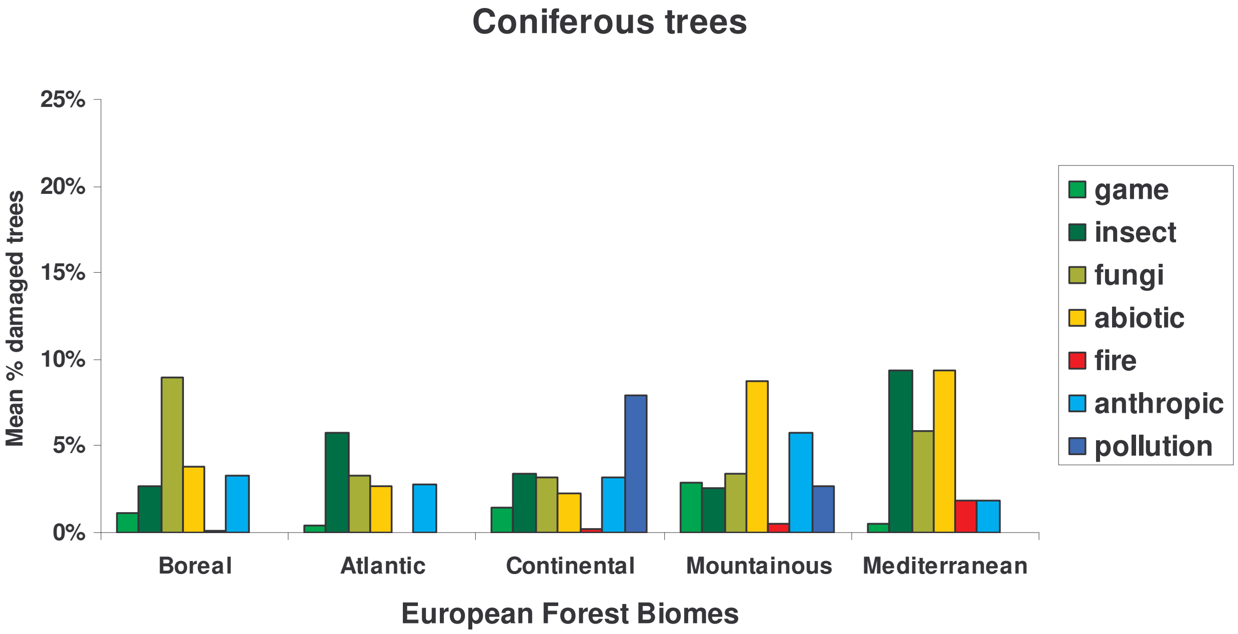


Figure 16 Mean absolute percentage of damaged trees per cause of damage in the 5 European forest biomes and the 2 tree taxa, from 1994 to 2005.

4. DISCUSSION

4.1. Methodological issues, relevance of the data

Surprisingly, there is very little global quantitative information about the prevalence of hazards in the world's forests. Most of the statistics on the frequencies of biotic or abiotic damage in forests are delivered on a tree species basis, for a particular area or for major sanitary problems (Tkacz et al. 2007). The USDA Forest Service manages a national forest health monitoring program but to our knowledge they only delivered synthetic information on the percent of annual tree mortality by cause of death, for the North Central Region in 1999 (USDA, 2007). Back to 1985 we found some interesting data on the sanitary status of the Canadian forests but they only concerned pests and diseases. For European forests, Schelhaas et al. (2003) estimated occurrence of biotic, abiotic and anthropogenic damages over the period 1950-2000 from an extensive literature review. However, this approach seems more appropriate for “catastrophic” types of damage, since such events are most likely to be reported. However, this is not valid when it concerns longer term observation networks. Moreover, they mostly expressed damage in terms of volume affected. Data provided by the European ICP Forest program therefore seem to be a unique example of long-term, generalist and quantitative information on the sanitary status and the main causes of damage in forest at a continent scale. Even though the local information, at the plot level, may be not very accurate due to the low number of sampled trees (ca. 20) and low frequency of damage assessment (once a year in summer), these drawbacks may be compensated by the large number of plots (almost 6000), the duration of the monitoring (more than 15 years) and the standardisation of the protocols.

However one should be aware of several limitations of ICP Forest data. The ICP manual indicates that the main objective of assessing damage causes is to provide information about their impact on crown condition. Some tree damages and their causes may be then overlooked if the tree crown is free of any symptom, leading to probable underestimation of the prevalence of hazards. Second it is difficult to estimate tree mortality and to unravel the causes of mortality since a tree may have been cut in between two successive assessments. Likewise the reasons why a complete plot has been renewed are not documented. It is therefore difficult to infer whether the plots have been harvested or completely destroyed by large scale hazards such as bark beetles outbreaks, wind storm or fires. The effects of latter two abiotic hazards are therefore likely to be underestimated as well. This is confirmed by comparison with the results of Schelhaas et al. (2003) who found abiotic factors to be most important, particularly storm (53% of annual volume damaged) and fire (16% of annual volume damaged).

This could also be tested by addressing a second source of information. We used the Forest Fire Statistics from the Joint Research Centre of Ispra for the years 1994 to 2005 on total number of fires in forest lands and compared the data with ICP Forest estimate of the mean percent of trees damaged by fire in the same years and the same 17 European countries (Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Netherlands, Norway, Poland, Portugal, Spain, Sweden, United Kingdom). We observed a highly significant correlation between the two fire damage variables ($N = 203$, $F = 376$, $P < 0.0001$, $R^2 = 0.65$). However in 42 out the 203 cases (ca. 20%), we had zero values in the ICP data when at least one fire was recorded in the same year and country, and the intercept of the regression line equalled 1600 ($P < 0.0001$) (Fig.17). ICP network seems to be unable to detect the occurrence of fires when they are less than 1600 per year and country. This confirms that, although fire data in ICP plots might be used to monitor overall trends and patterns of fire prevalence in European forests, they are likely to underestimate forest fire occurrence.

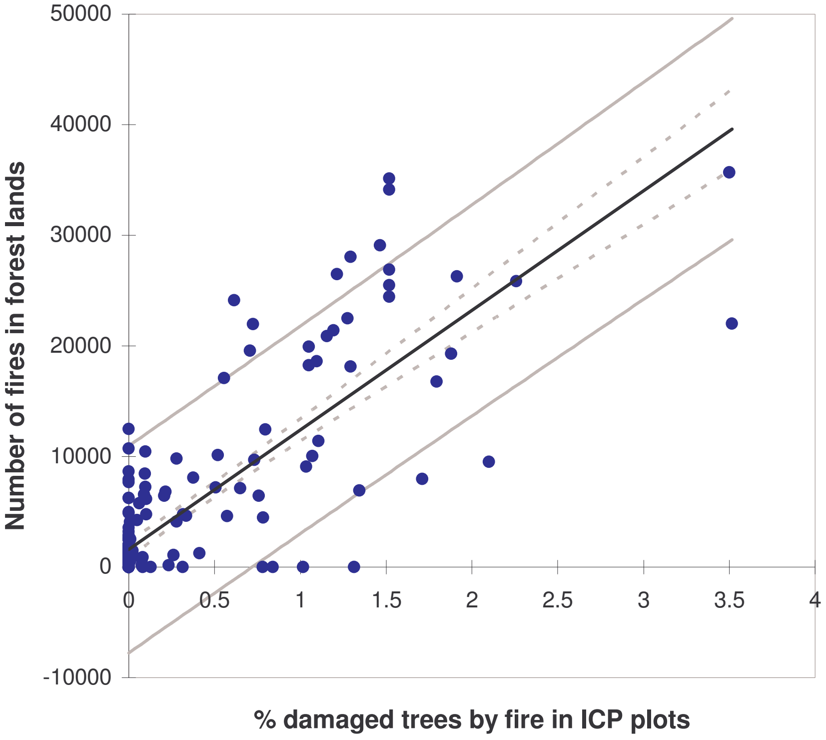


Figure 17 Relationship between the number of fires in forest lands (FFS = Forest Fire Statistics) and percentage of trees damaged by fire in ICP plots, in the same 17 European countries, during the 1994-2005 period. (Solid line: regression model; Dot line: 95% confidence interval)

Finally, ICP Forest data provide very useful information on the frequency and distribution of the main damaging agents but no clues on damage intensity. The intensity of damage and its effect on tree growth or survival also depend on the vulnerability of individual trees or stands and further monitoring procedures or modelling are needed to deliver this information.

4.2. General patterns and profiles of hazards exposure

What emerges from the analysis of ICP data is that the levels and the causes of biotic and abiotic hazard prevalence in European forests mainly depend on the tree taxa, the bioclimatic zones and to a lower extent on the management regimes (silviculture rotation).

Interesting enough, biotic damages caused by pest insect and pathogenic fungi displayed the same patterns.

First, these damages were more prevalent in broadleaved than in coniferous species. In the North Central Region of USA the percent of total annual mortality was also much higher in hardwood (80%) than in softwood (20%) (USDA, 2007). It has already been noticed that European deciduous tree species such as oak, birch and alder harbour the richest community of phytophagous insect species whereas several coniferous species such as spruce and fir are known to be quite poor in associated insect species (Southwood 1961; Kelly and Southwood 1999; Brandle and Brandl 2001). Similar results have been found about fungi by Strong & Levin (1975). Since a part of these phytophagous and pathogenic species can definitively be considered as damaging agents, it is likely that the probability of being damaged is higher in broadleaved than in coniferous species. Likewise *Pseudotsuga menziesii* and *Eucalyptus species* which are among the least damaged tree species in Europe, are exotic species that are known to accommodate fewer insect and pathogen species than native tree species (Kennedy and Southwood, 1984). Another evidence to support the hypothesis of a relationship between species richness and damage occurrence is that conservative estimates suggest that the figure of living species of insects is 2 million (Novotny et al. 2002) whereas the number of fungi species would be of almost 1 million (Mueller and Schmit 2007) i.e. a half of the insects number. And indeed the percentage of damaged trees by pest insect is consistently twice as high in our survey than the percentage of trees damaged by pathogenic fungi (for instance: 8.7% damaged by insect *vs*. 4.7% damaged by fungi on average in the 26 main European tree species; 8.9% *vs*. 4.5% in the 10 European forest types; 9.1% *vs*. 4.7% in the 5 European biomes). The second reason why broadleaved trees seem to experience more biotic damage than coniferous trees may be that they often last longer and grow more slowly. As they are harvested later broadleaved trees may cumulate more damages than conifers. This is consistent with the fact that not only biotic but also abiotic damages are more frequent in broadleaved than in coniferous species. Furthermore, among the least damaged species in our survey were the silver birch, the eucalypt, the Douglas fir, the European ash and the maritime pine, five tree species which are managed in short to medium rotation regimes and being harvested relatively early in their natural life time might limit the occurrence of damages. By contrast the five most damaged tree species are five oak species, of which the age of exploitability often exceeds 150 years. *Pinus halepensis*, which is the conifer with highest damage (39% damaged trees), is mostly used in southern European regions for soil protection or recreation areas. Therefore stands of *P. halepensis* often stay in the field until mature or even over mature stages such as the above cited oak species.

To test for these hypotheses we tried to predict the prevalence of insect damage in eleven European species (*Abies alba, Alnus glutinosa, Carpinus betulus, Fagus sylvatica, Fraxinus excelsior, Larix decidua, Picea abies, Pinus sylvestris, Populus tremula, Quercus petraea* and *Q. robur* (pooled), *Betula pendula and pubescens* (pooled)) for which we had an estimate of the number of associated insect species (Southwood, 1961). We also documented the longevity of these tree species in Europe and estimated the harvest age. Then we computed the relative Portion of the Lifespan for the tree species (Table 10) as following:

$$Portion\,Lifespan = 1 - \frac{(Longevity - Harvest\ Age)}{Longevity}$$

Table 10 Data on European tree species longevity, harvest age, number of associated insect species and average prevalence of insect damage.

Tree species	Longevity (years)	Harvest Age (years)	Relative Portion of tree Lifespan	Number of insect species*	mean % damaged trees by insects
Abies alba	500	80	16%	16	4.5%
Alnus glutinosa	100	80	80%	90	30.0%
Betula pendula + B. pubescens	300	50	53%	229	7.0%
Carpinus betulus	150	80	33%	28	20.5%
Fagus sylvatica	300	100	32%	64	20.8%
Fraxinus excelsior	250	80	16%	41	14.5%
Larix decidua	500	80	10%	17	6.1%
Picea abies	700	70	16%	37	1.1%
Pinus sylvestris	500	80	30%	91	2.9%
Populus tremula	100	30	29%	97	10.3%
Quercus petraea + Q. robur	700	200	17%	284	27.7%

* after Southwood (1961)

Using a linear multiple regression model we noticed that the mean percentage of damaged trees by insect per tree species was positively correlated with the number of insect species on this tree species ($P = 0.04$) and with the relative portion of tree lifespan ($P = 0.001$) for an overall highly significant model ($N = 11$, $F = 16.5$, $P = 0.001$, adjusted $R^2 = 0.76$). These results clearly indicate that the prevalence of insect damage in a particular tree species increases with the insect species richness on this tree and decreases as the tree species is early harvested (Fig.18). For example *Alnus glutinosa* would exhibit a high percentage of insect damage because it is harvested only soon before the completion of its lifespan thus accumulating attacks from most of its potential associated insect species. The oak species would be often damaged by insects due to the high diversity of associated insect species. Despite of their high richness in associated insect species, birch trees would escape from most the potential damaging insect due to their early harvesting (more than 80% of their lifespan is "missing" in managed forests).

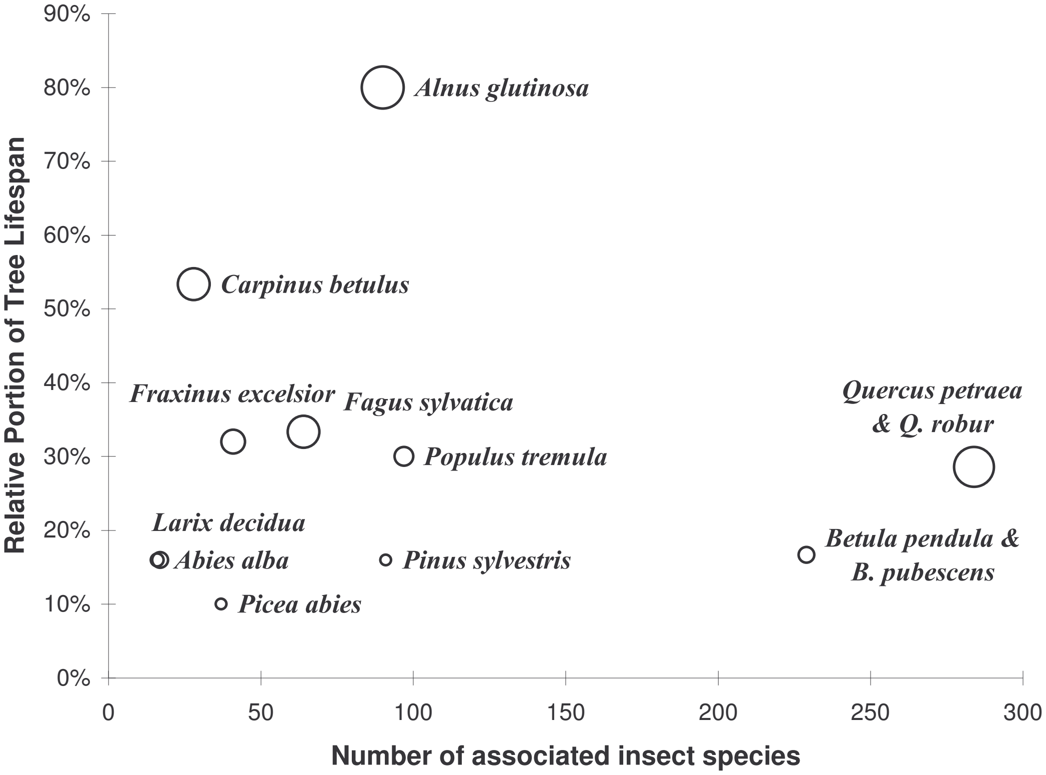


Figure 18 Relationship between the species richness of insects associated with European tree species (after Southwood, 1961), the portion of tree lifespan before harvesting and the mean percent of damaged trees by insect in the same tree species (proportional to the radius of bubbles).

Second, both insect and pathogen damages were more frequent in some European forest biomes and types. Irrespective of the tree taxa, the lowest levels of biotic damages were observed in the Boreal biome and secondly in the Mountainous biome. Furthermore alpine and boreal coniferous and hemiboreal forests were less damaged by biotic hazards than lowland beech forests, broadleaved evergreen and thermophilous deciduous forests. It is quite likely that some climatic features affect the prevalence of biotic hazards. In particular warm or temperate climates may favour the development of pest and pathogen infestations. For insects, as any poikilothermic animals, temperature is a critical environmental variable which affects activities and development (Speight and Wainhouse, 1989). In general development rates in forest insect populations increase with temperature, generation times are reduced in warm climates and dispersal or foraging abilities are higher on sunny days. It is also predicted that the impact of forest diseases increases with warmer temperatures due to more favourable conditions for fungi survival and number of cycles per year (Bergot et al. 2004). As a result pest insects and pathogenic fungi are likely to make more damage in forests under warm climates.

Game and grazers did not show the same patterns of prevalence as other biotic damaging agents. Their damages did not show significant differences between tree taxa or forest biomes. As homeothermic animals deer may not be so dependent on climatic conditions to build up their populations. Moreover they are known as generalist herbivores which can feed on both conifers and broadleaved species (Pietrzykowski et al. 2003). The composition (Vehvilaïnen and Koricheva 2006) and the climatic conditions of forests are therefore not considered as critical drivers of game damage. Prevalence of damage by game was overall much lower than other biotic damages. Mammal grazers such as deer mainly feed on young trees or seedlings (Vospernik 2006), which are not included in the ICP data. Conversely, damaging birds such as woodpeckers often use older forests as preferred habitats as they provide more food and nesting resources (Kosinski & Winiecki 2005). The two main damaging agents within the game group are therefore associated with transient phases in most of the European forests, i.e. very young and old or over-mature stages. It is therefore likely that ICP data do not allow a realistic evaluation of these damaging agents.

Abiotic damages were also more frequent in broadleaved than in conifer trees and in Mountainous or Mediterranean biomes than Boreal, Atlantic and Continental forests. The interpretation of this figure is not as straightforward as for biotic damaging agents as we had no detailed information about the different abiotic causes of damage. Trees that are damaged totally and then killed are removed from the ICP database and are thus not recorded. Only in 2005 we could notice that the three main abiotic hazards were drought, wind and snow. Vulnerability to xylem cavitation is considered as a good proxy for tree resistance to drought (Breda et al. 2006). However there is a considerable variation in vulnerability to cavitation among tree species and no significant difference between deciduous and conifer trees has been detected so far (Breda et al. 2006 and reference herein). Tree resistance to wind also seems species-specific (Dhôte 2005, Zhu et al. 2006). In general conifers are regarded as more vulnerable than broadleaves, except when windstorms occur if trees still have leaves. However, this occurs only very seldomly. Another reason might be that conifers preferably uproot or snap, whereas broadleaved trees more often loose branches and parts of their crown in storms. In addition to these assumptions, the hypothesis of damage accumulation with time is also relevant for abiotic damages. Because they are longer-lasting, broadleaved trees are later harvested and can cumulate more damages than conifers.

Abiotic damages were also more frequent in Mountainous and Mediterranean biomes irrespective of the tree taxa. Hemiboreal and Nemoral coniferous forests were less damaged by abiotic agents (1%) than Alpine or Mediterranean coniferous forests (8% and 11% respectively). Lowland beech forests suffered less from abiotic damages (3%) than Montane beech forests (7%). These differences clearly suggest that the harshness of the climate may induce more frequent damage in European forests. More frequent droughts are likely to occur in Mediterranean climates and snow falls are likely to occur more frequently in mountainous climates, thus resulting in higher prevalence of abiotic damages. In particular, as noticed in our survey, fire damages are significantly higher in Mountainous and Mediterranean biomes, where summer droughts are longer and more intense.

Pollution damages were always rarely observed in European forests with the exception of coniferous forests in Mountainous and above all in Continental biomes. A closer look at the ICP data revealed that these damages were mainly restricted to *Abies alba* in Croatia and to *Abies alba, Picea abies* and *Pinus sylvestris* in Poland. The results of the ICP Forest Level II monitoring are consistent with these patterns, indicating a high level of pollutant deposition (particularly sulphur) in these regions which are known to be much industrialised. The other types of anthropic damages which were mainly related to silvicultural and harvesting operations did not show any particular pattern. The peak of anthropic damage observed in Mediterranean broadleaved species may be the consequence of misclassification. There has been in Portugal and Spain (mostly in the south) an increasing and high tree decline and mortality during the last decades of *Q. suber* and *Q. ilex*. For a long period it has been a main believe that the primary cause was due to anthropic factors (soil mobilization leading to erosion and bleaching, intensive cereals cultivation in the undercover, compaction of soil by cattle, intensive debarking for cork removal, etc. (Sousa et al. 2000). Recent research studies uncovered that the main factor of decline is a root fungus: *Phytophthora cinnamomi*, an exotic which was introduced in South Europe about one century ago (Brasier et al. 1993; Robin et al. 1998; Tuset et al. 2002).

5. CONCLUSION

The results of this study clearly show that the most prevalent hazards in European forests are of biotic origin (2/3 pest insects, 1/3 pathogenic fungi) followed by abiotic agents such as drought, wind and fire. They also reveal that European forests greatly differ in their exposure to these hazards according to their species composition and bioclimatic zone. To make it simple, if not simplistic, overall broadleaved trees would experience more frequent damages (or cumulate more damages) than conifers and both biotic and abiotic hazards would occur more often in biomes with harsh climates such as Mediterranean and Mountainous climates. Shortening the silviculture rotation would help to avoid hazard occurrence. However these conclusions have to be "handled with care" as they just indicate very general patterns of hazard probabilities. They should not be used to predict damage on a particular tree species in a given region and for specific management practices since the latter also depend on the vulnerability of forest stands to hazards.

The next steps of the ICP data analysis will be to further investigate anthropic drivers of damage occurrence. In particular we will use the available information on site conditions (water availability), stand age, stand composition (mixed *vs*. pure) and stand structure (even-aged *vs*. uneven-aged) to test for the effect of these variables on the prevalence of damages in the most common tree species in Europe.

This information will be useful to proceed from in the sanitary risk analysis the WP 2.4 plan to undertake. A review will soon be made on the effects of silvicultural practices on the forest stand vulnerability to sanitary hazards. By joining the two reviews it will be possible to rank the risk of sanitary damage in European forests according to tree species composition, geographical situation and type of management. Collected data will also serve as a baseline to infer on the potential impact of new forest management alternatives on sanitary damage in European forests. The results presented in this report will contribute to the development of risk rating modules in the growth model platform managed by WP 2.5 and to document indicators in TOSIA.

6. ACKNOWLEDGEMENTS

We would like to thank the Programme Coordinating Centre (PCC) of the ICP Forests board for contacting the country focal points and for permitting us the use of the crown conditions data. As was demonstrated in this report, it is a valuable, consistent source of information both owing to its wide range in spatial and temporal sense and to the standardised inventory procedures. We would therefore recommend sustaining financial resources for this purpose.

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