Ozone Air Quality Standards and Vegetation: Where Are We?

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OUTLINE

- Ambient O₃ concentrations
- Milestones in O₃ vegetation response
- Technologies used in dose-response
- Standards to protect vegetation
- Index evaluation
- Conclusions
2008 provincial 4\textsuperscript{th} highest daily maximum 8h O\textsubscript{3}

Source: Tom Dann EC-NAPS
Yearly Variation in Ozone (ppb) from Alberta trend sites (1999-2008)

Source: Tom Dann EC-NAPS
Milestones in Ozone Forest Response

San Bernardino Mountains, CA (1980)
Key Historical Event I: The Discovery of Ozone’s Phytotoxicity to Forest Trees in the U.S.


Key Historical Event II: Population Changes Related to Ozone Documented in North American Forest Trees

Key Historical Event III: Ambient O\textsubscript{3} Decreases Tree Growth and Productivity


10-year-old southern Wisconsin *Populus tremuloides* clones differing in O\textsubscript{3} sensitivity near Millbrook, New York, where background O\textsubscript{3} is high.
Key Historical Event IV: $\text{O}_3$ Linked to Community Change

- Documented replacement of ponderosa pine (*Pinus ponderosa*) in San Bernardino Mts. by white fir (*Abies concolor*)


Experimental Technologies Used in O$_3$ Vegetation Response

Indoor Chambers (1970’s)

Open-top Chambers (1980’s-1990’s)

Ambient “Gradients”

Free-Air US and Germany 1998-2010
Automated (upper) and manual dendrometers monitor stem growth at time scales from minutes to days.


Common genetic material approach
(Karnosky et al.)

A. OTC study (Alberta, MI) 1986-96
B. Aspen FACE (Rhinelander, WI) 1998-2009
C. Ozone gradient study (Kenosha and Rhinelander, WI and Kalamazoo, MI) – 1995-2005
Common aspen genetic material reveals continuum of response mechanisms?

<table>
<thead>
<tr>
<th>Measurement</th>
<th>OTC</th>
<th>FACE</th>
<th>O₃ Gradient</th>
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<tbody>
<tr>
<td>Visible symptoms</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Premature leaf abscission</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Pest occurrence</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Stomatal conductance</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Height and diameter</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>Clonal variation</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Survival</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Reproduction</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

✓ = statistically significant O₃ effect found; - = not evaluated

Standards to Protect Vegetation

- **Standards-based**
  - Three-year average of annual 4th highest daily max. 8 h $O_3$ (EPA, CCME)
  - WHO 2005 guideline = 100 µg m$^{-3}$ (51 ppb) 8 hr mean
  - Alberta AAQO = 1 hr daily max. 82 ppb (160 µg m$^{-3}$) effective 1/2/2007
    - CASA PM and $O_3$ project team implementation?
- **Cumulative-based**
  - AOT40 (Führer et al., 1997)
  - SUM60 (Lefohn and Foley, 1992)
  - W126 (Lefohn and Runeckles, 1987)
  - Cumulative frequency distribution (Krupa et al. 1995)
- **Flux-based**


Proposed Federal Rule: Some limitations

1. Highest weighting given to highest $O_3$ concentrations
2. **Weighting decoupled from known plant physiology**
3. No rationale for arbitrary exponent 4403 and constant 126 ppm
4. W126 claims integration of uptake, $O_3$ exposure defence?
5. Developed under a different $O_3$ climate in California in the 1980’s
6. Developed largely from OTC experiments
7. **Statistical fit forced on biological response**
8. **Degree of W126 biological association not demonstrated in field**
9. Empirical, free-air evaluation shows lack of W126 biological association
10. Mathematically too complex: utility in standards?

2. Lack of synchrony in $O_3$ exposure and plant uptake

- Grünhage et al. 1994. Environmental Pollution 85, 125-129. “atmospheric conditions that facilitate the daily occurrences of peak (highest) $O_3$ concentrations in general do not coincide with the conditions that promote plant uptake.”

We have been at this a very long time!

Karnosky, Skelly, Percy, Chappelka 2007. Perspectives regarding 50 years of research on effects of tropospheric ozone air pollution on U.S. forests. Environmental Pollution 147, 489-506

Alberta: Which Index?

NAPS data from 7 rural AB stations with > 8 years of record
Index Evaluation in a Free-Air, Multi-Year Manipulative Experiment

Photo: aspen birch section Aspen FACE ring
The Aspen FACE experiment is examining the impacts of interacting elevated atmospheric CO₂ and O₃ on northern forest ecosystem structure and function.

Full Factorial, 3 reps:
- C, +CO₂, +O₃, +CO₂+O₃
- CO₂: 360 and 537 ppm
- O₃: 38 and 51 ppb

Growing season (daytime) fumigation from bud break to leaf drop (1998-2009)
Response of 5 aspen clones and white birch

Vertical inlet pipes (10 m)

Aspen (5 clones)
Aspen/maple
Aspen/birch

30 m dia

Prevailing wind (0.2 to 4 m sec$^{-1}$)
Central GHG facility for the 32 ha FACE site
Can a simple model be developed using an air quality standard $O_3$ predictors?

Response variable
basal area (BA)

Predictor variables (6)
$O_3$ (annual, 4th highest daily max. 8h conc.)
Temp (cumulative GDD to base 10°C)
Solar radiation (PAR seasonal sum)
Wind speed (seasonal average)
Precipitation (seasonal sum)
Soil moisture content (seasonal average, within stands)

30 cases (3 rep $O_3$ rings, 3 rep control rings) x 5 years (1999-2003)
5 aspen clones (n=498 trees) and birch (n=444 trees)
Growing season 4th highest daily max 8-h average ozone (ppb)

What 8-hour level might be protective?

Clone 216 mean cross-sectional area (sq m)

68-72 ppb

EPA NAAQS

CWS

Modified primary exposure-response function

Aspen Clone 216

Growing season 4th highest daily max 8-h average ozone (ppb)

Mean cross-sectional area (sq m)

95% CL derived from 3000 Monte Carlo scenario runs with O₃, WS, GDD

\[
Y = 0.00684 - 0.000031 \text{ 4th highest } O_3 - 0.00551 \text{ WS} + 0.000003 \text{ GDD}
\]
Aspen FACE O₃ exposure 1999-2003

EPA NAAQS
CWS

W126

K. E. Percy
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Evaluation of $O_3$ metrics as single predictors of basal area growth over five years

<table>
<thead>
<tr>
<th></th>
<th>Aspen clone</th>
<th>white birch</th>
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<tbody>
<tr>
<td>$O_3$ index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8L (pos.)</td>
<td>271 (tol.)</td>
<td>216 (med.)</td>
</tr>
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</table>

| 4th highest | 0.354(0.078) | 0.454 (0.021) | 0.479 (0.017) | 0.119 (0.112) |
| SUM06       | 0.228(0.078) | 0.228(0.160)  | 0.163(0.187)  | 0.031(0.251)  |
| AOT40       | 0.375(0.067) | 0.213(0.138)  | 0.190(0.159)  | 0.000 (0.877) |
| Max1h       | 0.371(0.069) | 0.197(0.152)  | 0.250(0.109)  | 0.331 (0.015) |
| W126        | 0.647 (0.006)| 0.618 (0.003) | 0.648 (0.002) | 0.376 (0.009) |

Data are $R$ sq. adj. ($P$ value)

Predicted aspen growth loss during 2001-2003

We have measured response close to predicted using common genetic material from Aspen FACE grown in 3 growth/biomass trials.
Conclusions

- $O_3$ is a concern in some regions of Alberta
- Alberta should re-consider current $O_3$ 82 ppb 1 hr AAQO
- SUM60, AOT40, W126 not suitable
- CWS form, averaging time, metric target level is suggested
- CWS biological association with 2 species, 5 genotypes over 5 years under free-air conditions, large inter-annual climate variation, stand dynamics, pest activity demonstrates utility
- changing averaging time to annual to protect sensitive vegetation
Upcoming Air Pollution Meetings Fort McMurray

  – May 23
  – Industry, source to sink papers, 1 hr Panel Discussion
  – Book (18 chapters) to be published in Elsevier Developments in Environmental Science Series

• 43rd Air Pollution Workshop  (www.apworkshop.org)
  – May 24-25
  – One-day Field Trip May 26
Thank You!