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Characterising the effects of high ammonia emission on the growth of Norway spruce

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Abstract

This paper studies the effects of high ammonia emissions and nitrogen deposition on tree growth. Wood cores of 125 Norway spruces were analysed along a transect (800 m) from forest edge to forest interior. The forest edge was exposed to a strong ammonia emission source (poultry farm, less than 50 m). Atmospheric nitrogen bulk deposition, ammonia concentration, soil solution concentration, soil nutrient content, foliar N concentration and C/N ratio of the humus layer were measured at five plots along the transect. The tree growth increment of two clusters of trees close to the forest edge and forest interior was compared. The results indicate extremely high nitrogen load at the forest edge. All nitrogen variables show an 'edge effect' with increasing values from forest interior to the forest edge. The growth of nitrogen-influenced spruce trees generally increases. Trees with excessive long-term nitrogen load appear to loose increment after a long-term nitrogen impact. The average gain of increment at the edge appears to be related to the amount of nitrogen emission.

Introduction

Numerous studies have been published investigating the effects of nitrogen deposition on forest ecosystem variables such as soil solution, foliar concentration, N transformation and general nutritional status (as representatives for many individual case studies: Gundersen et al., 1998; Kreutzer et al., 1998). But in fact, very few studies investigated the effects of high nitrogen load on the forest growth over a long time. One reason might be that the subject of forest growth is quite difficult to study as many factors influence the photosynthesis and therefore the tree increment, like stand establishment and stand treatment, site conditions, climate and provenience (Assmann, 1970).

Besides those 'classical' factors, there are also some other environment-related factors with effects on growth development, for example excessive air pollution. Trees grow slowly over a long time period, which makes it difficult to relate effects of fast changing environmental conditions to their growth development. The anthropogenic N_2 fixation doubled since the sixties (Vitousek, 1994), especially after the industrial implementation of the 'Haber-Bosch-technique' (Synthesis of ammonia from N_2 and H_2). Meanwhile, the concept of 'nitrogen saturation' is variously defined (Skeffington and Wilson, 1988). Perhaps the most popular and widely accepted description defines three (Gundersen, 1992; Erisman and De Vries, 1999) or, adding a zero stage of no influence, four stages (Smith, 1974; Bormann, 1982; summarized by Aber et al., 1989). In stage 1, increased deposition occurs, and a fertilization effect might result in increased ecosystem production (Aber et al., 1989). In accordance to

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this concept, some studies reveal growth accelerations, especially for coniferous forests (Binkley and Reid, 1984; Kenk and Fischer, 1988; Binkley and Hoegberg, 1996; Pretzsch and Utschig, 2000). But the same concept predicts negative effects on forest ecosystems, even forest decline with major impacts, if the elevated N input remains constant (Aber et al., 1989; Gundersen, 1992; Erisman and De Vries, 1999). Revealing this, some studies summarise observations of tree damages caused by high ammonia concentrations (Van Haut and Stratmann, 1967; Ewert, 1978; Hunger, 1978; Van der Eerden, 1982; Va, Breemen and Van Dijk, 1988; Hunger, 1989; Hofmann et al., 1990; Däßler, 1991; Van der Eerden and Perez-Soba, 1991). And according to Krauss et al. (1986); Heinsdorf and Krauss (1991) and Schencke (1994) the accumulation of soluble N compounds is or maybe connected with a strong growth decline. But so far there is little data following a long-term observation of the effects of elevated nitrogen deposition onto the growth of one and the same forest stand. However, to reveal the widely accepted concept of nitrogen saturation as described above, it might be useful to follow the development of a spruce stand mirroring the single stages of nitrogen saturation.

In order to investigate the effects of high ammonia concentrations and nitrogen deposition on growth development of a spruce stand (*Picea abies* L. Karst), wood cores of over 120 trees close to poultry housings were analysed. The edge trees are currently known to be influenced by excessive nitrogen deposition and probably have been influenced for over 30 years. Thus, we found a suitable site to study the influence of the ammonia concentration on the increment of the stand along the forest transect. Summarized, the aims of this study were:

1. To estimate and quantify the nitrogen load by measuring ecosystem variables of the nitrogen flux
2. To describe the tree increment at different levels of nitrogen load
3. Using the results of point 2 to answer the following questions: Did the tree increment change since the poultry farm was built? And if so, which level of nitrogen impact results in growth acceleration (stage 1, Aber et al., 1989)? Is there also a level of nitrogen impact detectable at which increment loss occurs (assumable stage 3, Aber et al., 1989)? How many years of constantly high deposition would be necessary to reach this stage?

Material and methods

Experimental and sampling design

The investigation was carried out in a spruce (*Picea abies* L. Karst) stand (89% spruce, 3% beech, and 8% larch, oak and maple) in Pielenhofen (Bavaria, Germany). The geographical coordinates are 49°06′58″ N 11°49′14″ E. The altitude is 450 m a.s.l. The average tree age was 69 years in 1999, and ranged from 50–60 years near the forest edge to 70–90 years in the forest interior. The soil is an Alfisol, a loamy Hapludalf with high base saturation (Table 1, Soil survey staff, 1975). The soil conditions are the same for the whole area except for a small hollow at the end of a slope in the middle of the forest (Spangenberg, 2002). Trees showed higher growth at this area as well. Thus, except for this middle part of the forest transect the site conditions can be described as homogenous.

The site was selected because of its location close to a medium sized poultry farm with approximately 200.000 animals in 1999 (and rather more during the seventies and eighties), including adults for egg production and young chickens. The forest edge of the spruce stand in Pielenhofen is located less than 100 m from the emission source (Figure 1). The farm was founded in 1967. The total annual amount of ammonia emission was estimated for the whole time period since 1967 on the basis of the annual animal stock counting.

Three phases with different amount of emissions could be determined according to LAI (1996) and VROM/NLV-NL (2000), which is in accordance to Van der Eerden et al. (1981): In the establishment phase (from 1967 to 1975) the amount of emission increased slowly from 10 t N year^{-1} to 40 t N year^{-1}, in the production phase (from 1976 to 2000) it increased over two years to a level of 85 t N year^{-1} to 99 t N year^{-1}, for the current phase (since 2001) the level was predicted to be about 58 t N year^{-1} due to the renovation of the buildings (Table 2). A diagram of the N-emission is given in Figure 9.

A transect sampling area from forest edge to interior was installed. Along this line (over 800 m) 125 trees were selected for increment coring. All trees were assigned to classes according to their location within the transect in order to condense the data (Figure 2). e.g. the edge trees belong to class 6.0. The classes close to the forest edge and the emission source (6.0–8.0) were combined to ‘cluster 1’ while classes far from the emission source (classes 9.5 and 10.0)

Table 1. Soil characteristics of a typical profile in Pielenhofen. Soil vegetation consists mainly of: *Oxalis acetosella, Rubus idaeus, Rubus fruticosus, Dryopteris carthusiana, Moehringia trinervia, Urtica dioica*

horizon	depth [cm]	clay [%]	sand [%]	silt [%]	C/N ratio	pH (KCl)	pH (H_2O)	CEC_e [μmol g^{-1} soil IE]	Sat[%]		
									Ca	Mg	K
Ah	−3	–	–	–	23.0	3.08	4.03	285.0	69.3	11.8	3.5
Al	−13	24.2	21.6	54.2	17.4	2.83	3.55	88.3	6.6	2.7	1.6
Bt	−20	32.3	20.6	47.1	13.4	3.26	4.31	97.2	43.4	14.4	2.33
IIT	−35	61.1	12.4	26.5	10.3	4.46	5.7	235.7	71.5	25.6	2.42
CvT	>35	67.5	10.3	22.2	9.9	4.51	5.9	251.3	75.3	29.7	2.59

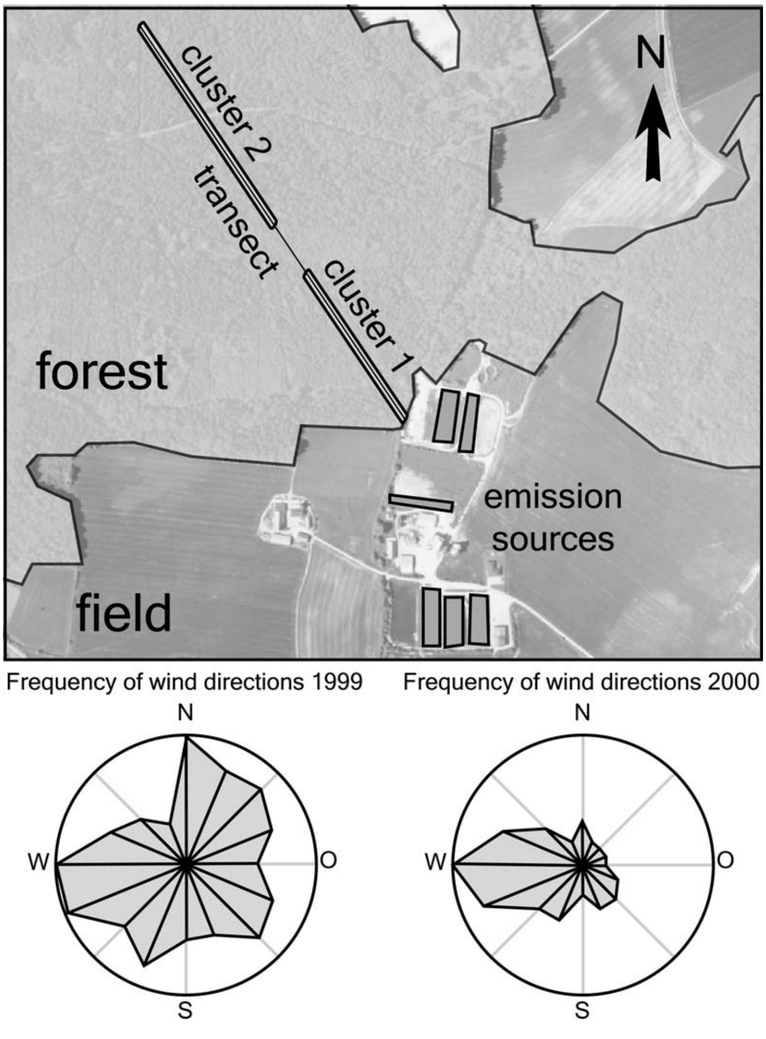

Figure 1. Aerial shot of the forest stand and the emission source. The transect reaches from forest edge to interior – the clusters have been sketched (compare Figure 2). The distances of the six poultry houses to the forest edge range from 20 m to about 300 m. Frequencies of wind directions of 1999 (complete year) and 2000 (January to July) of the Pielenhofen site are shown.

Table 2. Estimated amount of ammonia emission in the phases of the emission source according to emission factors (Source: LAI 1996, VROM/NLV-NL 2000)

Phase	Time period	Ammonia emission [1000 kg N year^{-1}]
Establish	1967–1968	10.6 - 13.1
	1969–1975	40.6
Production	1976–1977	68.5
	1977–1988	96.2–98.9
	1989–2000	85.7–88.3
Current	Since 2001 (prognosis)	58.0

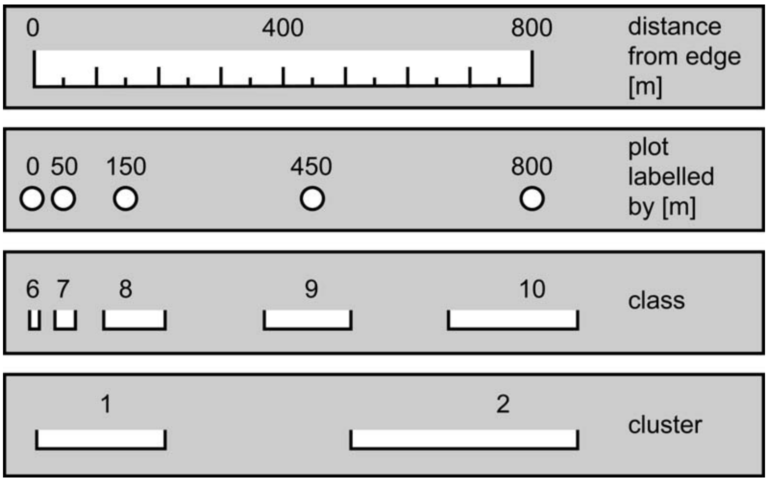

Figure 2. Experimental design and grouping of the sampling area. The transect reached from forest edge (0 m) to forest interior (800 m). Five measurement plots were placed along the transect. The trees along the transect were grouped into classes 6.0 to 10.0 (the non-integral classes have been omitted for better readability). Two clusters of trees were selected for increment-trend analysis.

were merged to ‘cluster 2’ (Figure 2). The classes 8.5 and 9.0 were removed later because of thinning during the seventies which resulted in a strong growth change of the remaining trees (Spangenberg, 2002) and due to the different soil conditions in the middle as described above.

A simple growth comparison between ‘cluster 1’ (strong nitrogen impact) and ‘cluster 2’ (less nitrogen impact by emission) was not valid due to the age structure of the stand. Thus, the ‘increment-trend method’ (Pretzch and Utschig, 1989; pp. 189ff, Chapter 2.2) was used to avoid implications of age on the main aim of the study.

Five measuring plots were installed along the transect sampling area in order to determine the nitrogen impact. They were placed at the forest edge, in 50 m, 150 m, about 450 and 800 m distance to the forest edge (Figure 2). Bulk deposition was measured as well as soil solution concentration, foliar concentration of the needles and C/N ratio of the humus layer. As the main focus of this publication lies on the nitrogen cycle only the related factors are referred to. Ammonia concentration in the air was determined using a passive sampler technique (Kirchner et al., 1999) and bark bio-monitoring (Spangenberg et al., 2002). For financial reasons ammonia was only measured at the forest edge, in 50 m and 450 m distance to the edge.

Field sampling and analysis of nitrogen variables

The ammonia concentration was determined at three plots (edge, 50 m and 450 m distance to forest edge) by diffusive samplers, which provided a good tool to measure ammonia concentration in high spatial resolution. We chose a diffusive sampler developed at the Institute of Balneology in Munich. The sampler was tested in an international field inter-comparison (Kirchner et al., 1999). It is a ventilated sampler, which contains an impregnated filter (sulphuric acid). The analysis of ammonia was done using the Berthelot reaction. The sampler yielded good results at exposition intervals of 1, 2 or 4 weeks. The detection limit was 0.05 μg/m^3 for an exposition interval of 1 week (Kirchner et al., 1999). Our sampling intervals ranged from fortnightly to monthly; altogether more than one year of measurements were analysed. Results were successfully compared to tree bark samples taken at the same locations (Spangenberg et al., 2002).

Two diffusive samplers were installed at each plot of the forest transect, one in about 1.5 m height and one in the tree crowns, about 20 m above ground. The mean value was used. Measurements were taken mainly throughout 1999 and continued until May 2000. Samples were usually taken every two weeks.

Bulk deposition was determined by sampling and analysing the throughfall beneath the tree canopy. This is the most convenient method for measuring both the dry and the wet deposition. The throughfall was collected at each plot using two plastic gutter installations (10 m length of each gutter, 20 m altogether) according to the description given in DVWK (1984). The gutters covered gaps in the throughfall as well as strong branches and dense areas of the tree crowns. Altogether 10 gutter installations with big tanks for rainfall collection were set up at the whole site. The samples were protected from direct sun light to avoid chemical reactions of nitrogen as much as possible. Sampling period extended from July 1999 to July 2000. Samples were taken fortnightly or monthly, depending on rainfall intensity. They were stored cold prior to analysis. Additionally, total volume of throughfall was determined in order to estimate element fluxes.

Water samples were analysed for concentrations of NO_3^-, NH_4^+, N_{tot}, $SO4^{2-}$, $PO4^{2-}$, Cl^-, Ca^{2+}, Mg^{2+}, K^+ and Na^+ (compare Spangenberg and Kölling, 2003), but only concentrations of $NO3^-$, $NH4^+$ and N_{tot} are presented in this paper. The element analyses were carried out using standard methods at the central laboratory of the Bavarian State Institute of Forestry in Freising. Concentrations of cations, sulphate (as total S) and phosphate (as total P) were determined using the inductive-coupled plasma atomic emission spectroscope technique (ICP-AES, Perkin Elmer, Optima 3000). Nitrate, ammonium and chloride concentrations were analysed either by Continuous Flow Analyser with photometrical detection (Skalar) or by Ion Chromatography (with conductivity detection after suppression, Dionex DX 80 and DX 120).

Five humus layer samples were taken at each plot (altogether 25 samples) using steel frames of 400 cm^2. Analyses of C and N were done using an Elemental Analyser with thermal combustion (Elementar Vario EL 3). Foliar N concentrations were taken from three trees at each plot (age classes 7.1–7.3) and were analysed as well using an Elemental Analyser (CHN 1000, Fa. LECO). All described analysis methods and quality control were ensured following the procedures of United Nations Economic Commission for Europe (1998).

Nitrate concentration in soil solution was extracted in about 100 cm soil depth below the main rooting zone. Samples were extracted with ceramic suction cups (P80 cups, UMS, Munich) using three cups per plot, altogether 15 cups were installed. Detailed descriptions are provided in Spangenberg and Kölling (2003).

Field sampling and analysis of increment cores

Increment cores are a well-developed tool to evaluate such tree characteristics as age, rate of growth, percentage of various types of tissue, chemical composition, and density (EPA, 1994). Furthermore, it is a suitable tool to investigate influences of environmental factors such as air pollution (Innes and Cook, 1989; Pretzsch and Utschig, 1989). All trees belonged to stem class 1 or 2 (according to Kraft, 1884). This is standard procedure and means, only the trees, which were not suppressed by other trees, were selected for sampling. Two wood cores – from opposite direction – were taken using a hand corer from every stem at DBH (diameter at breast height, about 4.5 feet above ground). Samples were taken if the wood center was hit, e.g. if the core reached from inner to outer wood parts and a wide range of density was covered. Additionally, sometimes a third core was taken to ensure existence of two valid cores per tree. Altogether over 280 wood cores were taken.

The annual diameter increment was determined on the basis of the wood cores using a digital positioning table (Kutschenreiter and Johann, Digitalpositiometer, Biritz and Hatzl, Wien). Computer programs by TSAP (Time Series Analysis and Presentation, Frank Rinn, Heidelberg, Germany) was used to determine chronology in a standardized way. Ring widths were assigned to years using TSAP's standard crossdating techniques. Crossdating correlates time series with others to determine optimal match position (Sheppard et al., 1988) – for this study known dry years were used, such as 1976 and 1992. Before any other statistical evaluation mean values were determined of the two opposite wood cores from each stem to create increment data of 125 trees. The main part of the statistical evaluation was done using SAS (Statistical Analysis System, SAS Institute Inc., Carey, USA).

Theory of the increment-trend method

The 'increment-trend method' by Pretzsch and Utschig (1989) was developed to judge the increment of spruce and pine trees in different forest decline regions of Bavaria. Initially, the increment of damaged trees is compared to the reference development of undamaged trees or slightly damaged trees. As the level of increment is not *a priori* identical between the different trees, first a reference period in time is selected, where the increments are ideally not affected by the damaging factor and where they evolve mostly in parallel. For both classes, the increment is expressed as relative values to the mean increment during the reference period (equation (a_1) and (a_2)). From these 'normalized' increments, the increment loss is determined using equation (b).

$$f_1 = \frac{\Delta g_1}{\Delta g_1} \tag{a1}$$

$$f_2 = \frac{\Delta g_2}{\Delta g_2} \tag{a2}$$

$$f_{loss} = \left(1 - \frac{f_1}{f_2}\right) \tag{b}$$

f_1 = *Increment factor of cluster 1 (forest edge)*
f_2 = *Increment factor of cluster 2 (forest interior)*
Δg_1 = *Basal area increment of cluster 1*
Δg_2 = *Basal area increment of cluster 2*
$\overline{\Delta g_1}$ = *mean basal area increment of cluster 1 in reference period*
$\overline{\Delta g_2}$ = *mean basal area increment of cluster 2 in reference period*
f_{loss} = *Increment loss factor*

Results and discussion

Ammonia concentrations and nitrogen deposition

The results of the diffusive samplers are shown in Figure 3. Each bar represents the average ammonia concentration in μg/m^3 of ground and crown samplers at each plot. Differences between ground and crown were not high, the trend from edge to interior was identical (Spangenberg, 2002). In most cases ammonia concentration above the forest was slightly higher than inside the forest close to the ground, but a reasonable vertical stratification could not be found (Spangenberg et al., 2002). Average ammonia concentrations range from 5 to 25 μg/m^3. Concentrations up to 30 μg/m^3 were measured outside the forest (not shown). The data shows a remarkable decrease of ammonia concentration with increasing distance from forest edge to forest interior, similar to atmospheric N deposition (Spangenberg et al., 2002). It is well known that ammonia concentration is strongly dependent on the distance to the source, because the molecules usually do not remain in the atmosphere for more than several hours or few days (Asman, 1994). But long transport is possible for example in the form of ammonium (Flaig and Mohr, 1996).

Meteorological monitoring of the wind frequency shows, that western to south-western directions prevailed during the sampling period (Figure 1). The forest edge in Pielenhofen is more south exposed while the wind blew mainly from west (Figure 1). Thus, it is possible that a significant part of the ammonia concentration is blown away from the forest during wind activity.

The ammonia concentrations in Germany ranges from approximately 1 μg/m^3 in ammonia unloaded areas to 15 μg/m^3 in highly ammonia loaded areas characterised by agricultural systems (www.umweltministerium.bayern.de/service/umwberat/; Ibrom et al., 1994). According to KRdL (1992) a region can be characterised as nitrogen loaded when about 12 μg/m^3 are reached. As it is usually cost-intensive to measure ammonia concentrations, not many studies exist, and even less have measured the ammonia concentrations within forest stands.

The nitrogen deposition data are presented in Figure 3 as average values for the whole sampling period (July 1999–July 2000). The deposition is divided into nitrate, ammonium and total nitrogen. The total nitrogen deposition is very high with almost 90 kg/ha/year at the edge in Pielenhofen. This is due to the high ammonia emissions from the poultry houses. Comparably high values were reported for example by Lamersdorf and Meyer (1993) in northern Germany, by Mulder (1985) in the Netherlands or by Påhlsson and Bergkvist (1995) in Sweden.

The pattern of the deposition data is very similar to that of the ammonia concentration. The site shows an 'edge effect' with high bulk deposition at the edge

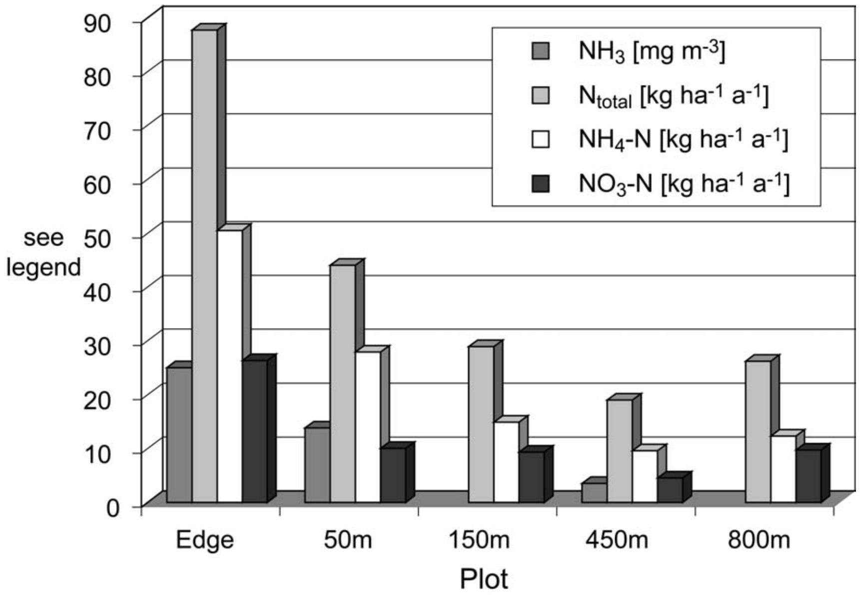

Figure 3. Nitrogen load at the five plots. Ammonia concentration [μg m^{-3}] and nitrogen deposition [kg ha^{-1} year^{-1}] of all plots along the forest transect at the Pielenhofen site. Axis of ordinates shows values in units of [μg m^{-3}] and [kg ha^{-1} year^{-1}], respectively (see legend). Ammonia concentration was not measured at 150 m and 800 m.

and decreasing N deposition with increasing distance from the edge. This applies to other sites in Southern Bavaria and other investigated ions (Spangenberg and Kölling, 2003). The edge effect usually disappears between 100 and 150 m distance to the edge. The ratio ‘forest edge : 50 m’ is often used to describe the shape of the forest edge effect. The ratio of the presented data ranges from 2.0 (N_{tot}), 2.6 (NO_3-N) to 1.8 (NH_4-N). In comparison, Hasselrot and Grennfelt (1987) even found a ratio of 2.7 (NH_4-N) and 2.9 (NO_3-N).

Additional nitrogen variables can be found in Table 3 (Spangenberg, 2002). All variables reveal the extremely high nitrogen load. Nitrate concentration time series of the soil solution never reached values lower than 100 mg l^{-1} over a time period of more than 12 months at the edge. There, estimated nitrogen budgets are almost balanced, which means that the nitrate outflow is almost as high as the total nitrogen input (Spangenberg and Kölling, 2003). Foliar analysis showed high N contents of over 1.7% (Table 3), within the range of N excess (Wilson, 1991; BMELF, 1997; Spangenberg, 2002). Thus, the forest ecosystem may be characterized as ‘saturated’ at the edge in comparison to standards or, in accordance to Aber et al. (1989) as being in stage 2.

Increment analysis

Due to the age structure of the stand a formal statistical comparison of tree populations did not seem appropriate. We decided to restrict ourself to descriptive statistics using a representative curve for each population of trees. For the initial description of growth variables by class, the median of the population was used for stability against single-tree behaviour.

Figure 4 presents the DBH increment since 1960. The time frame was chosen because the stand composition did not change since 1960. For better readability two years have been averaged into one point in the plot. The DBH shows an increase in the eighties for classes 6.0 to 8.0 (close to edge) – a maximum is reached. Classes 9.5 and 10.0 remain mostly on the same level. The generally expected trend of decreasing growth rates at increasing age is missing. Annual changes mainly induced by climate are strong, e.g. the DBH increment of all trees dropped during the summer draughts in 1976 and 1992.

Figure 5 shows the basal area increment since 1960. Compared to the DBH increment, the basal area increment increased strongly until the end of the eighties. For better readability two years have been averaged into one point in the plot. Considering the age of the trees, the point of culmination was reached very late. The basal area increment of spruce usually has a

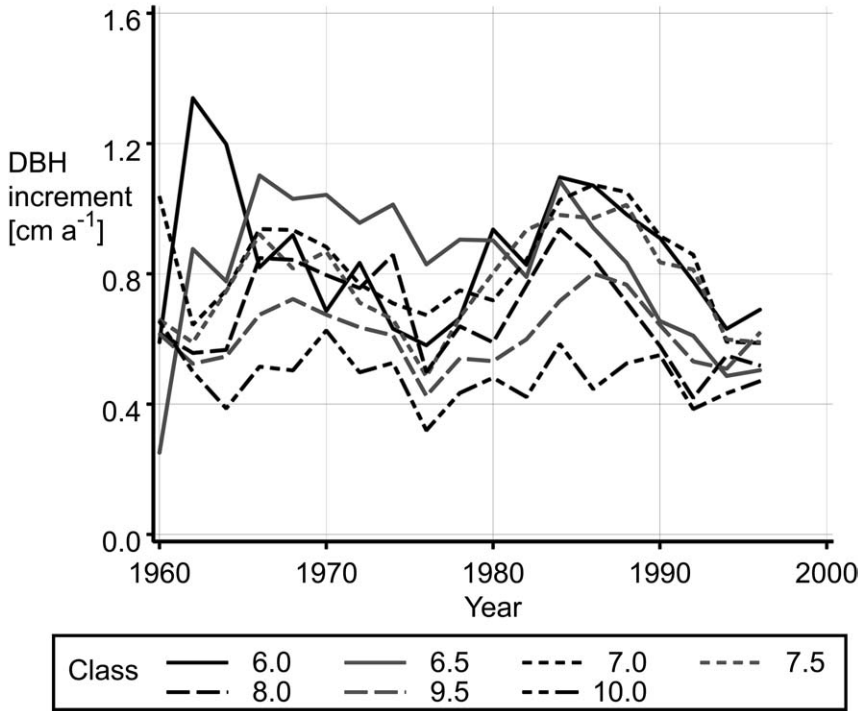

Figure 4. Median of annual DBH increment [mm year^{-1}] by class for classes 6.0–8.0 and 9.5–10.0. The time frame from 1960 to 2000 was selected because stand composition did not change since 1960. For better readability two years have been averaged into one point in the plot.

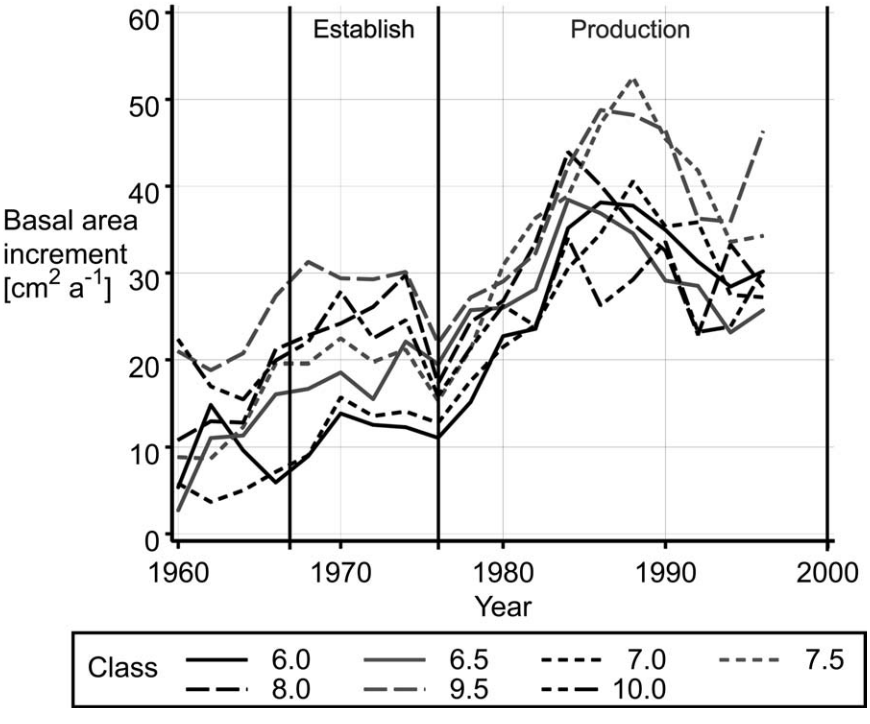

Figure 5. Median of annual basal area increment [cm^{2} year^{-1}] by class for classes 6.0–8.0 and 9.5–10.0. The vertical bars mark the phases of the emission source. For better readability two years have been averaged into one point in the plot.

Table 3. Further ecosystem variables describing the nitrogen cycle. C/N ratio is a mean of five samples per plot; foliar N concentrations and nitrate concentrations of the soil solution are mean values of three samples per plot, respectively

Distance to the forest edge (plot)	C/N ratio (humus)	Foliar N concentration [%]	Nitrate conc. in soil solution [mg l^{-1}]
Edge	19.3	1.85	176
50 m	21.5	2.92	168
150 m	22.9	2.05	85
450 m	23.2	1.75	77
800 m	26.3	1.92	69

climax at age 20 to 30 and the phase of culmination is shorter (Assmann, 1970). An overview of spruce growth in Bavaria is given by Pretzsch and Utschig (2000). Differences between the forest edge and the forest interior are remarkable within the classes.

Figure 6 shows the cumulative basal area growth since 1960. The classes 9.5 and 10.0 contain the older trees, thus having different starting positions than the rest in 1960. Independent of age in 1960 the trees right at the edge (6.0–7.0) have a different shape, as already seen in Figure 5. After the late 1980s, the basal area increment falls visibly – especially for class 6.5.

Further information on growth under nitrogen influence can be derived from Figure 7, which presents the basal area increment in dependency of the tree age for different decades. The basal area increment increased for most age classes from 1960 to 1980. Trees that were 30 years old in 1960 grew worse than 30 years old trees in 1970 probably due to the fertilizing effect of nitrogen deposition. This is confirmed by Pretzsch and Utschig (2000) and Kenk and Fischer (1988). On the other hand, older trees at the age of 55 grew worse during the nineties than during the seventies and eighties. In order to find out whether the nitrogen impact is related to this development, the 'increment-trend method' was applied to the data and the results are compared with the emission development.

Increment-trend method

This 'increment-trend method' was used to compare cluster 1 (near to edge, high nitrogen load) and cluster 2 (far from edge, less nitrogen load) whose main differences are nitrogen exposition and tree age. Direct comparison would have been difficult due to the tree age distribution. The reference period 1965–1975 was selected, as during this time the emission source was still being established, the amount of emission had not reached production level, and the change of basal area increment appeared sufficiently parallel. One aim was to select a valid period as late as possible to minimize the relative age difference. Mean values were estimated as references for both clusters at this time interval (Figure 8). The basal area increment was expressed, respectively for both collectives, as a percentage of the reference value. Then the increment loss factor was calculated (see equation (b)).

Figure 9 presents the result of the computation together with the amount of emission (compare Table 2). The increment loss factor is negative for the production phase – the more exposed population did grow better than the reference population. Additionally a parallel development of emission and increment loss factor is noticeable. A correlation plot (not shown) emphasized this impression, however the data seemed unsuitable for formal statistical correlation analysis.

At the end of the production phase, the increment gain tends downwards. Initially, this was unexpected, as a linear influence of the influencing factor 'nitrogen load' also could have ensured a continuously higher or continuously lower increment. A plausible explanation for this effect is, that the exposed trees left stage 1 and entered stage 2 (according to Aber et al., 1989). According to Heinsdorf and Krauss (1991) forest damage and reduced increment is expected after long-term nitrogen load. Schenke (1994) points out as well that loss of increment and crown damages due to high nitrogen load caused by animal livestock can be encountered. Thus, it may be that the exposed trees start to show the first signs of reduced increment due to the still elevated nitrogen load. Further investigation of this site would be desirable to test whether this trend continues, even if the amount of emission of the

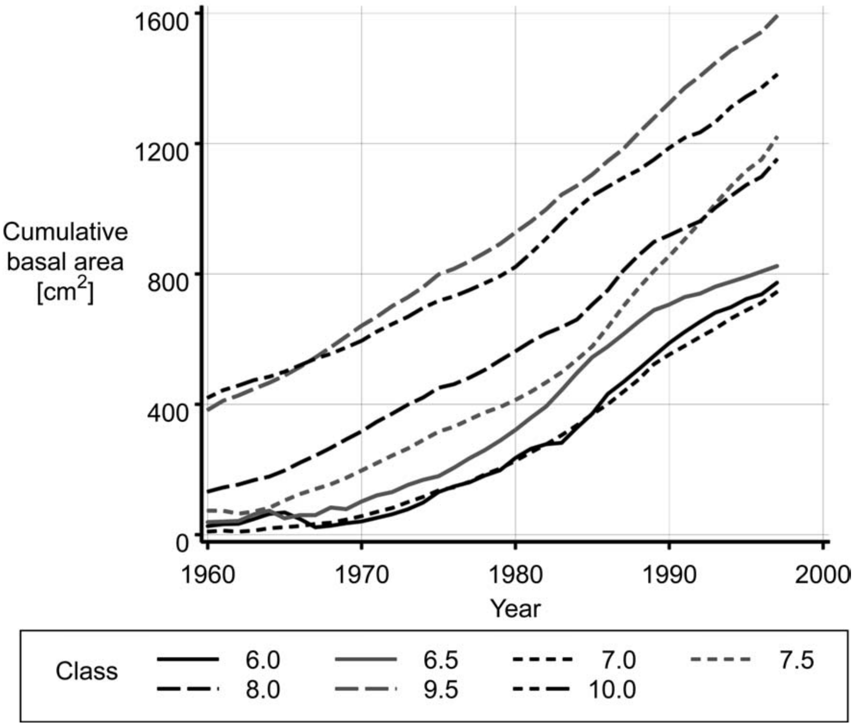

Figure 6. Median of cumulative basal area [cm^2] by class.

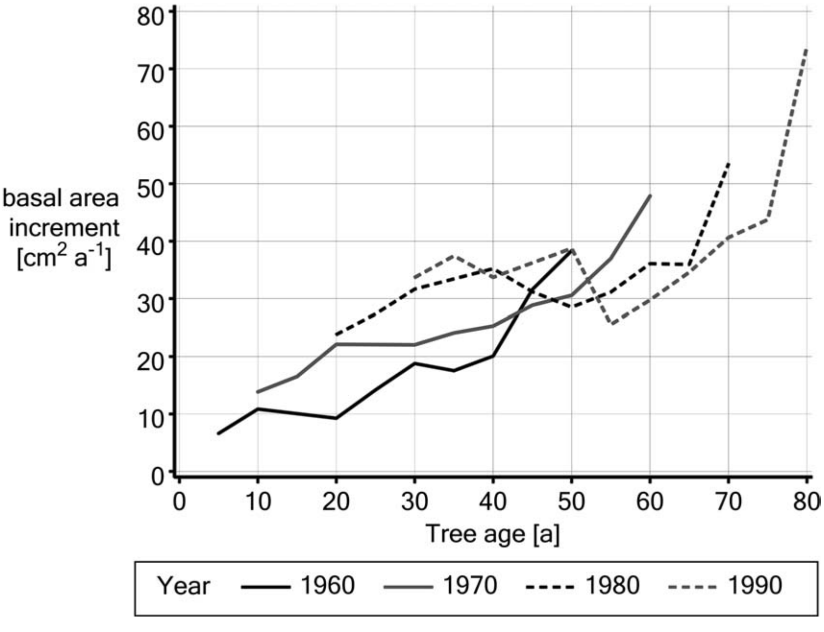

Figure 7. Annual basal area increment [cm^2 year^{-1}] in dependence of the tree age by decade.

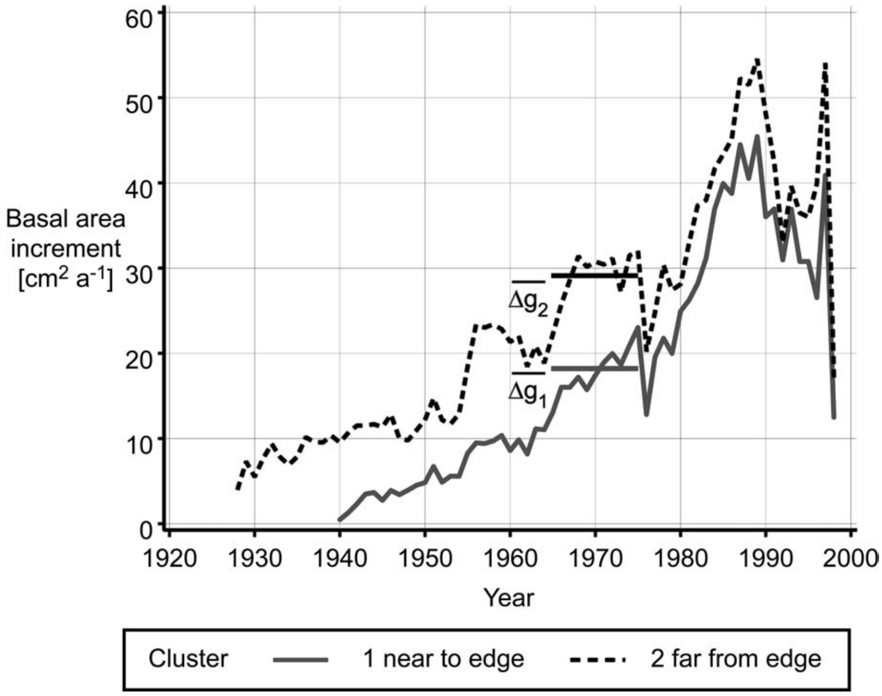

Figure 8. Basal area increment [cm^2 year^{-1}] by cluster – first step of the 'increment-trend method'. The reference periods (from 1965 to 1975) are marked.

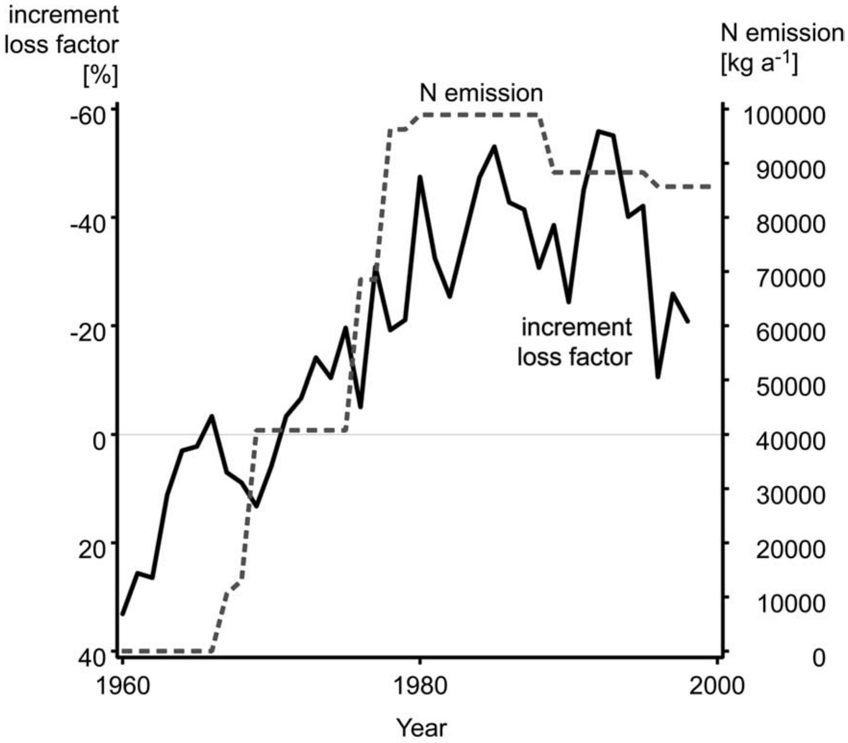

Figure 9. Nitrogen emission ([kg year^{-1}]) and increment loss factors ([%]) determined by the 'increment-trend method'. The reference line indicates the state of no increment loss, where both clusters show equivalent growth.

poultry farm is expected to be drastically reduced in the next years.

Conclusion

Generally higher increments are noticeable at the exposed parts of the site in Pielenhofen, probably due to the excessive nitrogen impact. The increment increased since the 1960s, but during the nineties a decrease is observable at least for the trees close to emission source. The increment loss factor appears negatively related to the nitrogen emission. Current knowledge of nitrogen impact to forest ecosystems assumes that trees first enter an accumulation phase, then a saturation phase and at last a forest damage phase. As the emission development at Pielenhofen is known, it can be summarized, that a continuous N_{tot} deposition of almost 90 kg ha^{-1} $year^{-1}$ over 20 years results in nitrogen saturation and appears to lead to increment losses, at least at this site. This is remarkable because of the proven high soil nutrient stock providing a good base saturation at the site. The better the base saturation the less impact on the forest trees due to nitrogen saturation is expected. However, Pielenhofen is one of the rare sites where the theory of effects of nitrogen impact was tried to be applied to real data. Unfortunately the results of the evaluation did not lead to statements with statistical proof due to the age structure of the stand.

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