Empirical and Simulated Critical Loads for N Deposition in California Mixed Conifer Forests

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Mixed Conifer Forest: Summer-Dry Mediterranean Climate
CL Methods and Approaches Used

- **Empirical**: Epiphytic lichen indicator groups; lichen chemistry; NO$_3$ leaching; PP fine root biomass
- **Simulated**: DayCent biogeochemical model; NO$_3$ leaching and trace gas emissions from soil
- **Critical values indicative of CL exceedance**: Litter C:N; foliar N; N concentration in the lichen *Letharia vulpina*
Ion Exchange Resin Throughfall Collector

Fenn & Poth, 2004
JEQ 33:2007-2014
*Letharia vulpina*; wolf lichen; In the Sierra Nevada of California concentrations of N in *L. vulpina* are correlated with N deposition and adverse changes in lichen community composition.
Clean Site Threshold Determination for N concentrations in *Letharia vulpina*

Based on data from 535 samples at urban, rural and remote sites east of the Cascade Crest in Oregon and Washington states. 1.0% N was selected as the upper limit for the expected background range.
Throughfall N vs. N in *L. vulpina*

Threshold N concentration = 1.0% N in *L. vulpina*; Corresponds with a CL of 3.1 kg N ha⁻¹ yr⁻¹ in the Sierra Nevada Mountains of California.
Lichen Indicator Groups

- *Acidophytes*: sensitive to even small increases in N; will disappear under continued N loading.
- *Neutrophytes*: are either tolerant to or enhanced by N deposition, but do not become ‘weedy’.
- *Nitrophytes*: fast growing species associated with NH$_3$ deposition and substrates with relatively high pH such as many hardwoods.
CL for lichen indicator groups:
Acidophyte abundance (A & D) and acidophyte dominance (C);
Acidophyte dominance shifts to neutrophyte dominance at 5.2 kg N ha\(^{-1}\) yr\(^{-1}\) (C).
Neutrophyte abundance (B);
Ecological Importance of Acidophytes

- Acidophyte dominance is the natural state in these forests
- Healthy acidophyte populations are an integral part of food webs; used as nesting material and habitat for insects, mollusks, birds and animals in the Sierra Nevada
- Reduced abundance of acidophytes has direct ecological consequences

*Bryoria fremontii*, known as the bearded lichen; an example of an acidophyte. Serves as forage for many species (e.g., squirrels, deer and a variety of invertebrates).
Platismatia glauca: A common acidophyte
Lichen Based Critical Loads: Summary

- Enhanced N in *L. vulpina*: 3.1 kg ha\(^{-1}\) yr\(^{-1}\)
- Our data suggest that acidophyte depression begins at even lower levels (< 2 kg ha\(^{-1}\) yr\(^{-1}\))
- Relative abundance of acidophytes decreased by 50% at 4.1 kg ha\(^{-1}\) yr\(^{-1}\)
- Acidophyte dominance shift to neutrophyte dominance at 5.2 kg ha\(^{-1}\) yr\(^{-1}\)
- Complete extirpation of acidophytes at 10.2 kg ha\(^{-1}\) yr\(^{-1}\)
- Lichens can be used as early warning indicators of other possible biological effects from N deposition
Nitrate Leaching or Runoff: Cardinal Indicator of N Saturation or N Excess

Nitrogen Deposition  ➔  Elevated NO$_3$ in surface runoff and in groundwater
Critical Value for Peak Runoff NO₃ Concentration Used for Estimating the Empirical CL:

If peak NO₃ concentrations are regularly > 14.5 μM or 0.2 mg L⁻¹ the CL has been exceeded by definition.
Empirical Throughfall CL for Mixed Conifer Forests: 17 kg N ha\(^{-1}\) yr\(^{-1}\)
(Based on UNECE acceptable leaching value of 0.2 mg L\(^{-1}\) or 14.3 μeq L\(^{-1}\))

\[ y = 8.69 + 0.58x \quad r^2 = 0.98 \]

CL for stream NO\(_3\) of 10 μeq/L = 14.5 kg N ha\(^{-1}\) yr\(^{-1}\)
Empirical Bulk Deposition CL for Mixed Conifer Forests: 4.7 kg N ha\(^{-1}\) yr\(^{-1}\)

\[ y = 4.65 + 0.04x \quad r^2 = 0.81 \]

CL for stream NO\(_3\) of 10 μeq/L = 4.7 kg N ha\(^{-1}\) yr\(^{-1}\)
Throughfall N Deposition in the San Bernardino Mountains

White bars represent the CL (14.5 kg N ha\(^{-1}\) yr\(^{-1}\)) for acceptable NO\(_3\) in runoff (10 µeq L\(^{-1}\))
Preliminary evidence for a biological effect of N deposition in ponderosa pine: Fine root biomass

An estimated 26% reduction in fine root biomass at N deposition of 17 kg ha\(^{-1}\) yr\(^{-1}\).
Litter C:N vs. N deposition. Critical value of 34.1 associated with CL for elevated NO₃ leaching.

\[ y = 148.08 - 3.81x \quad r^2 = 0.79 \]
Daycent simulated peak NO₃ concentrations in seepage water with increasing N deposition. Simulated CL similar to empirical CL in western SBM.
Daycent simulated peak NO$_3$ concentrations in seepage water. First exceedance in 1956 under historical deposition scenario.
Daycent simulated annual NO₃ export in seepage water. High leaching rates with historical deposition began after 1960.
Ideally, critical loads should include pests and multiple stress effects.

Bark beetle injury in Ponderosa pine: *Dendroctonus brevicomis*
Bark Beetle Mortality in 2003 in Ponderosa Pine in the San Bernardino Mountains

Forest stand with high mortality in the San Bernardino Mountains
Biodiversity; Invasive Species

Camp Paivika

Deep litter, dominance of *Galium aparine*
Breezy Point exotic annual grass, bracken fern

*Galium aparine* with native forbs
San Bernardino Cover of Herbaceous Understory Plants along Deposition Gradient

Site (W to E)
Empirical and simulated CL were similar for NO$_3$ leaching (17 kg ha$^{-1}$ yr$^{-1}$)

CL ranged from < 3 to 17 kg ha$^{-1}$ yr$^{-1}$

Lichen CL ranged from <3 to 10.2 kg ha$^{-1}$ yr$^{-1}$

Critical value for litter C:N was 34.1, higher than for mesic temperate forests (typically C:N of 25)

Preliminary data suggests that fine root biomass is highly sensitive to N and may be suitable for CL setting

Nitrogen also affecting forest susceptibility to insect pests, exotic invasions and biodiversity; but insufficient data to set a CL for these effects

Future work looking at effects of ozone, fire, Mediterranean characteristics, and management practices on CL
## Simple Mass Balance Estimates of N as a Nutrient

### CL for the San Bernardino Mountains

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mapping Manual</th>
<th>Revised</th>
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<td>N immobilization (N&lt;sub&gt;i&lt;/sub&gt;)</td>
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<td>Denitrification (f&lt;sub&gt;de&lt;/sub&gt;)</td>
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<td>Acceptable N leaching (N&lt;sub&gt;le(acc)&lt;/sub&gt;)</td>
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<tr>
<td>CL&lt;sub&gt;nut(N)&lt;/sub&gt;</td>
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*From: Breiner, Gimeno & Fenn, 2007*
The Principal Factors Affecting Forest Sustainability in the San Bernardino Mountains

- Summer drought; more particularly successive years of severe drought
- Ozone injury
- Chronic N deposition
- Stand densification y fuel accumulation, exacerbated by long term fire suppression and N deposition
- Insect outbreaks
- Mortality caused by the above multiple stress factors
- Severe stand replacement fires
- Soil acidification: unknown effects on forest health as base saturation is still relatively high compared to more heavily leached soils
- Climate change?
In N saturated chaparral catchments fire was not sufficient to return the system to a conservative state of N cycling:
“We drink what we drive.” (Mark Poth)
Barton Flats with Incense cedar encroachment, highest understory richness
Changes in understory species richness, 1973 to 2003, at selected locations across an atmospheric pollution gradient, highest rates of deposition to lowest, in the San Bernardino National Forest, CA.

<table>
<thead>
<tr>
<th>Location</th>
<th>% of plant species</th>
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<th>number of species</th>
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</tbody>
</table>

*Percent present only in 2003 or only in 1973
Dry N Deposition
CMAQ Simulation 2002 Total

January 1, 2002 1:00:00
Min= 0 at (32,116). Max= 99 at (92,51)
Simulated N Deposition in S. Cal. (from Gail Tonnesen, Center for Environmental Research and Technology, UCR)
4 km zoom in LA, Orange and western Riverside counties (s. California)
Figure 8

(a) Empirical CL (CP)

(b) Historical N deposition scenario (CP)

(c) Empirical CL (BF)

(d) Historical N deposition scenario (BF)
Figure 10

(a) CP (mean)

(b) BF (mean)

(c) CP (maximum)

(d) BF (maximum)
Figure 11

(a) CP (mean)
(b) BF (mean)
(c) CP (maximum)
(d) BF (maximum)