Capercaillie Tetrao urogallus decline and emissions from the iron industry

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Long-term emissions of calcium-containing dusts from an iron factory influenced soil pH, vegetation and perhaps contributed to the capercaillie *Tetrao urogallus* decline in the study area in eastern Germany. Dramatic changes of the ground vegetation were observed in time (vegetation analyses in 1956, 1965, 1983 and 1990-1993) and along the pH-gradient. Near the emission source the mean number of plant species has increased from 15 to 65 since 1956. Ericaceae (*Vaccinium myrtillus*, *V. vitis-idea*, *Calluna vulgaris*), which are essential to capercaillie for food and cover, were replaced by *Senecio fuchsii*, *Digitalis purpurea*, *Dactylis glomerata*, *Calamagrostis epigeios*, *Rubus idea*, *Myringia trinerva*, and *Urtica dioica*. The decline in capercaillie numbers was correlated with the eutrophication effects of the emissions as measured by the increase of plant species diversity. Increasing plant species diversity may also favour small rodents and thereby the density of predators (such as the red fox *Vulpes vulpes* and wild boar *Sus scrofa*), as indicated by the increased hunting bags. Therefore, the increased predation on capercaillie nests and chicks that was documented on the study area over time may be a secondary effect of air-borne pollution.

Key words: capercaillie, changes in ground vegetation, industrial emissions, predation, Tetrao urogallus

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The capercaillie *Tetrao urogallus* is declining dramatically in Central Europe. There is certainly a multifactorial complex of factors responsible for this decline, which makes it very difficult to conduct a causal analysis of the problem. Negative influences of modern forestry have been reported earlier (Klaus 1982, 1984, 1991). Air-borne pollution is often discussed as one of the complex of negative factors causing the decline (along with e.g. habitat loss, habitat fragmentation, predation, human disturbance), but few studies of its possible influences exist. The normally low-level effects of air-borne pollution on grouse are not easy to study. However, the heavy and long-term input of CaO into a pine forest ecosystem on our study area magnified changes of soil pH and mobilised nitrogen in the forest soils in a unique way. Therefore, we used the pollution gradient of a strong emission source to investigate environmental changes within capercaillie habitat. In this long-term study (1956-1993), our objectives were to analyse the influence of emissions on ground vegetation, on capercaillie decline, and on predation rates on capercaillie nests and chicks.

Study area

The reserve 'Uhlstädter Heide' (1,000 ha) was established in 1981. It is dominated by secondary Scots pine *Pinus sylvestris* forests on the Thuringian Saale-Sandstone-Plateau, near Saalfeld, eastern Germany. The long-term removal of litter in the last centuries resulted in poor acid soils and the former natural vegetation (Abieti-pinetum and Melico-Fagetum submontanum) was replaced by *Vaccinium*-rich pine forests mixed with ca 25% Norway spruce *Picea abies* and 5% beech *Fagus sylvatica*. The area is characterised by the following parameters: altitude: 400-450 m a.s.l.; mean annual temperature: 7-8°C, precipitation: 600-700 mm per year; soil types: podsol, brown soil or podsol-gley.

The capercaillie living in the reserve are part of the Thuringian capercaillie population, which has been isolated from other populations since about 1970. At the beginning of our studies, the Thuringian population of capercaillie numbered about 300 adults in spring. In 1990, the last time a capercaillie was observed in the reserve, about 30 adult capercaillie remained in Thuringia. The decline was more pronounced on the study area than in the rest of Thuringia. The decline of capercaillie was not influenced by hunting, because hunting of this species was prohibited before 1960 in the entire German Democratic Republic.

The iron and steel factory 'Max-Hütte Unterwellenborn' was established about 100 years ago near Saalfeld, East Germany and is located southwest of the study area (Fig. 1). The maximum level of emissions was recorded in 1974: 3,700 tonnes SO_2, 82,000 tonnes CO_2, and 19,000 tonnes CaO (in 1973: 25,000 tonnes CaO). After 1979, CaO was reduced to about 25% of the original level by filtration (all data from the chemical laboratory of the factory).

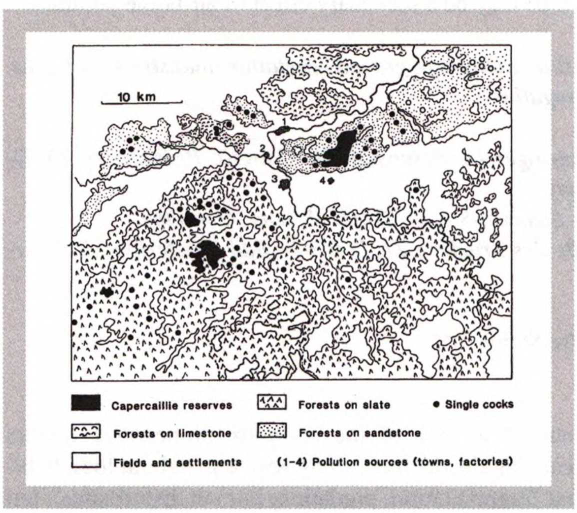

Figure 1. Location of capercaillie reserves in Thuringia; the uppermost (NE) is the study area, the reserve 'Uhlstädter Heide' and the nearby main pollution source (4) 'Max-Hütte' near Saalfeld. Towns in the Saale valley are marked by numbers 1-3. Prevailing wind comes from the southwest.

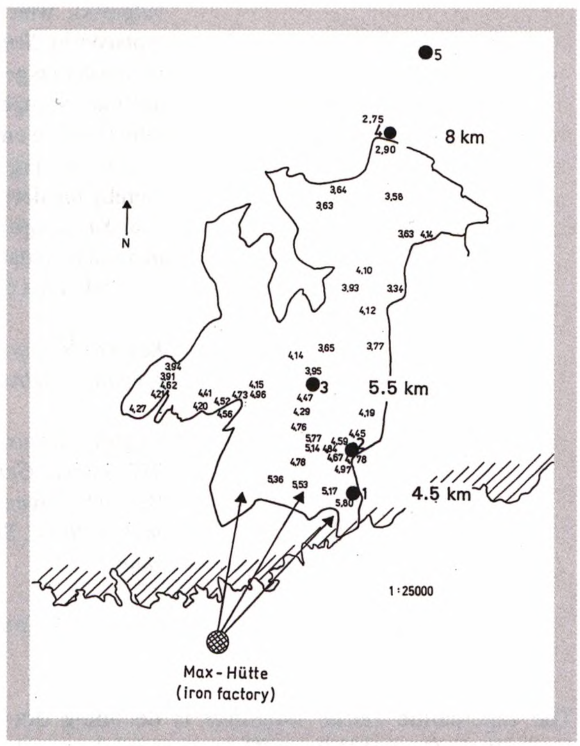

Figure 2. Location of the study area, the reserve 'Uhlstädter Heide' (black line) and of the iron factory 'Max-Hütte'. Prevailing wind direction is marked by arrows; the border of closed forests is shadowed; pH values (i.e. means of three measurements of samples taken from the surface of forest soil) are indicated by smaller figures and the study sites (in total 2,500 m²) for vegetation analysis are marked by filled circles and larger figures (1-5).

Methods

Capercaillie numbers and nest predation

Adult birds were counted yearly during spring display in April and May on the leks of the 1,000-ha study area. The sex ratio was estimated in the week when most females visited the displaying males. In addition, direct and indirect observations around the year were collected and used in an effort to map the home ranges of individual birds. Altogether 27 nests were used to calculate nest predation rate, hatching rate and cause of nest predation. Broods were counted in August-September and the sex ratio and daily mortality coefficient (see Lindén 1981) were determined. In addition to our own observations, observations of broods collected by the foresters were used. Two periods were compared, 1971-1975, when capercaillie numbers were high, and 1976-1985, when numbers were low.

Predator densities

The hunting bag of red fox *Vulpes vulpes* and wild boar *Sus scrofa* on the reserve and the surrounding area, consisting of 10,000 ha of forests and 10,000 ha of fields, was considered to represent an indirect measure of density, because the hunting activity remained the same throughout the study period. The bag records were collected by the State Forest Service. The annual harvest of red fox and wild boar was compared with the corresponding capercaillie census for each year between 1970 and 1990 using linear regression.

Soil pH and ground vegetation

The emissions from the factory resulted in a pH gradient in the naturally acid soils from 5.8 in the vicinity of the factory to 2.7, measured in water, 10 km from it (Fig. 2). At every point marked by numbers in Figure 2, representing the pH-values, three soil samples of 10 g were taken during the whole vegetation period (May-September), 2-5 cm below the surface of the soil; the samples were resuspended in distilled water and measured.

The method of Braun-Blanquet (1951) was used to analyse changes of the ground vegetation at the same plots (25 m^2) at different times and at different distances from the emission source along the pH-gradient. With this method the plant cover (in 10% intervals) was estimated within the different strata, i.e. moss layer, field layer, understory and tree layer. Jochen Huhn analysed the vegetation as early as 1956 (6 plots) and 1965 (7 plots), which allowed us to compare vegetation changes over a 37-year period. In 1983, 10 plots and in 1990-1993, 62 plots were investigated. The 62 plots analysed in 1990-1993 were distributed over five control fields along the pollution gradient. In this way, we tested vegetation changes in time and space along the gradient at the plots 3.5, 4.0, 5.0, 8.0 and 10.0 km from the emission source.

Table 1. Changes in the plant species composition of the ground vegetation in the early (1956 and 1965 combined) and the late (1993) period of observation, measured as occurrence in % of all plots.

Species	1956 & 1965 (N = 13 plots)	1990-1993 (N = 62 plots)
Declining species		
Molinia caerulea[1]	33	19
Vaccinium myrtillus[1]	92	34
Calluna vulgaris[1]	41	17
Increasing species		
Picea abies	50	100
Calamagrostis epigeios[3]	36	97
Fagus sylvatica	42	93
Senecio fuchsii[3]	14	93
Quercus robur[3]	3	90
Agrostis capillaris	28	87
Rubus idaeus[3]	14	87
Moehringia trinerva[2]	6	83
Mycelis muralis[2]	11	80
Holcus lanatus	14	67
Poa trivialis[3]	3	63
Poa pratensis[3]	6	60
Poa nemoralis	60	
Species absent in the past		
Festuca gigantea	0	57
Urtica dioica[3]	0	50
Galium rotundifolium[2]	0	50
Dactylis glomerata	0	47
Galium aparine[2]	0	43
Agrostis canina	0	30
Veronica chamaedris	0	30
Galeopsis bifida	0	30
Stellaria media[3]	0	27
Eupatorium cannabium	0	23
Viola riviana	0	23
Taraxacum officinale	0	20
Ranunculus repens	0	17
Epipactis helleborine[2]	0	17
Sambucus racemosa[3]	0	13

[1] acid adapted species; [2] base adapted species; [3] nitrophilic species

Results and discussion

Changes of ground vegetation and capercaillie decline

During the course of our studies the spring density of capercaillie declined from 24 birds per 1,000 ha in 1970 to one in 1990. The decline was significantly correlated with the eutrophication effects of the emissions, as measured by the increase in plant species diversity in the ground vegetation (Table 1, Fig. 3).

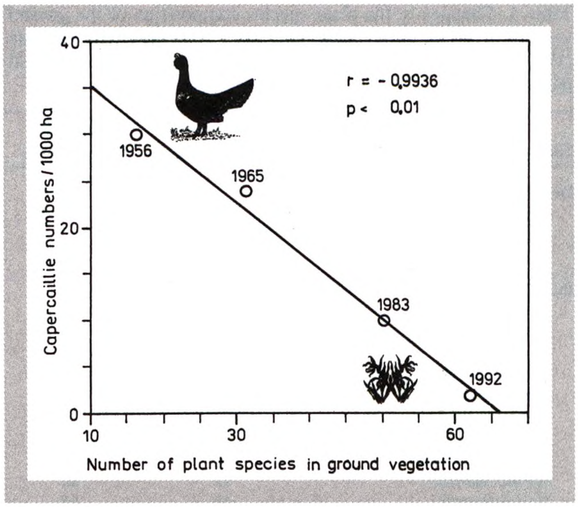

Figure 3. Negative correlation between capercaillie numbers/1,000 ha (in 1956, 1965, 1983 and 1990) and the mean number of plant species estimated in the study sites in each of the above-mentioned years.

The long-term action of calcium also favours the mobilisation of nitrogen, as indicated by the increase of nitrophilic species (see Table 1). The changes were observed in time and space. In the vicinity of the factory, the mean number of plant species per plot was 16 in 1956, 31 in 1965, 50 in 1983 and 65 in 1990-1993. In Table 1 the comparison between two time periods (1956-1965 and 1990-1993) showed that some plant species declined, some increased, and some new species emerged.

The pronounced vegetation changes observed were not caused by 'natural' succession but were due to the high CaO-input, because vegetation analyses carried out at different localities in the surroundings did not show comparable effects (unpubl. data). The appearance of *Picea abies*, grasses and herbs in the field layer of the pine forests showed the change from formerly poor to richer soils. The increase of *Fagus sylvatica* and *Quercus robur* in the field and shrub layers indicated the beginning of the natural regeneration of the former deciduous forests. The occurrence of nitrophilic species like *Urtica dioica*, *Dactilis glomerata*, *Rubus idea*, *Poa trivialis*, *Festuca gigantea*, *Myringia trinerva*, *Sambucus racemosa*, *Geranium robertianum* and *Calamagrostis epigejos* could be explained by eutrophication effects due to enhanced microbial activities resulting from the import of calcium-containing dusts into the forest ecosystem (Klaus, Dörfelt, Berger, Schwartze, Hüttermann & Rastin 1992). To a much lower degree, a 'natural' and/or an air-borne nitrogen-dependent process of succession was occurring, leading to the original forest societies typical for this stand and altitude. In addition to the nitrophilic and basophilic species, typical indicators of deciduous forest stands like *Poa nemoralis*, *Viola riviniana* and *Epipactis helleborine* were also invading the pine forests. Thus, an overlap of both processes is the most probable explanation for the observed changes of the vegetation.

At present, the decline of Ericaceae probably has the most dramatic influence on capercaillie. *Vaccinium myrtillus* was the dominating species before 1975, and is used for food and cover by capercaillie. Bilberry was found in 90% of all plots in the early period, but in only 34% today. The dying out of bilberry has been well documented since 1975; leaves became necrotic and were later lost, fruiting became poorer, and finally stems became brownish and dry. The close association of capercaillie with bilberry has been described by several authors (Storch 1995, Schroth 1995), and Klaus, Andreev, Bergmann, Müller, Porkert & Wiesner (1989) pointed out that the eastern border of the distribution of capercaillie coincides with that of *V. myrtillus*. In our study area 90% of all nests (N = 27) were found under bilberry shrubs. The decline of bilberry and of other Ericaceae, like cranberry or heather, results not only in the loss of cover for nests, chicks and adults, but also in lower food quality around the year (birds feed not only on fruits but also on bilberry shoots in winter when snow cover is low). Both factors, lack of cover

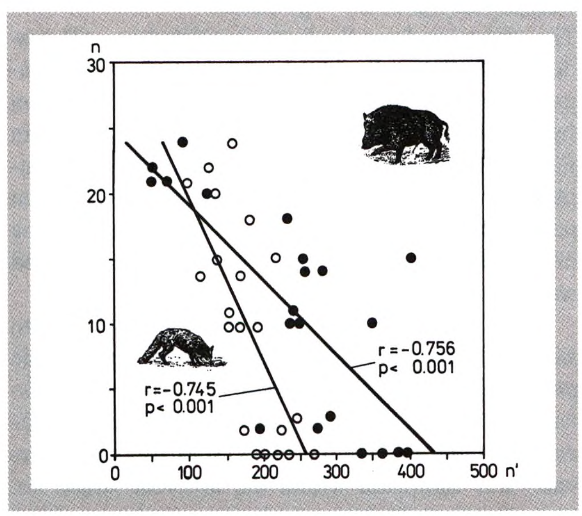

Figure 4. Negative correlation between capercaillie numbers/1,000 ha and the number of red fox (open circles) and wild boar (full circles) harvested per 20,000 ha each year between 1970 and 1990.

and lower food quality, may have contributed to the observed increase in predation (see below).

Densities of red fox and wild boar

The hunting bag of red foxes has increased continuously in both the reserve and the surrounding area (20,000 ha) since 1970 (Klaus 1984 and unpubl. data). The number of foxes killed per year correlated negatively with capercaillie numbers in the study area (1,000 ha, Fig. 4). The same significant correlation was found between the kill of wild boar and capercaillie numbers (see Fig. 4).

We assume that the increasing plant species diversity in the ground layer of the pine forests, caused by the long-term input of CaO-dust from the factory, has favoured small rodents and thereby red fox densities. We have no direct measurements of small rodent densities, but birds of prey that are dependent upon small rodents, such as the pygmy owl *Glaucidium passerinum* and Tengmalm's owl *Aegolius funereus*, birds typically present in capercaillie habitats, increased in number by a factor of 5-10 during the study period. Also wild boar may have benefited from higher plant species diversity and small rodent density. In addition, the wild boar has been favoured by modern forms of agriculture in the surroundings, e.g. larger fields, cultivation of maize.

The increase of both species is now a country-wide phenomenon and by no means restricted to the study area. High nitrogen-input into ecosystems by agriculture and traffic may favour this process throughout Central Europe. However, between 1970 and 1980, the increase in the hunting bag of red fox and wild boar within the study area was extremely high (Klaus 1991), suggesting an enhancing effect caused by the CaO-input described above.

Table 2 . Comparison of demographic data between two periods with high (1971-1975) and low (1976-1985) abundance of capercaillie.

Period	1971-1975		1976-1985	
Sex ratio on the leks[a]	1.1 ± 0.1	(N = 18)	1.3 ± 0.2	(N = 20)[b]
Mean clutch size	7.6 ± 1.3	(N = 14)	7.5 ± 0.5	(N = 13)
Hatching rate (%)	95 ± 7	(N = 9)	91 ± 13	(N = 7)
Chicks hatched per successful nest	7.2 ± 0.9	(N = 9)	7.2 ± 0.4	(N = 7)
Sex ratio in broods[a]	1.0 ± 0.2	(N = 8)	2.2 ± 0.8	(N = 11)
Nests destroyed (%)	35		67	
Daily mortality coefficient of chicks (no/day)	0.013 ± 0.007[c]		0.018 ± 0.009[c]	

[a] females/males;
[b] calculated for the period 1980-1985;
[c] number of broods in 1971-1975: N = 8; 1976-1985: N = 11

A pronounced increase in capercaillie nest predation in the study area from 35% before 1975 to 67% after 1975 has been reported before (Klaus 1984, Table 2). The wild boar was responsible for 31% of the destroyed nests. Other mammalian predators (such as red fox and stone marten *Martes foina*) destroyed an additional 44%, corvids 6% and humans 19% of all capercaillie nests. The comparison of demographic data between two periods with high (1971-1975) and low (1976-1985) abundance of capercaillie showed that, besides the increase in nest predation, the sex ratio in adults and in broods changed to favour hens in the later period and juvenile mortality was increased. Similar results have been reported by Wegge (1980) for declining capercaillie populations in Norway.

Conclusions

From the results presented in this paper and microbiological and enzymological analyses of the forest soils (Klaus et al. 1992 and unpubl. data), we conclude that the complex pine forest ecosystem has changed as the result of the long-term input of the CaO-dominated emissions involving pine-specific mycorrhiza, microbial activities, ground vegetation, forest health (results not shown here), and predation on capercaillie. Although we are aware of the limitations of results based on correlational analyses, we conclude that the disappearance of the capercaillie is one consequence of the chain of events leading from a poor acid adapted pine forest ecosystem dominated by bilberry in the ground vegetation to a rich deciduous forest, which is poor habitat for this inhabitant of the boreal taiga.

It should be pointed out that the forestry industry presently uses calcium-containing compounds country-wide and in an uncontrolled manner to stop forest die-off caused by air-borne acidification of forest soils.

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