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Long-term trends in biology and chemistry of the acidified Bavarian Forest lakes

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Abstract
This manuscript summarizes chemical and biological data on atmospherically acidified Bavarian Forest lakes and shows 15-year trends in their limnology as observed by the official monitoring program. Lake water chemistry has changed considerably during the last decade (decrease of sulfate, nitrate and aluminum concentrations and increase of pH) showing clear trends of lake reversal from atmospheric deposition. Biological recovery of the lakes and their tributaries has not yet been observed. The general trend to better chemical, physical and in part better biological conditions of acidified running waters cannot yet be observed in the lakes of Bavarian Forest and their tributaries in the same way. Probably there has not yet been enough reduction of acidifying emissions and the relaxing time for the lakes is still too short to get evident biological effects in the lake ecosystems.

Key words: atmospheric acidification, hydrochemistry, lake reversal, lake recovery, phytoplankton, benthos

Introduction

The Bavarian Forest as part of the geological formation Bohemian Forest is one of the regions in Bavaria where surface waters are sensitive for acidification. The catchment areas of the three natural lakes Kleiner Arbersee, Grosser Arbersee and Rachelsee are characterized by gneiss and granit bedrocks with spodosolic soils, covered mainly by spruce forests (Rachelsee) or spruce and beech forests (Grosser Arbersee, Kleiner Arbersee). The basic characteristics of these lakes are given in table 1.

STEINBERG and coworkers (e.g.: STEINBERG & al. 1984, STEINBERG & al. 1988) showed with paleolimnological methods based on bioindicators (Diatoms, Chrysophytes, Chydorids) that all the three lakes have been strongly acidified for a longer period and not only since the beginning of heavily atmospheric deposition in the last decades. There is no certain information whether there has ever been fish life in Rachelsee. For both, Grosser and Kleiner Arbersee, extinction of fish in the 1950s is described by ARZET (1987). In addition, STEINBERG &

Table 1. – Characteristics of three Bavarian Forest lakes.

Lake	Altitude [m]	Surface [ha]	Depth [m]	Watershed [km²]	Bedrocks	Vegetation of the catchment area
Rachelsee	1071	5.7	13.0	0.58	gneiss	spruce forest
Kleiner Arbersee	918	9.4	9.0	2.79	gneiss	spruce/beech forest
Grosser Arbersee	935	7.7	15.9	2.58	gneiss	spruce/beech forest

al. (1984) found effects on acidification by local industries at Rachelsee and Grosser Arbersee. The aim of this paper is to show some results of a monitoring program on acidified surface waters in Bavaria, especially from the three Bavarian Forest lakes. This program started in 1983 in responsibility of the Bavarian State Office for Water Management (München) and is still continued. Responsible for sampling and analysis are the regional water management departments (Regensburg, Deggendorf, Passau). The whole results are summarized in LEHMANN & al. (1999). The question of interest is in which way the surface waters in the sensitive regions react to the decreasing atmospheric deposition, which has been detected since the middle of the 1980s.

Methods

Vertical profile samples for biological and chemical monitoring where taken from the middle of Rachelsee and Grosser Arbersee. From Kleiner Arbersee and the tributaries of all lakes only surface samples were taken. Sampling was made between three and five times a year at Rachelsee and Kleiner Arbersee but only once a year at Grosser Arbersee. Grosser Arbersee and its tributaries were not included in this program, but there are data available from the regional water authorities, which are discussed in comparison with the two other lakes. The following chemical parameters were analysed: pH, conductivity, absorbancy at 254nm, O_2, Na^+, Ka^+, Mg^{2+}, Ca^{2+}, Al^{3+}, SiO_2, NO_3-N, NH_4-N, SO_4^{2-}, Cl^-, P_{total} and Chl.a. For the biological monitoring of the lakes and their tributaries samples of phytoplankton and macroinvertebrates respectively, were taken irregularly.

Results

STEINBERG & al. (1984) who had reconstructed the pH by bioindicators found a pH around 5.0 in Rachelsee and about 5.5 in the other two lakes for a longer historical period (Fig. 1).

The authors explain the differences in pH between the lakes by the different stock of trees in their catchment areas. A temporary decrease of the pH in Rachelsee and Grosser Arbersee in the middle of the nineteenth century might be explained by local industrial activities in the vicinity of these lakes. In the second half of the twentieth century until the beginning of the 1980s a contemporary decrease of pH in all three lakes to about 4.5 was observed. This is the result of atmospheric acidification. The emission of SO_2 and NO_x in Germany during the last decades is shown in Figs. 2 and 3.

The decrease of the SO_2 emission in the „Old Länder", the former Federal Republic of Germany, since the middle of the 1980s has mainly been caused by the change in using gas instead of oil in power plants and the installation of effective filter systems for cleaning the exhaust fumes. In the „New Länder", the former German Democratic Republic, the use of coal and the lack of filters in the powerplants caused an increase of the SO_2 emissions during the same period. Since 1990 these emissions have also been decreasing. The large NO_x emissions in the „Old Länder" are mainly caused by traffic. Since 1990, there has been a diminution of NO_x emissions in the whole Germany.

The monitoring program for observing the acidification of surface waters in Bavaria started in 1983, just when the decrease of the atmospheric deposition became obvious. Some results of the investigation of important parameters show the further development of acidification in the lakes of Bavarian Forest. Table 2 summarizes the composition of chemical analyses to charakterize the three lakes and to show differences between them.

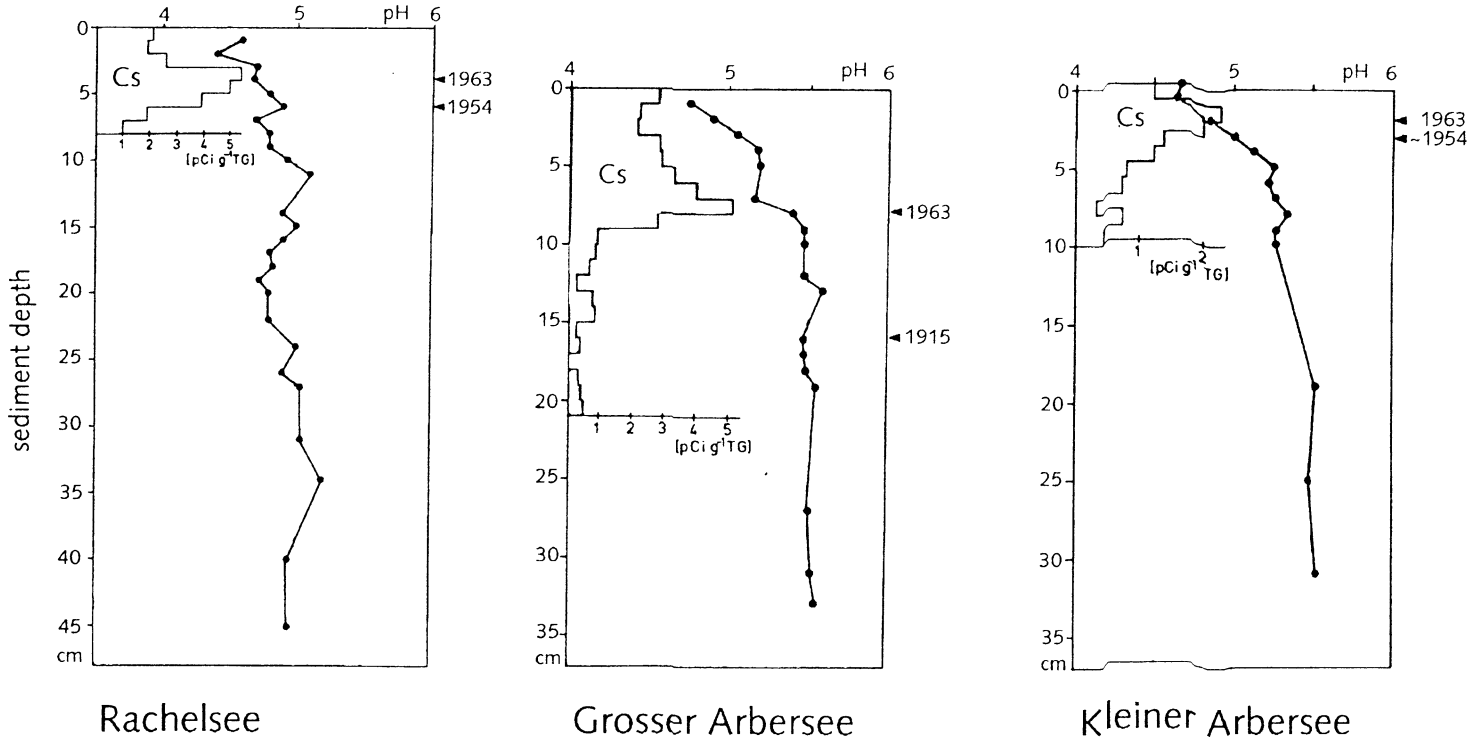

Fig. 1. – Reconstruction of pH with bioindicators from sediment cores; added Cs activities were used to get an approximate time scale. Derived from STEINBERG & al. (1984).

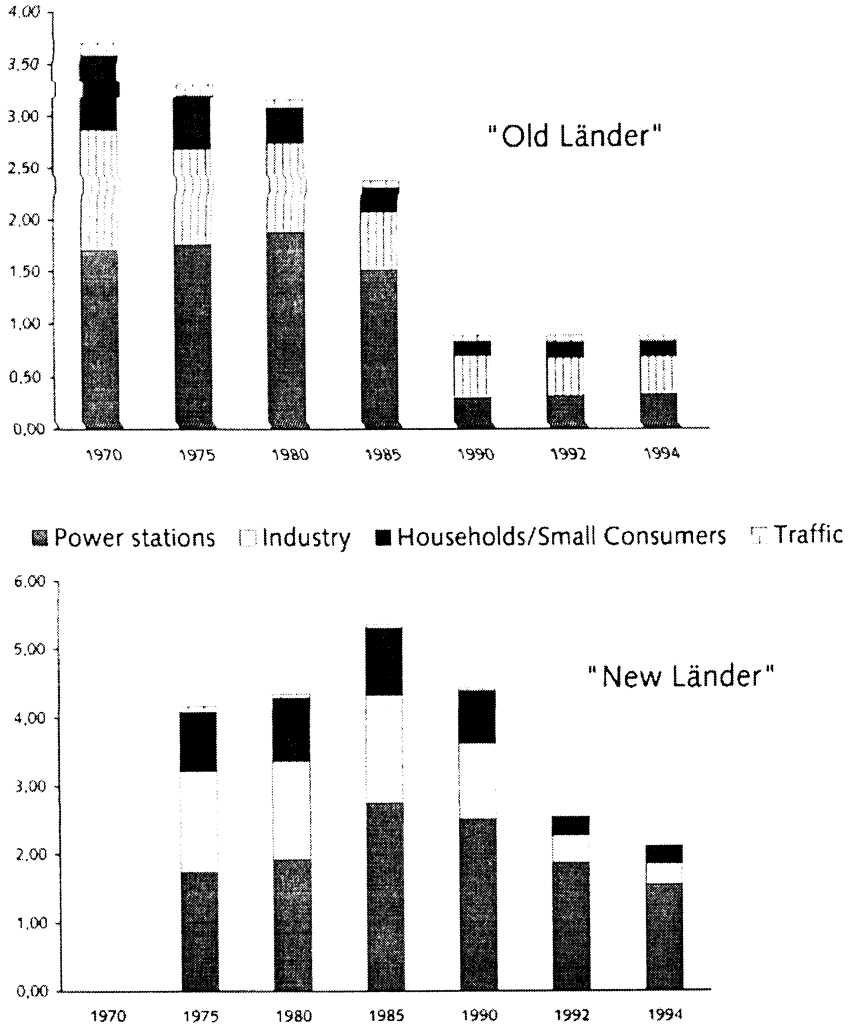

Fig. 2. – Emission of SO_2 in Germany from 1970 to 1994. Derived from UMWELTBUNDESAMT (1997).

Rachelsee

The chemistry of Rachelsee shows a slight recovery from acidification with pH increase from 4.5 to 5.0 and decreasing concentrations of SO_4^{2-}, NO_3^- and Al^{3+} in the period from 1984 to 1999 (Fig. 4).

The biological observations yielded only 22 phytoplankton taxa. The phytoplankton was dominated by *Dinophyceae* and *Chrysophyceae*, especially *Peridinium* and *Dinobryon* (Fig. 7). Also some filamentous algae like *Ulothrix* and *Mougeotia* as well as *Cyanobacteria* like *Oscillatoria* were found. In the beginning of the investigation, *Peridinium* dominated together with *Oscillatoria*. Later there was a change to the dominance of *Dinobryon sertularia,* in part with *Dinobryon divergens*. The phytoplankton characterizes Rachelsee as acidified.

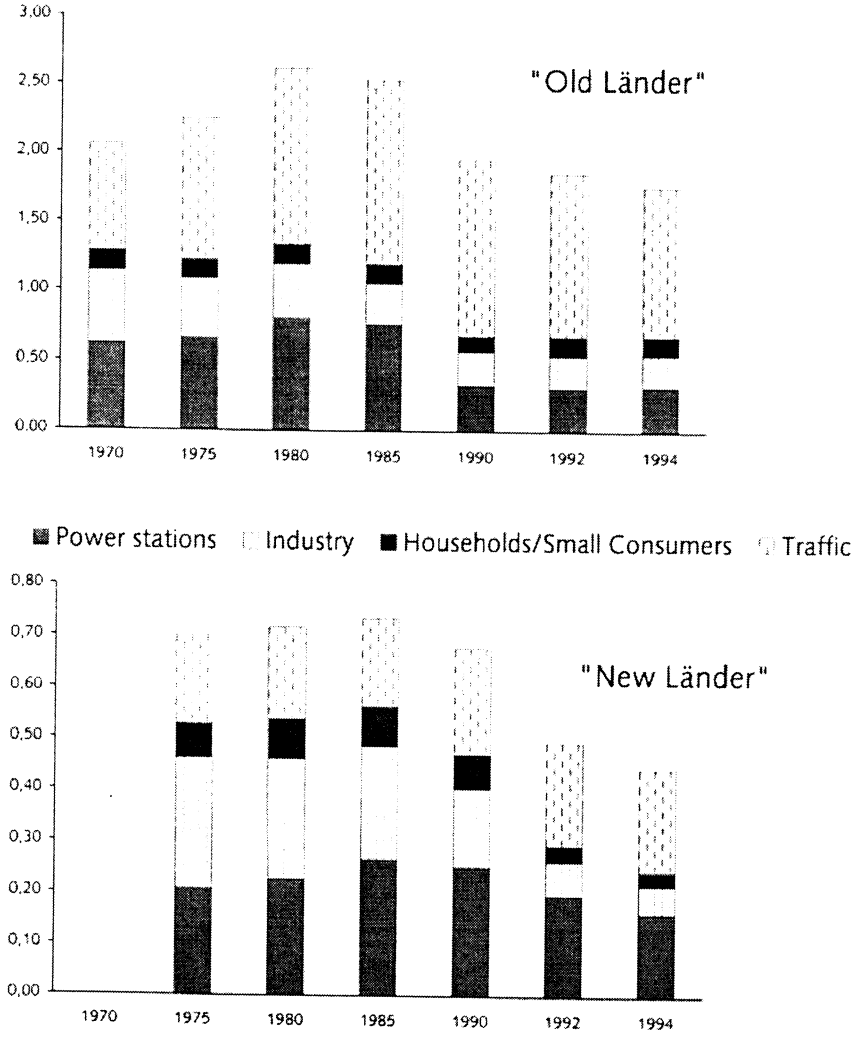

Fig. 3. – Emission of NO_x in Germany from 1970 to 1994. Derived from UMWELTBUNDESAMT (1997).

Due to the small number of samples it is questionable whether the change in dominance is a sign for an improvement in the last years.

There are not enough chemical data available for a trend analysis of the tributaries. The pH in two major tributaries increased from 4.0 in 1984 to almost 4.5 in 1997. The biological observations in 1987 and 1993 yielded only six taxa of macroinvertebrates. *Nemurella pictetii, Protonemura* and *Plectrocnemia conspersa* are known to be resistant to acidification. These results indicate the tributaries to be permanent strongly acidified.

Kleiner Arbersee

In Kleiner Arbersee the pH increased in a similar range as in Rachelsee i.e. from about 4.3

Table 2. – Summarized chemical data of Rachelsee, Kleiner Arbersee and Grosser Arbersee from 1983 to 1999; averages, minima, maxima and number of samples.

	Rachelsee				Kleiner Arbersee				Grosser Arbersee			
	average	min.	max.	number	average	min.	max.	number	average	min.	max.	number
temp. (°C)	10,1	4,8	21,5	261	11,1	0,2	20,9	38	11,6	4,8	22,8	74
pH	4,5	3,3	5,8	261	4,3	3,7	5,2	39	5,2	4,4	6,3	74
cond. (µS/cm)	22,3	6,0	31,0	198	27,6	19,0	66,0	39	20,5	13,0	46,0	74
absorbancy 254 nm (m^{-1})	2,4	0,1	10,1	219	7,4	2,3	14,0	19	9,2	4,8	16,0	24
O_2 (mg/l)	8,5	0,5	13,3	261	9,5	8,0	11,6	37	8,2	0,9	12,3	74
Na^+ (mg/l)	0,85	0,62	1,60	14	0,85	0,60	1,50	13	0,84	0,59	1,30	61
K^+ (mg/l)	0,31	0,17	1,20	14	0,35	0,20	0,60	13	0,30	0,20	0,45	68
Ca^{2+} (mg/l)	0,83	0,50	1,21	240	1,46	0,90	2,30	23	1,32	0,88	1,80	68
Mg^{2+} (mg/l)	0,43	0,30	0,63	240	0,49	0,40	1,00	24	0,44	0,33	0,60	68
$SO4^{2-}$ (mg/l)	5,60	3,20	10,80	240	5,81	4,40	9,00	35	4,20	2,30	6,10	62
NO_3-N (mg/l)	0,58	0,03	1,00	261	0,77	0,30	2,50	39	0,55	0,25	0,86	73
NH_4-N (mg/l)	0,12	<0,02	0,70	261	0,05	<0,02	0,26	39	0,10	0,02	0,49	18
P-tot. (mg/l)	0,010	<0,005	0,060	261	0,010	<0,005	0,017	39	0,007	0,005	0,021	54
Al^{3+} (mg/l)	0,59	0,28	0,99	254	-	-	-	-	0,34	0,18	0,97	68
Cl^- (mg/l)	0,90	<0,5	6,30	259	0,70	0,25	1,70	32	-	-	-	-
SiO_2 (mg/l)	3,06	0,92	4,58	198	3,86	2,50	7,70	29	4,56	3,40	6,60	68
chl. a (µg/l)	4	0	60	234	3	1	9	37	3	1	11	38

in 1983 to 4.8 in 1999. This and the decreasing concentrations of SO_4^{2-}, NO_3^-, and Al^{3+} in the same period and suggest also some recovery from acidification (Fig. 5).

The observed 63 phytoplankton taxa were dominated by *Peridinium goslaviense, Gymnodinium*, as well as *Dinobryon pediforme* and *Synura sphagnicola*. Similarly to Rachelsee, Kleiner Arbersee is characterized as an acidified lake with a dominance of *Dinophyceae* and *Chrysophyceae* (Fig. 7). An increase of *Dinophyceae* and *Chrysophyceae* and a decrease of diatoms were noticed in the last years of investigation, which surprisingly indicates an increasing rate of acidification. There are also available some data on zooplankton. The 23 taxa were dominated by *Rotatoria* species especially *Polyarthra vulgaris* and in part by *Keratella* species. Crustaceans were almost missing. In contrast to chemical parameters the biological data on Kleiner Arbersee might be interpreted as a shift to more acid conditions. The interpretation of phytoplankton and zooplankton data leads to the same result which does not fit the development of the pH. Although we have more biological data on Kleiner Arbersee than on Rachelsee further investigations are necessary to explain the above inverse trends in chemistry and biology of Kleiner Arbersee.

The results from the chemical monitoring of two major tributaries give no hints to a trend. The pH in both of them remains at a level of 4.3 and 4.6, respectively from1983 to 1997. There are six taxa of macroinvertebrates found in one of the tributaries in 1987 and 1993. Among them, *Nemurella pictetii* and *Protonemura* are indicators of permanent strongly acidified conditions.

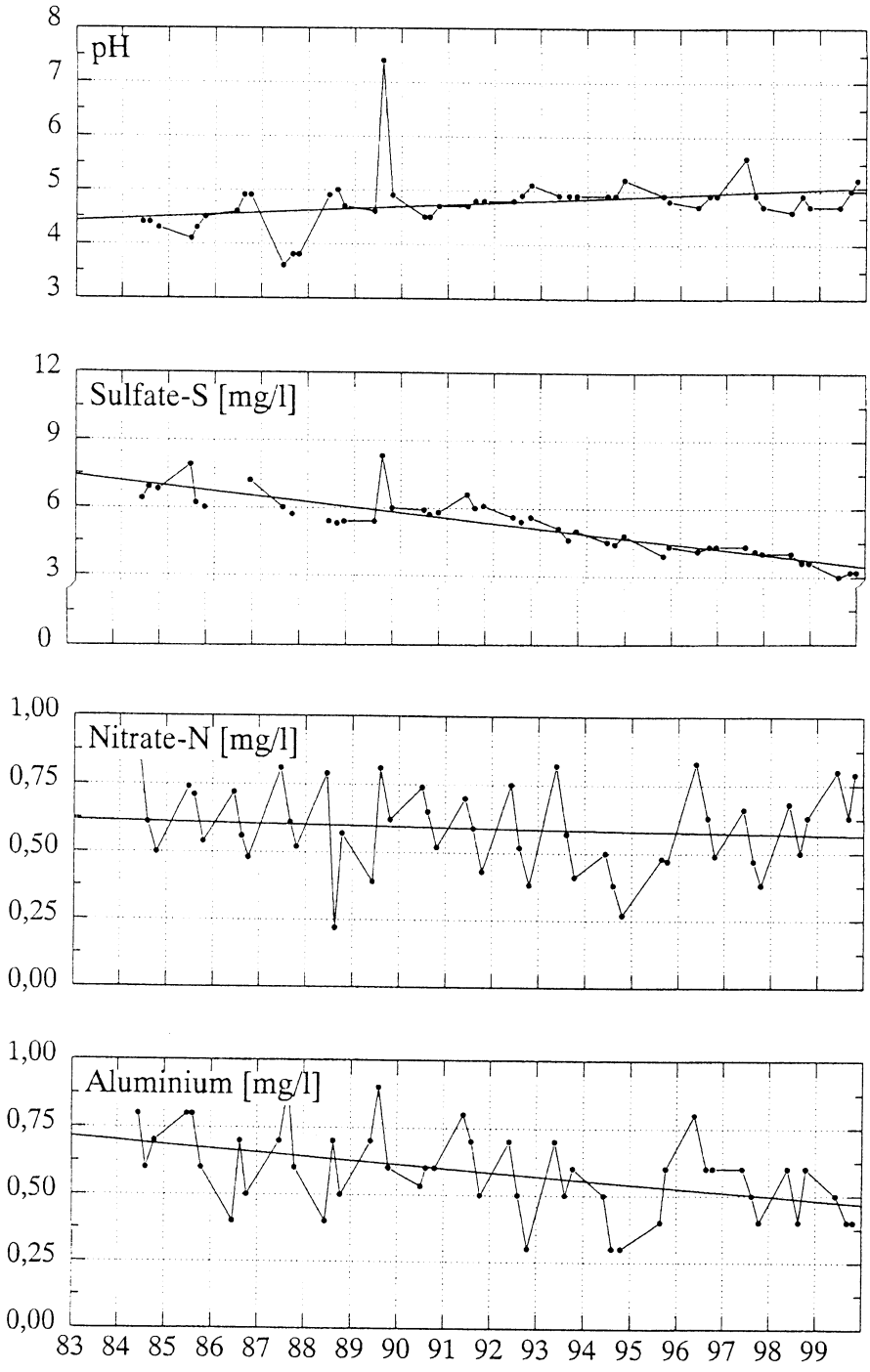

Fig. 4. – Development of selected chemical parameters in Rachelsee, single values from 1983 to 1999.

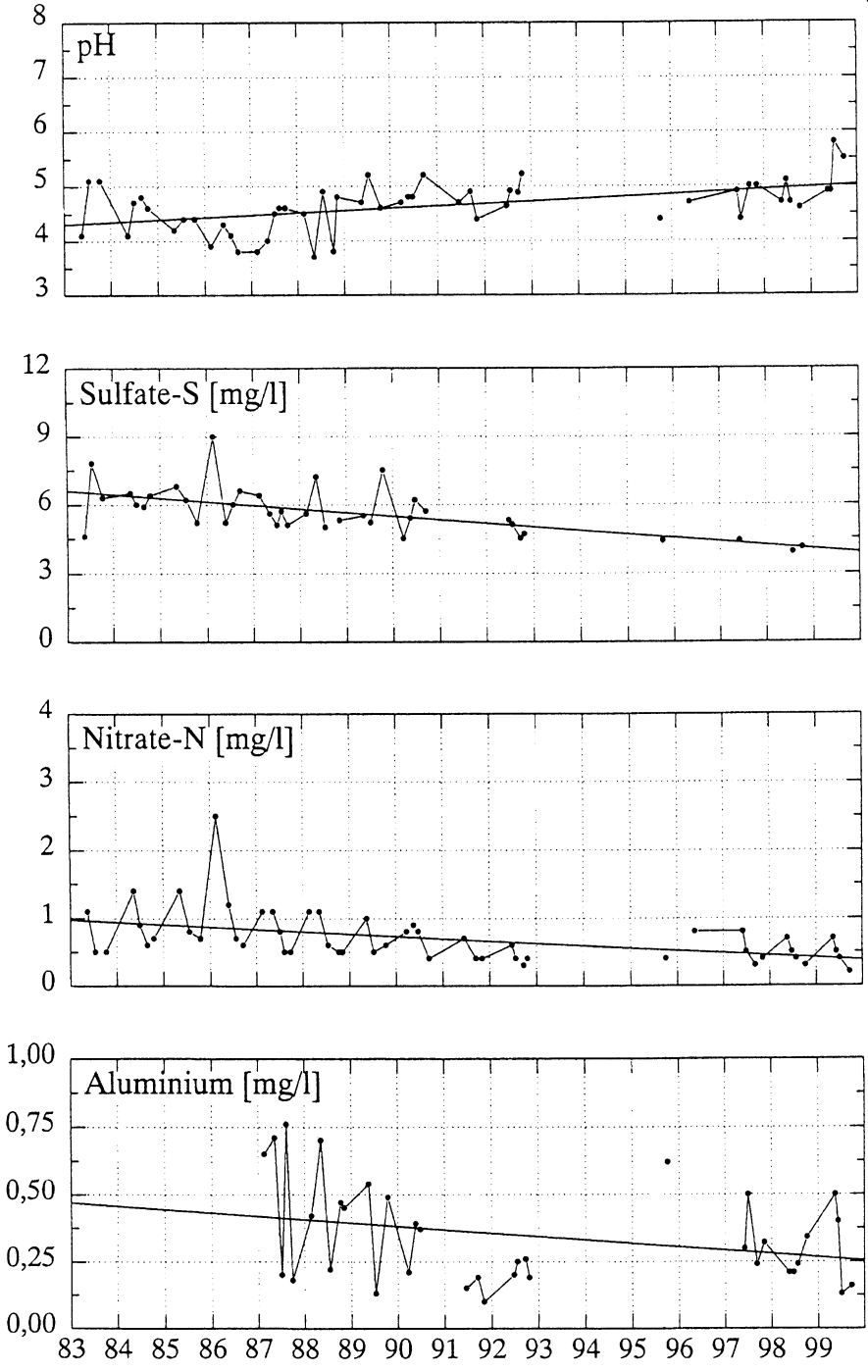

Fig. 5. – Development of selected chemical parameters in Kleiner Arbersee, single values from 1983 to 1999.

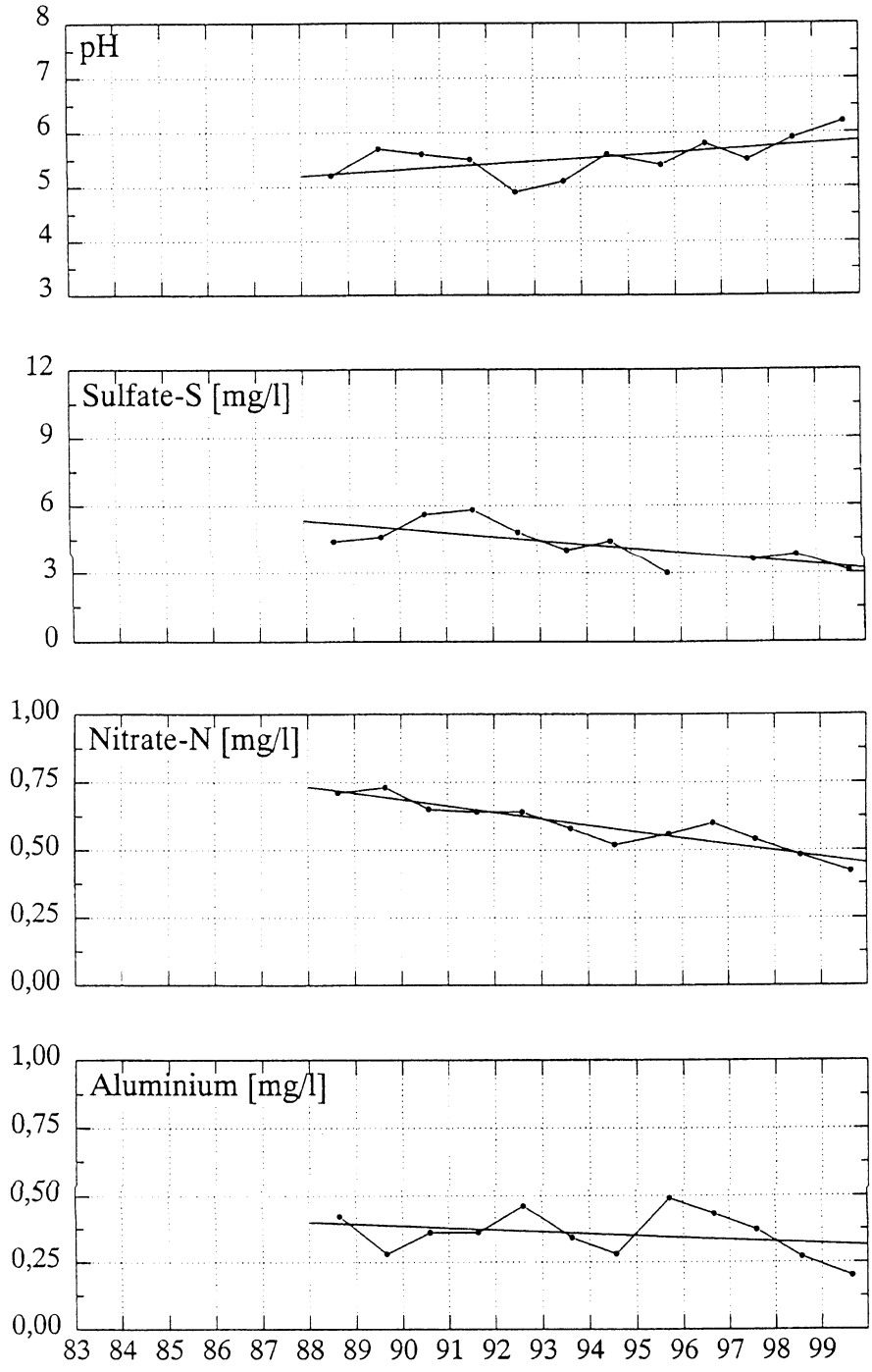

Fig. 6. – Development of selected chemical parameters in Grosser Arbersee, single values from 1988 to 1999.

Grosser Arbersee

Grosser Arbersee has been observed since 1988. At that time the pH was ~5.0. Then, pH has increased continuously to the present value of ~6.0 (Fig. 6). Similar to the other two lakes, SO_4^{2-}, NO_3^-, and Al^{3+} show a decreasing trend, which indicates decreasing acidification (Fig. 6).

The 39 observed phytoplankton taxa were dominated by *Peridinium inconspicuum* and *Gymnodinium*, as well as *Bitrichia olulla*, *Dinobryon cernulatum* and *Synura uvella*. In addition, some *Chlorophyceae* were partially abundant. Grosser Arbersee is just like the other two lakes characterized as an acidified lake with a dominance of *Dinophytes* and *Chrysophytes* (Fig. 7). The 11 zooplankton taxa were dominated by *Polyarthra* and *Cyclops strenuus* during the last two years. No trend in recovery from acidification can be observed from these data on biology. Hence, more detailed research is necessary to get better information.

There are no long-term chemical data available of the tributaries of Grosser Arbersee. The pH in the major tributary was 5.5 in September 1999. The biological data on the macroinvertebrate fauna of the main tributary indicate strongly acidified conditions.

Discussion

The results of the Bavarian monitoring program indicate that there is a general decreasing trend acidification of the surface waters of Bavarian Forest, especially the running waters (LEHMANN & al. 1999). The tributaries of the lakes represent an exception. Positive trends in the development of the biological indicators like macroinvertebrates and benthic diatoms were detected for the main number of the monitored running waters. Also the increasing number of macroinvertebrate taxa indicates decreasing acidification. Some examples are shown in Fig. 8.

In reaction to the decreasing atmospheric deposition a slight recovery of most running waters was found. The Bavarian Forest lakes show a trend to better chemical conditions (Table 3). Due to the small number of samples the results concerning changes of the biological situation are uncertain. The intensity of the biological monitoring program should be raised to get more reliable results (Table 3).

Table 3. – Trends of acidification in the Bavarian Forest lakes and tributaries from 1983 to 1999. Explanations: ++ better, + slightly better, – slightly worse, 0 no trend, ( ) uncertain.

	Rachelsee	Tributary	Kl. Arbersee	Tributary	Gr. Arbersee	Tributary
pH	+	+	+	0	+	
SO_4^{2-}	++		++	+	+	
NO_3^-	+		++	+	+	
Al^{3+}	+		+	(+)	+	
Ca^{2+}	+		(+)			
Mg^{2+}	+		(+)			
Phytoplankton	(+)		(-)		(0)	
Zooplankton			-		(0)	
Macroinvertebrates		0		(0)		0

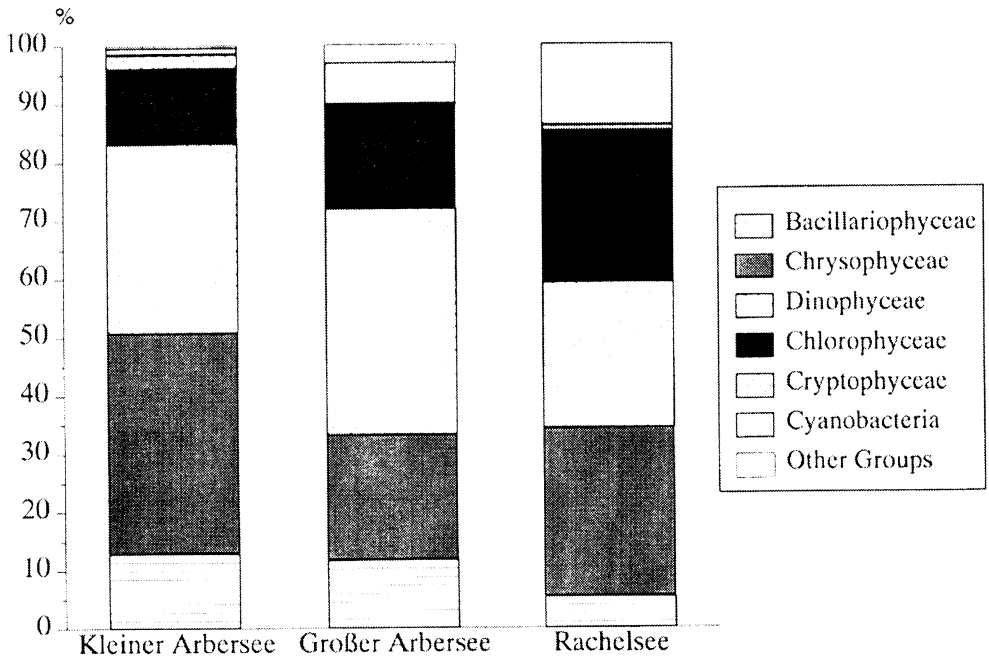

Fig. 7. – Percentage of abundance sum of phytoplankton classes in the Bavarian Forest lakes from 1993 to 1995.

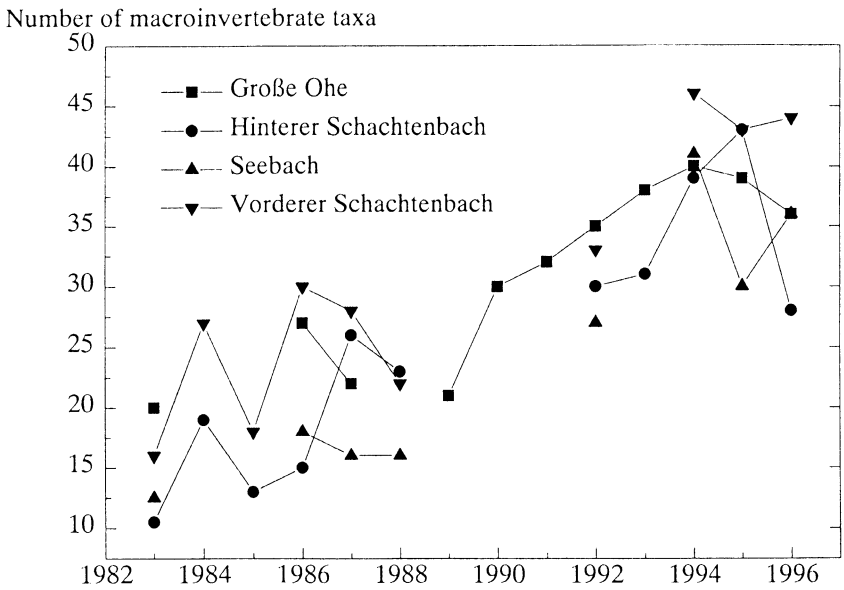

Fig. 8. – Number of macroinvertebrate taxa in four Bavarian Forest brooks. Derived from LEHMANN & al. (1999).

Conclusions

The main conclusions of the hitherto existing data on the monitoring of acidification of surface waters in the Bavarian Forest are as follow:

a) chemical parameters of lake water (SO_4^{2-}, NO_3^-, Al^{3+} and pH) show clear signs of lake recovery from acidification
b) in contrast biological parameters do not show any trend
c) most brooks and all lakes are still permanently acidified
d) the problem of acidified surface waters in Bavarian Forest is not yet solved
e) the chemical and biological monitoring program for the surface waters should be continued and, in addition, be intensified for the lakes and their tributaries

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References

ARZET K., 1987: Diatomeen als pH-Indikatoren in subrezenten Sedimenten von Weichwasserseen. *Diss. Abt. Limnol. Innsbruck 24: 266 pp.*

LEHMANN R., KIFINGER B., ZAHN H., HOFMANN G., DAHINTEN B., BAUER A. & SCHMEDTJE U., 1999: Versauerung oberirdischer Gewässer in Bayern – Entwicklung 1983–1996. *Informationsberichte des Bayerischen Landesamtes für Wasserwirtschaft, Heft 4/99: 1–343.*

STEINBERG C., ARZET K. & KRAUSE-DELLIN D., 1984: Gewässerversauerung in der Bundesrepublik Deutschland im Lichte paläolimnologischer Studien. *Naturwissenschaften, 71: 631–633.*

STEINBERG C., HARTMANN H., KERN J., ARZET K., KALBFUS W., KRAUSE-DELLIN D. & MAIER M., 1988: Gewässerversauerung durch Luftschadstoffe. *In: Hohenheimer Arbeiten 1988, Gefährdung und Schutz von Gewässern, KOHLER A. & RAHMANN H. (eds.): 79–103.*

UMWELTBUNDESAMT, 1997: Daten zur Umwelt. Der Zustand der Umwelt in Deutschland. *Erich Schmidt Verlag, Berlin.*