Special Issue
Ozone Exposure and Impacts on Vegetation in the Nordic and Baltic Countries
Ground-level ozone in the Nordic and Baltic countries occurs mainly as a result of emissions and long-range transport of the ozone precursors, nitrogen oxides and volatile organic compounds, from continental and southern Europe. There is also an increasingly important northern hemispheric, intercontinental transport component. Thus, the problem of the occurrence of ozone near the ground in northern Europe can only be solved through international negotiations to reduce emissions of ozone precursors over wide geographical areas.

Ozone has to be taken up through the stomata into the leaf interior in order to have a negative impact on vegetation. Thus, within the convention on Long-Range Transboundary Air Pollution (LRTAP), the concept of Accumulated Stomatal Flux of ozone above a threshold Y has been developed. As stomatal opening is promoted by high humidity in the air and in the soil, there will be a larger stomatal ozone flux, at a certain concentration of ozone in the air, at the more humid conditions in northern Europe as compared to, e.g., the dry conditions in the Mediterranean region. As a consequence, risk assessment based on stomatal ozone flux results in ozone impacts on vegetation with a different geographical distribution from that of ozone concentration.

In order to support the flux concept, the LRTAP convention has requested evidence for ozone affecting vegetation across the whole of Europe. In an initiative supported by the Nordic Council of Ministers and the Swedish Environmental Protection Agency, ozone impacts on vegetation in the Nordic Countries and the Baltic States have been addressed. A workshop was held in Gothenburg 17–18 June 2008 to assess current scientific understanding of the adverse impacts of ozone on vegetation in this region. The workshop was attended by 16 experts from Estonia, Finland, Lithuania, the Russian Federation, and Sweden. At the workshop, scientific evidence of ozone impacts on vegetation in Northern Europe at current, and future, ambient or near-ambient ozone concentrations.

In this issue of Ambio we present substantial evidence, especially from Sweden and Finland, that ozone, at levels realistic to Northern Europe, has the potential to cause important negative effects on vegetation. Forest trees, crops and (semi-)natural vegetation are all likely to be affected. For example, in Sweden the evidence indicated ozone impacts of up to 15% reduction in crop yield for wheat and potato and up to 10% reduction in tree growth and leaf chlorophyll content. From Finland there is considerable experimental evidence that increasing ozone concentrations impair the growth of several northern deciduous tree species. In Lithuania, visible ozone-induced leaf injuries were observed on various tree species. Furthermore, Scots pine seedlings of several different Russian provenances showed high ozone sensitivity. The considerable ozone impacts observed in the Nordic Countries and Baltic States at relatively low exposures might well be explained by climatic conditions favoring ozone uptake and/or plant development during the summer months, allowing high rates of ozone uptake to the leaves.

Climate change can promote the formation of ozone itself. In addition, climate change may promote higher stomatal opening of plants in the Nordic climate, thus enhancing ozone uptake and thereby the risk for effects on vegetation. Since periods with high or low ozone concentrations are closely associated with the weather conditions, any changes in the climatic pattern, as well as the dominating wind direction, may strongly influence future ozone patterns in the North European region. A significant problem is the rising hemispheric background ozone concentration, which has been shown to lead to rising average ozone concentration in northern Fennoscandia as well as in coastal Lithuania.

The boreal forest is today mainly a carbon sink, which removes carbon dioxide from the atmosphere. However, research has indicated high susceptibility of these forests to ozone. If ozone negatively affects the net carbon removal from the atmosphere through photosynthesis, this will lead to enhanced greenhouse warming.

The completion of this special issue of Ambio was made possible by financial support from the Nordic Council of Ministers and from the Swedish Environmental Protection Agency, which is gratefully acknowledged.

**Guest Editors**

Per Erik Karlsson

IVL Swedish Environmental Research Institute

Håkan Pleijel

University of Gothenburg

Elisabeth Kessler

Editor-in-Chief

---

**Ambient Ozone Concentration and Its Impact on Forest Vegetation in Lithuania**

Rasa Girdžiūnė, Brigita Serafiauskaitė, Vidas Stakėnas and Steigvīlē Byčkeniūnē

432–436

**Effects of the Nordic Photoperiod on Ozone Sensitivity and Repair in Different Clover Species Studied Using Infrared Imaging**

Cecilia M. Futsaether, Ane V. Vollsnes, Ole Mathis Opstad Kruse, Eli Otterholt, Knut Kvaal and Aud B. Eriksen

437–442

**Impact of Experimentally Elevated Ozone on Seed Germination and Growth of Russian Pine (Pinus sylvestris) and Spruce (Picea spp.) Provenances**

Nadezda Prozherina, Elena Nakvasina and Elina Oksanen

443–447

**Observations of Ground-level Ozone and NO2 in Northernmost Sweden, Including the Scandinavian Mountain Range**

Jenny Klingberg, Mats P. Björkman, Gunilla Pihl Karlsson and Håkan Pleijel

448–451

**Climate and Emission Changes Contributing to Changes in Near-surface Ozone in Europe over the Coming Decades: Results from Model Studies**

Magnus Engardt, Robert Bergström and Camilla Andersson

452–458

**Synoptic Weather Types and Long-range Transport Patterns for Ozone Precursors during High-ozone Events in Southern Sweden**

Lin Tang, Per Erik Karlsson, Yongfeng Gu, Deliang Chen and Perringe Grenntel

459–464

---

**Editorial**

401

**Ozone Exposure and Impacts on Vegetation in the Nordic and Baltic Countries**

Per Erik Karlsson, Håkan Pleijel and David Simpson

402–405

**Northern Plants and Ozone**

Sirkku Manninen, Salu Huttunen, Hans Temmervik, Lars R. Hole and Sverre Solberg

406–412

**Near-Ambient Ozone Concentrations Reduce the Vigor of Betula and Populus Species in Finland**

Elina Oksanen, Sirkku Manninen, Elina Vapaavuori and Toini Holopainen

413–417

**Rising Atmospheric CO2 Concentration Partially Masks the Negative Effects of Elevated O3 in Silver Birch (Betula pendula Roth)**

Elina Vapaavuori, Jarno K. Holopainen, Toini Holopainen, Riitta Jukkunen-Tiltto, Seija Kaakinen, Anne Kasurinen, Sari Kontunen-Soppela, Katri Kostainen, Elina Oksanen, Petri Peltonen, Johanna Riihikonen and Ingmar Tulv

418–424

**Evidence for Impacts of Near-ambient Ozone Concentrations on Vegetation in Southern Sweden**

Per Erik Karlsson, Håkan Pleijel, Helena Danielsson, Gunilla Pihl Karlsson, Kristin Pikki and Johan Uddling

425–431