Decreasing N₂-fixation in *Lobaria oregana* is likely caused by anthropogenic nitrogen emissions

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### Abstract

Nitrogen (N) fixation is the dominant natural source of N in Pacific Northwest ecosystems, but low N₂-fixation rates result in N limitations to net primary productivity. However, anthropogenic emissions of N have increased globally due to agriculture and burning of fossil fuels. Long term N deposition has adverse effects such as eutrophication, soil acidification, and loss of biodiversity. In Pacific coastal ecosystems, epiphytic lichen communities are a dominant source of N₂-fixation, but exceedance of the critical load of N from deposition may decrease N₂-fixation by epiphytic lichens. Here, we test the hypothesis that atmospheric N deposition from anthropogenic sources is decreasing N₂-fixation by the cyanolichen, *Lobaria oregana* (Tuck.) Müll. Arg. We tested the hypothesis by measuring the N stable isotope composition (δ¹⁵N) of herbarium lichen specimens from 1989 to 2014. A δ¹⁵N of 0 ‰ indicates N₂-fixation, negative values represent agricultural emissions while positive values indicate N originating from fossil fuel emissions.

Lichen δ¹⁵N suggests N₂-fixation was the dominant source of N until the 1970's. A large increase in δ¹⁵N in the 1970's corresponds to the completion of I-5 and rapid development along the I-5 corridor. Lichen δ¹⁵N values that correspond to fossil fuel emissions have steadily increased to present, but large spatial variation exists due to localized sources. This suggests that over the short term, anthropogenic N deposition is causing a decrease in N₂-fixation by *Lobaria oregana*. The long term consequences are a likely shift from N sensitive, to N tolerant species.

### Background

One of the most vital nutrients required by flora and fauna of the Pacific Northwest is nitrogen. Nitrogen often limits net ecosystem productivity, and while it is abundant in the atmosphere in the form of N₂, 99% of this nitrogen is not available for 99% of plants or animals until it has been converted to a reactive form by N₂ fixation (Galloway et al. 2003).

The primary organisms capable of N₂-fixation in mature temperate forests of the Pacific Northwest are epiphytic cyanolichens (Figures 1 & 2). These lichens consist of a fungus that lives in symbiosis with a cyanobacteria that is capable of N₂-fixation.

### Hypothesis

I hypothesize that anthropogenic N deposition will negatively impact N₂-fixation by canopy lichens in temperate forests by causing a shift in N input into forest ecosystems from natural N₂-fixation, to anthropogenic N deposition.

### Approach

In order to test my hypothesis, I measured the relative abundance of stable isotopes of nitrogen (N) and N₂ of *L. oregana* specimens that spanned from pre-industrial (before 1900) to present day. Since N₂-fixation and atmospheric deposition each have unique nitrogen isotope compositions (δ¹⁵N), they provide distinct "signatures" that allow us to understand the origin of N, and ultimately determine if atmospheric deposition is affecting N₂ fixation. Each sample was categorized as either either coastal (Coast Range ecoregion), urban (Puget Lowland and Willamette Valley ecoregions), or inland (Cascades and North Cascades ecoregions) in order to test if different locations were affected more or less by anthropogenic N deposition. This will give us a better understanding of which ecosystems are most affected by N deposition.

### Results

![Figure 1](https://example.com/figure1.jpg)

**Figure 1.** Wind River Canopy Crane located in the Gifford Pinchot National Forest in western Washington. *Lobaria oregana* (Tuck.) Müll. Arg. is located in the "transition zone," at approximately 33 to 37 m in canopy height (McCune et al. 1997).

![Figure 2](https://example.com/figure2.jpg)

**Figure 2.** Lichens are a dominant lichen in forest canopies and is capable of assimilating atmospheric nitrogen and converting it into organic forms via N₂-fixation. (2)

![Figure 3](https://example.com/figure3.jpg)

**Figure 3.** Agriculture and burning of fossil fuels releases reactive N into the environment. It is deposited back into terrestrial and aquatic ecosystems as atmospheric deposition. (NPS, 2014)

![Figure 4](https://example.com/figure4.jpg)

**Figure 4.** Specimens of *L. oregana* were sampled at regional herbaria to represent a spatial and chronological distribution.

![Figure 5](https://example.com/figure5.jpg)

**Figure 5.** Agriculture and burning of fossil fuels releases reactive N into the environment. It is deposited back into terrestrial and aquatic ecosystems as atmospheric deposition. (NPS, 2014)

![Figure 6](https://example.com/figure6.jpg)

**Figure 6.** Mean lichen δ¹⁵N (‰) (± S.E.) for herbarium specimens within 8 distinct time periods. Increasing values across time represent a shift from N₂ fixation towards fossil fuel emissions. Since N₂ fixation and atmospheric deposition each have a unique ratio of nitrogen isotopes, they provide distinct "signatures" that will be easy to compare. A δ¹⁵N of 0 ‰ indicates N₂-fixation, while positive values indicate N input from fossil fuels and negative values indicate agricultural sources (Hoffman et al. 2019).

### Conclusions

- Data from herbarium specimens supports our hypothesis; an increase in δ¹⁵N in the 1970's corresponds to the completion of I-5 and rapid development along the I-5 corridor.
- Over the short term, anthropogenic N deposition is causing a decrease in N₂ fixation by *L. oregana*. The long term consequences are a likely shift from N sensitive, to N tolerant species. N tolerant species often will not be affected by additional inputs of N into the ecosystem, while N sensitive species are likely to be heavily influenced.

### Literature Cited


Hoffman et al. 2019. Nitrogen deposition sources and patterns along elevation gradients in the Greater Yellowstone Ecosystem determined from ion exchange resin collectors and lichens. Revision Pending.


### Photo Credit

(2) [https://ashcom.com/Lobaria-oregana](https://ashcom.com/Lobaria-oregana)

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