Environmental Impact of Air Pollution

EOH 468
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Overview

• Most of the focus in concern about air pollution is on human health.
• Environmental impact can be significant:
  – Damage to vegetation and animals
  – Damage to buildings and materials
  – Damage to ecosystems
VEGETATION and ANIMALS

- Injury versus Damage
- USDA distinction
- Injury is a change in visible structure of the plant.
- Damage is a change in *intended use* of a plant.
  - USDA focuses on agricultural production; economic concerns.

![Diagram of biological response spectrum for plants and air pollution.](image)

Fig. 8-1. Biological response spectrum for plants and air pollution.
VEGETATION and ANIMALS

• Leaf structure affects diffusion of gases (oxygen and carbon dioxide) for photosynthesis.
• Root system supports transpiration of water and nutrients from soil.
• Pollutants can utilize or affect both systems.
• Pollutants interact with other environmental variables.

Fig. 8-2. Cross section of leaf showing various components.
VEGETATION and ANIMALS

• Visible injuries
  – Chlorosis (reduction in chloroblasts)
  – Glazing or silvering (damage to epidermal layer)
  – Flecking or stippling (spotty damage to epidermal layer)
  – Early senescence (leaf drop)
  – Structural or changes in shape of structures.

VEGETATION and ANIMALS

• Physiological changes
  – Net photosynthesis
  – Stomate response
  – Metabolic activity
  – Reproduction

• Physiological changes studied under controlled conditions – what is affect in the field?
VEGETATION and ANIMALS

• Pollutants of major concern:
  – Ozone
  – Sulfur dioxide
  – Nitrogen dioxide
  – Fluorides
  – Peroxyacetyl Nitrate

Minor phytotoxic pollutants

• Have caused isolated cases of pollutant-induced injury
  – Nitrogen dioxide
  – Chlorine
  – Hydrochloric acid
  – Ammonia
  – Particulate matter
Plant injury

• Symptoms
  – Chlorosis - chlorophyll destruction
  – Necrosis - killing of tissues
  – Growth abnormalities
    • Reduced growth
    • Accelerated senescence
    • Bolting of flower buds
    • Abscission of plant parts
    • Curvature of leaf petiole (epinasty)

• Severity depends on
  – Pollutant concentration and duration
  – Sensitivity of species, strains, etc.
  – Growing conditions
Effects of SO$_2$

- Typically causes acute responses
  - Interveinal necrosis in broad leaved species
  - Necrotic streaks in narrow leaved species
  - Tip necrosis in conifers

Interveinal necrosis
Vegetation

- Ozone damage
- Enters through stomata
- Depends on nature of ozone exposure, weather and plant genetics

Vegetation

- Ozone exposure results in yield loss
Peroxyacetyl Nitrate (PAN) Injury

- Responsible for “smog injury” on vegetable crops
- Injury appears on lower surface as “glazing”

Fluoride injury

- May occur from
  - Uptake of gaseous fluoride
  - Uptake of fluorides from the soil
- Results from transport and accumulation of fluorides
  - In leaf margins-broad-leaved species
  - In leaf/needle tips-narrow leaved and coniferous species
Fluoride injury-Oregon Grape

Ethylene injury

- Natural plant maturation hormone controls ripening, fruit maturation
- Types
  - Dry sepal of orchids
  - Premature bud break
  - Inhibition of flowering
  - Accelerated flower aging
Acidic deposition

• Injury to plants has only been documented in simulated acid rain events under control laboratory conditions
• Injury to plants at pH approximately equal to 3.0
• Most commonly reported symptoms - necrotic lesions

Effects of acidic deposition

• Leaching of plant metabolites and inorganic nutrients
• Leaching of soil nutrients
• Mobilization of toxic metals
Interaction effects of pollutant mixtures

• Theoretically effects can be additive, synergistic, or antagonistic
  – Synergistic effects
    • Sulfur dioxide plus NO$_2$
    • Sulfur dioxide plus O$_3$

Forest Decline

• Forests
  – Declines in forests and changes in composition (species in the forest)
  – Interaction with other factors (drought, temperature)
Forest Decline

• California Pines
  – Trees lost needles
  – More susceptible to pine beetle
  – Current concern about forests near LA

Forest Decline

• Forest declines associated with pollution
  – Eastern White Spruce
    • Foliar damage, reduced growth
  – Red Spruce and Fraser Fir
    • Dieback and reduced growth
    • Most significant at higher elevations
    • Associated with acid rain as well
Forest Decline

• Decline-describes processes by which large numbers of trees die
  – Death occurs progressively, trees are weakened and become less vigorous
• May be due to natural or anthropogenic stress factors

Forest Decline

• Natural
  – Drought
  – Insects
  – Freezing temperatures
• Anthropogenic
  – Chronic pollutant exposures
Major forest declines

- California pines
- Eastern White Pine
- Red spruce and Fraser fir
- Southeastern pines
- Northeastern hardwoods
- Multiple species in Central Europe

Decline of California pines

- Ponderosa and Jeffrey pines in San Bernardino Mountains
- Has been occurring since the 1950s
- Older needles become chlorotic and die prematurely
- Reduced tolerance to insects
- Causal factor appears to be $O_3$
Eastern White Pine

• In the Northeast
  – Selective-only sensitive trees are affected
  – Foliar injury, reduced height and radial growth
  – Most pronounced in regions with high ambient O$_3$ levels

Red spruce and Fraser fir

• Injury reported from New England to North Carolina
• First observed in 1960s
• More pronounced above 800 meters
• Dieback of branch tips from the top and inward from newly grown shoots, reduced tree growth, tree death
Red spruce and Fraser fir

- Red spruce in New England
- Red spruce and Fraser fir in the Smoky Mountains (NPC reports dieback of Fraser Fir due to insects)
- Effects may be to a combination of $O_3$ and acidic deposition

Decline of Frasier fir reportedly due to insects in the Smoky Mts
Pines in the Southeast

- Virginia, North and South Carolina, Georgia, Florida
- Reduced diameter growth on loblolly and slash pines
- Causal agent?

Hardwoods in the Northeast

- Pennsylvania, New York, Massachusetts, and Vermont
- Crown dieback and increased mortality
- Yellow birch, American beech, white birch
Declines in Central Europe

- Multiple species are affected
- First observed in the 1970s
- Needles become yellow followed by defoliation
- Silver fir in the Black Forest
- Other species affected similarly including pines, beeches, and oaks

Declines in central Europe

- Forest tree decline first recorded at higher elevations (> 800 meters)
- Older trees on west-facing slopes are most affected
- Surveys conducted in the 1980s showed upwards of 50% of the trees in western Germany affected
Decline of a European coniferous forest

Declines in Central Europe

- Exposure to air pollutants believed to be the primary cause
  - Large number of species are affected
  - Occurs over large geographical area
  - Rapid symptom onset
- Causal pollutants
  - Ozone and acid fogs
Domesticated Animals

Fluoride
- Fluorosis observed in cattle, sheep, horses, pigs.
- Dental and skeletal changes (affects calcium metabolism)
- Source is industrial operations, such as phosphate fertilizer production
- Now less common in developed world

Domesticated Animals

- Lead
  - Effects similar to human effects: diarrhea, colic, neurological disorders, etc.
  - Sources: lead arsenate insecticide, uncontrolled industrial operations.
Buildings and Materials

- Effects on metals
- Corrosion of surface, changes in electrical properties.
- Sulfur dioxide is important, through acidic activity.
- Iron, steel most affected
- Galvanized steel (zinc coated) can corrode.

Buildings and Materials

- Copper oxidizes to form green patina under exposure to sulfur oxides.
- Oxidation occurs more in Humid, acidic air, less in Desert, dry air

Oxidation of surface of metals in electric switches can cause problems.
Buildings and Materials

• Limestone (and other rock) contains CaCO₃
• Acid rain reacts chemically:
  – CaCO₃ + H₂SO₄ + H₂O = CaSO₄·H₂O + CO₂
  – This causes surface to crumble
  – Forms a coating of black gypsum (calcium sulphate)
Buildings and Materials

• Paints
  – Vehicles and pigments
  – One example is damage to auto paint from some pollutant ‘fallout’.

• Textiles and textile dyes
  – Natural fibers can be affected by sulfur dioxide.
  – Some synthetic fabrics (e.g. Nylon) affected by NO$_x$
  – Particulates cause soiling

Buildings and Materials

• Rubber
  – Ozone causes cracking and deterioration of rubber.
  – Butadiene – styrene; butadiene - acrylonitrile
    • Double bonds
  – Antioxidants can increase resistance to cracking.
Buildings and Materials

- Impact of acidic deposition
- Impact of Nitrogen input
- Impact of Mercury deposition

Ecosystems
Ecosystems (Acid)

- Acidic Deposition effects on buildings and materials already discussed
  - Acid rain: pH < 5.6
- Acidification affects aquatic chemistry.
- Some species cannot tolerate acidic water.
- Declines in fish populations.
- Fishless lakes

Sulfate Deposition Patterns

- [http://nadp.sws.uiuc.edu/amaps2/](http://nadp.sws.uiuc.edu/amaps2/)
Ecosystems (Nitrogen)

• Nitrogen input
• Nitrogen is an essential plant nutrient
• Modern-day deposition is higher than pre-industrial era.
• Increased nitrogen can alter mix of species in a forest.
  – Netherlands: grass species change; forest species change

Ecosystems (Nitrogen)

• Nitrogen can be transformed in soil to nitrate, which can be leached from the soil.
• Nitrogen load can alter microbiological composition of the soil (fungal to microbial).
• Increased runoff to lakes, rivers.
Ecosystems (Nitrogen)

• Nitrogen in aquatic ecosystems.
• Increased plant nutrients increases biomass
• Concern is algal blooms
  – Oxygen depletion as algae decay
  – Resultant fish kills
• Atmospheric nitrogen deposition only one source of N in aquatic ecosystems.
  – Up to 40 % of N in some systems.

Ecosystems (Nitrogen)

• Example of an algal bloom
Ecosystems (Mercury)

• Mercury Deposition

• Biomagnification
  – Microorganisms generate methyl mercury from inorganic mercury.
  – Mercury levels are higher in predatory fish (e.g. Tuna)
  – Mercury emission from power plants has not been well regulated in US (or many other places)
Ecosystems (Mercury)

- Power plants deposit mercury locally and distant from the source.
  - EPA: up to 14% deposited within 30 miles of the plant.
- Impact on wildlife may be significant.
  - Depends on intensity of mercury contamination
  - Eagles, ospreys, loons, herons, mink, sharks
  - Not much research; but human impact is known.

![Map showing total mercury wet deposition, 2005](image)
Odor pollution

• Associated with the presence of objectionable odiferous substances
• Odors may be pleasant, neutral, unpleasant
• Unpleasant odors described as malodors

Odor pollution

• Odoriferous substances have potential for inducing symptoms in some individuals
• Malodors are viewed as an annoyance
Odor measurement

• Can be sensed by humans but cannot be measured using instruments
• Sensory attributes may be quantified by exposures in controlled environments
  – Detectability
  – Intensity
  – Character
  – Hedonic tone (pleasantness/unpleasantness)

Odor measurement

• Odor threshold
  – Detection
    • Concentration of a substance detected from background
  – Recognition
    • Concentration of a substance at which one can positively identified an odor
Odor threshold/ characteristics

Table 6.1 Odor Thresholds and Characteristics of Selected Chemical Compounds

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Odor Threshold (ppmv)</th>
<th>Odor Character</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetaldehyde</td>
<td>0.21</td>
<td>Green, sweet</td>
</tr>
<tr>
<td>Acetone</td>
<td>100.0</td>
<td>Chemical sweet, pungent</td>
</tr>
<tr>
<td>Dimethyl amine</td>
<td>8.047</td>
<td>Fishty</td>
</tr>
<tr>
<td>Ammonia</td>
<td>46.8</td>
<td>Pungent</td>
</tr>
<tr>
<td>Benzene</td>
<td>4.03</td>
<td>Solvent</td>
</tr>
<tr>
<td>Butyric acid</td>
<td>0.001</td>
<td>Sour</td>
</tr>
<tr>
<td>Dimethyl sulfide</td>
<td>0.001</td>
<td>Vegetable sulfide</td>
</tr>
<tr>
<td>Ethanol</td>
<td>10.0</td>
<td>Sweet</td>
</tr>
<tr>
<td>Ethyl mercaptan</td>
<td>0.001</td>
<td>Earthy, sulfide-like</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>1.0</td>
<td>Hay, straw-like, pungent</td>
</tr>
<tr>
<td>Hydrogen sulfide</td>
<td>0.00047</td>
<td>Egg-sulfide</td>
</tr>
<tr>
<td>Methanol</td>
<td>100.0</td>
<td>Sweet</td>
</tr>
<tr>
<td>Methyl ethyl ketone</td>
<td>10.0</td>
<td>Sweet</td>
</tr>
<tr>
<td>Paracresol</td>
<td>0.001</td>
<td>Tar-like, pungent</td>
</tr>
<tr>
<td>Perchloroethylene</td>
<td>4.88</td>
<td>Chlorinated solvent</td>
</tr>
<tr>
<td>Phenol</td>
<td>0.047</td>
<td>Medicinal</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>0.47</td>
<td>Sulfury</td>
</tr>
<tr>
<td>Toluene</td>
<td>2.14</td>
<td>Methical, rubbery</td>
</tr>
</tbody>
</table>

Odor detection

- Logarithmic relationship with concentration
- Olfactory fatigue
  - Cannot be perceived after a few minutes
- Habituation
  - Getting used to an odor for an extended period
Odor problems

- Malodors common cause of citizen complaints
- Major malodorous sources
  - Rendering plants
  - Soap-making facilities
  - Petrochemical plants/refineries
  - Sewage treatment plants
  - Industrial livestock farms