Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

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Ozone pollution:

Damage to ecosystem services

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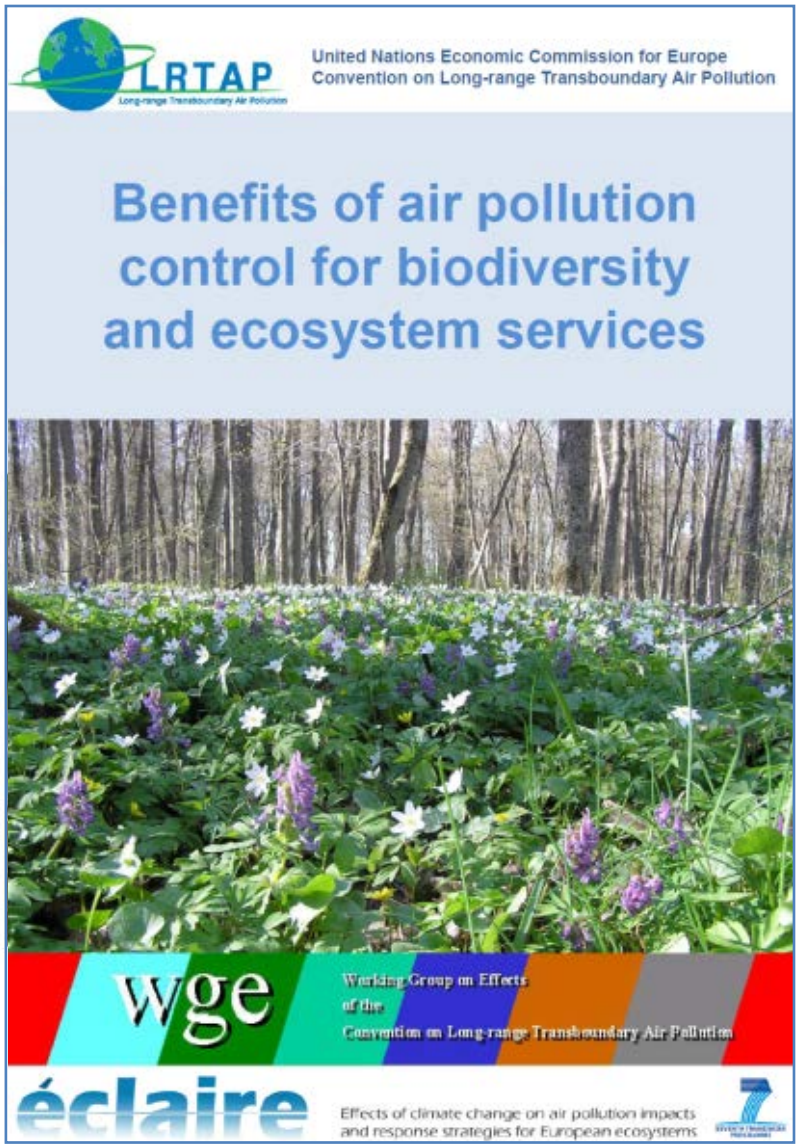
http://icpvegetation.ceh.ac.uk



Co-ordinated by ICP Vegetation PCC with contributions from all relevant ICPs/JEG

Review and case studies of current knowledge:

- ❑ Dose-response relationships and modelling of nitrogen impacts on plant diversity/ species composition; exceedance of nitrogen critical loads
- ❑ Dose-response relationships and modelling of ozone impacts on crop yield (including economic valuation) and other ecosystem services; ozone impacts on biodiversity
- ❑ Mercury accumulation in soil and fish
- ❑ Chemical and biological recovery from acidification in lakes

http://www.unece.org/env/lrtap/workinggroups/wge/welcome.html

ES, biodiversity & human well-being

Millennium Ecosystem Assessment

Ecosystem services:

- **Supporting** *('underpinning role')*
  (e.g. biomass production, soil formation, nutrient and water cycling)
- **Provisioning**
  (e.g. food, fresh water, fuel, wood)
- **Regulating**
  (e.g. water purification, water and climate regulation, pollination)
- **Cultural**
  (e.g. education, recreation, aesthetic)

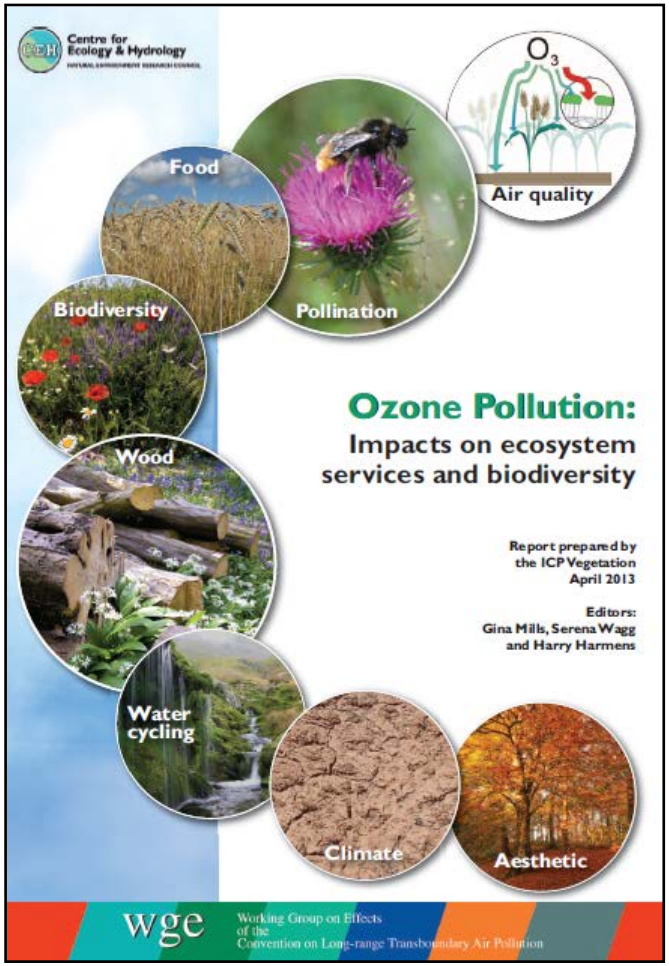
LIFE ON EARTH - BIODIVERSITY

HUMAN WELL-BEING

'Biodiversity enhances the ability of ecosystems to maintain multiple functions'
(Maestre et al. (2012) Science 335: 214-218)

'Species-richness has positive impacts on ecosystem services'
(Gamfeldt et al. (2013) Nature Communication 4: 1340

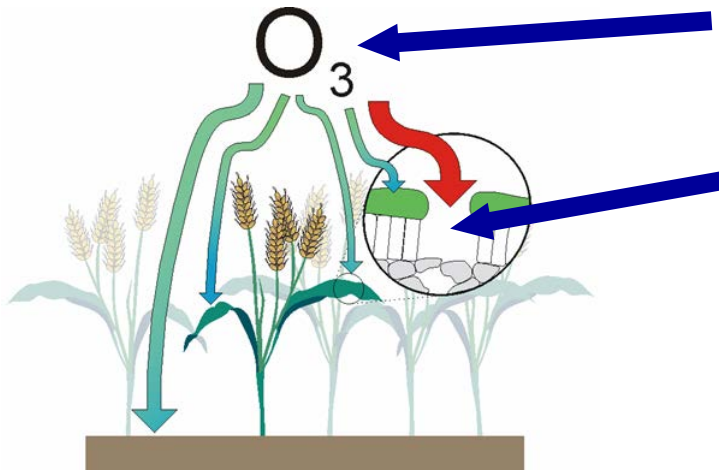
Ozone: Ecosystem Services & Biodiversity



Mills, Wagg & Harmens (2013)
http://icpvegetation.ceh.ac.uk

- **Supporting services** (ecological processes):
  - Primary production (and C cycling)
  - Nutrient cycling
  - Stomatal functioning (and water cycling)
- **Provisioning services**:
  - Crop production
  - Timber production
- **Regulating services**:
  - C sequestration and global warming
  - Air quality (via effects on vegetation)
  - Methane emissions
  - Water cycling
  - Flowering, pollination, insect signalling
- **Cultural services** (leisure, recreation, amenity)
- **Biodiversity** (including case-study Mediterranean)
- Valuing ozone impacts on ecosystem services

Ozone risk assessment



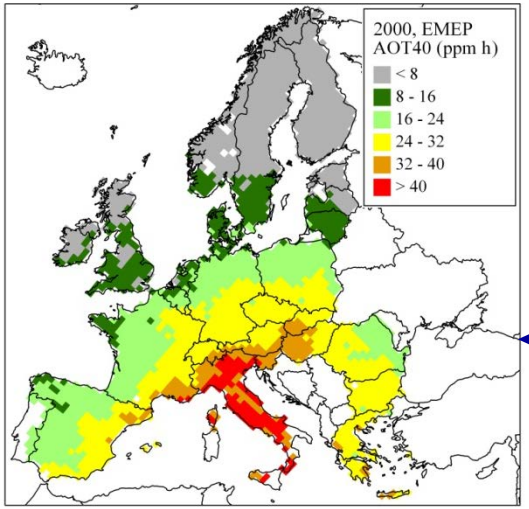
Emberson et al. (2000)
http://sei-international.org/do3se

Ozone concentration (**AOT40**) – EU

Ozone flux or Phytotoxic Ozone Dose (**PODy) –** LRTAP Convention

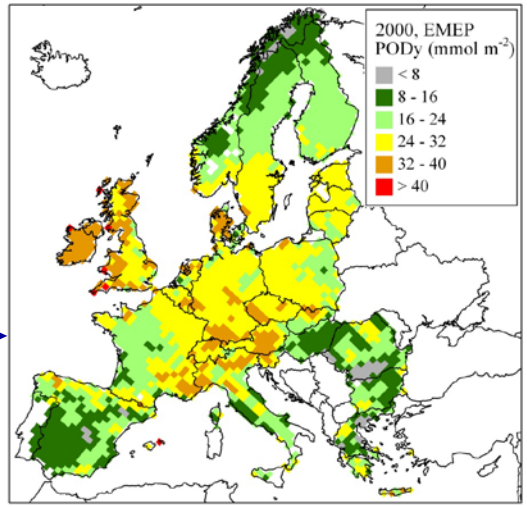
Calculated from hourly mean:
- Ozone concentration
- Light intensity
- Temperature
- Humidity (VPD)
- Soil moisture

AOT40 forests in 2000

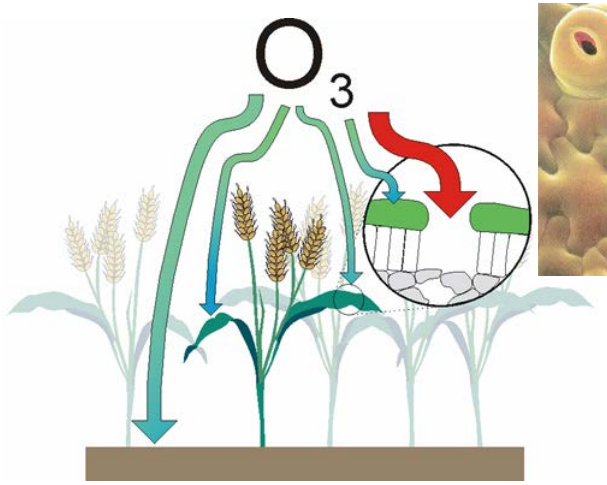


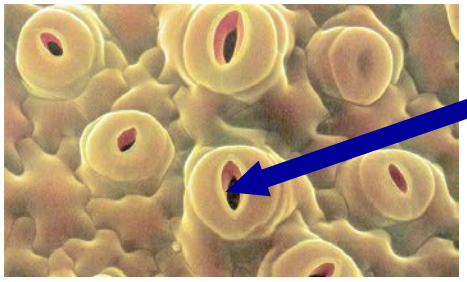
Different spatial pattern of risk of impact

Ozone flux forests in 2000(POD_1)



Stomatal functioning





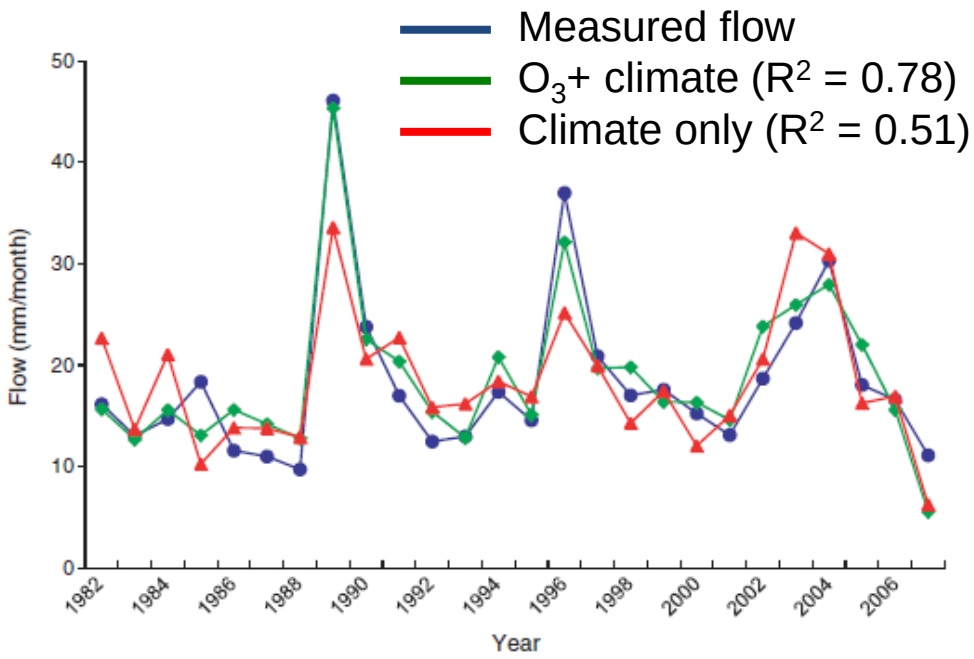
Stomatal ozone flux or Phytotoxic Ozone Dose (**PODy)** determines impact

- No clear pattern impact of ozone on stomata, except tendency for opening to occur at lower concentrations

	Total number	No effect	Sluggish control	Increased opening	Stomatal Closing
Crops (no. of species)	16	1	2	1	12
Crops (no. of experiments)	22	2	2	1	17
Trees (no. of species)	44	12	4	13	15
Trees (no. of experiments)	60	12	10	17	21
Grasslands (no. of species)	8	2	1	2	3
Grasslands (no. of expts.)	11	2	1	5	3
Total (no. of species)	68	15	7	16	30
Total (no. of experiments)	93	16	13	23	41
Ozone range (25th to 75th percentile)		35 – 80 ppb	70 – 120 ppb	50 – 90 ppb	59 – 100 ppb
Mean ozone concentration		**59 ppb**	**91 ppb**	**67 ppb**	**89 ppb**

Ozone and water cycling: catchment scale

SE USA, Appalachian region



Sun et al. (2012) GCB 18: 3395-3409

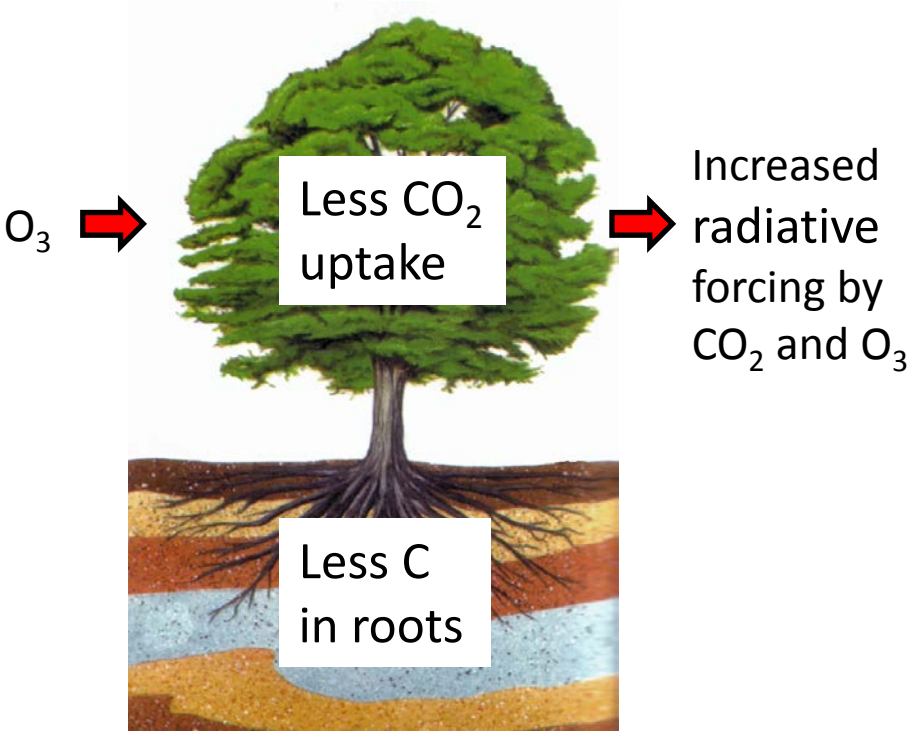
- ❑ Ozone contributes to variation in late season streamflow by as much as 23%
- ❑ Ozone at near ambient concentration reduces stomatal control

Consequences:

- ❑ Increase plant water use & transpiration, reduced stream flow
- ❑ Loss of stomatal sensitivity will increase drought frequency and severity, affecting ecosystem hydrology and productivity, and has implications for flow-dependent aquatic biota

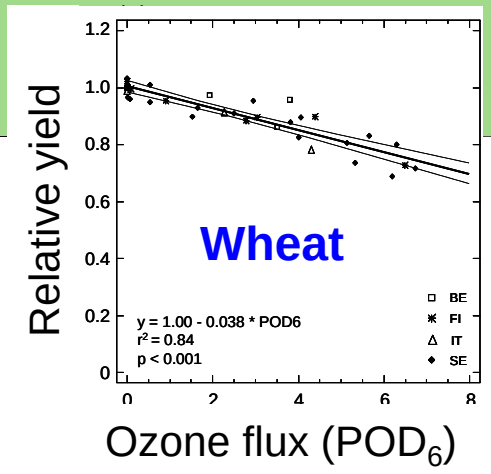
Regulation air quality and climate

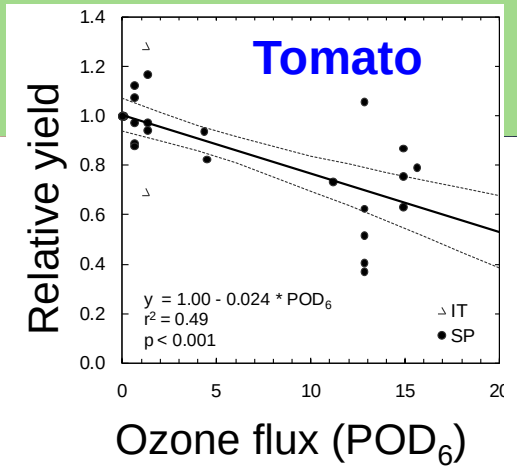
Meta-analysis Wittig et al. (2009): current ambient ozone reduces tree biomass by 7% (compared to pre-industrial ozone levels)

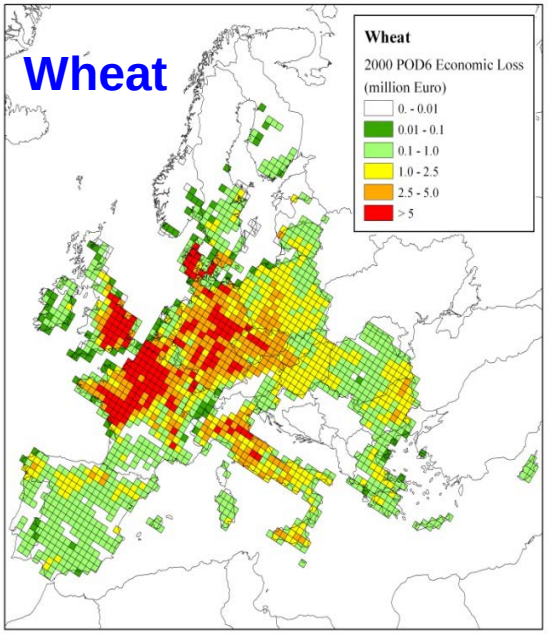


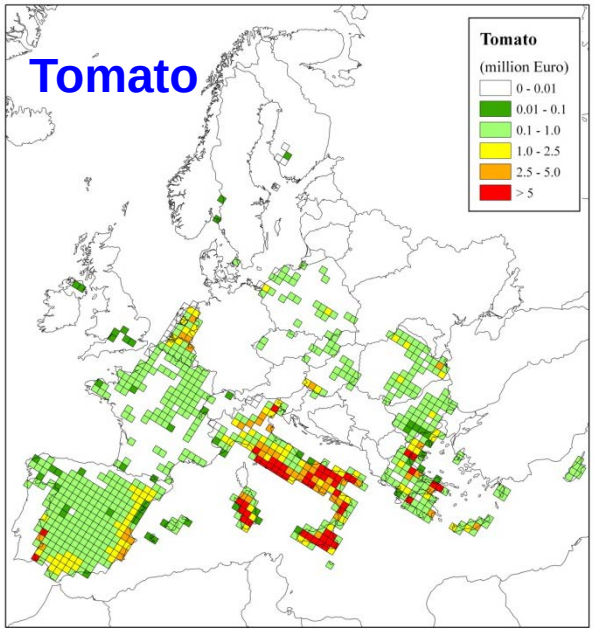
- O_3: third most important GHG
- Indirect radiative forcing via effects on vegetation could contribute as much to global warming as direct radiative forcing effect of ozone (positive feedback)
  Sitch et al., Nature (2007)
- Also consequences for global water cycle (see previous slide)

Food security









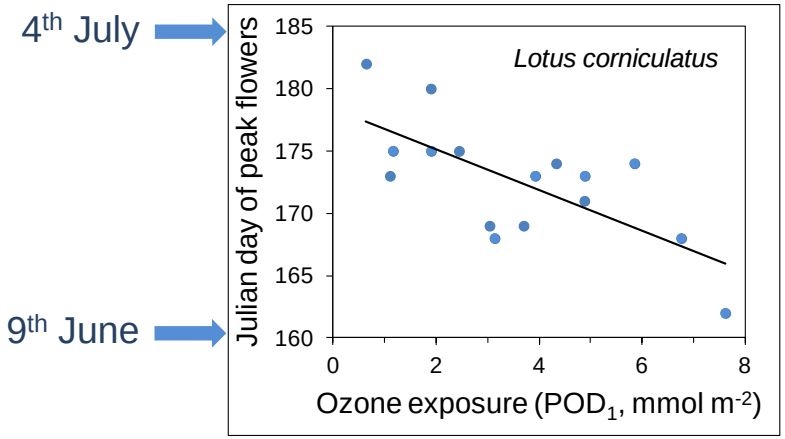
Ozone damage to leaves of salad crops reduces their market value

In 2000, ozone pollution reduced wheat yield by 14%, **a loss of €3.2 billion in EU27+CH+NO**

In 2000, ozone pollution reduced tomato yield by 9%, **a loss of €1.0 billion in EU27+CH+NO**

Mills & Harmens (2011) Ozone pollution: A hidden threat to food security.

Flowering and seed production



- Ozone can promote early flowering, affecting the synchronisation of pollinators and flowers

- Meta-analysis Leisner & Ainsworth (2012) Global Change Biology 18: 606-616: Current ambient ozone decreases seed number (-16%), fruit number (-9%) and fruit weight (-22%), but trend towards increased flower number and weight. Enhanced ozone, compared to current ambient ozone, decreases seed yield by 27%.

Research recommendations

- A systematic review and data mining exercise for ecosystem services to derive generic response functions for quantifying ozone effects

- Based on this review, identify services for which there is insufficient experimental data to derive response functions. Examples of further experimental research include:
  - impacts of ozone on C sequestration in roots and soils
  - ozone impacts in a future climate (warmer, higher CO_2)
  - large-scale field experiments on intact ecosystems
  - epidemiological analysis of field measurements to detect spatial patterns and temporal trends

- Further research on economic evaluation methods to aid cost-benefit analysis for current and future scenarios, where possible and appropriate