

Chapter 20

An intensive monitoring study of air pollution stress in a beech forest in Spain

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Abstract

The main objectives of this study were to gain insight into relationships between crown condition, foliar composition, and soil chemistry on the one hand and various environmental factors, including atmospheric deposition and air pollution, on the other. Defoliation of beech (*Fagus sylvatica* L.) trees was very similar across the different surveys, reaching a maximum in 1996, a year following a period of drought. Biotic effects also influenced forest health, especially *Rhynchaenus fagi* L., which was present during all surveys. Visible ozone-injury-like symptoms observed on beech and *Vaccinium myrtillus* L. leaves suggested that ozone and/or other air pollutants could be additional damaging factors in this area. The high ozone concentrations recorded in the field, and the detection of several anthropogenic hydrocarbons, supported this hypothesis. Foliar analysis of beech trees revealed relatively low contents of Cu and Fe and high levels of Ca and Na. Beech trees showed a good nutritional balance for other elements. Soils were desaturated in basic cations and had low nutrient contents. Several acid episodes (pH < 5.6) were detected, especially in winter, when industrial activity increases. Annual throughfall fluxes of elements were significantly higher than in Northern Europe but similar to those observed in the Mediterranean area. Finally, the vegetation assessment carried out in the Level II plot did not allow

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us to draw any conclusion about the vegetation dynamics. However, this is the first step in a long-term study that will provide information about changes in ecosystem variables in future inventories.

1. Introduction

The Pan-European Programme for Intensive and Continuous Monitoring of Forest Ecosystems was implemented in 1994 in order to gain a better understanding of the effects of air pollution and other stress factors on forests. At present, 864 permanent observation plots have been established in Europe, 513 in the European Union, and 351 in several non-EU countries.

This Programme is based on both the European Scheme on the Protection of Forests against Atmospheric Pollution (Council Regulation EEC No. 2528/86) and the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) under the Convention on Long-Range Transboundary Air Pollution (CLRTAP, UN/ECE).

Spain has participated in the Level II Monitoring Programme since 1994, establishing a total of 53 intensive monitoring plots throughout the country by the end of 1995. On all these plots, several surveys are carried out, including crown condition, foliage and soil chemistry, and forest growth. At 11 of these plots, assessments of atmospheric deposition, meteorology and ground vegetation are also made.

The forests of the province of Navarre, in the north of Spain, represent a great environmental, cultural, and productive resource, as well as a scenic landscape. For these reasons, the regional government has shown special interest in monitoring the state of the forest environment and in 1994, joined the Pan-European Programme for Intensive and Continuous Monitoring of Forest Ecosystems. Since then, the University of Navarre has responsibility for a Level II plot made up of a beech (*Fagus sylvatica* L.) forest, the most characteristic species of trees growing in this region.

This paper describes the results of the Level II surveys carried out in Navarre for the period 1994–1999. Besides the mandatory activities, several pilot studies have also been carried out, including the determination of biogenic and anthropogenic emissions of volatile organic compounds (VOCs), a short-term study to monitor ozone concentrations, and a phytosociological assessment.

This research will provide a better insight into crown, soil, and foliar condition of beech forests, focusing specifically on relationships between stand and site characteristics and environmental factors, such as meteorology and air pollution.

2. Materials and methods

2.1. Site

The permanent observation plot under study is a pure beech (*Fagus sylvatica*) stand that lies in the Cantabrian-Atlantic Province within the Eurosiberian region. This beech forest consists of a mosaic of two different communities: *Saxifrago hirsutae*–*Fagetum sylvaticae* subassociation *luzuletosum pilosae* and *Carici sylvaticae*–*Fagetum sylvaticae* subassociation *isopyretosum thalictroidis*. It is a 90-year-old homogeneous beech stand, located 963 m above sea level, with a basal area of $19 \text{ m}^3 \text{ ha}^{-1}$. It is subject to exploitation ($2 \text{ m}^3 \text{ ha}^{-1}$) and has a silvicultural rotation of 150 years.

The Level II plot (0.25 ha, $43^\circ 00' 03'' \text{ N}$, $1^\circ 20' 41'' \text{ W}$) is located in the Plain of Auritz-Burguete. This plain, carved of soft materials and partially filled with alluvial material, is formed by an east-west band limited by high areas like Tiratun (1217 m) and the Corona (1387 m) mountains. Geologically, the area belongs to the Quaternary period, made up from a mixture of colluvial apron and terrace containing semiangular pebbles, gravels, sands, limes and clays (Íñiguez et al., 1992).

The climate is hyperhumid, with a historic annual mean precipitation of 2183 mm (173 days of rain per year) and a thermal index of 123 according to Rivas-Martínez (1995). Consequently, the area belongs to the mountain floor, where climate conditions are characterized by cold winters with mean minimum temperatures of between 0 and -4°C . From September to June, frosts are statistically probable, especially at higher altitudes.

The soils of this beech forest (profile: Ao–Eg–Bt–BC–C–2Crg) are developed on Quaternary colluviums over Paleogen marls (Tertiary). According to spatial location, these colluviums have different thicknesses and compositions. On convex topographic locations, colluvium is approximately 1 m in depth and is dominated by marl residuum; on debris cones, it is several meters thick and it is composed of early Devonian (Paleozoic) sediments that are rich in schist, limes, and dolomites. All these materials are subjected to a very wet climate ($> 2000 \text{ mm yr}^{-1}$) with an udic soil moisture regime. Because of the environmental conditions, the soil is subject to very intense leaching, and even the marls lose all the limes before they lose their lithic structure.

Leaching is also the main pedogenic process characterizing these soils. The soils are very acid ($\text{pH}_{\text{KCl}} = 3.7\text{--}3.9$) and weathered to more than 1 m in depth. The residuum is a very fine material with a large proportion of clay and fine silt. On stable surfaces, there may be slight clay illuviation processes but it is not of taxonomic importance.

These incipient argilic horizons favor the appearance of slight redoxomorphic features, reddish mottles of pseudogley at the bottom of the eluvial hori-

zons (Eg). The weathering faces of the marl (Crg) also display some black coloration due to the presence of manganese oxides. Despite these acid and oxyaquic conditions, the short dry periods and surplus of nutrients provided by the beech trees mean there is good biological activity and a high rate of decomposition and removal of soil organic matter. The type of humus in these soils is an acid mull with a good incorporation of organic compound.

2.2. Field sampling and chemical analysis

We assessed crown condition by measuring defoliation (5% classes), discoloration, and the presence and intensity of insects and fungi (UN/ECE, 1998) in 30 sample trees. Assessments were carried out in July–August by forestry staff (3 people) previously trained in a 1-week calibration course aimed at harmonizing assessment criteria.

Deposition samples were collected from the forest stand and an adjacent open area throughout 1997–1999. The stand throughfall samples were collected at 2-week intervals using six systematically located precipitation collectors (1.5 m above the soil). The corresponding number of collectors for the adjacent open area was four. Precipitation amount was measured using four Helmann collectors (two under the forest canopy and two in an open field).

Additional meteorological parameters were solar radiation, precipitation, relative humidity, air temperature, wind speed, and wind direction, which were measured continuously in the open field at a fully automated meteorological station.

Deposition samples were analyzed for pH, conductivity, amount of precipitation, Cl, NO₃, SO₄, Na, K, Ca, Mg, Cu, Cd, Pb, Zn, Fe, and Mn. Anions were analyzed by ionic chromatography (Waters 432) and cations by plasma emission spectrometry (Jovin Yvon J-38 S) and atomic absorption (Perkin Elmer Analyst 800).

The chemical composition of the foliage was measured in eight predominant or dominant beech trees selected in the buffer area (5 m width around forest plot). Leaves were collected during the summers of 1995 and 1997 from the upper third of the crown using a long pruning device.

The unwashed samples were dried at 60 °C and pulverized in a mixer. The concentrations of Ca, Cd, Cu, Fe, K, Mg, Mn, Na, P, Pb, S, and Zn were determined, following wet digestion (HNO₃ : HClO₄), by plasma emission spectrometry (Jovin Yvon J-38 S) and atomic absorption (Perkin Elmer Analyst 800). Total nitrogen concentration was determined by the Kjeldahl method. The performance of the analysis was verified by analyzing certified reference material (CRM—*F. sylvatica*) and no method bias was detected. More details about the treatment and analysis of samples may be found in Santamaría and Martín (1998).

Besides the nutritional status, we also assessed the health of the sampled trees (*see Crown Condition*).

Soil samples (0–100 cm depth) were collected from the buffer zone of the beech forest. The soil was dried at 35 °C and gently ground to pass through a 2-mm sieve. In order to characterize the soil, the total content of each element studied in the exchangeable fraction was measured. Particle size was determined using a Robinson pipette, total N by Kjeldahl's method (semimicro Afora-Boet), and organic carbon according to Walkley-Blach. Metals were analyzed by atomic absorption (Perkin Elmer Analyst 800) and cation exchange capacity (CEC) was obtained by the ammonium acetate method. Finally, pH (1 : 2.5) was determined in water and KCl.

We determined biogenic emissions from *F. sylvatica* during a short-term study conducted in June 1998 through the bag enclosure method using Teflon cuvettes (volume = 21 l). The air circulating through the cuvettes was sampled and analyzed every hour by a cyclic procedure using a fully automated adsorption–desorption device. The measurements were conducted on June 15, 17, and 18. Sample analysis was done by thermal desorption (ATD 400, Perkin Elmer) gas chromatography (HP-5890)/mass spectrometry (HP-5972 MSD).

At the same time as VOC biogenic emissions were determined, the levels of anthropogenic hydrocarbons were also measured. Air was sampled during the course of the day (June 15 and 18) using Chrompack tubes filled with Carbotrap B and C.

Ozone concentrations were recorded in the Level II plot for a period of 8 days (13–20 June) using a continuous measuring device (Dasibi 1008 RS).

Finally, data related to vegetation were collected from five small sampling units (10 × 10 m), representative of the forest. Plots were visited monthly throughout 1999 (twice a month in the spring) and phytosociological inventories were carried out following the Braun-Blanquet method (Braun-Blanquet, 1979).

We collected data for each plant, including the abundance-dominance index, the phenological stage, and the life form. After completing 1 year of study, we deduced the degree of vitality of each species: (1) well-developed plants that complete their life cycle regularly; (2) poorly-developed plants that complete their life cycle or well-developed plants that have not completed their life cycle. In addition to this, a checklist from all the forest was recorded as a tool to explain future changes in the sampling units' vegetation.

3. Results and discussion

Excluding the 1994 survey, defoliation of sampled trees remained almost constant over the years, reaching a maximum in 1996, when mean defoliation

Table 1. Variation in defoliation of sampled trees, 1994–1999

Year	Mean	Minimum	Maximum	Std. deviation
1994	10.0	10	10	0.0
1995	18.5	10	25	4.3
1996	24.1	15	45	7.6
1997	18.0	10	25	3.6
1998	19.0	15	30	4.0
1999	18.7	15	25	3.5

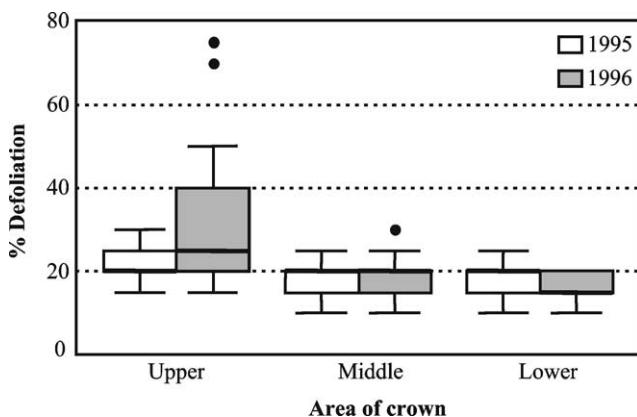


Figure 1. Variation of defoliation by crown thirds.

amounted to 24.6% (Table 1). The correlation analysis (Pearson's r test) carried out using all data showed a significant correlation between defoliation of years 1997–1998 ($r = 0.39$; $P < 0.01$) and 1998–1999 ($r = 0.58$; $P < 0.01$). These results suggest that the process of defoliation does not occur randomly among stand trees but mainly affects those individuals that are more predisposed and weakened by other circumstances. In the case of the 1996 survey, no correlation was found.

A high proportion of damaged trees (defoliation $> 25\%$) were detected in 1996, when 33.3% of all trees showed defoliation $> 25\%$. This is probably related to the drought of the previous year, when the annual mean precipitation (721 mm) was much lower than the historic mean precipitation (2.183 mm) of this area.

During the 1995 and 1996 surveys, canopy defoliation was estimated by thirds (Fig. 1). In both years, the upper third of the crown was the most defoliated, a fact that underlines the greater vulnerability of this part of the crown, which is more exposed to stress factors (biotic and abiotic ones). This was es-

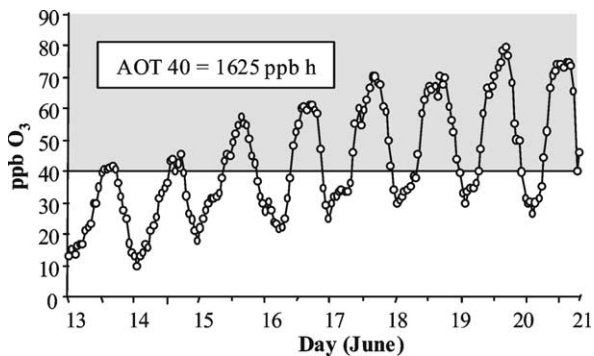


Figure 2. Ozone diurnal fluctuation by sampling day and calculation of AOT 40.

pecially true in 1996, when the increase in mean defoliation of stand trees was mainly related to the worsening of the upper leaves of the crown.

In general, the most frequently assessed damage causes were abiotic agents, mainly explained by drought and late frosts. In addition, classic damaging agents must be mentioned, especially the insect *Rhynchaenus fagi* L., which was present in all surveys.

Results support the hypothesis that the major cause of damage in forests is due to the adverse effects of stresses such as drought or pest infestations (De Vries et al., 2000). However, other stress factors (especially air pollutants) must not be overlooked. A small number of young beech trees (at the end of summer 1998) had visible injury symptoms attributable to ozone (dark pigmented stipple on interveinal tissue of upper leaf surface). Similar symptoms were also recorded in some individuals of *Vaccinium myrtillus* L. These observations are consistent with the ozone levels recorded in the forest stand (Fig. 2) during the short-term field study carried out in 1998 and they underscore the usefulness of both species as ozone bioindicators (Nygaard, 1994; Braun and Flückiger, 1995).

The AOT 40 calculated for the 8 sampling days was 1625 ppb h (Fig. 2), a value abnormally high for a remote area located far away from any pollution source. Moreover, the toxicity threshold fixed at $65 \mu\text{g m}^{-3}$ for a 24-h period was exceeded from June 15–20, which may have negatively affected vegetation. With respect to ozone variations, the fact that the mean profile showed minimum concentrations close to 30 ppb and no lower suggests that the measured ozone comes from long- or medium-range transport rather than from local production due to photochemical activity.

This hypothesis is also confirmed by the 15 anthropogenic hydrocarbon compounds detected during the sampling period (Table 2), probably related to road transport. The concentrations recorded were similar to those detected in

Table 2. Hourly variations in anthropogenic emissions at the Level II plot

Emission type	Units	Time (h)					
		10	12	14	16	18	20
Butene	pl ^{l-1}	181	163	204	146	178	200
Pentene	pl ^{l-1}	58	39	156	71	59	88
Hexene	pl ^{l-1}	26	27	43	39	43	78
Heptene	pl ^{l-1}	5	7	4	7	8	10
Octene	pl ^{l-1}	7	42	12	9	7	5
Butane	pl ^{l-1}	16	9	10	11	14	54
Pentane	pl ^{l-1}	111	28	77	51	34	70
Hexane	pl ^{l-1}	28	25	30	41	32	36
Heptane	pl ^{l-1}	42	49	42	80	84	49
Octane	pl ^{l-1}	7	13	38	33	15	25
Benzene	pl ^{l-1}	128	125	105	195	126	208
Toluene	pl ^{l-1}	156	160	271	292	161	253
Ethylbenzene	pl ^{l-1}	10	9	11	13	14	18
M + p-Xylene	pl ^{l-1}	28	28	25	52	27	29
o-Xylene	pl ^{l-1}	8	7	5	30	8	9

Table 3. Hourly variations in biogenic emission rates, PAR, and foliar temperature (*Fagus sylvatica* L.)

Time (h)	Emission rate (µg g ⁻¹ h ⁻¹)	PAR (µmol m ⁻² s g ⁻¹)	Foliar temp. (K)
7	0.02	46	277.8
9	9.56	698	292.4
11	18.41	1146	302.6
14	12.63	828	296.4
16	7.24	335	297.0
18	0.53	68	294.3

the forests of Italy and Holland (Gelencsér et al., 1994; Kalakobas et al., 1997). The meteorological conditions recorded on these days (prevailing winds from N and NE) support the notion that all these contaminants come from the south of France.

Aside from the anthropogenic sources, several biogenic compounds emitted from vegetation (mainly isoprene and monoterpenes) are also involved in the production of photooxidants such as ozone (Guenther et al., 1993). Analysis of biogenic emissions showed that the main monoterpene emitted by *F. sylvatica* L. was isoprene, which accounted for 95% of all emitted compounds (Table 3). These results are similar to those obtained by several authors (König et al., 1994; Tollsten and Müller, 1996; Schuh et al., 1997).

Table 4. Differences in defoliation and foliar element contents of sampled trees between 1995, 1997, and the foliar reference values for *Fagus sylvatica* L.

Element	Units	Foliar concentrations			Reference values
		1995	1997	Variation	
Ca	mg/g	10.6	9.4	1.2 ^a	4.0–8.0
K	mg/g	7.7	7.5	0.2	5.0–10.0
Mg	mg/g	1.9	1.4	0.5	1.0–1.5
N	mg/g	21	22	–1	18.0–25.0
P	mg/g	1.0	1.3	–0.3	1.0–1.7
S	mg/g	2.6	1.7	0.9 ^a	1.3–2.0
Cd	µg/g	0.05	0.04	0.01	< 0.5
Cu	µg/g	5.7	5.6	0.1	6–14
Fe	µg/g	117	101	16 ^a	200–2000
Mn	µg/g	1022	1017	5	1000
Na	µg/g	306	233	73 ^b	< 100
Pb	µg/g	1.2	1.3	–0.1	2–6
Zn	µg/g	23	25	–2	20–80
Def.	%	18.4	17.6	0.8	

^aSignificant at the 95% probability level.

^bSignificant at the 99% probability level.

The statistical analysis of data (Pearson's r test) showed that the mean diurnal variation profile of the monoterpene emission was strongly correlated to light intensity ($r = 0.98$), foliar temperature ($r = 0.86$), transpiration ($r = 0.95$), and photosynthetic activity ($r = 0.97$). Maximum emission rates were recorded around midday.

In order to extrapolate these results, we calculated the standard emission rate of beech trees using Guenther's G2 algorithm. This index suits beech well as it depends simultaneously on radiation and temperature. The standard emission rate calculated for beech was $21.7 \mu\text{g g}^{-1} \text{h}^{-1}$, indicating that this species is a strong emitting isoprene, an organic compound that may play an important role in ozone production.

The chemical composition of the foliage of forest trees is another important indicator for the functioning of trees, especially with respect to nutrition and the influence of air pollutants (Innes, 1993). Our evaluation of beech tree nutrition conditions (Table 4) revealed relatively low contents of Cu and Fe and high levels of Ca and Na (this last due to the proximity of the study stand to the Bay of Biscay). Beech trees showed a good nutritional status for the remaining elements, exhibiting no deficiency symptoms. Although no correlation between defoliation and nutrient contents of leaves has been found, the disturbances detected for several nutrients could be inducing a negative effect on the health of beech trees.

Table 5. Main nutrient ratios of sampled trees and reference values for *Fagus sylvatica* L.

Ratio	Mean values		Reference values (range)
	1995	1997	
S/N	0.12	0.08	0.05–0.11
N/P	20.8	16.9	10.6–25.0
N/K	2.7	2.9	1.8–5.0
N/Ca	2.0	2.3	2.3–6.3
N/Mg	11.0	16.1	12.0–25.0
K/Ca	0.7	0.8	0.6–2.5
K/Mg	4.0	5.4	3.3–10.0
Ca/Mg	5.6	6.7	3.7–8.0

The chemical composition of leaves was very similar in both sampling years. The paired-*t* test showed a significant increase in foliar N contents in 1997, and Ca, S, Fe, and Na concentrations were higher in 1995. Other elements remained constant throughout the two studies. With respect to heavy metals, all analyzed elements were well below toxicity levels.

As the absolute concentration of a particular element is sometimes of little value as an index of nutrition, the relationships between several elements were examined (Table 5). In all cases, ratios were within the reference values cited in the literature (Anonymous, 1997; Mankovska, 1998).

Other factors, such as soil acidification or soil nutrient imbalances, cannot be excluded as contributing factors to forest decline either. The Level II stand soil has the following profile: Ao–Eg–Bt–BC–C–2Crg. Analysis (Table 6) showed high acidity in this soil, even in the weathered marl (2Crg). Except on the superficial horizon (0–8 cm), the soil is pale brown when dry, and brown or yellowish brown when moist.

The soil particle size is very fine, with a clay increase between 20 and 47 cm depth. The soil is associated with clay skins but the illuviation index is much too low to consider that an argilic endopedon (SSSA, 1999) or argic horizon (FAO, ISRIC and ISSS, 1998) exists. The soil is strongly desaturated (less than 30%) despite the contribution of beech leaves and parent material to the bases. According to analytical results, this soil is an *Inceptisol* of the *Udept*, *Dystrudept* great group and *oxyaquix* subgroup because it has mottles due to precipitation of iron and manganese oxides. For the same reasons, it is classified as *Cambisol stagnic dystric* according to WRB.

The main characteristic of Burguete soils is their very high leaching rate because of the large amount of precipitation they receive. Consequently, soils are desaturated in basic cations and have low nutrient contents. As well, temporal anoxic conditions are developed. This fact, together with the high acidity levels of this soil, induces mobilization of Al and Mn, elements that can cause

Table 6. Variations in chemical and physical parameters according to depth of sampled soil

Parameters	Depth (cm)					
	0–8	8–20	20–47	47–65	65–100	> 100
pH H ₂ O	4.1	4.3	4.6	4.8	4.6	4.3
pH KCl	3.7	3.8	3.9	3.9	3.9	3.8
Organic C (%)	12.1	2.7	1.6	1.3	0.9	0.6
Organic matter (%)	20.9	4.6	2.7	2.2	1.6	1.0
N (%)	0.76	0.23	0.15	0.14	0.13	0.09
C/N	16	12	11	9	7	6
CEC (cmol+)/kg	53.9	25.2	23.4	21.7	20.1	21.1
Ca (cmol+)/kg	10.4	5.3	5.8	5.1	4.1	3.8
Mg (cmol+)/kg	2.1	1.1	1.1	1.0	0.8	0.7
K (cmol+)/kg	1.3	0.5	0.5	0.4	0.3	0.2
Na (cmol+)/kg	0.8	0.3	0.2	0.2	0.2	0.1
V (%)	27.1	28.5	32.7	31.0	26.4	22.8
Particle size (%)						
<i>Coarse sand</i>	1.9	2.1	2.5	2.8	2.7	2.1
<i>Fine sand</i>	5.7	6.8	6.5	6.0	5.9	2.5
<i>Coarse silt</i>	9.6	11.4	7.4	10.7	10.1	6.5
<i>Fine silt</i>	38.9	44.3	44.1	42.1	42.1	46.8
<i>Clay</i>	43.9	35.4	39.5	38.4	39.2	42.1

adverse effects on vegetation, especially young trees, that have less developed root systems.

Aside from all the above-mentioned factors, climate and atmospheric deposition also influence the soil solution chemistry and the nutritional status of forests (De Vries, 1996).

The amount of precipitation collected throughout the different sampling years was lower than the historic mean recorded for this area. This was especially true in 1995, when the total amount of precipitation collected did not exceed 721 mm.

This drought period influenced the phytosanitary state of beech trees, an important contributing factor being the high defoliation levels recorded in the 1996 survey. Winter and spring were the seasons with the highest precipitation amounts, summer being the driest period.

Several acid episodes (pH < 5.6) were detected, although acid input was not very high (Fig. 3). Generally, the pH of throughfall was higher than bulk deposition, a fact mainly related to the alkaline effect of Ca within the forest. The most acidic rains were collected in winter, when industrial activity is increased. Otherwise, the highest pH values corresponded to the summer season, when rain is often enriched with airborne alkaline particles.

Whether the input of S and N compounds from the atmosphere causes acidification is strongly influenced by the deposition of accompanying base

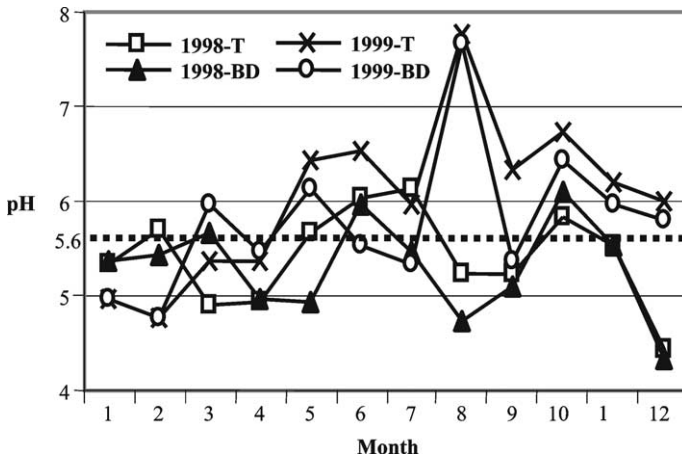


Figure 3. Seasonal variation of pH (throughfall and bulk deposition).

Table 7. Base cation to S + N ratios and acid input in throughfall and bulk deposition

Year	Throughfall		Bulk deposition	
	S + N ratio	Acid input	S + N ratio	Acid input
1997	4.7	37.9	0.2	-7.0
1998	1.1	-1.6	-0.3	-16.6
1999	2.1	11.5	0.5	-9.7
Mean	2.4	13.7	0.2	-11.5

cations. In this way, the relationship between Cl corrected base cation deposition ($\text{Ca} + \text{Mg} + \text{Na} + \text{K} - \text{Cl}$) and the sum of N + S deposition may be used as an indicator of the potential acid input. As displayed in Table 7, the input of corrected base cations in bulk deposition was lower than the S and N input, resulting in a positive acid input. In the case of throughfall, the results were the opposite, that is mainly because of the higher loads of K and Ca in throughfall.

These results partially explain the low pH values of soils found at the beech study site. Within a forest, Ca is the most important base cation, neutralizing the potential acid input from the atmosphere.

As expected, annual throughfall fluxes of elements were higher than in bulk deposition (Table 8), reflecting the effect of canopy interaction. The resulting deposition rates were significantly higher than in northern Europe but similar to those observed in the Mediterranean area. The N input received throughout the sampling years was below $15 \text{ kg ha}^{-1} \text{ yr}^{-1}$, the threshold at which species diversity may be at risk. However, below this value, tree growth may be inhibited. Sulfur inputs were also below critical levels.

Table 8. Annual average throughfall and bulk deposition fluxes ($\text{kg ha}^{-1} \text{yr}^{-1}$)

Year	Throughfall							Bulk deposition						
	Cl^-	NO_3^-	SO_4^{2-}	Na	K	Ca	Mg	Cl^-	NO_3^-	SO_4^{2-}	Na	K	Ca	Mg
1997	17.7	19.9	22.8	13.4	18.9	34.1	2.9	17.9	22.0	21.8	9.8	3.3	9.9	2.0
1998	43.1	29.6	28.0	19.2	17.3	20.3	3.5	37.0	21.6	25.1	17.1	6.3	9.1	2.7
1999	35.0	29.4	26.8	17.0	24.9	16.7	3.6	32.9	26.0	26.0	15.8	3.2	15.6	2.8
Mean	33.1	26.8	26.1	16.9	20.6	22.4	3.4	30.3	23.3	24.5	14.8	4.4	11.7	2.6

Finally, the vegetation assessment within the framework of the intensive monitoring activities at Level II is important for two important reasons. Firstly, vegetation plays a direct role in water or nutrient cycling, and interacts strongly with other biotic components. Secondly, vegetation is a good bioindicator of environmental changes. Thus, the current knowledge of the ecological niche of numerous plant species allows us to deduce changes in underlying environmental factors from vegetation changes.

Results of the flora inventory (Table 9) and the soil pH values of the Level II plot located in Burguete show that this beech forest consists of a mosaic of two different communities: *Saxifraga hirsutae*-*Fagetum sylvaticae* subassociation *luzuletosum pilosae* and *Carici sylvaticae*-*Fagetum sylvaticae* subassociation *isopyretosum thalictroidis*. Future monitoring of vegetation in this beech forest must take this into account.

The greatest flora richness was observed in May or June, when most of the species were in flower or fruiting, and identification was easier. Once the basal flora composition of the beech forest is known, long-term study of vegetation dynamics will provide information about changes due to natural or anthropogenic environmental factors. The best time to conduct the inventories is May or June and, if species vitality is to be studied, sampling frequency should be monthly (twice a month in spring).

4. Conclusions

The main aim of this study was to gain insight into relationships between crown condition, foliar composition, and soil chemistry and various environmental factors, including atmospheric deposition and air pollution.

Beech tree defoliation remained almost constant throughout the various surveys, reaching a maximum in 1996, a year that was preceded by a drought period. Aside from abiotic factors, biotic damaging effects were also noted, especially *R. fagi* L., which was present during all surveys, even before the appearance of leaves. Visible ozone-injury-like symptoms were observed on *F. sylvatica* L. and *V. myrtillus* L. leaves, suggesting that ozone and/or other air

Table 9. Abundance-dominance, phenological stages, degree of vitality and life forms in sampling unit 1

Date of inventory	Oct.	Nov.	Dec.	Mar.	Apr.	May	May	June	July	Aug.	Sep.	Vit.	Life form
Number of inventory	1	2	3	4	5	6	7	8	9	10	11	12	
Tree layer													
<i>Fagus sylvatica</i>	5 ^b	5 ^e	5 ^e	5 ^e	5 ^e	5 ^b	5 ^c	5 ^c	5 ^a	5 ^a	5 ^a	1	Phanerophyte
Shrub layer													
<i>Fagus sylvatica</i>	2 ^d	1 ^e	1 ^e	1 ^e	1 ^e	1 ^d	2 ^d	2 ^d	1 ^d	1 ^d	1 ^d	1	Phanerophyte
<i>Rubus sp.</i>	1 ^b	1 ^b	1 ^b	2 ^b	2 ^b	2 ^b	2 ^b	2 ^c	1 ^c	1 ^a	1 ^a	1	Nanophanerophyte
Herbaceous layer													
<i>Agrostis capillaris</i>	+ ^b	+ ^b	+ ^b	+ ^b	+ ^b	+ ^b	1 ^b	1 ^b	1 ^b	1 ^b	+ ^b	2	Hemicryptophyte
<i>Ajuga reptans</i>	+ ^b	+ ^b	1 ^b	1 ^b	1 ^b	1 ^b	1 ^c	1 ^a	1 ^b	1 ^b	1 ^b	1	Hemicryptophyte
<i>Cardamine pratensis</i>	+ ^b	1 ^b	1 ^b	2 ^b	2 ^c	2 ^c	2 ^c	2 ^a	1 ^a	+ ^b	+ ^b	1	Hemicryptophyte
<i>Carex sylvatica</i>	1 ^b	1 ^b	1 ^b	2 ^b	2 ^b	2 ^c	2 ^c	2 ^a	1 ^a	1 ^b	1 ^b	1	Hemicryptophyte
<i>Circaea lutetiana</i>						+ ^b	+ ^b	+ ^b	+ ^c	+ ^a	+ ^b	1	Hemicryptophyte
<i>Crocus nudiflorus</i>	+ ^c			1 ^b	1 ^b	1 ^b	1 ^b	1 ^c	+ ^c	+ ^a		1	Geophyte
<i>Deschampsia flexuosa</i>			+ ^b	+ ^b	+ ^b	1 ^b	1 ^b	1 ^c	+ ^c	+ ^a	+ ^b	1	Hemicryptophyte
<i>Euphorbia amygdaloides</i>	+ ^b	+ ^b	+ ^b	1 ^b	1 ^c	1 ^c	1 ^c	1 ^c	1 ^a	1 ^b	+ ^b	1	Camephyte
<i>Euphorbia angulata</i>				+ ^b	1 ^b	1 ^c	1 ^c	1 ^a	1 ^b	1 ^b	+ ^b	1	Geophyte
<i>Galium odoratum</i>	3 ^b	3 ^b	3 ^b	3 ^b	3 ^b	3 ^c	3 ^c	3 ^a	3 ^a	3 ^b	3 ^b	1	Geophyte
<i>Geranium robertianum</i>	+ ^b	+ ^b	+ ^b	+ ^b	+ ^b	+ ^b	+ ^b	+ ^a	+ ^a	+ ^b	+ ^b	1	Hemicryptophyte
<i>Helleborus viridis</i>				+ ^b	1 ^b	1 ^b	1 ^b	1 ^b	+ ^b	+ ^b	+ ^b	2	Geophyte
<i>Isopyrum thalictroides</i>				1 ^b	1 ^b	2 ^b	1 ^b	+ ^b				2	Geophyte
Labiate													
<i>Potentilla sterilis</i>	1 ^b	1 ^b	1 ^b	1 ^b	1 ^b	1 ^b	1 ^b	1 ^b	1 ^b	1 ^b	1 ^b	2	Hemicryptophyte
<i>Scrophularia alpestris</i>			+ ^b	+ ^b	+ ^b	1 ^c	1 ^a	1 ^b	+ ^b	+ ^b	+ ^b	1	Hemicryptophyte
<i>Veronica montana</i>				+ ^b	+ ^b	+ ^c	1 ^c	+ ^a	+ ^a			1	Hemicryptophyte
<i>Veronica officinalis</i>	1 ^b	1 ^b	1 ^b	1 ^b	1 ^b	2 ^c	2 ^c	2 ^a	2 ^a	2 ^a	2 ^b	1	Hemicryptophyte
<i>Viola riviniana</i>	2 ^b	1 ^b	1 ^b	1 ^b	2 ^c	2 ^c	2 ^a	2 ^a	2 ^a	2 ^b	2 ^b	1	Hemicryptophyte
Mosses layer													
<i>Atrichum undulatum</i>	+				+	+	+	+	+	+	+		
<i>Dicranum scoparium</i>	+	+	+	+	+			+	+	+	+		
<i>Fissidens exilis</i>			+										
<i>Frullania tamarisci</i>			+					+					
<i>Hypnum cupressiforme</i>	+	+			+	+	+	+	+	+	+		
<i>Isoetes myurum</i>									+	+			
<i>Plagiochila asplenioides</i>						+		+	+	+	+		
<i>Polytrichum formosum</i>	1	1	1	1	1	1	1	1	1	1	1		
<i>Thuidium tamariscinum</i>					+	+	+	+	+	+	+		

^aFruit.

^bVegetative.

^cFlower.

^dSterile.

^eLeaf buds.

pollutants may be an additional damaging factor in this area. The high ozone concentrations recorded during the field work and the detection of several anthropogenic hydrocarbons support this hypothesis.

Chemical composition of beech leaves is clearly related to soil composition. Thus, the high leaching of basic cations of these soils is correlated with the low foliar nutrient contents. Likewise, the high acidity levels of the soil, related to the positive acid input, induce mobilization of Al and Mn, elements that can have adverse effects on vegetation.

We cannot draw any conclusions yet about vegetation dynamics from the vegetation assessment carried out in the Level II plot. However, this is the first step in a long-term study that will provide information about changes in ecosystem variables in future inventories.

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