Effects of Ozone on European Forest Tree Species – A Concept of Local Risk Evaluation within ICP-Forests

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Introduction

As a reaction of the widespread concern that air pollution is of major cause for the decline of forests in various parts of Europe, the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP-Forests) was established under the UN-ECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) in 1985. Major objectives are

- to provide a periodic overview on the spatial and temporal variation in forest conditions in relation to anthropogenic as well as natural stress factors on an European and national large-scale systematic network (Level I) and
- to contribute to a better understanding of the relationships between the condition of forest ecosystems and anthropogenic (in particular air pollution) as well as natural stress factors through intensive monitoring on a number of selected permanent observation plots spread over Europe (Level II) and to study the development of important forest ecosystems in Europe.

In order to follow possible air pollution induced reactions in forest ecosystems, the development of stress factors and the state of ecosystems is monitored on an annual basis.

Photooxidants with ozone (O_3) as the major compound have been a concern for vegetation in Europe for a long time. It is, however, only during the last decade that impacts of ozone have become an issue of concern in Europe. There is evidence that the ambient O_3 concentrations found in Europe can cause a range of effects to vegetation, including visible leaf injury, growth and yield reductions, and altered sensitivity to biotic and additional abiotic stresses. Long-term effects on trees may impair the function of forest ecosystems, i.e. their role with respect to water and energy balances, soil protection against erosion, vegetation cover in dry areas as well as the aesthetic appearance of the landscape. Some of the most important impacts on plant communities may be through shifts in species composition and loss of biodiversity particularly in areas with large numbers of endemic plant species with unknown sensitivity to O_3. Since troposheric O_3 concentrations have not changed a great deal over Europe for the last decade, and so far, no realistic risk evaluation procedure for forest ecosystems has been established.

As discussed by Grünhage and Jäger (2002) it seems advisable to derive and provide approaches for risk assessments on different scales. While the European scale risk assessments in the frame of the UN-ECE Convention of Long-Range Transboundary Air Pollution are based on modelled ozone concentrations and meteorological parameters, risk evaluation procedures for forests at site or local (km) scale, i.e. for ICP-Forests plots, have to be based on measured data (Figure 1).

The big-leaf module developed for use within the EMEP (Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe) photochemical model can not be applied for site or local scale risk evaluations because the input parameters necessary are normally not measured above forest stands. Because the EMEP big-leaf module is based on leaf-level estimates which have to be up-scaled to canopy level (bottom-up approach), the estimated O_3 fluxes are more or less biased until e.g. the representatively of the leaf/needle, twig or branch estimates is not reflected in the model.

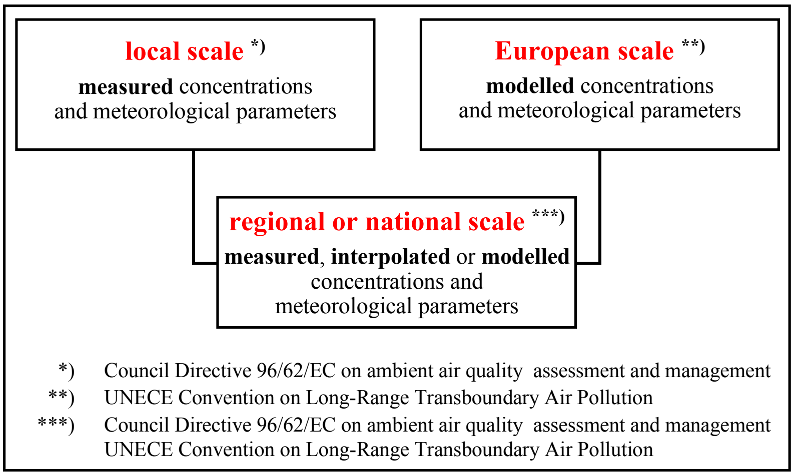

Figure 1: Levels of risk assessment, data used and legal basis (Grünhage et al., 2002)

Concept of local risk evaluation within ICP-Forests

The present concept of local risk evaluation for forest trees in the frame of the 3rd daughter guideline (Directive 2002/3/EC of the European Parliament and the Council of 12 February 2002 relating to ozone in ambient air) of the Council Directive 96/62/EC on the Assessment and Management of Ambient-Air Quality is based on the AOT40 Index, referring to a very limited number of open-top-chamber experiments (only 3 experiments with beech (*Fagus sylvatica*) in seedling age). However, the application of this concept under field conditions implies a saturated field capacity and the knowledge of the O_3 concentrations at the top of the canopy (the upper surface boundary of the (quasi)-laminar layer; (Fuhrer and Achermann, 1994; Kärenlampi and Skärby, 1996). The application of the AOT40 index in the frame of the 3rd daughter guideline disregards this definition "ozone concentration = ozone concentration in canopy height" leading in general to an overestimation of possible effects and are hence no basis for a realistic risk evaluations scenario, despite several other uncertainties.

Due to the above mentioned uncertainties with the current AOT40 indices the working group "Effects of Ozone on Plants" of the Commission on Air Pollution Prevention (KRdL) of the Association of German Engineers (VDI) and the German Institute of Standardisation (DIN) reanalysed the recent literature on O_3 effects on European plants species, subdivided in the groups agricultural species, semi-natural vegetation and forest species. In the following the alternative concept, and the derivation of maximum permissible O_3 concentrations to protect vegetation (Figure 2, Table 1) was elucidated as the basis for the revision of the German guideline VDI 2310 part 6 (1989, 2002). For the first time, the concept follows a flux related approach, since the guideline requires explicitly the transformation of ozone concentrations from ambient air monitoring stations measured in reference height (e.g. 3.5 m a.g.l.) [$\rho_{O3}(z_{ref})$] to the concentrations at the top of the canopy [$\rho_{O3}(d+z_{0m}$] (the upper surface boundary of the quasi-laminar layer, applying the micrometeorological big-leaf approach; Grünhage et al., 2000).

In a second step a risk evaluation concept was developed (VDI 2310 part 6, 2002; Grünhage et al, 2001). All single 1-hour means of a given ozone monitoring station are transformed to canopy height for the time span 1. April – 30. September, which has been defined as growing season, applying an appropriate big-leaf model and sorted in descending order (y= concentration in ppb, x= running number). By aggregation of a given number of hourly means, indices can be derived for e.g. 1h, 8h, 1-, 7-, 14-, 28-, 48- and 90-days as well as the mean for the whole time period. Indices derived by this method are conservative, since they imply that all high O_3 concentrations at the plant surface coincide within the chosen time for the describing index as well as that all O_3 concentrations at the plant surface are toxicologically effective, thus representing a worst-case-scenario.

Since in forest stands the necessary input parameters (O_3 concentrations, horizontal wind velocity, radiation, temperature, humidity) to model ozone fluxes at a reference height above the forest canopy are generally not available, a two case approach has been derived, giving realistic possibilities for a risk evaluation using the above mentioned VDI concept.

Case 1: If assumed

- that O_3 concentrations measured at an air quality monitoring station at the top of a hill, free for the approaching air flow, represent the upper limit of O_3 concentrations at the surface of the foliage of the surrounding forest canopies below

and

- the diurnal variation of the O_3 concentrations is unincisive

O_3 concentrations can be approximated in such cases by proper selection of an air quality monitoring station. Table 2 gives an example of local risk evaluations for a forest transect in Germany matching case 1. The air quality monitoring stations chosen are representative for the forested areas with the highest O_3 burden in North Rhine-Westphalia, Hesse and Baden-Wuerttemberg.

Comparisons of Table 2 and 1 show that short-term, high O_3 concentrations cannot be considered to have a persistent negative effect on forests according to the defined time period of 1 year (VDI 2310, part 6). Even though the long-term averages in Hesse and Baden-Wuerttemberg exceed the MPOCs, the compliance of which ensures substantial protection of forest trees is still given, but the development of symptoms can be expected. However, the closer the calculated value of the MPOC "*Compliance ensures substantial protection*" is reaching the MPOC "*Exceedance leads to permanent damage*" for the long term indices (>30 days) the greater the potential risk for adverse O_3 effects; thus applies only for long term means (e.g. >3 years), since with increasing time other influencing stress factors gain importance due to the predisposition by ozone. Therefore, values representing such a smooth transition are accordingly coloured.

Case 2: If automatic monitoring stations like described in case 1 are not available, or the O_3 concentration at Level II sites is monitored by passive samplers, exposed in open areas with a 14 or 28 day exposure period at the reference height of 3.5 m a.g.l., local risk assessments can also be done using data from passive samplers. "Open area" concentrations have to be transformed into the concentrations at the top of the forest canopies. Such a transformation factor was derived from data of a 3 year, EU co-financed experiment, carried out at the Egge Monitoring Station in North Rhine Westphalia, Germany, where ambient air concentration measurements were carried out on an hourly basis in open field at reference height (z = 1.5 m a.g.l.), as well as within and above the canopy of a forest stand (z = 12 m a.g.l., z = 18 m a.g.l) (Thiele et al., 1990; Prinz, 1991). In the vicinity of the experimental site (200 m) an automatic measuring station, fulfilling case 1 conditions, belonging to the North Rhine Westphalia air quality network was operated during the same time. Using these data, a mean transformation factor of 1.1 was derived, in order to approximate the O_3 concentrations at canopy level ($z = d+z_{om}$ within the big-leaf approach). Calculations are given in Table 3. Risk evaluations can then be done in a similar way as above described.

Table 3: Ratio of O_3 concentrations at forest canopy height (12 m) and at 1.5 m (MEXFO) or 3.5 m (North Rhine Westphalia air quality network)

	12 m / 1.5 m		12 m / 3.5 m	
	1.4 – 30.9.1987	1.4 – 30.9.1988	1.4 – 30.9.1987	1.4 – 30.9.1988
mean	1.07	1.07	1.10	1.09
standard deviation	0.21	0.19	0.33	0.14
median	1.04	1.03	1.05	1.09

Considerations for future risk assessments within ICP-Forest

Risk estimations for forests using the described approach still have uncertainties of course, however, a great step forward is taken in deriving more realistic scenarios, since the developed dose-response relationship, is based on peer reviewed European experimental work of the last 10 years, and uses only (i) integrative parameters, (ii) European tree species and takes in account (iii) experiments from the open field as well as (iv) experiments carried out in open top and (v) closed chambers.

However, the MPOC approach (local scale, low-cost risk assessment) as well as the flux approach within EMEP (European scale) need a validation for the different climatic zones in Europe with their specific species varieties. Therefore, a network of O_3 flux-monitoring sites have to be established over Europe, at which at the same time the MPOC approach have to be validated. For Germany 3 or 4 sites seems to be adequate (e.g. Egge Monitoring Site in North Rhine-Westphalia, Fuerth im Odenwald in Hesse, Schauinsland in the Black Forests in Baden-Wuerttemberg and a station in East Germany).

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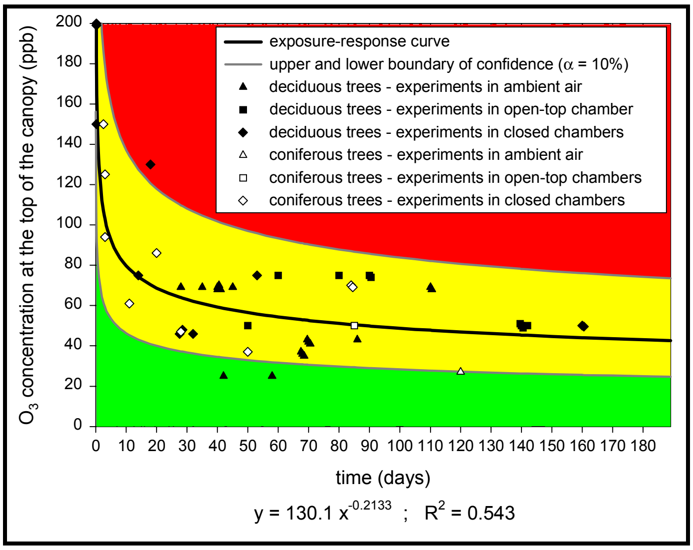

Figure 2: Dose-response relationship for ozone effects (effects are based on the integrative parameters: growth, yield, photosynthesis) for European coniferous and deciduous tree species (22 peer reviewed publications with 50 single relationships; see VDI Guideline 2310 part 6).

Table 1: Maximum permissible O_3 concentrations (MPOC) at the top of the canopy to protect European conifer and deciduous tree species (Grünhage et al., 2001; VDI 2310 part 6, 2002)

exposure (April – September)	**MPOC (ppb) at the plant surface**		
	Compliance ensures maximum possible protection	**Compliance ensures substantial protection** *)	**Exceedance leads to permanent damage**
8 h	**92**	**164**	**295**
24 h	**74**	**130**	**229**
7 days	**50**	**86**	**148**
30 days	**37**	**63**	**108**
90 days	**29**	**50**	**86**
Apr – Sep	**25**	**43**	**74**

*) forest functions: e.g. growth, productivity, biodiversity, recreation

Table 2: Local O_3 risk evaluation for forests in Germany

exposure (April – September)	**Eggegebirge** North Rhine-Westphalia			**Fuerth im Odenwald** Hesse			**Schauinsland** Baden-Wuerttemberg		
	1999	**2000**	**2001**	**1999**	**2000**	**2001**	**1999**	**2000**	**2001**
	O_3 concentration (ppb)								
8 h	**76**	**91**	**89**	**93**	**97**	**107**	**80**	**102**	**109**
24 h	**74**	**86**	**85**	**89**	**91**	**100**	**79**	**94**	**97**
7 days	**66**	**72**	**70**	**76**	**77**	**86**	**73**	**79**	**84**
30 days	**56**	**56**	**56**	**66**	**64**	**70**	**66**	**68**	**71**
90 days	**45**	**42**	**44**	**55**	**52**	**55**	**57**	**58**	**59**
Apr – Sep	**36**	**32**	**34**	**43**	**39**	**41**	**49**	**49**	**48**

- maximum possible protection of forest functions is expected
- substantial protection of forest functions is expected
- potential risk for adverse effects increase with time (e.g. >3 years)
- permanent damages are expected