Forest Biota under Changing Concentration in Acidifying Compounds in the Air and Their Deposition

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Abstract

Effects of acid deposition on forest ecosystems despite a drastic decrease in sulphur emission and deposition at the end of the 1990s are still among the most significant ecological issues. The key reason for this is that atmospheric concentrations of ammonium and nitrate which have a tendency to increase in the last period became the main acidifying compounds of precipitation. These changes in acid deposition resulted in main objectives of the presented study which were to estimate the effect of rain acidity and atmospheric deposition of pollutants on crown defoliation and diversity of soil microarthropods, stream macrobenthos and small mammals (rodents) on territories under changing regional pollution level. Investigation was carried out in 3 Lithuanian Integrated Monitoring Stations over the period 1994-2004. The obtained data indicated that lower life forms were more affected than higher. Acid deposition was shown to have the most significant effect on pine tree defoliation as well as on the diversity of soil microarthropods and diversity of stream macroinvertebrates and least on the diversity of small mammals. These results have indicated that regional pollution level which is below the critical level for forest ecosystem has a significant effect on the biota.

Key words: acid deposition, crown defoliation, small mammals, soil microathropodes, stream macroinvertebrates, correlation analysis.

Introduction

Convention on Long-Range Transboundary Air Pollution has been one of the main ways of protecting the environment in Europe and North America from air pollution. A considerable decrease in sulphur emissions was a prime example of what can be achieved through intergovernmental cooperation (Bull *et al.* 2001). Acid rain was among the most relevant environmental stresses resulting in negative changes in forest ecosystems. Therefore it seems that the problem of acid rain has already been solved. Nonetheless, investigation of study sites demonstrates that even after complete implementation of the Gothenburg Protocol and other current legislation, acidification with commensurate adverse biological effects will remain a significant problem in Europe as well as in the USA and Canada (Wright *et al.* 2005). To date, it is necessary to see what further measures are needed to understand and estimate the effect of the changing environment on the biota. There are large uncertainties concerning the response of European forest ecosystems to reduced acid deposition (Falkengren-Grerup *et al*. 2002). At what level of acid deposition can we expect recovery of the ecosystems, especially their biological components (diversity and abundance)? What is the effect of different forms of nitrogen deposition (NHx and NOy)?

Activities of International Co-operative Programme on Integrated Monitoring of Air Pollution Effects provide for extended data on these issues and may be one of the ways of advancing our knowledge on recovery and functioning of the forest ecosystems under changing environment. Data obtained in Integrated Monitoring Stations (IMS) could revise the critical load of acid deposition not only for trees but also for such representatives of the biota as soil micro arthropods, stream macro benthos and small rodents. Therefore, in this study investigating "stress – effect" relationship in forest ecosystems the main attention was paid to the changes in atmospheric deposition fluxes as well as their effect on different components of the biota, to the aim to answer the question whether pollution which is markedly lower than the critical level for forest ecosystem can result in changes in the biota.

Method and materials

The investigation was carried out in 3 Lithuanian Integrated Monitoring Stations (IMS) established in Aukstaitija, Dzukija (1993) and Zemaitija (1994) National Parks (NP) and representing three different landscape types of Lithuania: Aukstaitija IMS – in East, Dzukija IMS – in the South and Zemaitija – in the West of the country. In 2000 Dzukija IM Station was closed due to underfinancing and estimation of the pollution level was stopped. Therefore to pursue the objectives of the presented study only the data on pollution and biota over the period from 1994 to 1999 were used from this IM station.

Climate in Aukstaitija IMS is characterised as average cold with high humidity and abundant precipitation. Annual mean air temperature is 5.8˚C, mean annual precipitation amount – 682 mm. Length of vegetation period – 189 days.

Glacioaquatic accumulation forms with sand, gravel and stones are typical of Aukstaitija IMS (LT-01) catchment which with the decrease of altitude transfers into fliuvioglacial terrace delta plain with fine sand, and at the source- into marsh accumulation forms with organic sediments. Multi-aged and multi-layered mature and over mature pine and spruce stands on haplic arenosol, passing at lower places into albic and gleyic arenosol and into histosol (eutrophic deep peat soil) prevail in LT-01 catchment.

Climate in Dzukija IMS (LT-02) is very similar to the one in Aukstaitija IMS. Annual mean air temperature is 6.0˚C, mean annual amount of precipitation - 625 mm. The length of vegetation period is 195 days.

The geomorphologic structure of LT-02 catchment is formed by more intensive glacioaquatic and in addition eolian processes than in LT-01. Relief represents a re-modified fliuvioglacial plain, with clearly defined continental dunes of complicated shapes, where fine-grain sand dominates. Soils are formed on quartz sands of eolian origin and contain no carbonates. Forest specific diversity is much poorer than in Aukstaitija IMS. Premature and mature pure pine stands on the haplic arenosol, transfering into albic arenosol dominate in the catchment.

Zemaitija IMS (LT-03) is situated at 50 km distance from the Baltic Sea, which generally defines the climatic conditions of this territory. The mean air temperature is 5.9˚C, the amount of precipitation reaches up to 788 mm and is significantly higher than in other stations. The length of vegetation period is 187 days.

The geomorphologic structure of the catchment is different from that in other locations. In LT-03 the marsh accumulation forms with organic sediments transfer into limnoglacial accumulative forms and glacioaquatic accumulative sandy hilly formations with typical limnoglacial sand. Spruce forest with two or more age classes and with up to a 20-30% pine mixture on albic arenosol transfering to gleyic arenosol and various histosols (eutrophic shallow and deep and distrophic peat soil) dominates in Zemaitija IMS.

Crown condition of about 1000 trees (pine trees – 20%, spruce – 70% and birch – 10%) was assessed according to the methodology of ICP Forest monitoring programme over the period 1994-2004 (UN-ECE 1994) on 50 permanent observation plots (POP) in LT-01; of about 1200 trees (pine trees – 90%, spruce and birch – 10%) on 58 POP in LT-02 and of about 600 trees (pine trees – 10%, spruce – 85% and birch – 5%) on 37 POP in LT-03.

The diversity and abundance of soil microarthropods was investigated in autumn annually on prevailing forest type of catchments: in Aukstaitija IMS in haplic arenosol of mixed pine-spruce overmatured stand, in Zemaitija IMS in albic arenosol of premature spruce stand and in Dzukija IMS in haplic arenosol of pure premature pine stand.

Small rodents were investigated in bilberry pine-spruce forest and nemoral bog spruce wood in Aukstaitija IMS, in cowberry pine forests and pasture in LT-02 and in suboceanic bilberry spruce forest and pasture in LT-03. Small mammals in each IMS were caught by 150 snap traps over 3 day period. Specific diversity of small mammals community assessed by number of species (unit.), while abundance - by total number of caught small mammals (ind. per ha).

Investigation of stream macroinvertebrate diversity, abundance and biomass was carried out annually in May and October months in streams of IMS over 1994-2004. The bed of LT-02 and LT-03, where investigations were carried out consists of sand, gravel and pebble while the bed of LT-01 – of sand and peat.

Investigation of the abundance and diversity of the mentioned components of the biota was carried out according to the Manual for Integrated Monitoring (UN-ECE, 1993).

Sulphur dioxide (SO_2), sulphates (SO_4^{2-}), sum of nitrate ($\Sigma NO_3^- = NO_3^- + HNO_3$) and sum of ammonium ($\Sigma NH_4^+ = NH_4^+ + NH_3$) concentration in the air and SO_4^{2-}, NO_3^-, NH_4^+, hydrogen (H^+) ion and major base cation (Na^+, K^+, Ca^{2+}) concentration in precipitation as well as their wet deposition were estimated in IMS over 1994-2004.

The air sampling was carried out at weekly intervals. The sampling equipment for SO_2 and particulate sulphate collection consisted of a two-stage filter pack sampler with a cellulose filter (Whatman 40). SO_2 was collected by retention of particles using potassium hydroxide (KOH) impregnated Whatman 40 filter. ΣNO_3^- and ΣNH_4^+ were collected using an open-face separate samplers with an alkaline (KOH) and oxalic acid impregnated Whatman 40 filters, respectively.

Precipitation samples were collected weekly in a polyethylene bulk-collector from December to March and in an automatic wet-only sampler during the remaining months. All samples were stored at 4^0 C until laboratory analysis.

Ion chromatography using Dionex 2010i with conductivity detection was used for the chemical analysis of anions in precipitation and in water extracts from the impregnated Whatman 40 filters. NH_4^+ concentration in precipitation as well in the extraction solutions from oxalic acid impregnated Whatman 40 filters was analysed spectrophotometrically using the indophenol blue method. Precipitation pH and electric conductivity were determined with a pH glass electrode and an electric conductance meter, respectively.

The overall measurement and analytical procedures were based on a quality assurance/quality control (QA/QC) programme as described in the EMEP CCC manual for sampling, chemical analysis and quality assessment (EMEP 1997). Analytical methods were controlled through the international (EMEP and GAW) analytical intercomparisons.

For selection and chemical analysis of soil water lizimeters (plate type, surface area 625–1000 cm²) were installed on prevailing forest type of each catchment. Water samples were collected from two layers: at 10-20 cm (main root zone) and 30-50 cm (below main root zone) depth, installing 3 collectors in each layer; sampling period 3–4 times per vegetation period.

Fisher test was used for estimating significance of spatial and temporal differences in changes of pollution among IMS; multiple regression analysis was used to estimate main acidifying compounds resulting in changes in precipitation pH over the different periods; linear, Spearman and partial correlation analysis - to derive relationships between the biological parameters and acid deposition within the IMS as well as among IMS by using techniques of "Statistica 6.0" software.

Results

Rain acidity and atmospheric deposition fluxes. Results on the main acidifying compounds obtained in IMS indicated a significant decrease in pollutants until 2000. Mean annual SO_2 concentration in the air of Aukstaitija IMS (LT-01) decreased by 82% (from 2.76 to 0.49 μgS/m³) in Zemaitija IMS (LT-03) by 79 % (from 2.22 to 0.47 μgS/m³), in Dzukija IMS (LT-02) by 63 % (from 2.30 to 0.84 μgS/m³ in 1999). From this year onwards some increase in the concentration was recorded (Fig. 1). However, in 2004 SO_2 concentration decreased again to 0.51 μgS/m³ in LT-03 and 0.55 μgS/m³ in LT-01.

The most significant decrease in nitrogen compounds in the air lasted until 2001. ΣNH_4^+ concentration in the air in LT-03 decreased by 86% (from 8.55 to 1.15 μgN/m³), in LT-01 – 77% (from 4.44 to 1.02 μgN/m³) and in LT-02 – 65% (from 3.91 to 1.37 μgN/m³). However, a slight increase in the concentration was registered in 2002-2003 and only in 2004 ΣNH_4^+ concentration in the air dropped to 1.1 μgN/m³ in LT-01 and LT-03.

Only annual means of ΣNO_3^- concentration in the air were quite stable at the level of 0.5-0.7 μgN/m³ in all stations. Nonetheless, the increase in ΣNO_3 mean annual concentration, since 2001 has been observed (Fig. 1).

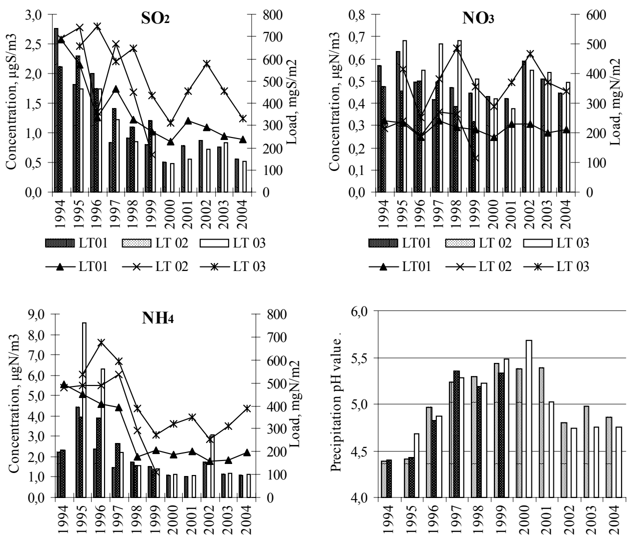

Figure 1. Changes in mean annual concentration of sulphur and nitrogen compounds in the air, their load and precipitation pH in IM stations over 1994-2004. (LT-01 – Aukstaitija IMS; LT-02 – Dzukija IMS; LT-03 – Zemaitija IMS)

The changes in annual wet deposition for the period 1994-2004 had a very similar pattern to that in the air. SO_4^{2-} deposition until 2000 decreased by 67% (from 685 to 225 mgS/m^2) in LT-01, by 52% (from 657 to 312 mgS/m^2) in LT-03 and by 40% (from 739 to 447 mgS/m^2) in LT-02. Between 2001 and 2003 a slight increase in deposition was recorded, however in 2004 it fell again to 235 mgS/m^2 in LT-01 and 328 mgS/m^2 in LT-03.

The decrease in annual wet deposition of NH_4^+ made from 492 to 198 mgN/m^2 in LT-01 and from 537 to 303 mgN/m^2 in LT-03 during the last 11- year period. No significant change in wet deposition of NO_3^- over the whole period was observed. The values of annual wet deposition of NO_3^- fluctuated from 241 to 211 mgN/m^2 in LT-01, from 241 to 270 mgN/m^2 in LT-02 and from 414 to 342 mgN/m^2 in LT-03.

Changes in the main acidifying components resulted in significant changes in precipitation acidity (pH). Between 1994 and 1997 precipitation pH increased from 4.4 to 5.4. For the period 1997 - 2001 pH values in precipitation were rather stable, while in the next three year period fell to 4.7-4.8 again (Fig. 1). A significant decrease in SO_2 concentration in the air had essential impact on a decrease in precipitation acidity over 1994-2000 (Table 1). A slight increase in NO_3^- and NH_4^+ concentration in precipitation as well as NH_4^+ concentration in the air resulted in significant ($p<0.05$) increase in acidity of the precipitation over the last period. A decrease in Ca^{2+} concentration in precipitation since 1999 (Aukstaitija IMS from 0.63 mg/l to 0.41 mg/l; Zemaitija IMS from 0.82 to 0.59 mg/l) had some additional significant effect on this process.

Analysis of the spatial pattern of regional pollution level indicated statistically significant differences in SO_2 concentration in the air ($p<0.036$) and acid deposition (NO_3^- $p<0.000$; SO_4^{2-}, $p<0.035$; NH_4^+, $p<0.058$) among IMS. As a result of this Western and Southern parts of Lithuania were more polluted, what was most likely related to proximity of these territories to the major pollutant sources in Central Europe as well as to the difference in the amount of precipitation.

Effect of acid deposition on soil and runoff water acidity. In Aukstaitija IMS at the first stage of investigation (1994-1996), water pH at the depth of 20 cm decreased from 6.08 to 4.99 (Table 2). From this year onwards soil water pH started to increase and in the last year made about 7.1. Between 1995 and 2004 soil water pH at the depth of 40 cm increased from 4.7 to 7.3. In Zemaitija IMS soil water pH was at the stable level - at the depth of 20 cm a little more than 4.0 and at the depth of 40 cm – 5.0. In Dzukija IMS between 1994-1999 soil water pH decreased from 5.6 to 4.7.

Key factors contributing to theses changes were wet deposition of the main acidifying compounds SO_4^{2-}, NO_3^- and NH_4^+. The strongest and the most significant relationships were found between acid deposition of the previous year and soil water pH ($r= -0.5-0.6$, $p<0.05$) while the relationships between acid deposition of the current year and soil water pH were far lower ($r= -0.25-0.28$, $p>0.05$) with exceptions for nitrate ($r= -0.6$, $p<0.05$).

Stream water pH was quite stable in all IM stations: in LT-01 and LT-03 at the level of 7.4; in LT-02 - 7.8 (Table 2). NO_3^- wet deposition was the key factor contributing to the changes in stream water pH in all IM stations over the whole period under investigation.

Relationship between tree crown defoliation and acid deposition. In 1996 mean defoliation of trees reached the highest level over the whole period under investigation: in LT-01 30.7±0.7%, in LT-02 35.6±0.9% and in LT-03 26.4±0.9%. Afterwards until 2001 a significant decrease in defoliation was observed (in LT-01 to 23.2±0.4%; in LT-02 to 30.0±0.8%; in LT-03 to 20.3±0.6%). Between 2001 and 2003 the increase in defoliation was recorded and in the last year tree crown defoliation in LT-03 in-

Table 1. Effect of the main acidifying components on precipitation acidity (pH)

Period	Concentration in the air			Concentration in precipitation				Statistical data		
	SO_2	NO_3^-	NH_4^+	SO_4^{2-}	NO_3^-	NH_4^+	Ca^{2+}	r^2	p	Std. error
1994-2000	+							0.722	0.000	0.224
2000-2004			+		+	+	+	0.839	0.032	0.170
1994-2004	+				+	+	+	0.706	0.000	0.217

Table 2. Soil and stream water acidity (pH) over the period 1994-2004

Year	Aukstaitija IMS (LT-01)		Dzukija IMS (LT-02)		Zemaitija IMS (LT-03)	
	Stream water	Soil water at 20 cm	Stream water	Soil water at 20 cm	Stream water	Soil water at 20 cm
1994	7.42	6.08	7.94	5.62	-	-
1995	7.32	5.89	7.87	4.63	7.16	4.81
1996	7.20	4.99	7.80	4.67	7.45	4.65
1997	7.42	5.05	7.86	4.67	7.27	4.38
1998	7.31	5.39	7.92	4.38	6.94	4.05
1999	7.37	5.53	7.86	4.73	7.30	4.26
2000	7.45	5.60	-	-	7.44	4.42
2001	7.52	5.48	-	-	7.42	4.29
2002	7.51	5.52	-	-	7.18	4.42
2003	7.42	5.84	-	-	7.34	4.30
2004	7.38	7.09	-	-	7.67	3.87

creased up to 23.6±0.6% while in LT-01 decreased to 23.3±0.6%.

Analysis of the relationships between pollution and crown defoliation of different tree species indicated the highest susceptibility of Scots pines to the impact of air pollution and acid deposition (Figure 2). SO_2 concentration in the air as well as SO_4^{2-} and NH_4^+ deposition had the most significant direct effect on pine crown defoliation what is in full agreement with ICP Forest Monitoring data (de Vries *et al.* 2000). Changes in crown defoliation of Norway spruce were least related to changes in acidifying compounds. It could be explained by the impact of forest pests (*Ips typographus* L.) over the whole period under investigation.

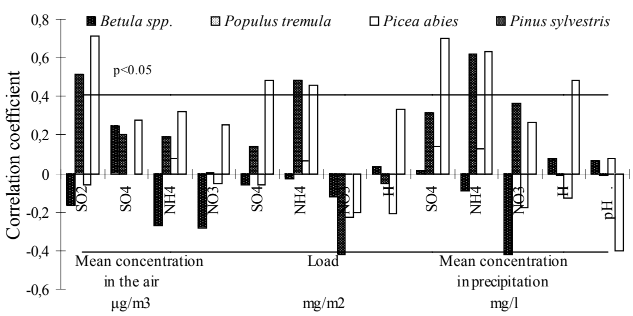

Figure 2. Relationships between crown defoliation of different tree species and air pollutants and acid deposition on IMS territories over 1994-2004

Relationship between soil microarthropods and acid deposition. Individual groups of microarthropods are bioindicators reflecting the impact of air pollution and acid deposition as well as climatic conditions on the biological processes in the soil. High doses of nitrogen fertilizers or high nitrogen loads reduce the abundance of microarthropodes, especially Collembola (Vilkamaa and Huhta,1986; Koposzki 1992; Deleporte and Tillier 1999) while a decrease in the nitrogen deposition in pine stands increases specific diversity of microarthropodes (Boxman *et al.* 1995). Notwithstanding this, in nitrogen-limited vegetation type increase in soil fauna on plots receiving liquid nitrogen fertilisers was detected (Lindberg and Persson 2004).

Data presented in this paper are in full agreement with these findings. Nutrition status of soils was predetermined by richness and abundance of microarthropod complexes. The least abundance and diversity of microarthropods was registrated in haplic arenosol of pure premature pine stand in Dzukija IMS – on average about 140 thou.ind./m^2 and 49 species. In Aukstaitija IMS in haplic arenosol of mixed pine-spruce overmatured stand community of microarthropods was richer. Their average abundance was 233 thou.ind./m^2 and the mean number of identified species - 56. In Zemaitija IMS in albic arenosol of premature spruce stand microarthropod community was richest - 385 thou. ind./m^2 and 65 species. Oribatidic mites represented the dominant group both in prevailing forest soils on IMS territories.

Common trend of changes in abundance and species number over the period under investigation was not statistically significant, however, between 1995-2001 some increase of microarthropod diversity is remarkable (Figure 3).

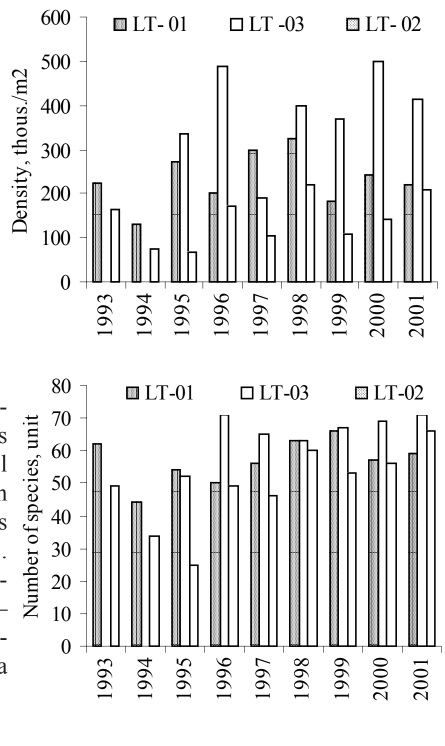

Figure 3. Abundance and species number of soil microathropods on IMS territories over 1994-2001. (LT-01 – Aukstaitija IMS; LT-02 – Dzukija IMS; LT-03 – Zemaitija IMS)

The changes in microarthropod abundance and specific diversity resulted in significant changes in the ratio of mineralization–humification process. Until 1999 the ratio in most cases showed a trend towards the dominance of humification, while since 1999 - towards the dominance of mineralization.

Estimated changes in soil fauna biodiversity and abundance were in full agreement with the changes in tree crown defoliation. Correlation coefficient between tree crown defoliation and arthropods diversity was the most significant and reached -0.8, $p<0.05$. Therefore, it was expected that the same pollution components which resulted in changes in crown defoliation will result in changes in biodiversity of arthropods. The obtained results confirmed this hypothesis (Figure 4). Correlative analysis of the generalized data of all three IMS indicated that the number of microarthropod species, especially Oribatidae, was the most susceptible to air pollution caused by SO_2 and SO_4^{2-} concentration in the air as well as SO_4^{2-}concentration in precipitation and precipitation pH. The latter had the most significant effect on integrated parameters of microarthropod abundance and number of species – on the ratio of mineralization–humification process in the soil ($r=-0.6$; $p<0.05$). An increase in precipitation pH resulted in the changes in M/H ratio towards the dominance of humification. Contrary to the estimated effect of precipitation pH, the effect of soil water pH was inverse and in general not significant.

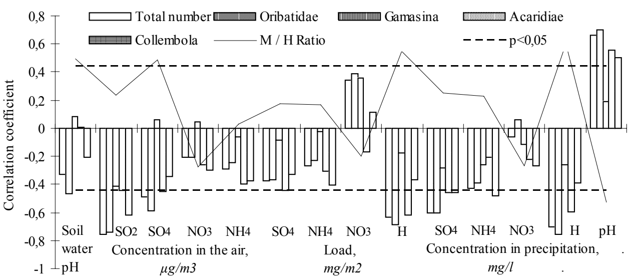

Figure 4. Generalized impact of environment acidifying compounds on soil arthropods diversity and mineralization-humification (M/H) ratio on IMS territories over 1994-2001

Relationship between stream macroinvertebrates and acid deposition. The stream benthos in LT-01 was dominated by stoneflies (Plecoptera) and caddisflies (Trichoptera) with respect to abundance and biomass. Mayflies (Ephemeroptera) were the most numerous, while caddisfies comprised the largest part of the biomass in LT-02. In LT-03 the domination in abundance and biomass changed across different years between mayflies and amphipods (Amphipoda). The greatest specific diversity was determined for dipterans (Diptera) on all monitoring sites.

During 1994-1999, the increase in macroinvertebrate diversity and biomass was observed in all streams. Later, until 2004, diversity estimates remained at the same level.

In freshwater ecosystem decline due to increasing acidity is greater among the fauna than plants. Studies in Sweden indicated that diversity among benthic species decreased by 40% for a pH reduction of 1 unit, while plant species decreased by only 25% (Engblom and Lingdell 1991). Small organisms are commonly the first to be affected. In polluted areas population declines occur among tiny plankton, snails, crayfish, mussels and insects (Kahn 1985) until streams and lakes become inhospitable to many of animals like at the end of 1980[th] (COEJL 2003). Recently, in response to the decrease in emission the first signs of recovery for invertebrates in lakes and rivers in several countries were detected (Keller *et al*. 1999; Raddum *et al*. 2004; Harriman *et al*. 2001; Alewell *et al*. 2001). Meanwhile, at the most acidified sites of Central Europe, improvements of biology cannot be detected (Wright *et al*. 2005). Main reason – stream water pH should reach 7, as the negative effect of acidity starts at 6.0-6.5 pH level due to the loss of a few highly acid-sensitive species (Baker *et al*. 1990).

Water pH in streams in IM stations exceeds 7 and its effect on macroinvertebrates is negligible (Figure 5). Notwithstanding this, estimated trends in macroinvertebrate diversity correlated well with the changes in acidity of precipitation (pH<5) and atmospheric pollution by SO_2 or SO_4^{2-}.

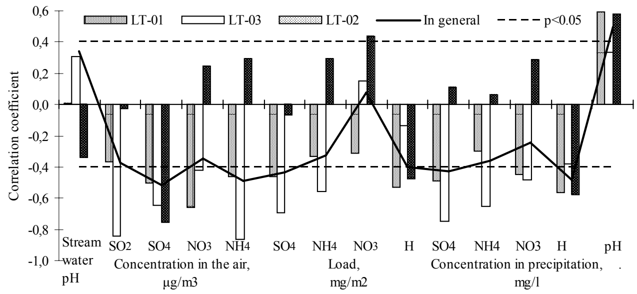

Figure 5. Impact of environment acidifying compounds on diversity of stream macroinvertebrates on IMS territories over 1994-2004. (LT-01 – Aukstaitija IMS; LT-02 – Dzukija IMS; LT-03 – Zemaitija IMS)

Relationship between small mammals and acid deposition. Small mammals due to their link between plants and other animals are an important component of forest ecosystems. However, relatively few examples are known of them suffering direct toxic effects from either acidity or gaseous air pollution instead of negative direct effect of heavy metals (Dudley and Stolton 1994).

Over the ten year period 15 species were registered and 1646 animals caught. The species most frequently met in all of the stations were: *Clethrionomys glareolus* (Schreber), *Sorex minutus* (Linnaeus), *S. araneus* (Linnaeus), *Apodemus* (*Sylvaemus*) *flavicollis* (Melchior) and *Microtus agrestis* (Linnaeus). Additionally in station LT-01 - *Microtus agrestis* (Linnaeus) and *Mus musculus* (Linnaeus); in LT-02 - *Microtus rossiaemeridionalis* (Ognev) and *Apodemus* (*Sylvaemus*) *sylvaticus* (Linnaeus); in LT-03 *Apodemus* (*Sylvaemus*) *uralensis* (Pallas), *Mirotus oeconomus* (Pallas) and *Micromys minutus* (Pallas) were found.

Over the whole period under investigation the greatest number of species was registered on the territory of LT-02 (13 species), lower in LT-03 and LT-01 (10 and 8 respectively). There was no significant trend in changes in species number and mammal abundance (Figure 6). However, data on abundance of small mammals which is one of the main ecological parameters of site condition (Pearce and Venier 2005) indicated the peak in 1999. Afterwards a decrease in abundance was observed in all IM stations.

Some increase in the diversity was recorded until 1999 in LT-01 and LT-03. However, between 1999 and 2003 a significant decrease in the number of species was registered in both of these stations (Figure 6). No regular pattern was observed over the period under investigation in LT-02.

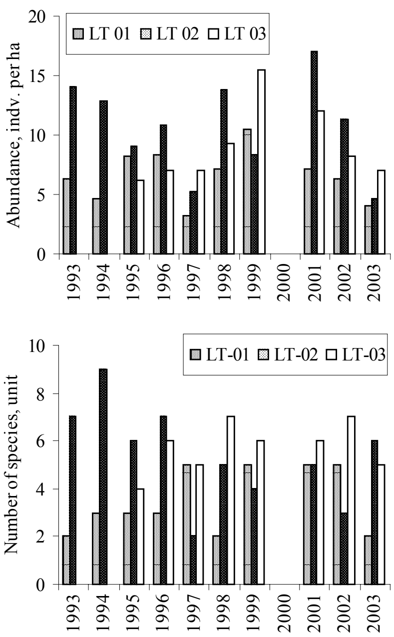

Figure 6. Abundance and species number of small mammals on IMS territories over 1994-2003. (LT-01 – Aukstaitija IMS; LT-02 – Dzukija IMS; LT-03 – Zemaitija IMS)

Strong year-to-year variation at the levels of small mammal population means that long time frames would be required to detect trends and their relationship with acid deposition. Nonetheless, 10-year experience allows starting this investigation. Air pollution had a more significant impact on the diversity than abundance of small mammals. SO_2 concentrations in the air as well as SO_4^{2-} and NH_4^+ concentration in precipitation had quite weak but significant relationship with mammal diversity (Figure 7). Negligible relationship between soil water pH at the depth of 20 cm and the diversity of small mammals was detected.

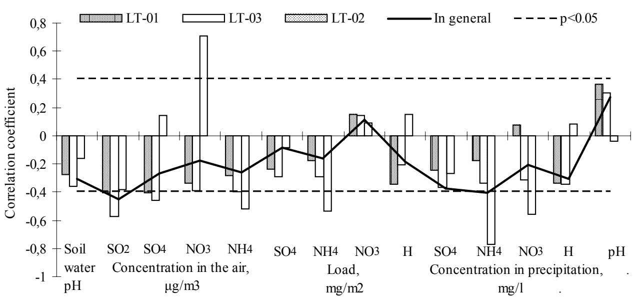

Figure 7. Impact of environment acidifying compounds on diversity of small mammals on IMS territories over 1994-2003. (LT-01 – Aukstaitija IMS; LT-02 – Dzukija IMS; LT-03 – Zemaitija IMS)

Discussion

Over the past 30 years, scientists have gained greater insight into the ways in which acidic deposition has altered ecosystems. Acids and acidifying compounds of atmospheric origin are transported through soil, vegetation, and surface waters, resulting in adverse ecological effects on forest and aquatic ecosystems (Driscoll *et al*. 2003). Forest ecosystems consist of different compartments which may be differently affected by changing environment pollution. Review of the data on the impact of air pollution on the biota has indicated that lower life forms are usually more affected by air pollution than higher. Plants are more affected than animals on land, but not in freshwater. Most affected species decline, but a minority increase (Dudley and Stolton 1994). Land mammals, contrary to aquatic are among the most resistant to air pollution and acid deposition (Air pollution and biodiversity 1997).

These statements are in full agreement with the findings presented in this study. However, contrary to the data presented by the mentioned authors, pollution level on the territories of IMS is remarkably lower than in the western or northern part of Europe. Notwithstanding this, acid deposition was shown to have the most significant effect on tree defoliation, especially of Scots pine trees as well as on the diversity of soil microarthropods (Figure 8). This could be explained by the estimated significant relationship between pine defoliation and soil microarthropods diversity, which, to our mind, could have causative character. Humus is a part of forest soil within which happen the most dynamic and complex chemical processes. Air pollution drops directly on to the humus layer through wet and dry deposition and influences its chemical composition changing the dynamics of complicated decomposition processes. Decomposition of organic material through microorganisms and soil fauna leads to mineralization and humification, and the rate of these processes determines the kind of humus, which develops (Niemtur *et al*. 2002). *Mull* type of humus, the formation of which is related to richer and more abundant microanrthropod communities, results in higher productivity and better condition of trees. Higher acidity of rain decreases specific diversity of arthropods and their abundance what results in the change of the mineralization-humification ratio towards the dominance of mineralization. Therefore soils over this period become poorer and contribute to higher level of pine defoliation. This finding confirms the statement that decomposition of organic material and the ratio of mineralization-humification process is used as an indicator of biocenosis and site condition.

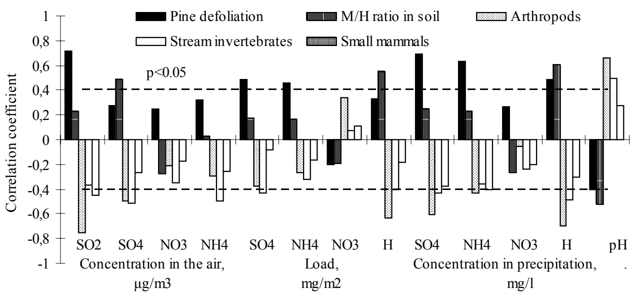

Figure 8. General effect of air pollution and acid deposition on different components of biota in forest ecosystems on IMS territories

A little lower was the effect of acidifying compounds on the diversity of stream macroinvertebrates (Figure 8). Streams runoff yield, which is very low resulted in significant effect of precipitation acidity instead of stream water acidity on macroinvertebrates. Abundant and more acid precipitation could change in a short time stream water pH, mean value of which reaches 7.0, until the level, when negative impact on macroinvertebrates could be estimated. According to this hypothesis the relationship between soil water pH and microarthropod diversity could be explained as well.

The least was the effect of acidifying compounds on the diversity of small mammals (Figure 8), which are likely to be limited to sensitive species, and acts on the whole through secondary effects, such as changes in food supply, or inter-specific competition (Dudley and Stolton 1994).

It should be noticed that in general the effect of pollution on the abundance of all investigated components of the biota was lower and in most cases not significant than on the diversity. The same detected relationships between pollution compounds and different components of the biota indicated causative effect of the regional pollution load. SO_2 concentration in the air and SO_4^{2-} and NH_4^+ concentration in precipitation are the main compounds of pollution resulting in changes in health and diversity of the biota. Therefore, acidity of precipitation is still one of the key factors among other natural and anthropogenic environmental factors contributing to positive or negative changes in biota in general.

Estimated concentration of sulphur and nitrogen compounds in the air and their deposition did not reach the critical level in the air NOx – 30 µgN/m^3; NH_3 – 8 µgN/m^3; SO_2 – 20 (15) µgS/m^3 (UN/ECE 1989) and critical loads 15 ir 20 kgN/ha for coniferous and deciduous forest respectively (Bobbnik *et al*. 1992) and 5 kgS/ha (UN/ECE 1997). However, the data obtained from these investigations indicate that these pollutant concentrations have significant impact on changes in the biota and these findings should be taken into account when we discuss the critical level of air pollution and critical loads, especially stating that pollution level below which significant harmful effects of specified sensitive elements of the environment do not occur (De Vries *et al*. 2000).

Conclusions

The changes in main acidifying components resulted in significant changes in precipitation acidity (pH). Significant decrease in SO_2 concentration in the air on average from 2.5 to 0.5 mgS/m^3 had the essential impact on a decrease in precipitation acidity over 1994-2000. Precipitation pH reached 5.4.

Slight increase in NO_3^- and NH_4^+ concentration in precipitation and NH_4^+ concentration in the air resulted in the increase in acidity of the precipitation over the last period (pH decreased to 4.7-4.8). Decrease in Ca^{2+} concentration in precipitation since 1999 (Aukstaitija IMS from 0.63 mg/l to 0.41 mg/l; Zemaitija IMS from 0.82 to 0.59 mg/l) had some additional significant effect on this process.

Wet deposition of the main acidifying compounds SO_4^{2-}, NO_3^- and NH_4^+ had the most significant effect on soil water pH at the depth of 20 cm especially in the previous year. Over the whole period under investigation wet deposition only of NO_3^- resulted in significant changes in stream water acidity (pH).

Due to detected causative relationships between soil microarthropod diversity and abundance and pine tree defoliation, key factors resulting in their changes were SO_2 concentration in the air as well as SO_4^{2-} and NH_4^+ concentration in precipitation.

Stream water acidity, pH of which exceeded 7, did not have essential effect on macroinvertebrate. Notwithstanding this, main acidifying compounds SO_2 and SO_4^{2-} concentration in the air as well as SO_4^{2-}, NH_4^+ concentration in precipitation and precipitation pH resulted in their diversity changes.

Due to the effect of acid deposition on small mammals through secondary effects, such as changes in food supply, or inter-specific competition, the relationship between pollution and mammal diversity was least significant. However, concentration of sulphur compounds in the air and precipitation as well as precipitation pH resulted in small mammal diversity changes.

Obtained relationships on IMS territories under regional pollution load, which do not exceed the critical values for the biota in general, confirm the statement of higher sensibility of lower life forms (plant and invertebrates) against acid deposition than higher forms (land mammals). Acidity of precipitation on these territories is still one of the key factors contributing to positive or negative changes in different components of the biota.

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ИЗМЕНЕНИЯ В ЛЕСНОЙ БИОТЕ ПОД ВОЗДЕЙСТВИЕМ КИСЛОТНЫХ СОЕДИНЕНИИ В АТМОСФЕРЕ И ИХ ОСАДКОВ

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Резюме

Кислотные соединения, несмотря на существенное снижение выбросов серы в конце 90тых годов прошедшего века, остаются одним из основных факторов влияющих на состояние лесных экосистем. Поэтому, установление воздействия кислых осадков на дефолиацию кроны сосны обыкновенной, а также и на разнообразие микроартроподов почвы, воденных безпозвоночников и мелких млекопитающих (в основном грызунов) суши на территориях станций интегрированного мониторинга в период с 1994 по 2004 г.г. явилось основной задачей представленной работы. Установлено, что концентрация SO_2 в атмосфере и концентрации SO_4^{2-} и NH_4^+ в осадках статистически значимо влияют на дефолиацию кроны сосны обыкновенной, а также и на разнообразие микроартроподов почвы, воденных безпозвоночников и мелких млекопитающих суши. Однако, уровень значимости этого воздействия зависит от уровня формы жизни, т.е. чем она выше, тем воздействие слабее. Представленные данные показывают, что даже загрязнение окружающей среды, уровень которой ниже критического, установленного для лесных экосистем, имеет значимое влияние на различные компоненты лесной биоты.

Ключевые слова: кислотные соединения, дефолиация кроны, микроартроподы почвы, водяные безпозвоночники, мелкие млекопитающие, корреляционный анализ.