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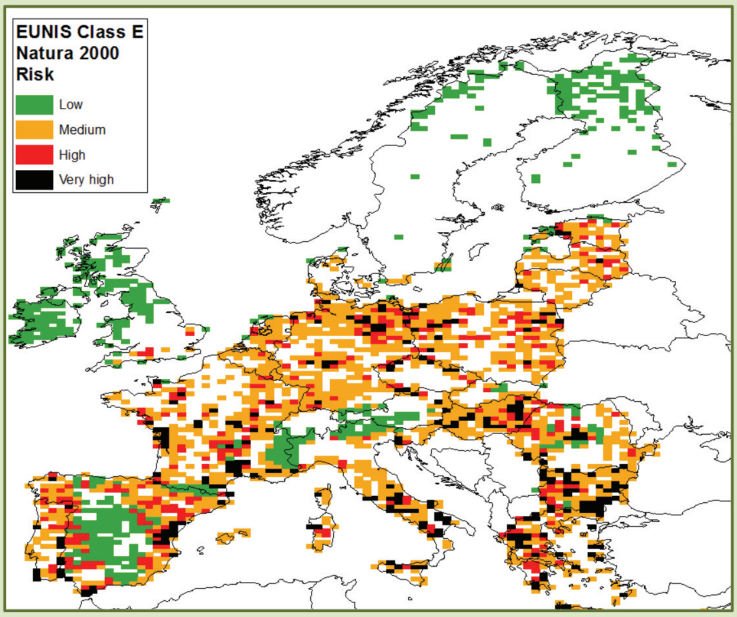
NATURAL ENVIRONMENT RESEARCH COUNCIL

LRTAP
Long-range Transboundary Air Pollution

Impacts of ozone pollution on biodiversity



In many parts of Central and Southern Europe, Natura 2000 grassland habitats (EUNIS class E) are at risk from impacts of ozone pollution. Risk is highest in regions with high ozone fluxes and relatively large grassland area.

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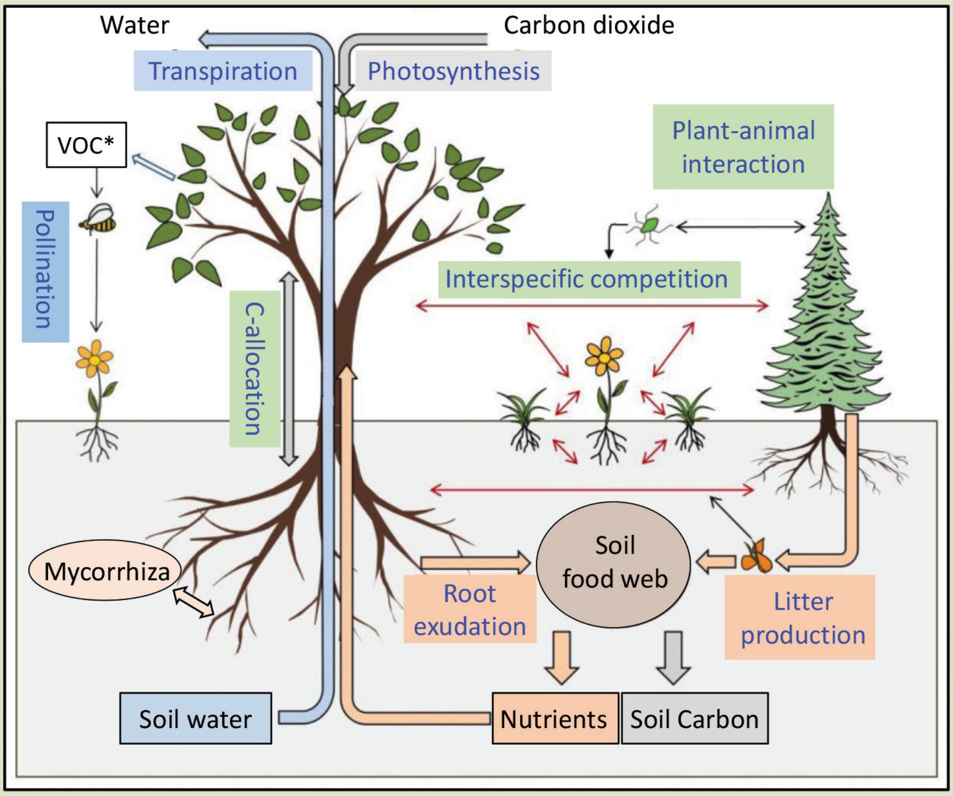
wge Working Group on Effects of the Convention on Long-range Transboundary Air Pollution

Declining biodiversity and ozone pollution: A global concern

The rapid decline in **biodiversity** in recent decades triggered the establishment of the Convention on Biological Diversity at the Rio 'Earth Summit' in 1992. The main factor contributing to the loss in biodiversity is the exponential increase in human population, leading to, for example, an increased need for biomass for fuel and construction, changes in land-use towards food and fodder production, industrial and residential developments, introduction of invasive species, climate change and pollution of the air, water and soil. Biodiversity is important for the sustainability of ecosystem functioning and services, it enhances the ability of ecosystems to maintain multiple functions and has positive impacts on the services provided by ecosystems.

Ozone is the third most important **greenhouse gas and at ground level is an air pollutant** that has negative impacts on human health and vegetation. Although impacts of ozone on individual plant species have been studied and ozone-sensitive species have been identified, little is known about the implications for biodiversity. In spite of evidence for widespread exposure of ecosystems to ozone pollution, the potential threat to biodiversity was not included in the recent assessment by the Convention on Biological Diversity 'Global Diversity Outlook 4'. Typical effects of ozone on sensitive species include visible leaf injury, premature and enhanced die-back, and changes in biomass, resource allocation and/or seed production. These effects can impact on the vitality of component species of plant communities, as well as that of animals, fungi, bacteria and insects that live in close association with these plants (see scheme).



* VOC: Volatile organic compound.

Schematic of how ozone affects various interactions between species, processes, and pools and flows of carbon, nutrients and water in terrestrial ecosystems. Impacts of ozone might result in changes in species abundance, composition and potentially diversity. Processes affected by ozone are written in blue.

Modified from Bergmann et al., 2015. Growth response of plant species to ozone. Texte 71/2015, Umwelt Bundesambt, Germany. http://www.umweltbundesamt.de/

Ozone sensitivity of individual plant species

The existence of wide differences in sensitivity between plant species (see table) suggests that ozone stress can cause shifts in species composition (evenness or richness) in diverse plant communities. However, field evidence is scarce, and most evidence for the impact of ozone on plant diversity is from data from controlled experiments with either artificial model communities or with intact ecosystems exposed to varying ozone concentrations. During the 1970s, high concentrations of ozone in the San Bernardino National Forests, California, had resulted in part in a replacement of the more ozone-sensitive species ponderosa pine (*Pinus ponderosa*) by the ozone-tolerant species white fir (*Abies concolor*). The results from field exposure studies are limited and rather mixed, with ozone affecting plant species composition in some studies but not in others (*Mills et al., 2013. Ozone pollution: Impacts on ecosystem services and biodiversity; http://icpvegetation.ceh.ac.uk*).

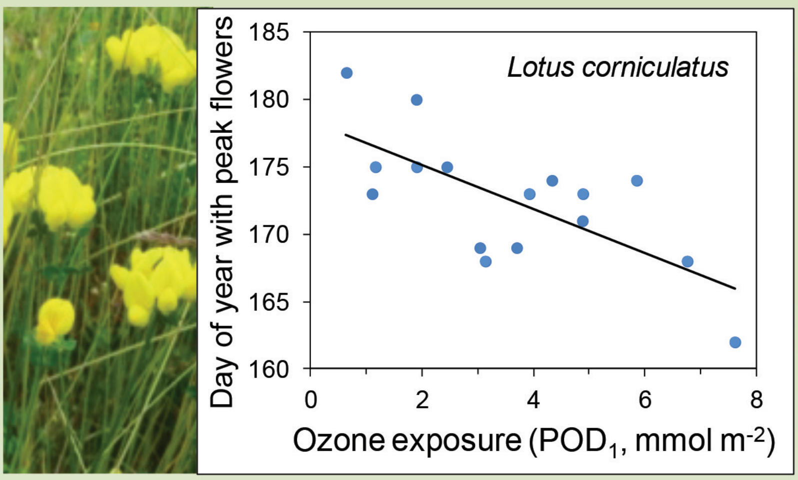
Number of plant species with known ozone effects on growth.

Plant group	Reduction*	Stimulation*	No effect
Forbs	85 (68)	13 (11)	79
Grasses	27 (20)	6 (3)	42
(Bi)annuals	31 (23)	3 (2)	21
Perennials	75 (60)	16 (12)	103
Trees	70 (55)	2 (0)	37
Deciduous	40 (32)	2 (0)	19
Evergreen	34 (28)	0	23
Conifers	19 (16)	0	17
Broadleaved	56 (45)	2 (0)	25

* Values within brackets indicate number of plant species with a response of more than 15%.

A review by Bergmann et al. (2015) showed that forbs and deciduous trees tend to be more responsive to ozone than grasses and coniferous trees. Although several ozone-sensitive plant families were identified, in general no significant relationship between plant traits and ozone-sensitivity was found. However, in some individual studies included in the review, such relationships have been reported.

Source: Bergmann et al., 2015. Growth response of plant species to ozone. Texte 71/2015, Umwelt Bundesambt, Germany. http://www.umweltbundesamt.de/



Whilst ozone has been shown to delay flowering of some plant species in northern meadow communities, it accelerated flowering of Lotus corniculatus, *a calcareous grassland species. Such shifts play an important role when flowering is closely synchronized with pollinating species, potentially affecting plant reproduction.*

Source: Hayes et al., 2012. Environmental Pollution 16: 40-47.

Ozone sensitivity of plant communities

As field-based evidence of ozone impacts on terrestrial ecosystems is scarce, studies attempting to predict the sensitivity of plant communities to ozone are often confined to compiling data from exposure of plants in semi-controlled systems such as solardomes, open top chambers or field exposure systems. Here we provide an update of the analysis described in *Mills et al. (2007, Environmental Pollution 146: 736-743),* with some modifications. Ozone dose-response relationships for above-ground biomass were based on reported 24 hr mean ozone concentrations rather than AOT40. Using the UK National Vegetation Classification (NVC; http://jncc.defra.gov.uk/page-1425), communities for which at least 20% of the species were tested for ozone sensitivity, were converted into EUNIS habitat code (http://eunis.eea.europa.eu/habitats.jsp).

Ozone (O_3) sensitivity at EUNIS level 2 determined from the relative sensitivity of component species.

EUNIS habitat	Abbreviated name	Mean no. of spp. in habitat	Mean % of species tested for O_3 sensitivity	No. of O_3-responsive species*	% of tested species affected by O_3*	No. of NVC communi-ties included
B1	Coastal dunes, sandy shores	49.0	25.5	5.0	42.8	8
B3	Rock cliffs and shores	47.3	25.7	5.0	40.1	6
D2	Valley and transition mires	25.0	20.0	3.0	60.0	1
D5	Sedge and reed beds	40.0	22.5	3.0	33.3	1
E1	Dry grasslands	86.9	26.5	10.1	41.9	9
E2	Mesic grasslands	71.7	35.9	10.3	41.4	6
E3	Seasonally wet grasslands	63.0	25.1	6.6	43.4	7
E4	(Sub)alpine grasslands	70.0	21.4	7.0	46.7	1
E5	Woodland fringes	58.9	22.8	6.8	51.1	9
F3	Montane scrub	61.5	23.9	6.0	38.7	2
F4	Temperate shrub heathland	65.0	22.1	4.0	27.2	2
I1	Arable and market gardens	57.3	23.8	7.5	56.4	6
I2	Cultivated gardens, parks	31.0	29.0	5.0	55.6	1

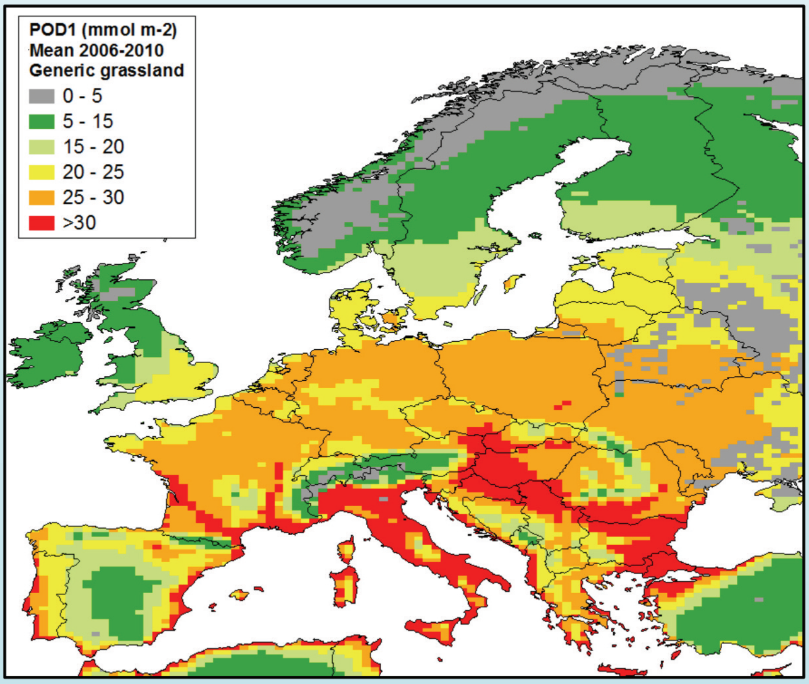
** Species for which above-ground biomass was either reduced or stimulated.*

It should be noted that the above data has a restricted geographical coverage in Europe, with the majority of data being from experiments conducted in Sweden, Denmark, UK, Netherlands, Germany and Switzerland. Application of the UK NVC classification contributes further to this geographical bias.

Although 'Valley and transition mires' had the highest percentage of ozone responsive species, only five species were tested, representing one NVC community (see table). Mostly tested were grassland species, with 'Woodland fringes' being most responsive to ozone. Of the species tested, the percentage of ozone-responsive species was more than 40% in many EUNIS habitats. Hence, there is a clear potential for vegetation community composition to change with increasing ozone exposure, with sensitive species being outcompeted by non-responsive or stimulated species in their competition for light, nutrients and water.

Natura 2000 habitats at risk from ozone

For grasslands (EUNIS code E and sub-classes), gridded UNECE harmonized land-cover data from the Coordination Centre for Effects (http://wge-cce.org/) were combined with gridded data on the Phytotoxic Ozone Dose above a threshold of 1 nmol m^{-1} s^{-1} (POD_1) for grasses, calculated with the EMEP atmospheric chemistry transport model, including a soil moisture index*. The risk of ozone impact on grasslands per 0.5° (longitude) by 0.25° (latitude) grid was calculated using a risk matrix (see table below). POD_1 was given more weight than the percentage habitat area per grid by being allocated twice as many risk classes. Multiplied risk values were divided into four risk categories and mapped: low (green), medium (orange), high (red) and very high (black; see table below and maps on the next page).



Phytotoxic ozone dose (POD_1) for grass per 0.5° x 0.25° grid, accumulated over a six months period (April – September) and averaged for 2006 – 2010.*

The highest phytotoxic ozone dose (POD_1) to grasslands is found in areas where ozone concentrations are intermediate and climate conditions are conducive to high ozone uptake by vegetation (Central Europe) or where ozone concentrations are high and the climate conditions (such as drought) do not limit ozone uptake by vegetation (Southern Europe).

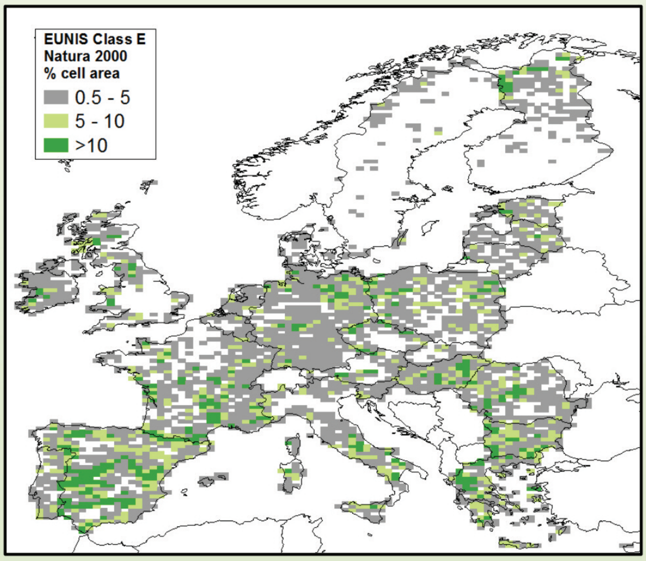
Matrix for calculating the risk of ozone impact on grasslands, based on the phytotoxic ozone dose (POD_1) for grass and the grassland area (%) per grid cell (0. 5° (longitude) by 0.25° (latitude)). POD_1 was calculated over a six months period (April – September).*

Grassland area in grid cell (%)	POD_1 grass (mmol m^{-2})*	<5	5 - 15	15 - 20	20 - 25	25 - 30	>30
	RISK	**1**	**2**	**3**	**4**	**5**	**6**
0.5 – 5	**1**	**1**	**2**	**3**	**4**	**5**	**6**
5 - 10	**2**	**2**	**4**	**6**	**8**	**10**	**12**
>10	**3**	**3**	**6**	**9**	**12**	**15**	**18**

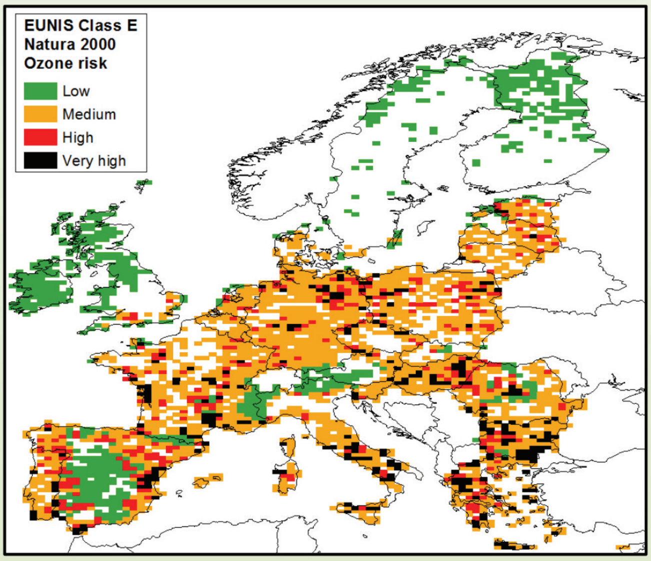
* *Simpson et al., 2012. Atmospheric Chemistry and Physics 12: 7825-7865.*

Mapping Natura 2000 habitats at risk

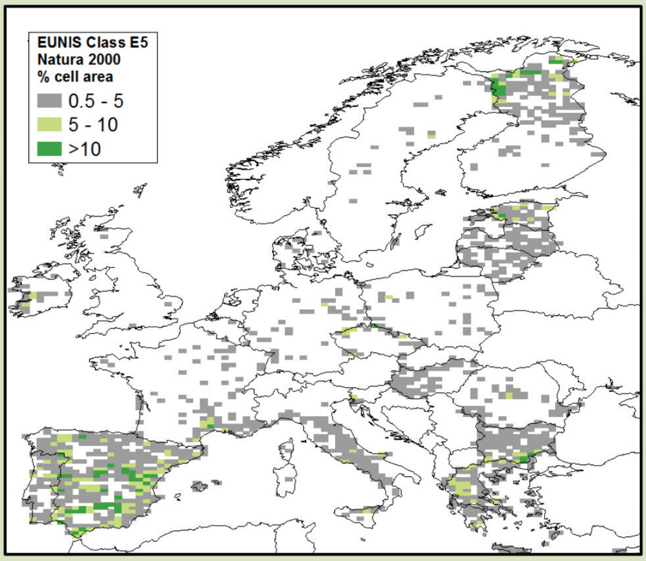
Grasslands (EUNIS code E) and woodland fringes (EUNIS code E5) in Natura 2000 areas at risk from impacts of ozone were mapped by applying the developed risk matrix. Natura 2000 grassland areas at highest risk from ozone are spread across Central and Southern Europe, in those areas where grasslands are most abundant and where the phytotoxic ozone dose (POD_1 grass) is medium to high. Areas at highest risk include parts of the Iberian Peninsula, the east coast of Spain, southern Italy and south-eastern Europe. Woodland fringes are most abundant in parts of the Mediterranean, Estonia and Northern Finland, with those in the Mediterranean area being at highest risk from ozone impacts. However, it should be noted that considerable uncertainty is associated with mapping habitats at risk in Southern Europe based on the ozone responsiveness of plant species and communities that primarily occur in Western and Central Europe.



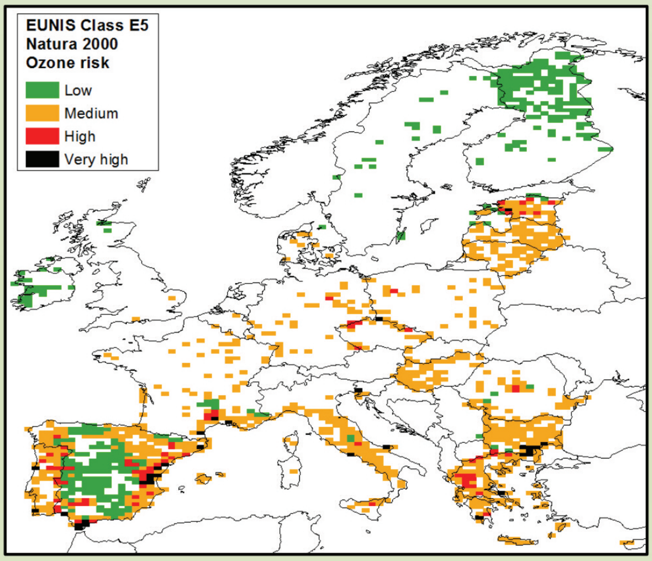
Percentage area of grasslands (EUNIS class E) per 0.5° x 0.25° grid in Natura 2000 areas.



Risk of ozone impact on grasslands (EUNIS class E) in Natura 2000 areas. Areas at highest risk are scattered across Central and Southern Europe.



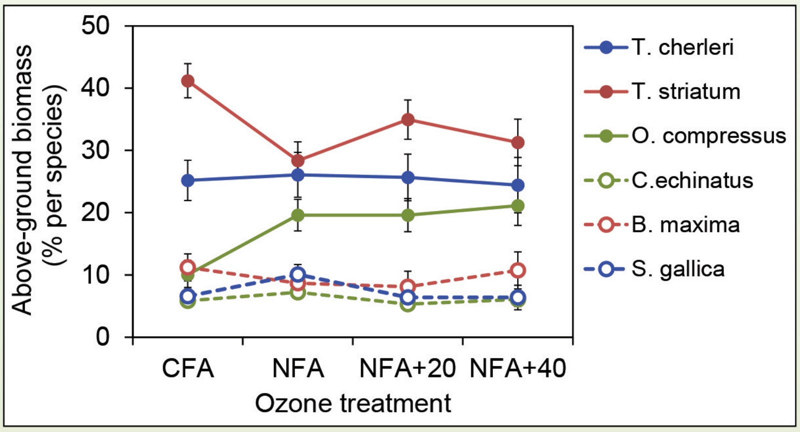
Percentage area of woodland fringes (EUNIS class E5) per 0.5° x 0.25° grid in Natura 2000 areas.



Risk of ozone impact on woodland fringes (EUNIS class E5) in Natura 2000 areas. Areas at highest risk are primarily in parts of Southern Europe.

Ozone impacts on Mediterranean habitats

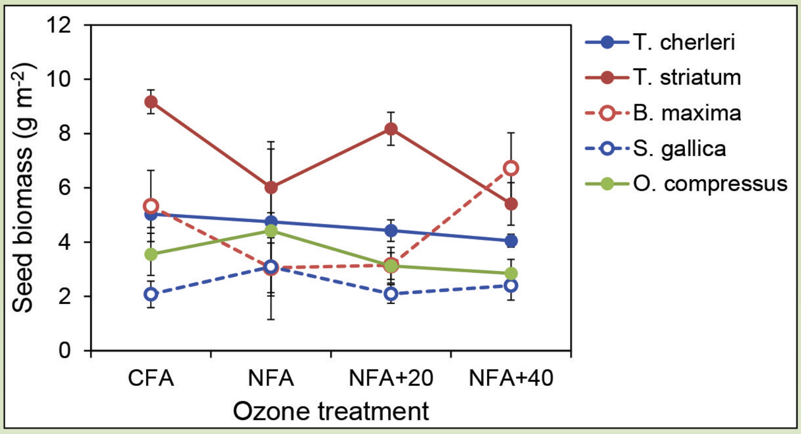
The Mediterranean Basin is recognized as one of the top 25 Global Biodiversity Hotspots for conservation priorities. In Spain alone, the biodiversity of fungi, lichens, mosses and vascular plants represents 80% of the EU biodiversity and almost 60% of that of the European continent. However, very limited information is available on the ozone sensitivity of individual species or communities taking into account the huge plant biodiversity present in this area.



Values are mean percentage of the total biomass ± one standard error. CFA = Carbon-filtered air, NFA = Non-filtered air, NFA+20/+40 = Non-filtered air +20 or +40 ppb ozone.

Ozone-induced changes in species composition of an experimental community of six annual Dehesa pasture species grown in open-top chambers. The above-ground biomass of the ozone-sensitive legume **Trifolium striatum** *declined in favour of the tolerant legume* **Ornithopus compressus** *in ambient and above ambient ozone concentrations compared with carbon filtered air (Modified from Calvete-Sogo et al., 2016, Oecologia).*

Dehesas are high biodiversity Mediterranean ecosystems that are protected under the EU Habitats Directive. Recent research has shown that ozone may induce changes in plant species composition of Dehesa pastures by changing competitive relationships, causing a decline in the abundance of ozone-sensitive species (*Calvete-Sogo et al., 2016)*. Ozone has shown also to affect differently the seed production of different pastures species which can result in long-term effects on the species composition of the pasture, thus altering the biodiversity of this valuable ecosystem (*Calvete-Sogo et al., in prep).* The effect of ozone pollution on seed production might be modified by the amount of nitrogen pollution (*Sanz et al., 2007. Atmospheric Environment 41: 8952-8962*). However, field validation of effects observed under experimental conditions is still lacking for many plant species and communities.



Ozone-induced effects on seed production of five annual Dehesa pasture species grown in mesocosms in open-top chambers (Calvete-Sogo et al., in preparation).

Values are mean seed biomass per square metre ± one standard error CFA = Carbon-filtered air, NFA = Non-filtered air, NFA+20/+40 = Non-filtered air +20 or +40 ppb ozone.

Summary

- In many parts of Central and Southern Europe, Natura 2000 grassland habitats are at risk from impacts of ozone pollution. Risk is highest in regions with high ozone fluxes (Phytotoxic Ozone Dose) and relatively large grassland area.

- There is evidence that current ambient ozone levels are sufficiently high enough to change plant community composition, flowering and seed production at the species level. Changes in plant community composition can potentially lead to changes in soil microbial communities and carbon, nutrient and water cycling. Such changes are slow, hence there is a requirement for long-term monitoring of terrestrial ecosystem responses to ozone.

- There is a lack of field-based evidence for the impacts of ozone on plant species diversity, especially in biodiversity hotspots such as the Mediterranean Basin. Results from European grassland field exposure experiments have been rather mixed regarding the impacts of ozone on plant growth and species composition. Whilst there is evidence that ozone might affect plant species composition, consequences for biodiversity require further study.

This brochure was produced by the Programme Coordination Centre of the ICP Vegetation. The ICP Vegetation is an International Cooperative Programme reporting on effects of air pollution on vegetation to the Working Group on Effects of the UNECE Convention on Long-range Transboundary Air Pollution.

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For further information, please contact:

Harry Harmens, Gina Mills
ICP Vegetation Programme Coordination Centre
Centre for Ecology & Hydrology
Deiniol Road, Bangor, Gwynedd, LL57 2UW, UK
Tel: +44 (0) 1248 374500
Email: hh@ceh.ac.uk, gmi@ceh.ac.uk

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