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RECENT RESULTS AND UPDATING OF SCIENTIFIC AND TECHNICAL KNOWLEDGE

ELLENBERG MODELLING APPROACH TO IDENTIFY (SEMI-)NATURAL VEGETATION AT RISK FROM OZONE

Report by the Programme Centre of the International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops (ICP Vegetation)

INTRODUCTION

1. In Europe, background ozone concentrations continue to rise. Numerous studies have indicated that many of Europe's (semi-)natural vegetation species are potentially at risk from damage by ozone pollution. Whilst some species are strongly negatively affected by ozone, others appear to be stimulated by it. A significant proportion of species tested in ozone exposure studies respond to ozone by developing one or more of the following: visible injury, premature and enhanced senescence, changes in biomass, resource allocation, and/or seed production. Since

each of these effects might impact on the vitality of plant communities, there has been a growing need to draw the published information together to identify which communities across Europe are potentially sensitive to ozone. To date, the effects of ozone have been studied in a relatively small proportion of the European flora and it is impractical to screen all species for ozone response. Therefore, if ozone effects on (semi-)natural vegetation are to be assessed, tools are required which can extrapolate from the existing knowledge base to make predictions about the responses of the rest of the flora.

2. Existing datasets have been collated into a database named OZOVEG (ozone effects on vegetation) to allow identification of ozone-sensitive species and analysis of relationships between ozone sensitivity and plant characteristics. Meta-analysis of the biomass responses of 83 species revealed Ellenberg indicator values to be the best predictor of individual species' sensitivity to ozone (Hayes et al. 2007). Ellenberg indicators have been widely used in ecology to interpret responses to environmental gradients or changes in vegetation communities over time. The principal advantage of Ellenberg indicators is that values have been assigned for most of the temperate European flora, nearly 3000 species in all (Ellenberg et al. 1991). Therefore, if robust relationships between ozone sensitivity and Ellenberg indicator values can be established, this provides an invaluable starting point from which to predict the sensitivity of the bulk of the species in the European flora. This allows us to move from estimating ozone sensitivity of individual species to estimating that of whole communities based on the responses of the component species. The results of the Ellenberg modelling approach are presented here in accordance with the 2007 workplan (item 3.5).

I. DEVELOPMENT OF A SINGLE-SPECIES PREDICTIVE MODEL

3. For the 83 species in the OZOVEG database, the ozone response of each species was determined by regression of the biomass changes found at a range of ozone exposures relative to a control. From this information, a sensitivity index RS (relative sensitivity) of each species to ozone was calculated. It was standardized to be the biomass response at 15 parts per million times hours (ppm h) relative to that at 3 ppm h (Hayes et al. 2007). An RS value of 1 indicates no change in biomass due to ozone, RS < 1 a reduction, and RS > 1 an increase; thus, RS=0.80 indicates a 20% reduction in biomass. The number of useable species in the database for developing the Ellenberg model was 65, as some species of American or Mediterranean origin did not have Ellenberg indicator values assigned and a minority of species did not have a specific Ellenberg indicator value assigned due to their wide ecological amplitude.

4. Figure 1 illustrates the relationship between RS and each Ellenberg indicator value assessed. Regression analysis showed that light-loving plants were more sensitive to ozone than plants that normally occur in the shade. However, species representing the most shade-tolerant Ellenberg values (1–4) are not represented in the OZOVEG database. Plants of Ellenberg

moisture value 3 (dry site indicator) tended to be more sensitive to ozone than those found in more moist soils. Plants that can tolerate moderately saline conditions (Ellenberg salt value of 1) are more sensitive to ozone than those of non-saline habitats. It should be noted, however, that species with Ellenberg salt values of 2 to 9 are not represented in the OZOVEG database. There were no relationships between the Ellenberg nutrient, “reaction” (pH) or temperature values and ozone sensitivity. The OZOVEG database represents quite faithfully the distribution of species across the European flora, with the exception of some of the lower values for Ellenberg light, and the higher values for Ellenberg moisture and salinity (Jones et al. 2007).

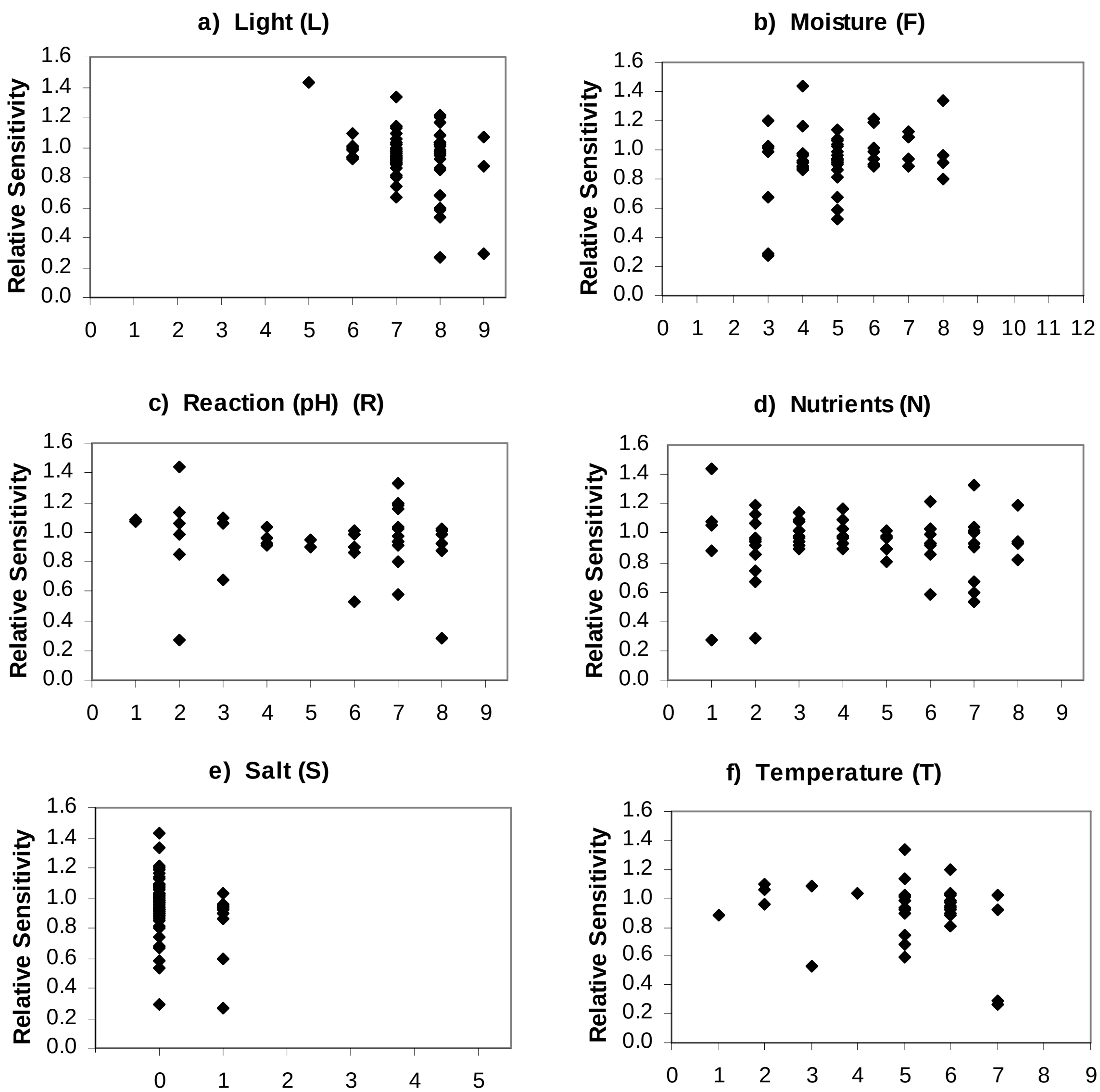

Figure 1. Relationship between relative sensitivity (RS) to ozone and individual Ellenberg indicators showing (a) light, (b) moisture, (c) reaction (pH), (d) nutrients, (e) salinity, and (f) temperature. Only the lower part of the range is shown for salinity values (Jones et al. 2007).

5. It was likely that a combination of Ellenberg indicators would give the best predictive power. Therefore, multiple linear regression was used to build the model and equation 1 was the best predictor for individual species (Jones et al. 2007):

$$RS_p = 1.805 - 0.118 Light - 0.135\sqrt{Salinity} \qquad (1)$$

where RS_p is predicted relative sensitivity, light is the Ellenberg light value and salinity is the Ellenberg salinity value for the species being predicted. The square root of salinity is used to reduce the influence of high salinity values on predictions of ozone sensitivity. This is because the range for this indicator extends up to 9 for inundated species of saltmarsh habitats, and predicted ozone effects on species with high salinity values cannot be substantiated based on the coverage of species in the OZOVEG database.

II. APPLICATIONS OF THE MODEL AT THE COMMUNITY LEVEL

6. An important next step was to apply this approach to whole communities to predict the net change in biomass in response to ozone and to produce a ranking of sensitivity of different vegetation communities. A list of the dominant species in a community, accounting for as much of the total cover as possible, is required for an estimate of the net change in biomass. RS_p was calculated for each species using equation 1 and the difference in RS_p from the theoretical state of no change (RS_p=1) was calculated (i.e. RS_p–1). The net percentage change in biomass in the community, termed the ozone response index (ORI%), was then calculated by averaging the predicted changes in biomass for all species in the community and multiplying by 100 to give a percentage change:

$$ORI\% = \frac{\sum_{i=1}^{n} (\mathrm{RS}_{\mathrm{p}_i} - 1)}{\mathrm{n}} \times 100 \qquad (2)$$

where RS_{pi} is the predicted RS for species i and n is the number of species utilized in the prediction of biomass change.

7. Equation 2 applied to data on simple presence or absence can give a rough estimate of the net predicted change in biomass. However, it assumes equal cover distribution between all species. A more realistic estimate will be achieved by weighting the predicted change in biomass by some measure of the relative abundance of each species. Cover-weighting proceeds as follows: RS_p is obtained for each species and the difference from RS_p=1 is calculated as in equation 2 above. This is then multiplied by the percentage cover for each species and all values are summed to give a net change. The final value is scaled as a proportion of the total cover

available in the community to give the cover-weighted prediction of net change in biomass $ORI\%_{cw}$:

$$ORI\%_{cw} = \frac{\sum_{i=1}^{n}\left[(\mathrm{RS}_{\mathrm{p}_i} - 1) \times (\mathrm{cover}_i)\right]}{\sum_{i=1}^{n}(\mathrm{cover}_i)} \times 100 \qquad (3)$$

where $cover_i$ is the percentage cover or other measure of abundance of species i.

III. TESTING OF THE MODEL ON FIELD DATA

8. As an example, these methods were applied to the only vegetation community on which the techniques can at present be tested: the Le Mouret field exposure experiment in Switzerland. The system was a mid-elevation grassland of low to medium productivity (about 0.9 kg m^{-2} a^{-1}) containing 53 species of vascular plants. The study comprised five years exposure of ozone at an average accumulated concentration above a threshold of 40 parts per billion (ppb), AOT40, of 34.0 ppm h. The results, compared against an average background ozone concentration of 8.4 ppm h, indicated a net change in above-ground biomass of – 23% (Volk et al. 2006). For accurate comparison with the ORI% tools, the biomass change at Le Mouret was rescaled by the actual ozone exposure in each year. This gave a compound biomass change of – 22.3 % over the five years. The ORI% and $ORI\%_{cw}$ were calculated using the species presence and abundance data at Le Mouret for each year. This gave a compound predicted change in above-ground biomass of –25.1% for the ORI% method and a compound cover-weighted prediction of –26.9% for the $ORI\%_{cw}$ method over the five years (Jones et al. 2007). The results for Le Mouret show that both methods accurately predict the direction of response and achieve a fairly close prediction of actual change in biomass. However, it should be noted that the biomass change in the field showed a strong lag in the response to ozone (Volk et al. 2006), whereas the predicted changes using $ORI\%_{cw}$ were reasonably similar from year to year as the relative dominance of species in the community did not change markedly and there was no great reduction in species number. Thus, while the ORI parameters can predict the direction of change, the timescales when communities are likely to change are uncertain.

IV. DEVELOPMENT OF A COMMUNITY SENSITIVITY INDEX

9. The second potential application of this model is to predict the sensitivity of a community to ozone, since an estimate of the predicted change in above-ground biomass may not show the full picture. For example, as species of high conservation value usually occur at low cover and at low frequency in a community, cover-weighted predictions of change in biomass will not highlight potential damage to these species. In addition, while many species are negatively

affected by ozone, some species are stimulated. Co-occurrence of both positively and negatively affected species in the same community may cancel each other out, leading to a low predicted change in biomass, concealing real ecological changes in community composition. For these reasons, a separate tool was developed, designed to predict the sensitivity of a range of communities. This tool was named the community ozone response index (CORI) and was calculated as follows: a species list for the community was obtained. The RS_p of each species was predicted, and the difference in RS_p from the theoretical state of no change was calculated (i.e. RS_p–1). In order to give greater weight to those species more strongly affected by ozone, and to take account of species which respond both positively and negatively to ozone, the root mean square of (RS_p–1) for all species was calculated. The resulting index was scaled within a range of 0 to 10, using a theoretical maximum value based on the maximum predicted change in biomass of any species in the European flora (69% using equation 1 above):

$$CORI = \sqrt{\frac{\sum_{i=1}^{n}(\mathrm{RS}_{\mathrm{p}_i} - 1)^2}{n}} \times \frac{10}{0.69} \qquad (4)$$

10. The technique was applied to 48 grassland and montane communities under the United Kingdom's national vegetation classification (NVC) system (Rodwell 1992), equivalent to level 4 in the European Nature Information System (EUNIS) hierarchy. This classification was chosen because comprehensive species lists for NVC communities are readily available. The predicted CORI values for these grassland and montane communities ranged from 1.53 to 4.75. In practice, the CORI value for most communities will lie in the lower half of the range, as the majority of species in the European flora are not strongly affected by ozone. The five most sensitive and five least sensitive of the 48 tested communities are shown in table 1. The two communities predicted to be most sensitive to ozone were calcareous grasslands (CG2 and CG3). The two communities predicted to be least sensitive to ozone were also calcareous grasslands (CG8 and CG9). This suggests that community sensitivity is strongly driven by the component species, rather than broad community type.

Table 1. Prediction of community sensitivity to ozone using the community ozone response index (CORI) scaled from 0 to 10, applied to 48 grassland communities in the United Kingdom's national vegetation classification (NVC). The five most sensitive and five least sensitive communities are shown (Jones et al. 2007).

NVC code	NVC community description		CORI (0–10)
Most sensitive			
CG2	*Festuca ovina-Avenula pratensis*	grassland	4.75
CG3	*Bromus erectus*	grassland	4.49
U17	*Luzula sylvatica-Geum rivale*	tall-herb community	3.52

U2	*Deschampsia flexuosa*	grassland	3.17
U1	*Festuca ovina-Agrostis capillaris-Rumex acetosella*	grassland	3.11
Least sensitive			
MG4	*Alopecurus pratensis-Sanguisorba officinalis*	grassland	1.86
MG5	*Cynosurus cristatus-Centaurea nigra*	grassland	1.86
U12	*Salix herbacea-Racomitrium heterostichum*	snow-bed community	1.67
CG8	*Sesleria albicans-Scabiosa columbaria*	grassland	1.56
CG9	*Sesleria albicans-Galium sterneri*	grassland	1.53

IV. SENSITIVITY ANALYSIS

11. The basic requirement for calculating a CORI value for a community is a list of species and their Ellenberg numbers. The question then arises: How many species are required to get a reliable estimate of CORI? A sensitivity analysis was conducted using two of the NVC communities shown in table 1, to determine a minimum number of species required to provide an acceptable estimate of the community sensitivity. Communities of contrasting species richness were chosen. The species list for the CG9 calcareous grassland contained 48 typical species, while the U17 tall-herb montane community contained 24 typical species. A repeat-sampling routine was written to run in Minitab v14.1 programme, which took random samples of species from the community and calculated the CORI value. The number of species sampled initially was three, increasing in steps of one until all species were included. For each subset size tested, the population was sampled 200 times, and the average CORI and the standard error were calculated (figure 2). The results suggest that to be reliably within 5% of the CORI value, a sample of nine species is required. As a relatively low proportion of the European flora is strongly affected by ozone, smaller sample sizes will tend to under-predict sensitivity. Therefore, as the sample size increases, so does the estimate of CORI until it approaches the calculated value. The minimum number of species required for a reliable estimate will increase slightly with the species richness of the community. In addition, variability in the prediction will alter with the community, depending on the sensitivity of the component species.

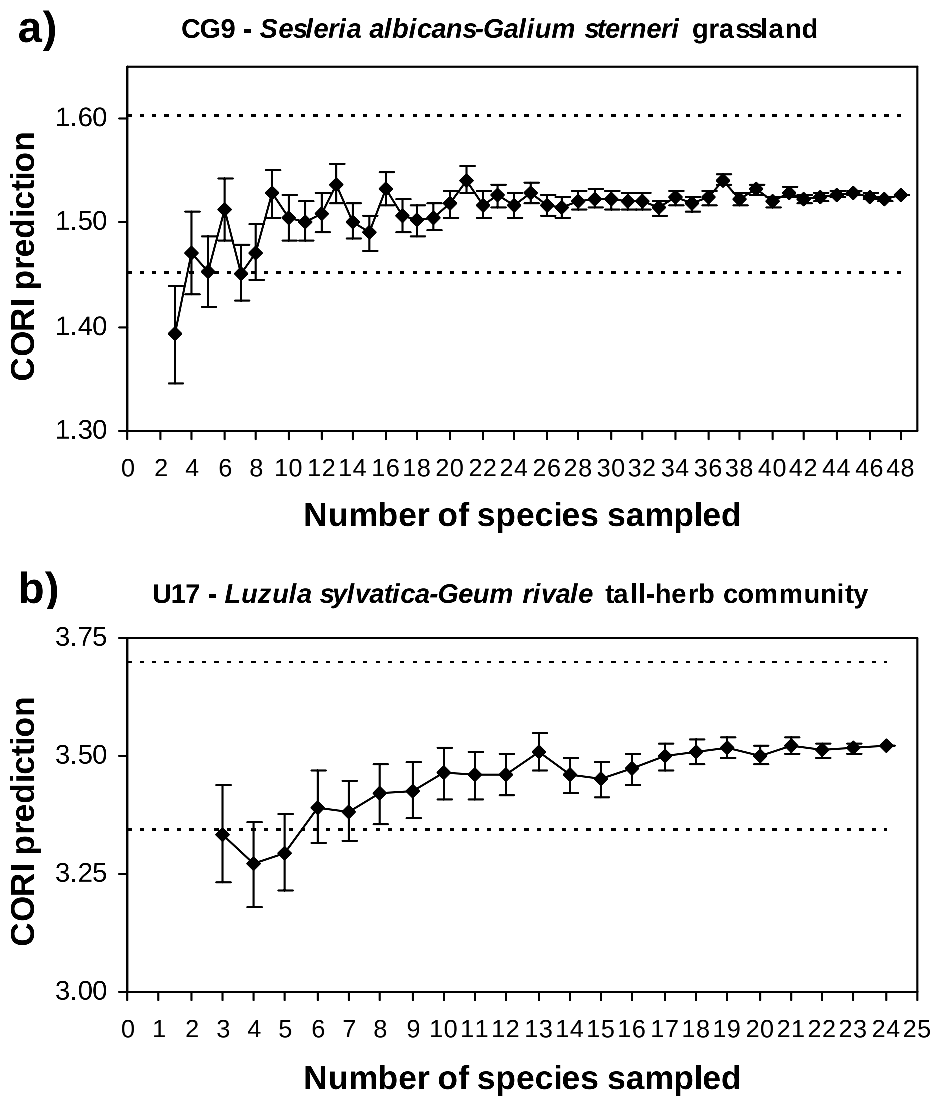

Figure 2. Sensitivity analysis illustrating how the CORI prediction varies with increasing sample size in two communities of contrasting species richness, where (a) n=48 species and (b) n=24 species. Bars show ± one standard error. Dotted horizontal lines show limits of ±5% from CORI value calculated using all available species (Jones et al. 2007).

IV. DISCUSSION

12. The principle advantage of this model is that it can be applied to any European plant species for which Ellenberg values have been assigned, almost 3000 species and subspecies in all. There are some species where caution should be exercised when predicting ozone sensitivity with this model, due to poor representation in the underlying database. These include strongly shade-adapted species, aquatic or periodically submerged plants and halophytic species. A weakness of this model from the European perspective is the limited application to

Mediterranean regions due to the low number of southern European species for which Ellenberg numbers have been assigned.

13. The underlying mechanisms by which Ellenberg numbers are able to predict sensitivity to ozone are unclear. The poor relationship between ozone sensitivity and stomatal density (Hayes et al. 2007) suggests that physiological controls are unlikely to be simple. Whatever the mechanism, these results provide important pointers for new research avenues in this field.

14. The community level predictions in this model ignore the likely effects of competitive interactions between species. This simplification is because research to date has focused mainly on individual species responses to ozone, and because modelling of species interactions is complex and requires information at a level of detail not available for most species. Currently, there has been only one community-scale ozone fumigation in the field (Volk et al. 2006). Thus, there is little empirical evidence of how species interactions are likely to affect community responses to ozone.

IV. CONCLUSIONS AND FUTURE CHALLENGES

15. The Ellenberg modelling approach is a useful tool in predicting plant community sensitivity to ozone. It complements work developing flux-based models for (semi-)natural vegetation and techniques, which predict the response of communities where we know the ozone sensitivity of many of the component species (Mills et al. 2007). Potential applications of the Ellenberg modelling approach include: screening of communities for ozone sensitivity; using critical loads to set threshold changes in biomass from which to identify “at-risk” communities; targeting potentially sensitive species or communities for further investigation; and modification of the CORI tool to add a rarity weighting for species of conservation importance.

16. There is a need for more research, in particular community-scale field exposure experiments are required to validate the predictions using the ORI% and CORI tools. Ozone exposure experiments are needed which assess effects on whole plant biomass, rather than just above-ground biomass responses, which are the basis of this model. There is also a need to assess whether the observed species’ responses are similar when plants are grown in competition, and when exposed to ozone in the field under more natural conditions. Lastly, there is a need to expand the database to improve representation of species with lower Ellenberg light values and higher moisture and salinity values.

17. Work is under way to assess whether the Ellenberg modelling approach can be extended to Mediterranean and other key European habitats for which the majority of species do not have Ellenberg numbers assigned. A preliminary assessment of two Mediterranean grassland communities suggests that the overlap in species composition in some communities is sufficient

to allow calculation of ozone sensitivity of the whole community based on the predicted response to ozone of the species for which Ellenberg numbers have been assigned. In these Eastern sub-Mediterranean dry grassland and a tall-herb humid Mediterranean grassland communities 39% and 50% of the species have Ellenberg numbers assigned, respectively. The calculated CORI index suggests that the humid grassland is more ozone sensitive than the dry grassland, and that these two communities lie within the range of ozone sensitivity calculated for United Kingdom grasslands (see table 1).

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