Practical and ecological considerations in ozone risk assessments

J. Bender[1*], G.H.M. Krause[2], L. Grünhage[3], H.J. Jäger[3], B. Köllner[2] & H.J. Weigel[1]

[1]Institute of Agroecology, FAL, 38116 Braunschweig, Germany
[2]North Rhine Westfalia State Environmental Agency, 45133, Essen, Germany
[3]Institute for Plant Ecology, University of Gießen, 35392 Gießen, Germany
* correspondence to: Juergen.Bender@fal.de

1. Introduction

The recent developments in modelling ozone flux provide a promising, mechanistic and biologically-relevant basis for future assessments of ozone risks for vegetation. Ozone flux – yield response relationships have been developed for wheat and potato from open-top chamber experiments (Danielson et al. 2003; Pleijel et al. 2004) showing that stomatal flux rather than external exposure (AOT40) produced a better fit to the observed yield reductions. The latest revision of the Mapping Manual (UNECE 2004) (i) provides AOTX-based critical levels for three vegetation types (crops, forest trees, semi-natural vegetation), (ii) considers MPOC (Maximum Permissible Ozone Concentration) as an alternative approach for mapping potential risk in national/local evaluations and (iii) includes stomatal-flux based critical levels for wheat and potato as a first step in the derivation of new critical levels. To date, the currently existing AOTX-based critical levels do not allow to estimate economic impacts of ozone because of several important limitations and uncertainties that are recognized for this approach (UNECE 2004), particularly because AOTX do not include or account for environmental variables that affect ozone uptake via stomata. Nevertheless, evaluations of the economic impact of ozone were performed for agricultural crop production in Europe (Holland et al. 2002) as well as in a case study for crop yields and forest production in Southern Sweden (Karlsson et al. 2005). The development of stomatal flux – response relationships may now provide a mechanistic basis for a better quantification of the impacts of ozone on crops, although further validation under 'real world' conditions and development of response relationships for other species and cultivars, respectively, are needed.

At present, a flux-based risk assessment approach based on yield responses might be suitable for crop monocultures to quantify ozone impacts in economic terms, but quantitative relationships focussing on single endpoints and individual receptors, respectively, may be inappropriate to assess the potential for ecological risks of ozone, especially in forests and semi-natural ecosystems. Furthermore, modelling of ozone flux into plants is complex and highly data-intensive. As fluxes are not directly measurable quantities, it is difficult to make this approach transparent to the public, including decision makers. The paper will discuss the potentials of existing concepts for an assessment of the ecological risk of ozone, including practical aspects on how to make scientific issues associated with ozone risk analysis more transparent to the general public and policy-makers, and highlight ways for an ecological risk assessment on the basis of fluxes.

2. Possibilities of ecological risk assessment

Approaches that aim to estimate the ecological risk of ozone impacts may be different from those that aim to assess the economic risk. For example, the most important impact of ozone in forests and semi-natural vegetation may be on ecological functions like biogeochemical fluxes of elements, population dynamics, biodiversity etc. rather than on productivity; it is thus unlikely that a critical level (flux) deduced from single flux-response relationships (as for crops) can be applied for forest ecosystems or semi-natural ecosystems for which assessment endpoints related to the function of these systems including ecosystem services may be more relevant for an estimation of the ecological risk of ozone. Also, it appears questionable whether an economic evaluation of ecologically-relevant effects of ozone on e.g. stand or species composition, genetic diversity, hydrologic function or recreation value is meaningful or even possible. In addition, the currently available database for the derivation of ozone flux-plant response relationships for forest and semi-natural ecosystems is extremely inadequate and thus, sound quantitative definitions of cause and effect for these systems are very limited. At present, it is not possible to assess the long-term effects of ozone on e.g. mature trees and ecosystem development. Hence, a derivation of dose-response relationships for single species and single endpoints that relate to relatively short exposure periods appears inadequate for an ecological risk analysis of diverse perennial vegetation. An approach that is based on generalized cause-effect relationships including different endpoints and species and considering different ozone exposure periods may provide a more realistic estimation of the ecological risk due to ambient ozone exposures than approaches that use single species and endpoints, respectively.

Given the aforementioned shortcomings in the application of currently existing critical levels for evaluations of the ecological risk of ozone, we developed a simple and broad concept (Maximum Permissible Ozone Concentrations; MPOC) to evaluate the relative risk of ambient ozone concentrations to vegetation which can serve as an intermediate approach until robust ozone-flux response relationships are developed for real world conditions. MPOC is a first order concept of flux-based comparative risk assessment using peer-reviewed European work (Grünhage et al. 2001). It is related to flux, since it demands the transformation of ambient ozone concentrations from some measurement height to the top of the upper leaf surface boundary of the quasi-laminar layer, applying the big-leaf approach (Grünhage et al. 2001). Moreover, in contrast to a single endpoint, a broad scope of integrating plant response parameters (growth, biomass, physiology, vitality etc) was used to derive ozone-exposure response relationships. Data from a wide variety of species and experiments were pooled to include intra- and interspecies variability, i.e. MPOC deliberately mixed data from species with differing ozone sensitivities and results from different endpoints in order to avoid the search for the most sensitive species and a single dose-response relationship. Thus, the exposure-curves of MPOC e.g. for forest trees represent a broad range, reflecting the uncertainties within the statistical evaluation of the experimental data.

Meanwhile, the MPOC methodology has been validated and applied for local ozone risk evaluation under the framework of ICP-Forests for several sites in Germany (Krause et al. 2003; Beudert, pers. communication), Switzerland and Italy (ICP-Forests 2005). Transformed, calculated ozone indices obtained from different years were compared with a dose-response curve of ozone effects on trees (Figure 1) which has been extended and modified from the original response curve published in the MPOC background paper (Grünhage et al. 2001). One general conclusion from these validation studies is that MPOC seems to provide a more realistic estimate of the local risk by ozone compared to the AOT40-based critical level for forest trees (ICP-Forests 2005).

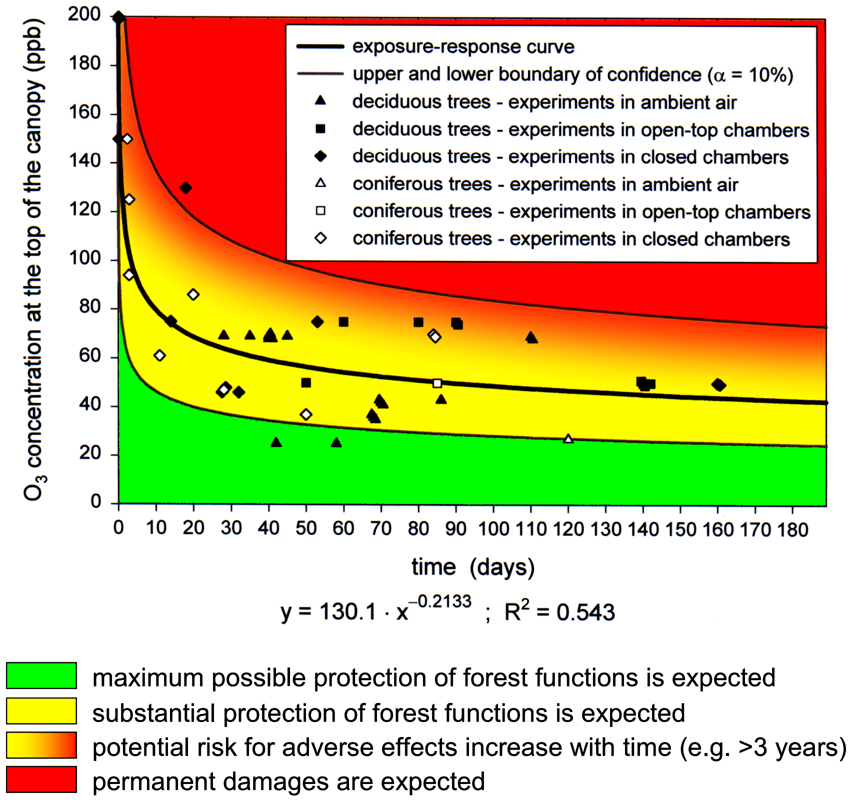

Figure 1: Dose-response relationship for ozone effects for European coniferous and deciduous tree species (Grünhage et al. 2001; extended and modified)

It is obvious from Figure 1 that MPOC allows not only deriving an index for a defined exposure period but also for other exposure periods, so that short-term (acute) ozone exposures and longer-term (chronic) exposures can be evaluated separately for their potential risk. The 10 % confidence intervals of the curve contain the area (yellow) where compliance ensures substantial protection with respect to growth, productivity, vitality and recreation (this does not exclude the development of ozone injury symptoms), while the area above and below signal either maximum protection (green) or permanent damage (red). The smooth transition between red and yellow takes into account that the potential risk of adverse ozone effects may increase with time, i.e. according to the MPOC approach the longer forest trees are exposed to ozone the greater is the potential to suffer from chronic ozone stress. In this regard, it should be noted that the daily-averaged ozone concentrations used in MPOC can inversely be related to the cumulative dose ($c \times t$) (Figure 2), i.e. MPOC is a cumulative exposure approach, thus not restricted to daytime exposure but also considering the influence of nocturnal conductance that may significantly contribute to the potential for plant ozone injury (Massman 2004).

There has also been some debate about the importance of threshold values in ozone risk assessments. While MPOC, for example, does not provide a single exceedance value or a threshold, the new proposed flux-based critical levels for crops include a threshold (in analogy to AOT40) assuming that there is no ozone effect below the threshold flux. However, a threshold value is unlikely to be constant and depends on the biological response parameter considered as well as on the capacity of defense mechanisms to detoxify ozone. Using the concept of 'hormesis' (Calabrese 2005), an instantaneous fixed threshold appears questionable in phytotoxicology mainly because thresholds ignore possible hormetic effects of pollutants such as ozone (Jäger and Krupa 2005). Based on these considerations, there is no doubt that appropriately derived stomatal uptake-response relationships are the preferred biologically relevant tools for estimating ozone risk to vegetation, but, at the moment, MPOC provides a more realistic estimate of ecological risk due to its more generalized approach than, for example, AOT40. However, the MPOC approach must be seen as a worst-case scenario (Grünhage et al. 2001) and, of course, has also its own limitations (for details, refer to a recent discussion issued in Atmospheric Environment; Ashmore et al. 2004, 2005; Krause et al. 2005a, b).

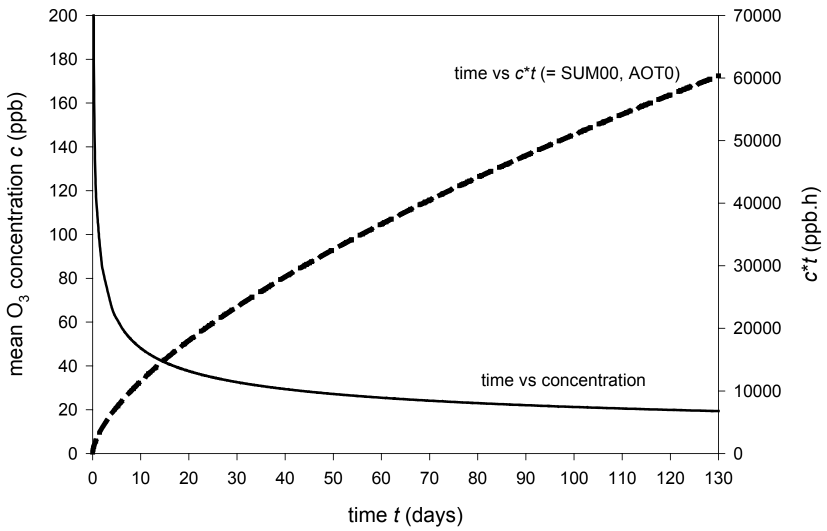

Figure 2: Relationship between ozone concentration at the plant surface and cumulative ozone exposure (c*t) at the plant surface as a function of exposure time (t)

3. Practicability of ozone risk assessment approaches

There is a very strong and concerted movement among plant effect scientists to arrive at a flux-based ozone critical level to protect vegetation. Although this approach is now well accepted, appropriate and validated flux-response relationships for forests and semi-natural ecosystems are still needed as a basis for an ecologically meaningful flux-based risk assessment. However, national/local risk assessment is important to meet the requirements in the implementation of the recently issued EU directive (EU directive 2002/3/EC). We therefore propose to use MPOC as a practical, intermediate step for local ecological risk assessments when the required input data to calculate ozone flux and/or validated flux-effect relationships are not available. Figure 3 illustrates the different steps to reach to an ecologically-relevant risk estimate depending on available input data and effect information. In that regard, it should be noted that MPOC may not only use hourly ozone concentrations from monitoring stations for risk calculations but also aggregated data from ozone passive samplers, as has been shown in the recent technical report of ICP-Forests (ICP-Forests 2005).

A further complicating and important factor in the application of flux-based assessment methods is associated with the acceptance to society, including decision makers. As fluxes are not directly measurable quantities, it might be difficult to make this approach transparent to the public (Amann and Schöpp, 2003). The MPOC concept has deliberately made use of different colorations to provide a visualized, comprehensive overview of the ozone risk potential at different time scales. Similarly, Nunn et al. (2005) recently presented a new approach based on a three-grade colour coding to evaluate response patterns at different scaling levels of adult forest trees to chronic stress. Those approaches would definitely help to make complex research findings more understandable and transparent to the general public. It is expected that stomatal-flux – response relationships for more species and further application and development of the flux-based approach will be presented at the Oburgurgl workshop. It should be feasible in the future to present ozone flux data (e.g. accumulated flux *vs*. time) in a similar way, i.e., according to MPOC, statistically sound data from flux-response relationships may be used to illustrate the relationship between absorbed doses and exposure time.

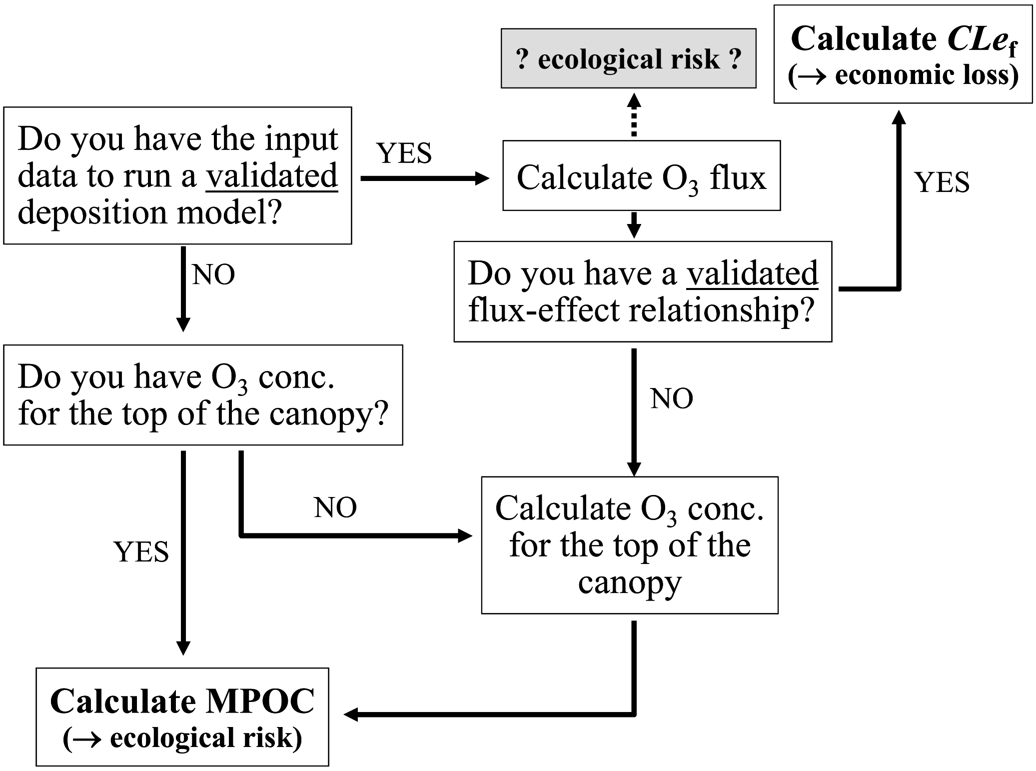

Figure 3: A simplified schematic diagram illustrating different possible steps in ozone risk assessment

References

Amann, M., Schöpp, W. 2003. Introducing ozone fluxes in integrated assessment modelling. In: Karlsson, P.E., Sellden, G., Pleijel, H. (Eds.): Establishing ozone critical levels II. UNECE Workshop Report. IVL report B 1523, 48-50.

Ashmore, M., Emberson, L., Karlsson, P.E., Pleijel, H. 2004. New directions: A new generation of ozone critical levels for the protection of vegetation in Europe. Atmospheric Environment 38: 2213-2214.

Ashmore, M., Emberson, L., Karlsson, P.-E., Pleijel, H. 2005. New Directions: Discussion of "A new generation of ozone critical levels for the protection of vegetation in Europe" by Ashmore et al. - Reply. Atmospheric Environment 39: 5214-5215.

Calabrese, E.J. 2005. Paradigm lost, paradigm found: The re-emergence of hormesis as a fundamental dose response model in the toxicological sciences. Environmental Pollution 138: 378-411.

Daniellson, H., Pihl Karlsson, G., Karlsson, P.E., Pleijel, H. 2003. Ozone uptake modelling and flux-response relationships – an assessment of ozone-induced yield loss in spring wheat. Atmospheric Environment 37: 475-485.

Grünhage, L., Krause, G.H.M., Köllner, B., Bender, J., Weigel, H.J., Jäger, H.J., Guderian, R. 2001. A new flux-orientated concept to derive critical levels for ozone to protect vegetation. Environmental Pollution 111: 355-362.

Holland, M., Mills, G., Hayes, F., Buse, A., Emberson, L., Cambridge, H., Cinderby, S., Terry, A., Ashmore, M. 2002. Economic Assessment of crop yield losses from exposure. Report to U.K. Department of Environment Food and Rural Affairs, DEFRA Contract EPG 1/3/170. Centre for Ecology and Hydology.

ICP Forests 2005. Forest condition in Europe. 2005 Technical Report of ICP Forests. Federal Research Centre for Forestry and Forest Products, Hamburg, Germany.

Jäger, H.J., Krupa, S.V. 2005. Hormesis – Its relevance in phyto-toxicology. In: Legge, A.H. (Ed.); Relating atmospheric apportionment to vegetation effects: establishing cause and effect relationships. Elsevier Science, Amsterdam, The Netherlands (in press).

Karlsson, P.E., Pleijel, H., Belhaj, M., Danielsson, H., Dahlin, B., Andersson, M., Hansson, M., Munthe, J., Grennfelt, P. 2005:Economic Assessment of the negative impacts of ozone on crop yields and forest production. A case study of the Estate Östads Säteri in Southwestern Sweden. Ambio 34: 32- 40.

Krause, G.H.M., Köllner, B., Grünhage, L. 2003: Effects of ozone on European forest tree species – a concept of local risk evaluation within ICP-Forests. In: Karlsson, P.E., Sellden, G., Pleijel, H. (Eds.): Establishing ozone critical levels II. UNECE Workshop Report. IVL report B 1523, pp. 230-235.

Krause, G., Köllner, B., Grünhage, L., Jäger, H.-J., Bender, J., Weigel, H.-J. 2005a. New Directions: Discussion of "A new generation of ozone critical levels for the protection of vegetation in Europe" by Ashmore et al. - Comments. Atmospheric Environment 39: 5213-5214.

Krause, G., Köllner, B., Grünhage, L., Jäger, H.-J., Bender, J., Weigel, H.-J. 2005b. New Directions: Discussion of "A new generation of ozone critical levels for the protection of vegetation in Europe" by Ashmore et al. - Further response. Atmospheric Environment 39: 5216-5217.

Massman, W.J. 2004. Toward an ozone standard to protect vegetation based on effective dose: a review of deposition resistances and a possible metric. Atmospheric Environment 38: 2323-2337.

Nunn, A.J., Reiter, I.M., Häberle, K.H., Langebartels, C., Bahnweg, G., Pretzsch, H., Sandermann, H., Matyssek, R. 2005. Response patterns in adult forest trees to chronic ozone stress: identification of variations and consistencies. Environmental Pollution 136: 365-369.

Pleijel, H., Danielsson, H., Ojanpera, K., de Temmerman, L., Högy, P., Badiani, M., Karlsson, P.E. 2004: Relationships between ozone exposure and yield loss in European wheat and potato. A comparison of concentration and fluy based exposure indices. Atmospheric Environment 38: 2259-2269.

UNECE (United Nations Economic Commission for Europe) 2004. Manual on methodologies and criteria for modelling and mapping critical loads & levels and air pollution effects, risks and trends. Umweltbundesamt, Berlin, Germany (http://www.oekodata.com/icpmapping/).