51 Reents, H., Die Entwicklung des sektoralen End- und Nutzenergiebedarfs in der Bundesrepublik Deutschland, Ber. 1452, KFA Jülich 1977.
52 Reichelt, G., Zur Frage des Zusammenhangs zwischen Waldschäden und dem Betrieb von Atomanlagen – vorläufige Mitteilung. Forstwiss. ZentBl. *103* (1984) 290–297.
53 Reichelt, G., Zusammenhänge zwischen Radioaktivität und Waldsterben, in: Ökologische Konzepte, pp. 25–53. Halbjahresschrift der G. M. Pfaff Stiftung, Kaiserslautern 1984.
54 Rentz, O., and Weibel, M., Acid rain, the international problem, in: 6th Int. Conf. on Air Pollution, pp. 1–38. Pretoria, S. A. 1984.
55 Rose, D. J., Miller, M. M., and Agnew, C., Global energy futures and CO_2-induced climate change, US Dept. of Commerce, NTIS PB 84-145 895, Washington, DC 1983.
56 Rosenfeld, A. H., Colborne, W. G., Hollowell, C. D., Meyers, S. P., and Schipper, L. J., Building energy use compilation and analysis (BECA): An international comparison and critical review. Pt. A: New Residential buildings. Energy Buildings *3* (1981) 315–332.
57 Ruske, B., und Teufel, D., Das sanfte Energie-Handbuch. rororo actuell, Rowohlt, Reinbek 1980.
58 Sant, R. W., A Strategic Look at Energy Markets 1980–2000: The Least-Cost Energy Strategy Revisited. Carnegie-Mellon Univ. Press, Arlington (Va.) 1981.
59 Scheifele, M., Zum Waldsterben in Baden-Württemberg. Allg. Forstz. *43/44* (1984) 1071–1074.
60 Schütt, P., Der Wald stirbt am Stress. Bertelsmann, München 1984.
61 Seiffert, U., and Walzer, P., Development trends for future passenger cars, paper pres. at 5th Automotive News World Congress, reprint Res. Div., VW, Wolfsburg 1980.
62 SERI (Solar Energy Research Institute), A New Prosperity: Building a Sustainable Energy Future. Brick House, Andover (Mass.) 1981.
63 Sorensen, B., Energy choices: Optimal path between efficiency and cost, paper pres. at 1st U.S.-China Conf. on Energy Res. and Environment, Peking 1982.
64 Spreer, F., Dezentrale Wärmeversorgung – neue Wege zur besseren Energienutzung. Bild Wissensch. *9* (1982) 120–134.
65 Streets, B. G., Acid rain control and United States energy policy. Energy *9* (1984) 1049–1063.
66 Swedish Ministry of Agriculture (SMA), The 1982 Stockholm Conference on Acidification of the Environment, June 21–30, 1982, Stockholm 1982.
67 Teufel, D., Können Umweltschützer für die Kohle sein? in: *Kohle*, pp. 76–108. Eds Hatzfeld et al., fischer alternativ 4071, Frankfurt 1982.
68 Ulrich, B., Auswirkungen der Immissionen auf die Bodenökologie des Waldes, in: Waldschäden durch Immissionen? pp. 47–90. Gottlieb Duttweiler-Institut, Zürich 1982.
69 Ulrich, B., Effects of air pollution on forest ecosystems and waters – the principles demonstrated at a case study in Central Europe. Atmosph. Environ. *18* (1984) 621–628.
70 Wentzel, K. F., Das Ausmass der Waldschäden – ihre ökologische und landeskulturelle Bedeutung in Zentral-Europa, in: Waldschäden durch Immissionen? pp. 7–25. Gottlieb Duttweiler-Institut, Zürich 1982.
71 Wisniewski, J., and Klinsman, J. D., An overview of acid rain monitoring activities in North America. Bull. Am. met. Soc. *63* (1982) 598–618.
72 Yan, T. Y., Fueling power plants with high sulfur coal in compliance with emission standards. Energy *9* (1984) 265–274.
73 Zumr, W., and Landa, M., Zu den Auswirkungen der Immissionsschäden in der CSSR. Allg. Forstz. *14/15* (1984) 364–365.

0014-4754/85/091095-10$1.50 + 0.20/0

Heavy metal levels and cycling in forest ecosystems

by H. W. Zöttl

Institut für Bodenkunde und Waldernährungslehre, Albert-Ludwigs-Universität, D–7800 Freiburg im Breisgau (Federal Republic of Germany)

Key words. Heavy metal; spruce ecosystem; trace element input; trace element turnover; soil macrofauna; Black Forest.

1) Physiological effects of heavy metals in plants

Heavy metals can be essential, beneficial or toxic for forest ecosystems. A number of heavy metals are essential nutrients for plants, animals, and men. An insufficient supply may therefore lead to deficiency symptoms in forest trees. Zinc deficiency occurs in large areas of Australia and New Zealand where pines were afforested on poor soils[26,31], and also on latosols in southern Brazil[22]. Copper deficiency is known for *Larix* and *Pseudotsuga* on heath podsols in Western Europe[28]. Manganese deficiency in *Pinus* and *Picea* is found on calcareous mineral soils and calcareous lower moorland, e.g. in southern Bavaria[15]. Iron deficiency may also occur on such sites[32]. The deficiency may be due to low reserves of these elements in the bedrock or soil or may be caused by extensive fixation in the rooting zone.
There are sites with an extremely high content of heavy metals in minerals and soils. This prevents tree growth, and only adapted (tolerant) plants are able to develop; well known examples are sites on serpentine with very high concentrations of nickel, chromium, and cobalt, or plant communities with *Viola calaminaria*[2]. In these cases high concentrations of heavy metals can be toxic. Tree species differ in their tolerance to high heavy metal concentrations. On moist and acid soils with a high mobility of manganese, spruce and silver fir accumulate an extremely high content of this element in their needles whilst, however, showing good growth[18]. The same applies to Scots pine[29].
There is also a species-related difference in tolerance to toxic elements such as cadmium, lead, chromium, and nickel. This is shown in table 1. *Populus* and *Betula* (as well as *Salix*, which is not listed) accumulate zinc and cadmium in their leaves when cultivated in sewage sludge strongly contaminated with heavy metals. *Quercus* has in comparison a higher copper uptake. No toxic effects were noticed during this experiment.

2) Damaging effects in the vicinity of sources of emission

Extensive contamination of the biosphere with heavy metals occurs mainly in the vicinity of sources such as smelters and metal refining plants. Vegetation close to such sources of pollution is heavily affected; the extent of damage decreases with the decrease in accumulation of heavy metals at larger distance from the source; an example is given in figure 1.

A very high input of heavy metals may have a negative impact on the microbial turnover in forest soils. Nitrogen mineralization as a vital process has been particularly well studied in this respect. An inhibiting effect does not occur until the input is extremely high[23]. This is also evident in laboratory experiments. According to Wilke[30] an inhibition of microbial activity was only found with a lead content of 10,000 $\mu g \cdot g^{-1}$ dry matter. Tyler[27] showed a reduction of nitrogen mineralization in the humus layer of coniferous stands parallel to the increasing accumulation of copper. An inhibition became evident at a copper concentration of some 100 $\mu g \cdot g^{-1}$, and reached a maximum at several 1000 $\mu g \cdot g^{-1}$.

Areas distant from sources of emissions, e.g. the Black Forest, show much lower levels of heavy metal pollution

Table 1. Heavy metal contents in leaves from trees cultivated in sandy soil (Zn: 26; Cu: 6; Cd: 0.3 $\mu g \cdot g^{-1}$ d.m.) and sewage sludge (Zn: 5700; Cu: 1430; Cd: 9 $\mu g \cdot g^{-1}$ d.m.)

Species Substrate	$\mu g \cdot g^{-1}$ d.m. Zn	Cu	Cd
Populus × euramericana			
Sandy soil	170– 476	2.7– 7.9	0.6 – 2.6
Sewage sludge	423– 894	5.2– 6.4	4.7 –27.8
Betula pendula			
Sandy soil	363– 527	7.0– 7.9	0.1 – 0.6
Sewage sludge	963–1284	7.7– 8.2	7.5 –17.0
Quercus robur			
Sandy soil	47– 68	6.2– 7.2	0.15– 0.2
Sewage sludge	128– 315	7.7–23.8	0.46– 0.7

From Smilde and van den Burg[24].

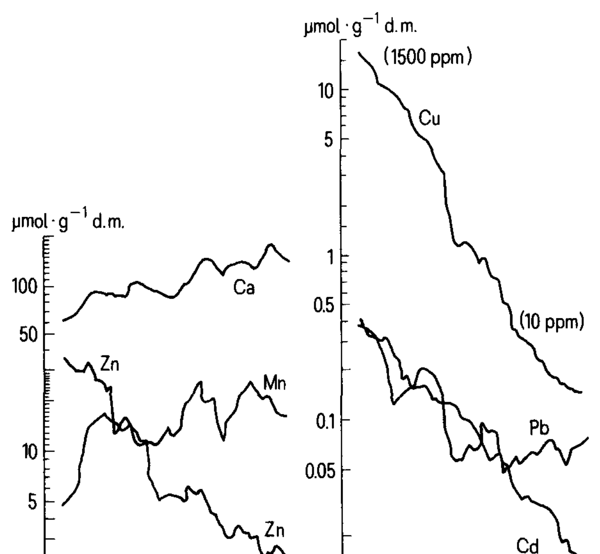

Figure 1. 'Finspang': Levels of six elements found in the organic layer under spruce at varying distance from a copper smelter (after Rühling and Tyler[23]).

(table 3), and no negative impact on the biological turnover activities has to be expected.

3) *Forest ecosystems as sinks for heavy metals*

Low input rates, however, may also affect terrestrial ecosystems by increased accumulation over long periods. The natural 'sink function' plays an important role. Heavy metal aerosols brought in by medium- or long-range transport are filtered out of the air stream and absorbed by the multistructured biomass. Dying tissue, epiphytic lichens and some mosses accumulate heavy metals particularly well. In the soil, humic acids, iron oxides, clay minerals, and particularly carbonates have a high fixation capacity for heavy metals. Soils are thus effective filters for heavy metals.

Most forest ecosystems are a sink for heavy metals. The solubility of heavy metal compounds, however, increases with decreasing pH value, thus causing reduced fixation or increased mobilization in very acid soils. The latter may also occur during the decomposition phase in humus layers.

Any estimate of the impact of environmental pollution depends on a reliable knowledge of input levels and the element turnover in the particular ecosystem. 10 years ago a biogeochemical inventory including measurements of element turnover in forest ecosystems near the 'Bärhalde' (Black Forest) was initiated and continued for up to five years. The following chapters present several results of this study concentrating on input, output, storage, and turnover of five selected elements in these forest ecosystems.

4) *Levels in soil and vegetation compartments of the southern Black Forest*

We would like to begin with data on the content of heavy metals in bedrock, soil, and vegetation. With reference to the previously mentioned sites with a high heavy metal content it may be interesting to have a look at such sites, for example the waste heaps of ancient ore mines in the Black Forest. Today these slopes are covered by trees through natural regeneration as well as planting. A very high content of lead, zinc, and arsenic is found[9] in the rooted soil. In table 2 the levels in the soil substrate as well as in the needles of trees growing on mine waste are given. A comparison with trees distant from waste heaps shows high heavy metal levels, particularly as far as lead is concerned. Such a level cannot be explained by airborne emissions only. Obviously, some of the lead must have been taken up by the root system. In acid soil (pH $\sim$ 4) such an uptake might occur to a considerable extent. The very high lead content with several 1000 $\mu g \cdot g^{-1}$ is of greatest significance as natural soils in this region have levels of less than 50 $\mu g \cdot g^{-1}$ (see table 4). The growth of the trees examined on the mining waste corresponds to that on sites with a relatively low water capacity and nitrogen supply. Damage related only to heavy metals was not observed. This agrees well with the previously-mentioned high tolerance of trees for heavy metals.

In the following paragraphs two heavy metals with a nutrient function (manganese, copper), two toxic elements (cadmium, lead), and the trace element beryllium are selected to demonstrate the nutritional status and pollution level of Norway spruce *(Picea abies)*, the dominant tree species in the southern Black Forest. Manganese and copper are found in trees at different levels, ranging from deficiency to surplus (luxury uptake). Cadmium and lead are two of the most dangerous toxic elements and are of importance in long-range transport of emissions. The trace element beryllium has no physiological function for plants and is potentially toxic; little is known about its turnover in forest ecosystems. Since it is a component of metal alloys used in aircraft and nuclear reactors an anthropogenic input into the environment appears to be possible.

The element contents for 47 spruce stands in the southern Black Forest[3] are given in table 3. The high level of the manganese supply should be noted. This is typical for the dominant soils in this area, i.e. acid brown earths and wet podsols. On these sites spruce needles obtain up to 5000 $\mu g \cdot g^{-1}$ manganese, showing optimum growth[18]. Copper concentrations are much lower (by a factor of 200), reaching the deficiency level ($< 2\ \mu g \cdot g^{-1}$). This is mainly caused by the low copper reserves of the crystalline bedrock. Cadmium levels are still lower (by a factor of 50); the final level is the result of the interaction of atmospheric immission, uptake through the roots and leaching of the needles. This will later be discussed in detail in the context of the element turnover in the ecosystems. Lead is present at levels considered normal for areas distant from heavy traffic. A clear increase is noticed with the age of the needles. This is believed to be caused by the longer period of exposure to lead carried in the atmosphere which is thought to be the main source of lead in (or more precisely: on) needles. Worth mentioning is that the same stands showed higher lead contents in the mid-seventies than today[39]. This decrease was probably caused by the reduction of the lead content in gasoline to 0.15 g/l in 1976.

Table 2. Mine waste sites (southern Black Forest): Element contents ($\mu g \cdot g^{-1}$ d.m.)

Mine	Soil		Needles			
	< 0.2 mm		1 year		4 years	
Species	Pb	Zn	Pb	Zn	Pb	Zn
'Leopold'						
Picea abies	1900	11930	15	77	17	334
'Roggenbach'						
Picea abies	15550	4500	12	52	21	166
'Wilhelm'						
Pinus silvestris	3340	2140	19	125	20	190
'Barbara'						
Pseudotsuga menziesii	6475	2730	12	204	15	491

From Hurrle[9].

Table 3. Southern Black Forest: Element levels in spruce needles ($\mu g \cdot g^{-1}$ d.m.)

	1 year			4 years		
	Min.	Max.	Mode	Min.	Max.	Mode
Mn	224	1832	700	96	2080	620
Cu	1.5	9.7	3.0	1.5	6.3	2.4
Cd	0.03	0.17	0.07	0.02	0.11	0.06
Pb	0.6	4.4	1.2	1.1	7.0	2.7
Be	0.01	0.22	0.02	0.04	0.15	0.06

From Ferraz and Zöttl[3].

Table 4. 'Bärhalde': Element contents of soils ($\mu g \cdot g^{-1}$ d.m.); Br = brown earth; Po = podsol

	Parent rock		Fine skeleton (2–6 mm)		Soil horizons (fine earth < 2 mm)			
					A_h	A_{he}	B_v	B_{sh}
	Br	Po	Br	Po	Br	Po	Br	Po
Mn	560	220	444	114	330	145	577	190
Cu	67	17	22	15	37	18	27	20
Cd	0.52	0.19	0.21	0.19	0.49	0.18	0.46	0.27
Pb	45	33	40	35	43	43	36	39
Be	8.7	6.6	3.1	4.34	6.0	6.8	7.6	15

From Keilen[13].

In the next chapters data of an element inventory and measurements of the turnover in spruce stands in the 'Bärhalde' region will be discussed. The 'Bärhalde' is a NE facing slope, east of the 'Feldberg' in the southern Black Forest, with an altitude of approximately 1200 m above sea level. Its climate is characterized by 1800–2000 mm precipitation p.a. and an annual mean temperature of 5 °C. Bedrock is a very acid granite, extremely poor in calcium and magnesium, and of coarse grain. Moraines and periglacial solifluction layers are formed only from this granite. Recent soil types are brown earth and podsol, further down the slope stagnogley (surface water gley) and ockererde (slope gley). The present vegetation is dominated by spruce stands and a few extensively managed pastures. A comprehensive description is given by Zöttl et al.[36].

For the five elements sequence of their contents from unweathered bedrock to fine earth is presented in table 4. Results from two of the stands investigated (brown earth and podsol, respectively, both with spruce stands) are presented. The parent material of the brown earth is influenced by a porphyr trail running through the granite. This is evident in the high content of manganese and of copper in the parent material. Following the manganese content with the decreasing particle size fraction a reduction is already found in the fine skeleton material, especially in the podsol. The fine earth fraction of the A-horizon is always poorer in manganese than the B-horizons. This can be related to the translocation in the moist solum, depending on the redox potential. There is no big difference in lead between bedrock, fine skeleton, and fine earth fraction. This element is relatively immobile during the process of weathering[13], as a result of its strong fixation on organic matter and clay minerals[7]. For beryllium (similar to manganese and copper) the fine skeleton material is poorer than the bedrock. There is a higher level in the A-horizon, and again in the B-horizon, especially in the podsol. Atmospheric deposition and heavy translocation in the solum may explain the differences. Beryllium is similar to aluminium during pedogenetic processes in acid substrates[14].

We will now concentrate on successive changes in element contents from the living needles to the litter and the humus layer above the mineral soil (table 5). Manganese increases markedly in older needles as a result of a permanently high uptake from the soil; it is then reduced in the dead needles of the litter due to leaching and reaches its minimum value in the humus layer. This highlights the importance of this element in the biological turnover, and

its high mobility becomes obvious. Copper is by far less mobile. It is enriched in the humus layer because of a strong fixation by humic acids. Atmospheric deposition is for both elements not relevant compared with its turnover rates (see figs 7 and 8). The lead content increases significantly with needle age and is even higher in the litter needles and the humus layer. This is caused by relative accumulation due to mass losses during decomposition of organic material and accumulation. The minimal content of beryllium in the needles is an indicator for its insignificant level of incorporation in the biological cycle.
These data already indicate the different dynamics of the elements mentioned. We will come back to this when dealing with the results of turnover measurements.

5) Levels in the components of an old spruce stand at the 'Bärhalde'

Based on the data of the ecosystem inventory[19] the content of various elements in the above-ground biomass of a 130-year-old spruce stand on a podsol soil will be discussed. Levels were estimated in needles, twigs, branches, bark, and wood (see fig. 2 for further subdivision).
Considering the content of manganese, its high values in the physiologically active components attract attention. It is necessary to mention that the levels in the needles of this spruce stand are relatively low. Most of the other stands in the study area showed a content of more than 1000 $\mu g \cdot g^{-1}$. Typical for conifers on very acid soils are high manganese levels in the bark. Much lower, but still significant levels of 30–60 $\mu g \cdot g^{-1}$ were found in the wood. The manganese contents of conifers are at the level of macroelements. Manganese is significantly accumulated in longer-living organs, e.g. bark, not exposed to high rates of leaching.
The copper content of needles (fig. 3) is very low (3–5 $\mu g \cdot g^{-1}$), near to the deficiency level, and in the wood itself only a little copper is accumulated. Noticeable are the high levels in twigs and branches which are probably absorbing atmospheric deposition in their bark (and its epiphytic community of young lichens and algae). It appears that there is a relatively low supply from the soil and a detectable input through emissions.
As far as the toxic elements are concerned, cadmium (fig. 4) shows the highest content in the longer-living organs, which are more exposed to the air stream. The content in the sapwood and in the bark of different stem segments apparently increases considerably from the upper parts to the lower parts. This differentiation is not noticeable in the heartwood. It is possible that there is an accumulation of atmogenic cadmium due to the stemflow in the lower part of the trunk. The very low (0.1 $\mu g \cdot g^{-1}$) content in needles and in twigs was to be expected, as cadmium has no nutritional function; it is, on the other hand, a sign of a certain uptake through the root system. This can be explained by the relatively high mobility of cadmium in the acid soil substrate of the forest stand analyzed. Generally, the cadmium content of all tree components is very low. Other parts of the vegetation, e.g. ferns or *Luzula silvatica,* have a content of more than 2 $\mu g \cdot g^{-1}$ (see fig. 12).

Table 5. 'Bärhalde': Element contents ($\mu g \cdot g^{-1}$ d.m.) of spruce stands on brown earth (Br) and podsol (Po)

	Needles Current Br	Po	Older Br	Po	Litter fall Br	Po	Organic layer Br	Po
Mn	444	197	780	214	280	190	180	70
Cu	3.74	4.20	3.13	3.40	6.9	7.6	37.6	34.1
Cd	0.05	0.15	0.07	0.10	0.21	0.36	3.4	2.6
Pb	0.30	0.82	1.96	2.64	38	41	156	112
Be	0.01	0.01	0.04	0.03	0.18	0.06	0.30	1.15

Data from Raisch[19], Holzapfel[8], Keilen[13].

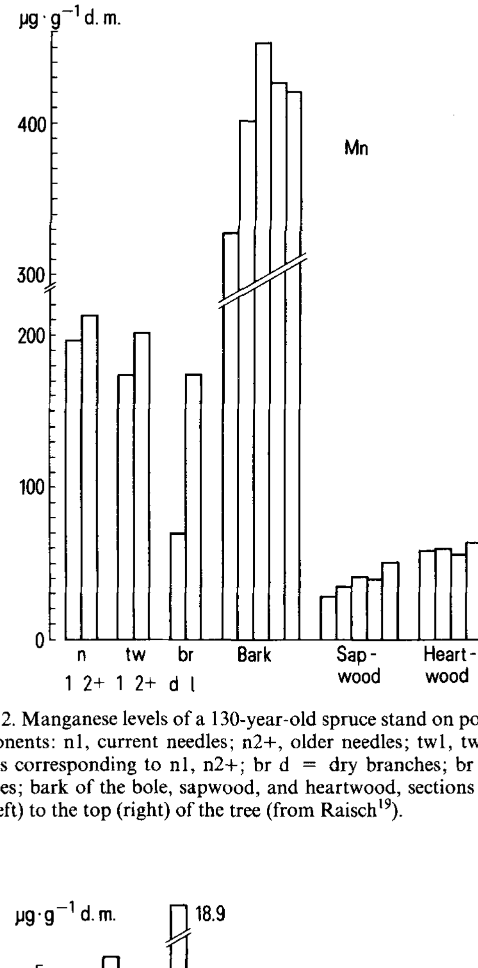

Figure 2. Manganese levels of a 130-year-old spruce stand on podsol soil. Components: n1, current needles; n2+, older needles; tw1, tw2+, twig sections corresponding to n1, n2+; br d = dry branches; br l = live branches; bark of the bole, sapwood, and heartwood, sections from the base (left) to the top (right) of the tree (from Raisch[19]).

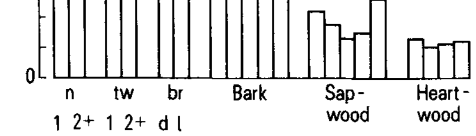

Figure 3. Copper levels of a 130-year-old spruce stand on podsol soil. Components see figure 2 (from Raisch[19]).

There is a minimal lead content (fig. 5) in the wood, in the bark of the lower stem segments, and in one-year-old needles. A clear increase was noticed with increasing needle age, and also in the bark of the upper stem. Peak values are reached in older twigs, and particularly in dead branches. This is typical for an element which is hardly taken up from the soil, with the exception of substrates with extremely high levels (see table 2). Absorption from immission, however, appears to occur at a noticeable level.

Beryllium contents (fig. 6) in sapwood are extremely low, and below the limit of detection in the heartwood. Needles, twigs, and branches show an increasing content with advancing age; bark also shows a higher content. This suggests that it is related to the time of exposure to atmogenic input. A passive uptake through the roots also seems to be possible, because of the high mobility of beryllium in the acid soil substrate. Generally, concentration levels in the biomass are extremely low.

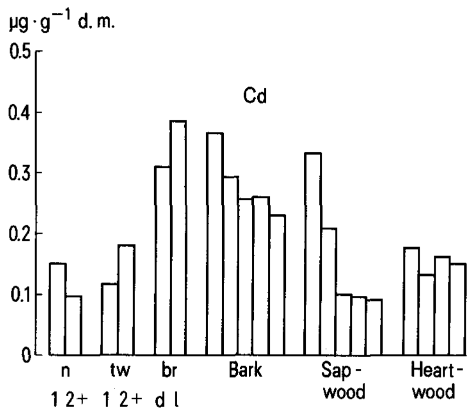

Figure 4. Cadmium levels of a 130-year-old spruce stand on podsol soil. Components see figure 2 (from Raisch[19]).

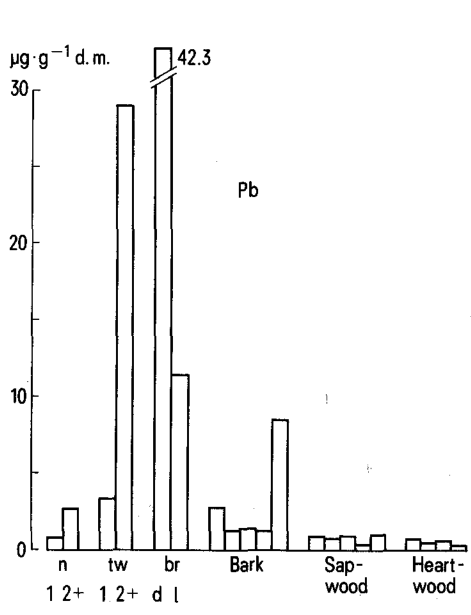

Figure 5. Lead levels of a 130-year-old spruce stand on podsol soil. Components see figure 2 (from Raisch[19]).

6) Turnover in ecosystems of the 'Bärhalde'

Data from Raisch[19] demonstrate the differences in accumulation rates in trees for all five selected elements. In the following paragraphs, we would like to examine fluxes of these elements for some of the sites at the 'Bärhalde'. We will compare the podsol site (already discussed) with the brown earth site presented in the element inventory, and with the nonforested ecosystem 'Weidfeld'. 'Weidfeld' is an extensively used pasture *(Leontodonto helvetici – Nardetum)*, which has already existed for several hundred years; it is unfertilized and on brown earth. In figures 7–11 the annual input-output turnover is given, calculated from weekly sampling data (except for frost periods) during the period from May 1977 to April 1979. Open-land precipitation at the side of the spruce stands, as well as throughfall in the stands was collected with bulk deposition samplers[37]. Litterfall was determined with polyethylene-covered frames[8]. The soil solution or percolation water was sampled with tension lysimeters attached to an Al_2O_3 ceramic draining plate located below the humus-rich upper soil horizon at a depth of 30 cm and below the root zone at a depth of 80 or 100 cm, respectively[5,25].

Manganese input by open precipitation is small (fig. 7); throughfall is 11 to 14 times of the open-land input. The high manganese content in the living needle mass causes high leaching. Input into the soil by litterfall is less than by throughfall. The manganese fluxes with seepage are lower than in the throughfall; this is probably caused by the uptake of plant roots. Percolation water flux in the upper soil of the highly acid podsol (pH 2.8–3.3) is clearly higher than in the less acid brown earth (pH 3.0–3.9 and 3.3–4.1, respectively). The high flux rates demonstrate the important role of manganese in the biological cycling and its easy mobilization in acid, wet soils such as this podsol. Only about ⅓ of the amount which percolates in the spruce ecosystems percolated in the less acid brown earth of the pasture.

Copper input (fig. 8) is only ¼ of the manganese input. Throughfall is similarly low, and approximately the same amount is introduced by litterfall. The copper output from the rooted solum of the brown earth is less than input into the soil. The same applies to the podsol ecosystem, but the turnover rate is clearly higher, which can be explained by the higher copper solubility due to the lower pH. Copper is clearly retained in all ecosystems investigated. This is due to fixation in organic matter and

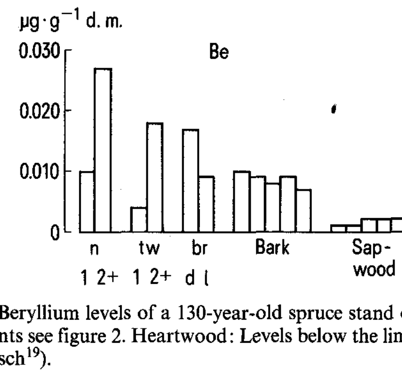

Figure 6. Beryllium levels of a 130-year-old spruce stand on podsol soil. Components see figure 2. Heartwood: Levels below the limit of detection (from Raisch[19]).

also in oxides and clay minerals, as well as accumulation in the biomass.

The cadmium input (fig. 9; please note that levels are in µg) is of the order of ⅕ of that of copper. This is, however, relatively high considering the medium distance between the sample area and industrial sources of emission. On its way through the canopy the amount of cadmium increases 3-fold due to wash-out or leaching. Only a little reaches the ground through litterfall. The washing-off of cadmium deposited on the needles is therefore of importance. Only a little is translocated in the soil solution; this applies particularly to the brown earth ecosystem where humus-rich upper soils with slightly higher pH values cause a stronger adsorption compared with the podsol. All soils analyzed fix cadmium in the lower part of the solum. An additional reason for the reduction in the amount of cadmium percolating through the soil is to some extent the take-up by the roots. The graduation of the seepage values below 80 (100) cm soil depth from the pasture brown earth to the spruce podsol demonstrates the different fixation rates. It causes a positive balance in the brown earth ecosystems. Considering that measurements of open-land deposition do not include dry deposition filtered by the tree crowns and thus increasing the throughfall we can conclude that the balance for the podsol ecosystem is also positive.

The input of lead (fig. 10) is significant despite the very low traffic load of the research area. The retention of emitted lead in the crowns of the spruce stands is evident–especially when additional dry deposition is taken into account. Much more lead reaches the ground through litterfall than as a result of throughfall. Since only a small part of the lead in the litter needles may have been absorbed by roots the increase must be caused by immitted lead deposited on the needle surface. There is a decrease in the amount of lead in seepage soil water with increasing depth. Since the take-up through the roots can be assumed to be insignificant, this depth function is a sign of fixation. Despite pH values of about 4 in the B-horizons the fixation rate is apparently high. The relatively high humus content of these soils is probably mainly

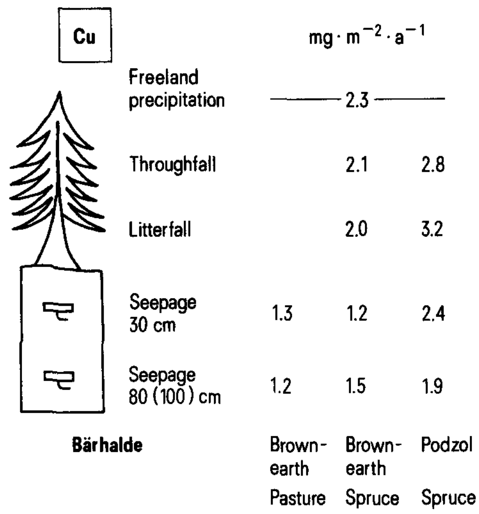

Figure 8. Turnover of copper in three ecosystems in the 'Bärhalde' (from Zöttl[35]).

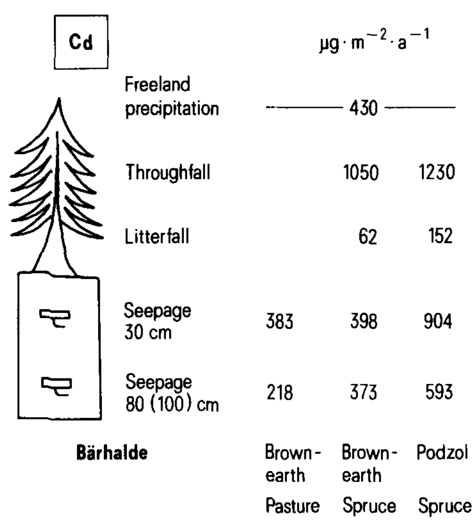

Figure 9. Turnover of cadmium in three ecosystems in the 'Bärhalde' (from Zöttl[35]).

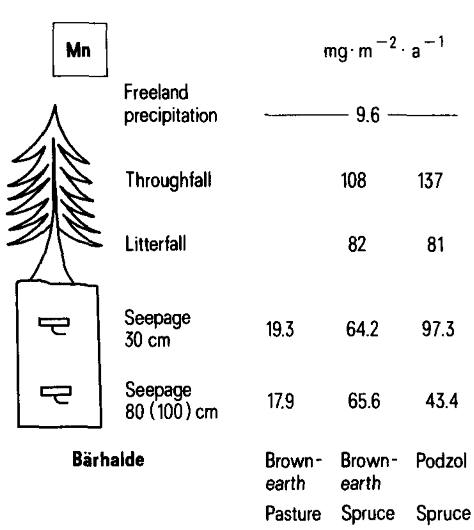

Figure 7. Turnover of manganese in three ecosystems in the 'Bärhalde' (from Zöttl[35]).

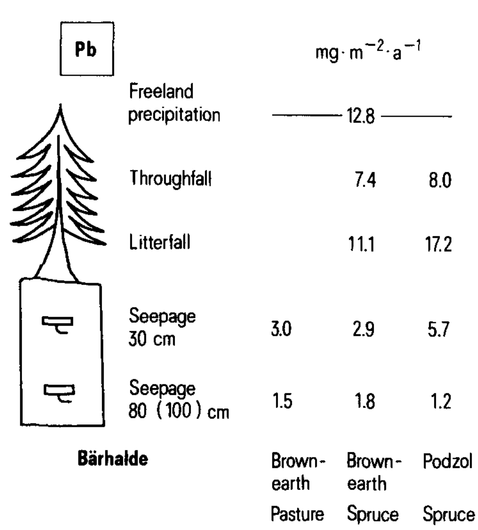

Figure 10. Turnover of lead in three ecosystems in the 'Bärhalde' (from Zöttl[35]).

responsible for this. There is still a strong retention of the lead input despite increasing solubility of lead with decreasing pH; the ecosystems investigated are thus effective sinks.

The situation regarding beryllium (fig. 11) is totally different. There is hardly a change in the amount during transit through the tree canopy. Additionally, there is the flux contained in the litter fall. Assuming that beryllium is hardly absorbed by the roots the content of the litter needles must also derive from emission. Since canopy drip and litterfall contribute almost twice as much to the beryllium input into the soil as open-land precipitation, this surplus must be a result of dry deposition in the spruce stands. The quantities transported through the soil are many times higher than those found in the throughfall, especially in the very acid podsol. There is a high mobilization rate from mineral reserves in these substrates[14]. The different ecosystems presented here consequently show an output of beryllium, with a peak level found in the podsol.

These aspects of element cycling in the 'Bärhalde' ecosystems show the different behavior of the elements analyzed. There is a gradual accumulation of lead and cadmium in the ecosystems. Mobilization pushes would only be possible through intensive decomposition of humus layers after clearcut of the stands. The beryllium input is only a small fraction of the pedogenetically caused output. A similarly negative balance is found with manganese, too. Copper cycling appears to be balanced; it is even slightly positive. With reference to the supply of these two nutrient elements the considerable manganese output losses are not critical because of the extensive reserves of this element, and its mobility. As regards copper, the slight increase caused by immission is to be seen as beneficial.

7) Comparison between 'Bärhalde' and 'Solling'

The results described show the situation for a representative part of the southern Black Forest, with a slight atmogenic heavy metal input. The extent of pollution of geographic areas or ecosystems only becomes clearer when comparing results from different areas. We are going to do this using the data obtained at the 'Bärhalde' and results of the IBPstudy in the 'Solling'[1]. This area in southern Lower Saxony is exposed to emissions originating from the industrial centers in the Ruhr area. The 'Solling'data refer to the spruce stand of this research site[6].

The 'Solling' is at an altitude of 500 m above sea level, on a mesozoic sandstone plateau (Buntsandstein) with a cover of silty loam. The spruce stand itself is about 90 years old. This largely corresponds in age and biomass with the two older spruce stands at the 'Bärhalde'. Some characteristic data for both stands are given in table 6; they are based on the following periods of measurements: May 1977 to April 1979 for 'Bärhalde'; November 1974 to April 1979 for 'Solling'.

Data for manganese, copper, cadmium, and lead are listed; beryllium was not analyzed in the 'Solling' study. There is a considerably higher open-land input in the 'Solling'. The input of cadmium and lead is three times that of the 'Bärhalde', for manganese even higher. The copper input in the 'Solling' is 10 times higher. This indicates that the immission loading of the 'Solling' is higher than at the 'Bärhalde'; it is also more concentrated as the 'Solling' has only half the annual precipitation of the 'Bärhalde' (1066 mm and 1900 mm, respectively). In consequence, the 'Solling' shows higher values for throughfall and litterfall. In the case of manganese the rise in the throughfall is more than proportional. The higher mobility of this element in the more acid soil of the 'Solling' ecosystem appears to play a role.

The differences between the two ecosystems are also obvious in the element contents of the tree components. Proportions of cadmium are largely the same. Lead, however, increases markedly in the exposed older parts (older needles, twigs, branches, bark) of 'Solling' spruces, and we conclude that there is a higher input by dry deposition in the 'Solling'. The manganese content of the ecosystem compartments in the 'Solling' are comparable to those measured at the 'Bärhalde'. This can be attributed to the very high manganese mobility at both sites. The high copper content of all the tree components at the 'Solling' are somewhat astonishing. This does not only apply to exposed parts of the tree, as the data for wood (46 $\mu g \cdot g^{-1}$) are also extremely high. Nevertheless, the results of Isermann[12] from spruce wood of the same 'Solling' stand have shown levels of 1.5–4.5 $\mu g \cdot g^{-1}$, i.e. in the range of the 'Bärhalde' results. Manganese, lead, and cadmium data reported by Isermann were at a similar level to those given by Heinrichs and Mayer[6] for the 'Solling'(table 6). Summarizing these results it appears to be clear that the 'Bärhalde' is less exposed to stress originating from emissions than the 'Solling' site.

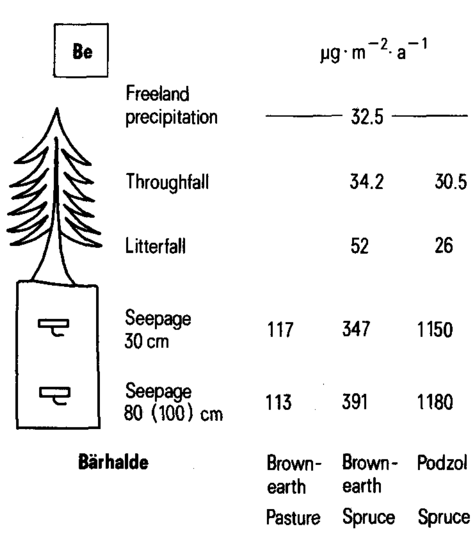

Figure 11. Turnover of beryllium in three ecosystems in the 'Bärhalde' (from Zöttl[35]).

8) Turnover rate and soil fauna

The soil fauna also participates in the heavy metal turnover in forest ecosystems, especially in the transformation of litter and humus layers. Deep-burrowing animals also have an effect on important transformations in the mineral soil. As far as the southern Black Forest is con-

Table 6. Heavy metals in spruce stands. 'Bärhalde': 75–130 years; above-ground biomass 249,000–219,000 kg · ha^{-1}. 'Solling': 90 years; above-ground biomass 245,000 kg · ha^{-1}

	Mn		Cu		Cd		Pb	
	Bärhalde	Solling	Bärhalde	Solling	Bärhalde	Solling	Bärhalde	Solling
Quantities (g · ha^{-1} · a^{-1})								
Freeland precipitation	96	388	23	236	4	16	128	285
Throughfall	1225	6480	25	227	11	20	77	467
Litterfall	820	5800	26	240	1	2	142	256
Contents (µg · g^{-1} d.m.)								
Needles (current)	320	560	4.0	24	0.10	0.31	0.56	5.4
Needles (older)	500	1320	3.3	37	0.08	0.31	2.30	11.8
Twigs (current)	240	440	11.4	39	0.12	0.61	2.95	8.6
Twigs (older)	320	560	9.9	40	0.18	0.81	24.21	56
Branches	210	485	11.8	34	0.31	1.20	8.63	53
Bark	460	355	4.9	32	0.42	1.45	1.76	19
Wood	70	160	1.6	46	0.16	0.36	0.96	7

Data for 'Bärhalde' from Zöttl[35], Holzapfel[8] and Raisch[19]; for 'Solling' from Heinrichs and Mayer[6] and Mayer[17].

cerned this applies mainly to the very big earthworm *Lumbricus badensis*[16].

So far only few research studies on the heavy metal content of the soil macrofauna and the element distribution in the various microhabitats have been published. We would like to present some results of our studies of lead and cadmium in the Upper Münstertal[38] (site conditions similar to the 'Bärhalde'). The content of these elements in the dry matter of epiphytic lichens, ground vegetation, and litter layers is presented *in figure 12*. As far as lead is concerned the previously mentioned high adsorption capacity for heavy metals of some long-living cryptogams with a fine structured surface can be confirmed for lichens. Fruiting bodies of basidiomycets developing within a few days show very low lead contents, because of their short time of exposure and low rate of uptake of this particular element. In contrast, the cadmium content in fungi is relatively high. This corresponds with other results[4] showing that cadmium is very effectively enriched in the mycelium of higher fungi. The contents of both elements in ground vegetation species *(Deschampsia flexuosa, Luzula silvatica, Luzula luzuloides, Rubus idaeus)* were found to be at a medium level.

The heavy metal levels in the food chain: litter–earthworm–earthworm excrements (see fig. 12, right-hand side) give further information. Average values for the litter layer, i.e. the already microbially decomposed spruce needles and beech leaves, are presented. They represent the potential food of the earthworm *Lumbricus badensis*. The lead contents of the litter, the cleaned earthworm, and its excrements are quite similar. There are apparently no changes along the food chain. The lead contents found are rather high, due to the longer exposure time of the litter material (first on the tree and then on the soil surface), and to the relative increase caused by mass losses during microbial decomposition.

A totally different picture becomes apparent when looking at cadmium. The concentration levels in the earthworm dry matter are about 10 times higher than in the food itself; the excrements, however, reach the same low level as the food. There is obviously a noticeable cadmium enrichment in the animal tissue. Similar results regarding cadmium in invertebrates are reported by Ireland[10,11]. The data of figure 13 clearly underline this enrichment of cadmium in the tissue of the earthworm *Lumbricus badensis*. The astonishingly high values (up to 130 µg · g^{-1} dry matter) depend partly on the long lifetime

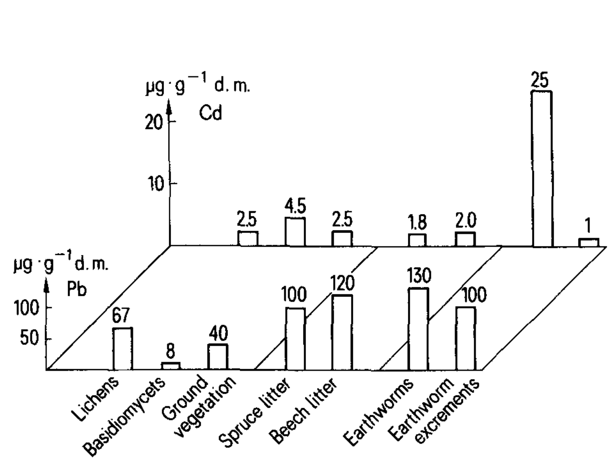

Figure 12. Contents of lead and cadmium in research area 'Münstertal' (from Zöttl and Lamparski[38]).

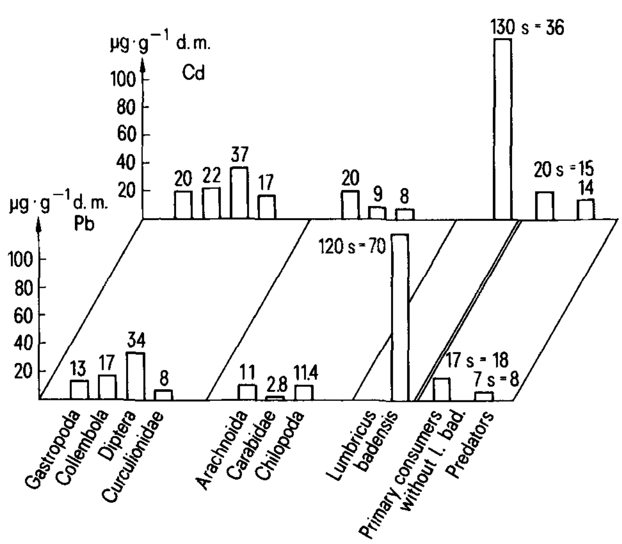

Figure 13. Contents of lead and cadmium in the soil macrofauna in research are 'Münstertal'; s, standard deviation (from Zöttl and Lamparski[38]).

of the examined animals (they may be as old as 10 years). On the other hand, we have to consider that these earthworms do not feed on the litter itself, but rather on microorganism colonies on the surfaces of litter particles. Thus they take their food mainly from highly structured soil surfaces which receive the full input of the canopy drip. Finally, it should be noted that the cadmium contents in figure 12 may be a bit too low as a different method of combustion was used[37]. This has to be considered when comparing these results with the data given in figure 13. The lead values, however, are not affected by this modification in the method of analysis.

In figure 13 different components of the soil fauna are presented. We have selected groups with a significant turnover capacity and high abundance on the respective site. Slugs (Gastropoda), springtails (Collembola), flies (Diptera), weevils (Curculionidae) (fig. 13, left part) are mainly primary consumers and detritus feeders. The center of figure 13 details zoophagous animals (predators): spiders, carabid beetles (Carabidae) and centipedes (Chilopoda). The two groups show different levels for cadmium and lead. It is surprising to see that the values for the predators are lower than those for the detritus feeders. There is apparently no accumulation of these elements in the food chain. The lower metal contents of the predators can be explained by their feeding habits. They often eat only parts of their prey, sometimes after external digestion. Furthermore the accumulation of heavy metals is limited by repeated molting in the larval phase. The low values for carabid beetles are probably caused by the higher proportion of dry matter (chitin shell) in relation to the fresh weight. This assumption is supported by the very low values for weevils in the group of detritus feeders.

These few summarized data already show that there are marked differences in heavy metal contents. Certain regularities in the turnover processes also become evident. Considering the high biomass of the big earthworm *Lumbricus badensis* the turnover activities of other components of the soil macrofauna appear to be insignificant. This can be demonstrated by comparing the humus profiles of microhabitats with or without earthworms. Without *Lumbricus badensis* there is a moder humus with a pronounced litter layer (L-layer), a laminar fermentation layer (F-layer) filled by mycelium and a thin humification layer (H-layer) above the mineral soil. The presence of earthworms leads to fast litter decomposition with incorporation of organic material into the upper mineral soil, thus producing a special form of mull humus with an A_{hr}-horizon.

In table 7 the contents of cadmium and lead of different ecosystem compartments are compared with each other. The high accumulation of cadmium in the macrofauna and particularly in the earthworm community increases cadmium values to the same level as lead in the macrofauna dry matter. The contents of the two elements in the mineral soil differ by a factor of 200.

The amounts ($mg \cdot m^{-2}$) of cadmium and lead are presented in table 8. Naturally, the lithogenic soil reserves exceed the amounts contained in the ground flora and the fauna by a factor of 100. The *Lumbricus badensis* population, however, contains 4 mg Cd per m^2. This corresponds to $\frac{1}{20}$ to $\frac{1}{10}$ of the cadmium reserves in the upper 15 cm of the soil and indicates a considerable rate of accumulation in animal biomass.

Table 7. Contents of lead and cadmium ($\mu g \cdot g^{-1}$ d.m.) in research area 'Münstertal'

	Pb	Cd
Mineral soil	50	0.3
Ground vegetation	40	2.5
Basidiomycetes (fruiting bodies)	8	4.5
Macrofauna	3–30	10–40
Lumbricus badensis	120	130

From Zöttl and Lamparski[38].

Table 8. Quantities of lead and cadmium ($mg \cdot m^{-2}$) in research area 'Münstertal'

	Pb	Cd
Soil	6000–10000	40–100
Ground vegetation	3	0.2
Soil fauna without *Lumbricus badensis*	0.1	0.1
Soil fauna with *Lumbricus badensis*	3.5	4.0

From Zöttl and Lamparski[38].

9) *Long-range transport of heavy metals and forest decline*

'Clean air areas' like the Black Forest are also affected by pollutants generated a long distance away; heavy metals are part of this immission. The element inventories and turnover data presented, however, show that the extent of this stress is low. However, trees have a high filtering capacity, particularly for dry deposition of heavy metal aerosols. Generally, forest ecosystems act as a sink, especially for toxic elements such as cadmium and lead. This applies also to the 'Bärhalde', even with its very acid soils. The accumulation of the elements occurs in a characteristic way in the different compartments of the ecosystems studied. The heavy metal contents found are so low that no direct damage to trees or other components of the ecosystem is to be expected. Higher copper and zinc inputs may even mean an improvement of the partly insufficient supply[39]. No causal relationship between heavy metal immissions and the forest decline, which has been increasing over the last years in the Black Forest, could be observed[33]. This may also apply to other forest areas affected by the decline and stressed by long-range immission of heavy metals, although there are of course regional differences in input levels[21]. The 'Solling', for example, apparently shows a higher input than sites in southern Germany.

Increasing heavy metal accumulation may in the long run pose a potential danger. It is less dangerous in times of increasing fixation compared with times of increased decomposition of organic layers, when aquatic ecosystems and the drinking water supply could become endangered.

Acknowledgment. I would like to thank the Deutsche Forschungsgemeinschaft for financial support and Dr L. W. Blank for correcting the language.

1 Ellenberg, H. (ed.), Integrated Experimental Ecology. Methods and Results of Ecosystem Research in the German Solling Project. Ecological Studies, vol. 2. Springer, Berlin, Heidelberg, New York 1971.

2 Ernst, W., Schwermetallvegetation der Erde. Fischer, Stuttgart 1974.
3 Ferraz, J., and Zöttl, H.W., Nährelementspiegel und Spurenelementverteilung in Fichtenbeständen des Grundgebirgs-Schwarzwaldes. Mitt. dt. bodenkdl. Ges. *29* (1979) 587–593.
4 Fleckenstein, J., Artspezifische und selektive Affinität von Wildpilzen zu Schwermetallen im Ökosystem. Mitt. dt. bodenkdl. Ges. *29* (1979) 451–456.
5 Hädrich, F., Stahr, K., and Zöttl, H.W. Die Eignung von Al_2O_3-Keramikplatten und Ni-Sinterkerzen zur Gewinnung von Bodenlösungen für die Spurenelementanalyse. Mitt. dt. bodenkdl. Ges. *25* (1977) 151–162.
6 Heinrichs, H., and Mayer, R., The role of forest vegetation in the biochemical cycle of heavy metals. J. envir. Qual. *9* (1980) 111–118.
7 Hildebrand, E., Die Bindung von Immissionsblei in Böden. Freibg. bodenkundl. Abh. *4* (1974) 1–147.
8 Holzapfel, W., Die Rolle des Streufalls im Bioelementumsatz verschiedener Fichtenökosysteme an der Bärhalde (Hochschwarzwald). Dipl. Arb. Forstwiss. Fak. Freiburg i. Br., 1980.
9 Hurrle, H., Schwermetalle in Nadelbäumen auf alten Bergbauhalden im Südschwarzwald. Allg. Forst- Jagdztg *152* (1981) 234-238.
10 Ireland, M.P., The effect of the earthworm *Dendrobaena rubida* on the solubility of lead, zinc, and calcium in heavy metal contaminated soil in Wales. J. Soil Sci. *26* (1975) 313–318.
11 Ireland, M.P., Metal accumulation by the earthworms *Lumbricus rubellus, Dendrobaena veneta* and *Eiseniella tetraedra* living in heavy metal polluted sites. Envir. Pollut. *13* (1979) 201.
12 Isermann, K., Bewertung natürlicher und anthropogener Stoffeinträge über die Atmosphäre als Standortfaktoren im Hinblick auf die Versauerung land- und forstwirtschaftlich genutzter Böden. VDI-Ber. *500* (1983) 307–335.
13 Keilen, K., Spurenelementverteilung und Bodenentwicklung im Bärhaldegranitgebiet (Südschwarzwald). Freibg. bodenkdl. Abh. *8* (1978) 1–278.
14 Keilen, K., Stahr, K., Von der Goltz, H., and Zöttl, H.W., Zur Pedochemie des Berylliums – Untersuchungen einer Bodengesellschaft im Gebiet des Bärhaldegranits (Südschwarzwald). Geoderma *17* (1977) 315–329.
15 Kreutzer, K., Manganmangel der Fichte (*Picea abies* Karst.) in Süddeutschland. Forstwiss. Centbl. *89* (1970) 275–299.
16 Lamparski, F., and Zöttl, H.W., Der Regenwurm *Lumbricus badensis* als bodenprägender Faktor im Südschwarzwald. Mitt. dt. bodenkundl. Ges. *30* (1981) 499–508.
17 Mayer, R., Natürliche und anthropogene Komponenten des Schwermetallhaushaltes von Waldökosystemen. Göttinger bodenkdl. Ber. *70* (1981) 1–292.
18 Nebe, W., Zur Manganernährung der Fichte. Arch. Forstwes. *16* (1967) 109–118.
19 Raisch, W., Bioelementverteilung in Fichtenökosystemen der Bärhalde (Südschwarzwald). Freibg. bodenkdl. Abh. *11* (1983) 1–239.
20 Rehfuess, K.-E., Standort und Ernährungszustand von Tannenbeständen (*Abies alba* Mill.) in der südwestdeutschen Schichtstufenlandschaft. Forstwiss. Zentbl. *86* (1967) 321–348.
21 Rehfuess, K.-E., Walderkrankungen und Immissionen. Allg. Forstztg *38* (1983) 601-610.
22 Reissmann, B., and Zöttl, H.W., Mineral nutrition and growth of pine plantations in Southern Brazil. IUFRO Symposium on Site and Productivity of Fast Growing Plantations, p. 647–658. Pretoria, Pietermaritzburg (South Africa) 1984.
23 Rühling, A., and Tyler, G., Heavy metal pollution and decomposition of spruce needle litter. Oikos *24* (1973) 402–416.
24 Smilde, K.W., and Van den Burg, J., Mogelijkheden en problemen bij het toepassen van zuiveringsslib in bossen. H_2O *16* (1983) 446–450.
25 Stahr, K., Zöttl, H.W., and Hädrich, F., Transport of trace elements in ecosystems of the Bärhalde watershed in the southern Black Forest. Soil Sci. *130* (1980) 217–224.
26 Stoate, T.N., Nutrition of the pine. Bull. Forest. Timber Bureau Canberra *30* (1951).
27 Tyler, G., Heavy metal pollution and mineralisation of nitrogen in forest soils. Nature *255* (1975) 701–702.
28 Van Goor, C.P., Spurenelemente bei der Ernährung von Koniferen, in: Ernährung und Düngung der Fichte. Dt. Akad. Landwirtschaftswiss. Berlin, Tagungsber. *84* (1968) 147–155.
29 Wehrmann, J., Mangan- und Kupferernährung bayerischer Kiefernbestände. Forstwiss. Zentbl. *80* (1961) 167–174.
30 Wilke, B.-M., Über Sorption und Wirkung von Blei auf die biologische Aktivität terrestrischer Humusformen. Z. Pflanzenern. Bodenk. *145* (1982) 52–65.
31 Will, G.M., New Zealand J. Forest Sci. *8* (1978) 4–14.
32 Zech, W., Kalkhaltige Böden als Nährsubstrat für Koniferen. Diss. Naturwiss. Fak. Univ. München, 1968.
33 Zöttl, H.W., Zur Frage der toxischen Wirkung von Aluminium auf Pflanzen. Allg. Forstztg *38* (1983) 90–91.
34 Zöttl, H.W., Wirkung von Luftschadstoffen auf Waldökosysteme. Allg. Forstztg *38* (1983) 1360.
35 Zöttl, H.W., Schwermetalle im Stoffumsatz von Waldökosystemen. Bielefelder Ökologische Beiträge *1* (1985) 31–49.
36 Zöttl, H.W., Stahr, K., and Keilen, K., Spurenelementverteilung in einer Bodengesellschaft im Bärhaldegranitgebiet (Südschwarzwald). Mitt. dt. bodenkdl. Ges. *25* (1977) 143–147.
37 Zöttl, H.W., Stahr, K., and Hädrich, F., Umsatz von Spurenelementen in der Bärhalde und ihren Ökosystemen. Mitt. dt. bodenkdl. Ges. *29* (1979) 569–576.
38 Zöttl, H.W., and Lamparski, F., Schwermetalle (Pb, Cd) in der Bodenfauna des Südschwarzwaldes. Mitt. dt. bodenkdl. Ges. *32* (1981) 509–518.
39 Zöttl, H.W., and Mies, E., Die Fichtenerkrankung in Hochlagen des Südschwarzwaldes. Allg. Forst- Jagdztg *154* (1983) 110–114.

0014-4754/85/091104-10$1.50 + 0.20/0

Full Papers

Studies on some enzymes of the toad (*Bufo melanostictus*) testis and their probable role at the time of fertilization

M. Shylaja and H.S. Seshadri[1]

Department of Postgraduate Studies and Research in Biochemistry, University of Mysore, Manasagangotri, Mysore–570006 (India), 6 April 1984

Summary. Glycosidases like sialidase, β-galactosidase, α-L-fucosidase, N-acetyl hexosaminidase and proteases were detected in toad testis. Neuraminic acid aldolase activity was also detected. The enzyme activities were found to vary as production of spermatozoa varied. All enzymes, except N-acetyl glucosaminidase, were shown to decrease after injection of toad pituitary extract and they were also found to be absent from testis containing no spermatozoa. The glycosidases were found to act on toad oviduct jelly and they may therefore be involved in the degradation of the jelly after fertilization, into smaller bits, which may be utilized as nutrients by the fertilized zygote.
Key words. Bufo melanostictus; glycosidases; testis; pituitary extract; fertilization; oviduct jelly.