Influence of emissions from Cu-Ni smelters on forest ecosystems in the Kola peninsula

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Network of monitoring stations, 1991
Concentration of Nickel (mg Ni/kg, nitric acid soluble) in birch leaves along the three transects.
Emissions from Cu-Ni smelters in the Kola peninsula

- Emissions of SO₂, th. tons/yr
  - Severonikel
  - Pechenganikel

- Solid particles, tons/yr
  - Severonikel
  - Pechenganikel

- Emissions of Ni in dust, tons/yr
  - Severonikel
  - Pechenganikel

- Emissions of Cu in dust, tons/yr
  - Severonikel
  - Pechenganikel
Copper-nickel smelters “Severonikel” (central part of the Kola peninsula) and Pechenganikel” (north-western part of the Kola peninsula) are the most powerful sources of air pollution in the Northern Europe.

Industrial pollution results in forest degradation succession (digression).

Three main degradation stages could be identified:

1. defoliating forests;
2. sparse forests;
3. industrial barrens.
Pollution-induced sparse Pinetum
Pollution-induced sparse Betuletum
Monitoring
Monitoring network ICP-Forsts, 500 km along the western border

Green points – grid 32 x 32 km

Red points– addition to grid 16 x 16 km
Monitoring activity

• Monitoring activity on Level I plots includes: crown condition assessment (defoliation/crown transparency, discolouration, stand and site characteristics which support the interpretability of the crown condition results and serve as a basis for upscaling Level II results), forest soil condition, forest foliar survey (tree nutrition).

• Intensive monitoring on Level II is carried out to detect how various stress factors influence forest ecosystems. The activities require expensive technical equipment for a larger number of surveys.
Monitoring station of Level I
<table>
<thead>
<tr>
<th>Survey</th>
<th>Frequency</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crown condition</td>
<td>at least annually</td>
<td>all plots</td>
</tr>
<tr>
<td>Soil (solid phase)</td>
<td>every 10 years</td>
<td>all plots</td>
</tr>
<tr>
<td>Soil solution</td>
<td>continuously</td>
<td>parts of the plots</td>
</tr>
<tr>
<td>Foliage</td>
<td>every 2 years</td>
<td>all plots</td>
</tr>
<tr>
<td>Deposition</td>
<td>continuously</td>
<td>parts of the plots</td>
</tr>
<tr>
<td>Forest growth</td>
<td>every 5 years</td>
<td>all plots</td>
</tr>
<tr>
<td>Ground vegetation</td>
<td>every 5 years</td>
<td>all plots</td>
</tr>
<tr>
<td>Phenology</td>
<td>several times per year</td>
<td>optional</td>
</tr>
<tr>
<td>Litterfall</td>
<td>continuously</td>
<td>parts of the plots</td>
</tr>
<tr>
<td>Remote sensing</td>
<td>at plot installation</td>
<td>all plots</td>
</tr>
</tbody>
</table>
Stem flow collectors
LITTERFALL SAMPLING
COLLECTORS FOR SOIL WATER
Rain waters
Precipitation below the crowns of spruce trees are characterized by higher acidity resulting from leaching the organic acids and ammonium exchange with protons on the needle surface. This phenomenon can also be explained by high capacity of conifer trees for capture of aerosols owing to large surface of their canopy.

In forest ecosystems total deposition below the canopy consists of wet and dry deposition, gases and aerosols, and substances adsorbed by and emitted from plants. Damaged and old organs of trees are subjected to the more intense leaching of
pH in rain water

Distance, km

(C – below the crowns; EC – edge of crowns; O – open area)
SO$_4$ and Ni in rain water
(C - below the crowns; EC - edge of crowns; O - open area)
Heavy metals in rain waters

Below the crowns

Between the crowns
Ca, Mn, K in rain water
Soil water
Intense downward water migration of element compounds is one of the distinctive features of Al-Fe humus podzol. This soil waters are dilute solutions with total concentration of elements below 1 g/l. **Carbon**, concentration of which ranged from 3 to 100 mg/l, is the predominant element in these waters.

**NH$_4$**, Ca and K are dominating in cationic part (up to 9 and 5 mg/l correspondingly), **SO$_4$** are prevailing among anions (up to 7 mg/l).
Concentrations of the organic matter and major part of elements in soil waters below the crowns were significantly higher than that of between the crowns. In waters below the crowns actual acidity was lower, whereas total acidity was significantly higher in comparison with waters between the crowns.
The reasons for variations in total concentration of nutrients are input of them with litterfall, biological uptake, antagonism between elements, and reactions in soil exchange complex. Concentrations of \textbf{Ni, Cu, Co, Cr, Cd}, constitutes of emissions, in waters of both compartments (below and between the crowns) increased with decreasing distance to the smelter. Concentration of \textbf{S}, the main pollutant, linearly increased only in waters between the crowns but no below, where the maximum in this element concentration has been observed on the defoliation intensification stage.
Ni in soil water from organic horizon, mg/l

Below the crowns

Between the crowns
Cd in soil water from organic horizon below the crowns

Cd in soil water from organic horizon between the crowns
SO$_4$ in soil water from organic horizon below the crowns, mg/l

Mean ±SE ±SD

7 km  28 km  100 km  260 km

SO$_4$ in soil water from organic horizon between the crowns, mg/l

Mean ±SE ±SD

7 km  28 km  100 km  260 km
Pollution-induced changes in acidity and in concentration of organic matter, metals (except for pollutants), and non-metals in soil waters, especially below the crowns, bear non-linear in relative to distance to the source of pollution character, related to variation in litterfall amount and changes in concentration of the organic matter in soil. As a rule, maximal concentrations of all these substances as well ANC have been observed on the stage of intensification of defoliation. Significant increase in carbon and organic anion concentration in waters on this stage was, probably, related to hydrolysis of accumulative forms of humus by catalytic effect of mineral acids and to increase in litterfall amount.
pH in soil water from organic horizon between the crowns
C in soil water from organic horizon below the crowns

Mean ±SE ±SD

7 km 28 km 100 km 260 km
K IN SOIL WATER FROM ORGANIC HORIZON, mg/l

Below the crowns

<table>
<thead>
<tr>
<th>7 km</th>
<th>28 km</th>
<th>100 km</th>
<th>260 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ±SE ±SD</td>
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</tr>
</tbody>
</table>
Mn IN SOIL WATER FROM ORGANIC HORIZON, mg/l

Below the crowns

![Box plot](image-url)
Macronutrients and lanthanides in soil waters
Soil
Organic horizon acidity, pine forests

**Total acidity, A0 (n=74)**

- $R^2 = 0.505$

**Exchangeable acidity, A0 (n=74)**

- $R^2 = 0.271$

**pH, AO (n=74)**

- $R^2 = 0.270$

**Exchangeable H+, A0 (n=74)**

- $R^2 = 0.317$
pH in the organic horizon, birch forests

- pH in organic horizon, Northern gradient
  - N1: 3.8
  - N2: 4.2
  - N3: 4.6
  - N4: 5.0
  - N5: 5.4
  - N6: 5.8

Diagram showing pH values with mean, ±Std. Dev., ±Std. Err., and Mean markers.
Heavy metals in the organic horizons of soil

- Ag: \( R^2 = 0.797 \)
- Cu: \( R^2 = 0.933 \)
- Au: \( R^2 = 0.841 \)
- Se: \( R^2 = 0.941 \)
- Ni: \( R^2 = 0.794 \)
- Co: \( R^2 = 0.959 \)
- Ir: \( R^2 = 0.718 \)

Graphs show the distribution of metals with distance from the source in mg/kg.
Organic horizon—barrier against the downward migration of metals
Ca^{2+}
Mg^{2+}
Mn^{2+}
Zn^{2+}

Nutrient leaching

H^{+}
Ni^{2+}
Cu^{2+}
NUTRIENTS IN HUMUS HORIZON

- **Ca**
  - Pine: 3 g/kg
  - Lichens: 1 g/kg

- **Mg**
  - Pine: 250 mg/kg
  - Lichens: 150 mg/kg

- **Mn**
  - Pine: 150 mg/kg
  - Lichens: 60 mg/kg

- **Cu**
  - Pine: 300 mg/kg
  - Lichens: 100 mg/kg

- **Al**
  - Pine: 50 mg/kg
  - Lichens: 5 mg/kg

- **Ni**
  - Pine: 80 mg/kg
  - Lichens: 10 mg/kg
An explanation for the lower concentration of nutrients is replacement of their cations with protons, $\text{Al}^{3+}$, $\text{Ni}^{2+}$, $\text{Cu}^{2+}$ ions from the soil exchange complex.

$\text{Al}$ mobilization is observed in mineral profile.
Extractable aluminium in B horizon, g/kg

Northern transect

Southern transect
Plants
Concentrations of trace elements in birch along transect through Nikel
Ni, Cu, Pb, S in birch leaves
Concentration of Ca and Mn in leaves of birch on the north gradient and K in blueberry leaves along the north (blue colour), south (green colour) and west (brown colour) gradients.
K in pine current needles, mg/kg
N in pine current needles, mg/kg

Distance from the smelter, km

N in current needles

±Std. Dev.
±Std. Err.
Mean
Concentration of elements in 1-year spruce needle class
1-260 km; 2- 100 km; 3- 31 km;
4 -25 km; 5- 7 km
Concentration of elements in 1-year spruce needle class
1-260 km ; 2- 100 km; 3- 31 km;
4 -25 km; 5- 7 km
Spruce needles length, mm

Background

Defoliation intensification

Defoliation diminishing

Sparse forests
Needle length, mm

Distance from the smelters: 1 - 260 km, 2 - 100 km, 3 - 30 km, 4 - 7 km
Distance from the smelters: 1- 260 km, 2 -100 km, 3- 30 km, 4 - 7 km
Rehabilitation
Under air pollution usually observed natural processes of successions could not develop. The main reasons are:
1 – high level of air pollution (pioneer post-fire species of Cladonia are very sensitive);
2 - insignificant soil seed bank and absence of below the ground reproduction organs because of previous intensive fires;
3 – unfavourable soil conditions.

Improvement of soil nutrient status accelerates rehabilitation succession in sparse forests and triggers successions in barren lands.
Ways for rehabilitation succession

Ways for facilitation
Ameliorative substance application and treatment with fertilizers (dolomitic or calcitic limestone + NPK-fertilizers) without site preparation in order to promote colonization by native plant species and to support the vitality of living plants.

a) to promote colonization by native plant species;
b) to establish plant cover without energy- and time-consuming site preparation;
c) to restore plant community with corresponded to environment structural and functional organisation;
d) to establish plant community tolerant to pollution;
e) to establish a maintenance-free plant cover.
Pioneer stage of succession

Colonization by mosses *Ceratodon purpureus*
Pioneer stage of succession
Colonization by herbaceous plants and willow
Establishment of a herbaceous cover, treatment with ameliorative substances and fertilizers and the use of grass seed mixture without site preparation
Фон

внесение элементов питания:

Ca K Mg

Дефолиационный лес

g/кг хвои

Ca Mg Mn
Thank you for your attention!