What is the critical load for nitrogen deposition in northern Great Plains grasslands?

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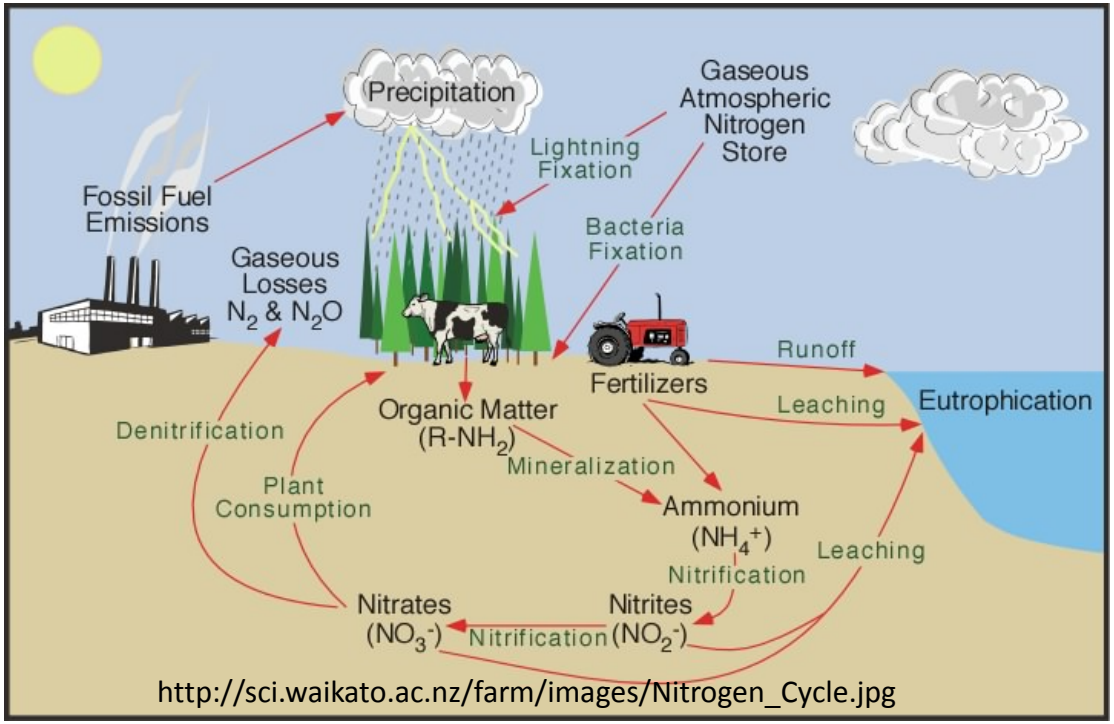
BHABEW XII – March 12, 2015
Rapid City, SD

U.S. Department of the Interior

Context

- Human activities play a major role in the global nitrogen cycle; our activities are responsible for ~40% of all nitrogen fixation.



http://sci.waikato.ac.nz/farm/images/Nitrogen_Cycle.jpg

- Adding nitrogen to natural vegetation can alter species composition, reduce diversity, and increase invasive species abundance.
- Critical load: the quantitative exposure to one or more pollutants below which significant harmful effects on sensitive elements of the environment do not occur

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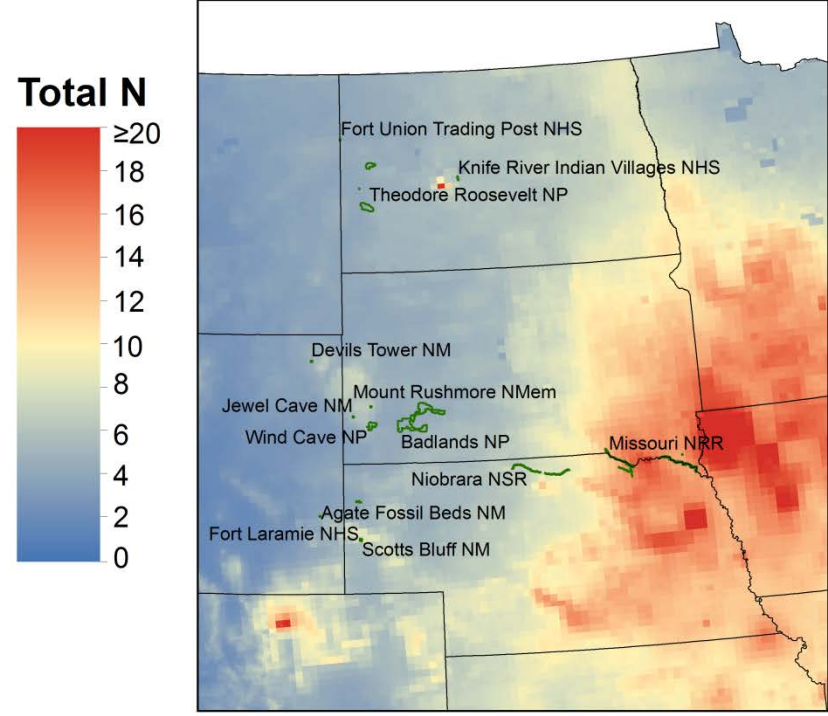
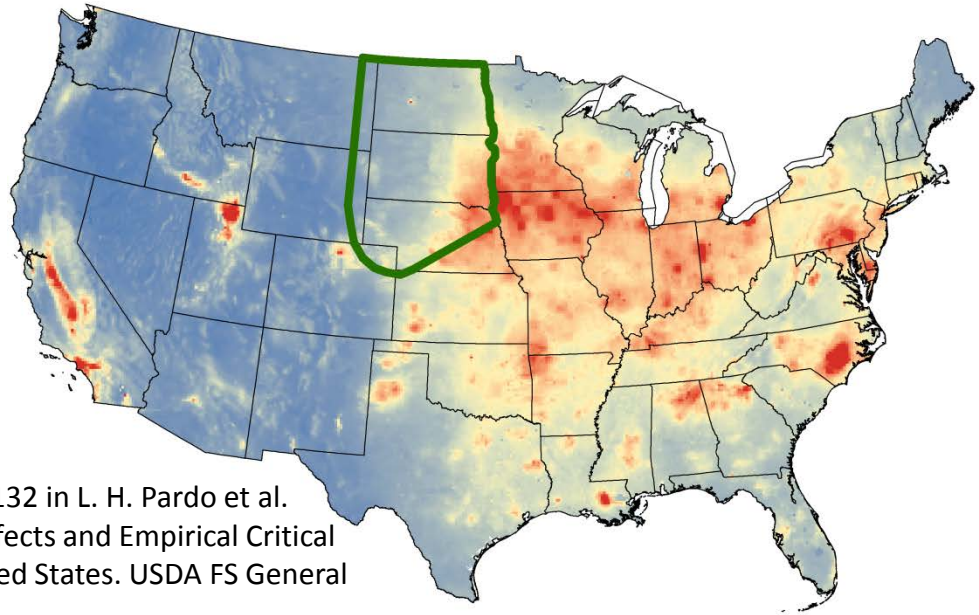
Context

- The NPS wanted to know the critical load for N in the NGP.
- Literature review* suggested Great Plains grassland vegetation will show some effects at 10-25 kg N/ha/yr.
- Few studies have investigated the effects of N addition at rates realistic for atmospheric deposition in the western US, and none have done this for the northern Great Plains (NGP).





*Clark, C. M. 2011. Great Plains. Pages 117-132 in L. H. Pardo et al. (eds). Assessment of Nitrogen Deposition Effects and Empirical Critical Loads of Nitrogen for Ecoregions of the United States. USDA FS General Technical Report NRS-80.

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Experimental Design: Sites

- Badlands Sparse Vegetation (BSV) at Badlands NP
- Low organic matter, nutrients, water holding capacity, and productivity
- Non-natives 15% of production, 25% of richness

- *Elymus trachycaulus, Poa secunda, Bouteloua gracilis, Bouteloua curtipendula, Gutierrezia sarothrae, Bromus japonicus, Eriogonum pauciflorum, Phlox hoodii*

Experimental Design: Sites

- Terrace at Wind Cave NP
- High organic matter, nutrients, water holding capacity; productivity approximately 4x BSV's
- Diversity similar to BSV
- Non-natives 34% of production, 12% of richness

- *Poa pratensis, Pascopyrum smithii, Nassella viridula, Hesperostipa comata, Bouteloua curtipendula, Bouteloua gracilis, Schizachyrium scoparium, Carex filifolia*

Experimental Design: Sites

- Hilltop at Wind Cave NP
- Shallow, cobbly soils, limited water holding capacity, productivity 75% higher than Terrace
- Greater diversity
- Non-natives 15% of production, 24% of richness

- *Amorpha canescens, Bromus japonicus, Bromus tectorum, Poa pratensis, Pascopyrum smithii, Hesperostipa comata, Andropogon gerardii, Carex filifolia, Carex inops*

Experimental Design: Treatments

- 2.5 x 2.5 m plots in blocks of 7 established in 2010
- add nitrogen as ammonium nitrate in water, 4x per summer

2010-2011	2012-2013
0, 2.5, 5, 7.5, 10, 20, 45, 68, 100	0, 2.5, 5, 7.5, 10, **15**, 20, **32**, 45, **56**, 68, **84**, 100

kg N/ha/yr

- 5 replicates per treatment (in blocks), except 10 replicates of control, at each site
- 70 plots per site

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Data Collected

Ecosystem characteristic	Response variable	Rationale
Soil N availability	Soil inorganic N ('10-'11)	N available for growth, leaching
Plant tissue N	C:N ratio of dominant native C3 grass, C4 grass, non-native C3 grass ('11 & '13)	Are plants using the additional N?
Aboveground net primary production	Total, herbaceous, and native herbaceous biomass	Does N limit plant growth? Of all types of plants?
Foliar cover	Total plant cover	Proxy for production measured by long-term monitoring programs
Litter load	Litter biomass, bare ground cover	Mechanical barrier to germination, growth
Non-native species	Non-native biomass	Undesirable species benefiting from additional N?
	Non-native proportion of cover	
	Total species richness	
Biodiversity	Native species richness	NPS mandate to preserve and protect
	Diversity	
Community composition	C3 proportion of biomass and cover	Seasonality of production; NPS mandate to preserve and protect
	Individual species' cover	

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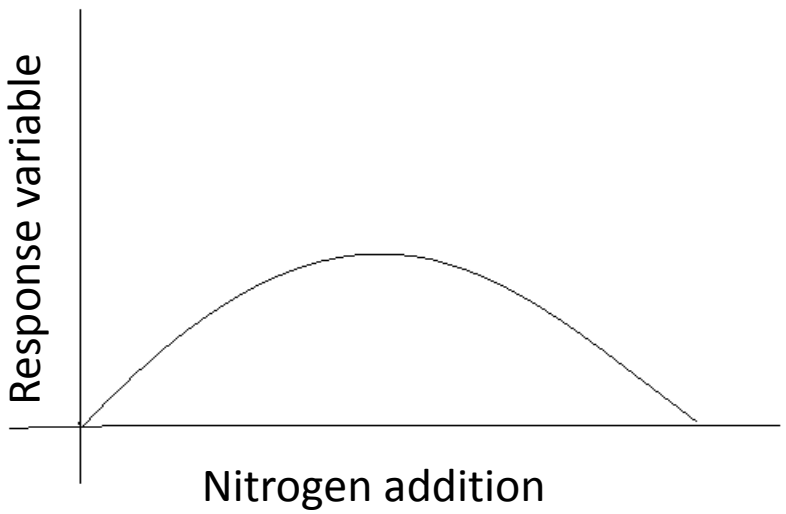
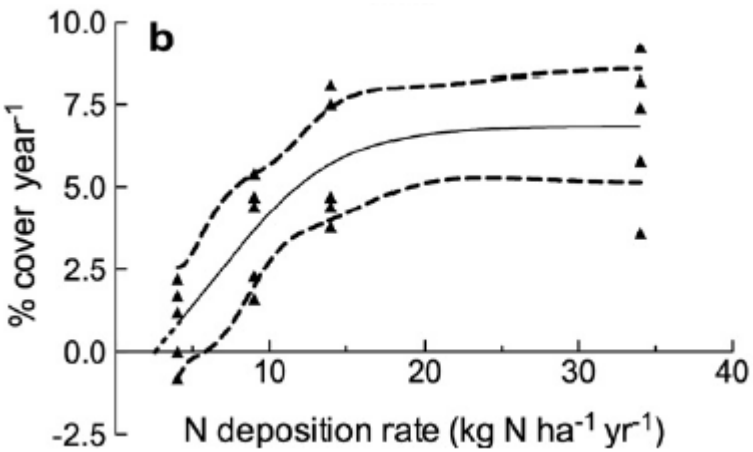
Questions

- At what level of N addition is the treatment different than the control?
- At what level of N *load* would we expect no effect?



Analysis

- Repeated measures analysis of variance (BSV, Terrace) or covariance (Hilltop, to account for *Amorpha*)
- Extrapolate curve fit to relative response back to “no response”



Bowman et al. 2012 *J. Environ. Mgmt.* 103: 165-171

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Results: BSV site

Ecosystem characteristic	Response variable	Response			
		2010	2011	2012	2013
Soil N availability	Soil inorganic N	▲	▲	--	--
Plant tissue N	*Elymus trachycaulus* C:N ratio	--	▼	--	▼
	Bouteloua gracilis C:N ratio	--	0	--	▼
	Bromus japonicus C:N ratio	--	0	--	▼
ANPP	Total biomass	▲	▲	▲	▲
	Native biomass	▲	▲	▲	▲
Foliar cover	Total plant cover	▲	▲	0	0
Litter load	Litter biomass	--	0	▲	▲
Non-native species	Non-native biomass or cover	0	0	0	0
	Total species richness	▲	0	0	0
Biodiversity	Native species richness	▲	0	0	0
	Diversity	0	0	0	0
Community composition	C3 proportion	0	0	0	0

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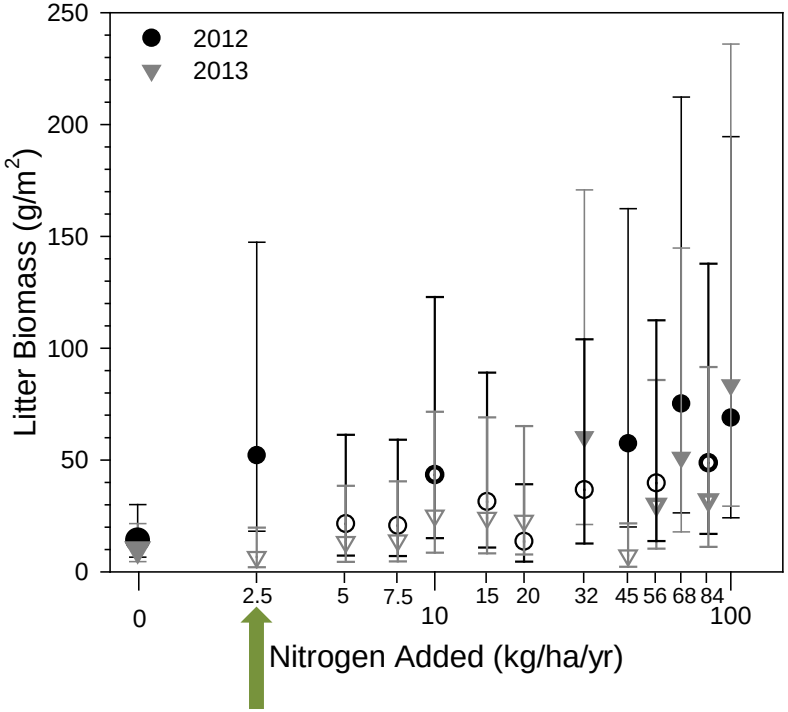
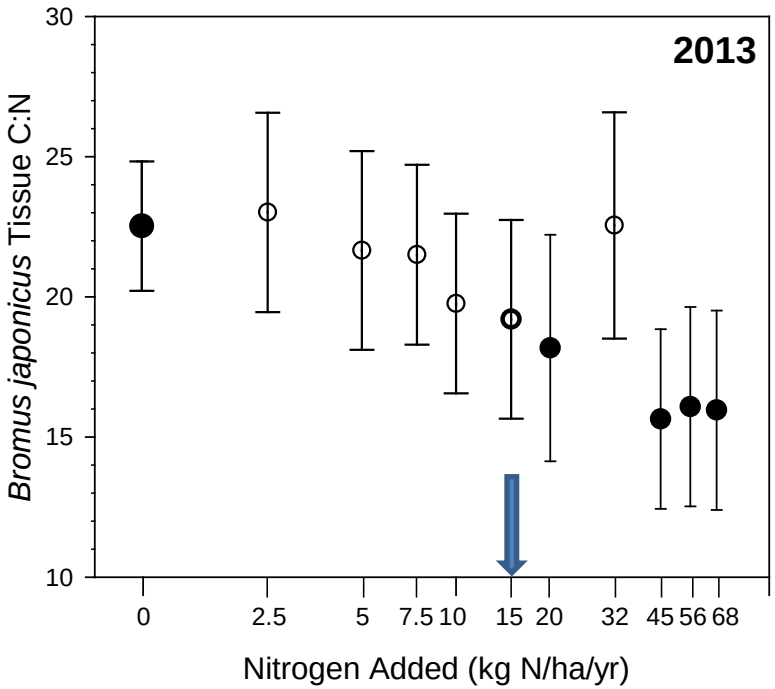
Results: BSV site

A: 5.9 kg N/ha/yr
B: 21 kg N/ha/yr

Type A Critical Load: Lowest



Type B Critical Load: Consistent



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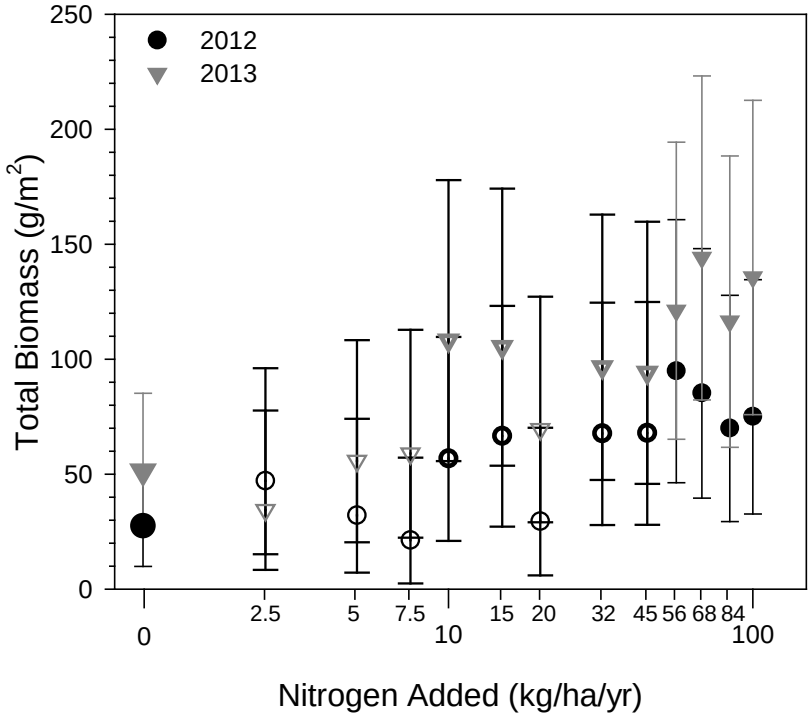
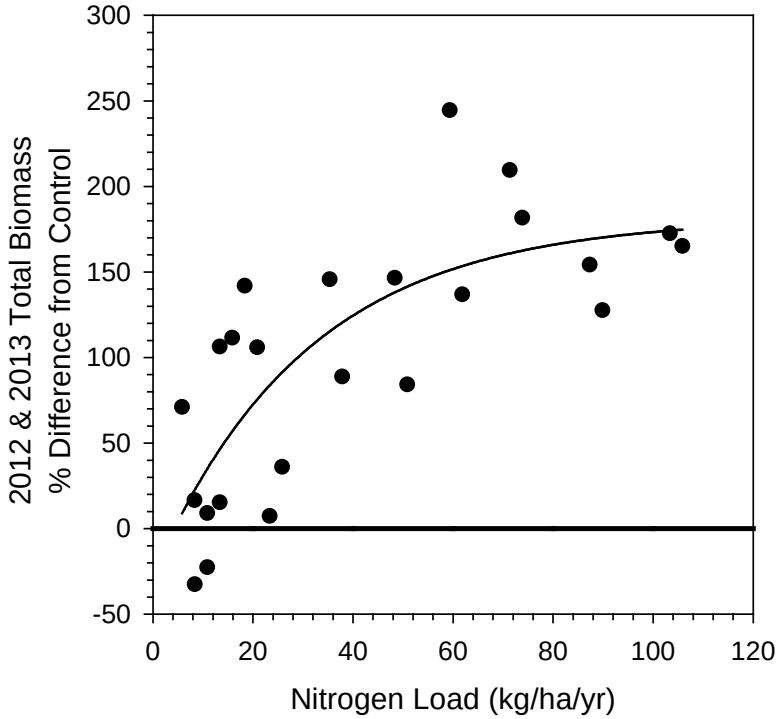
Results: BSV site

A: 5.9 kg N/ha/yr
B: 21 kg N/ha/yr
C: 4.3 kg N/ha/yr



Type C Critical Load: Extrapolate



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Results: Terrace site

Ecosystem characteristic	Response variable	Response			
		2010	2011	2012	2013
Soil N availability	Soil inorganic N	0	▲	--	--
Plant tissue N	*Pascopyrum smithii* C:N ratio	--	▼	--	▼
	Bouteloua curtipendula C:N ratio	--	0	--	▼
	Poa pratensis C:N ratio	--	▼	--	▼
ANPP	Total biomass	▲	▲	0	0
	Native biomass	0	0	0	0
Foliar cover	Total plant cover	0	0	0	0
Litter load	Litter biomass	--	0	0	0
Non-native species	Non-native biomass or cover	0	0	0	0
Biodiversity	Total species richness	0	0	0	▼
	Native species richness	0	0	▼	▼
	Diversity	0	0	▼	▼
Community composition	C3 proportion	0	0	0	0

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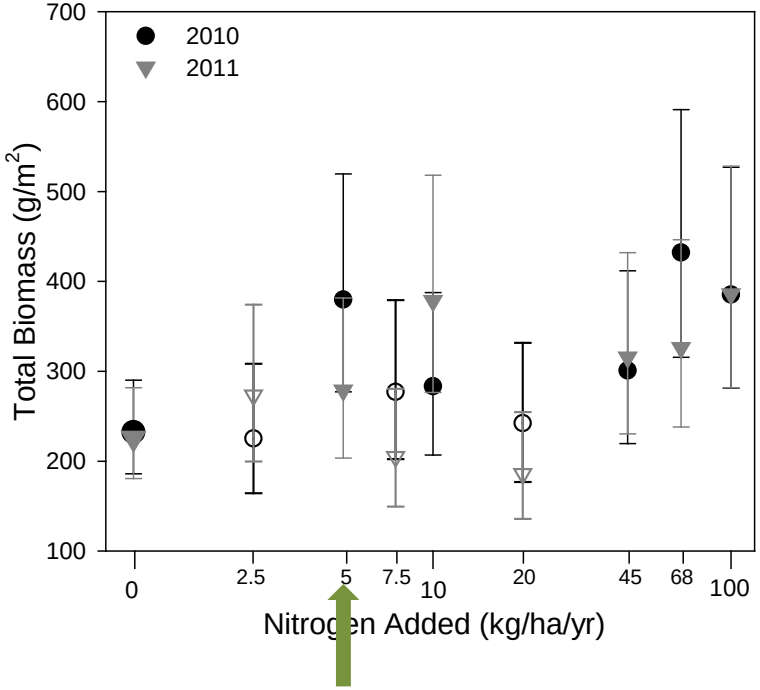
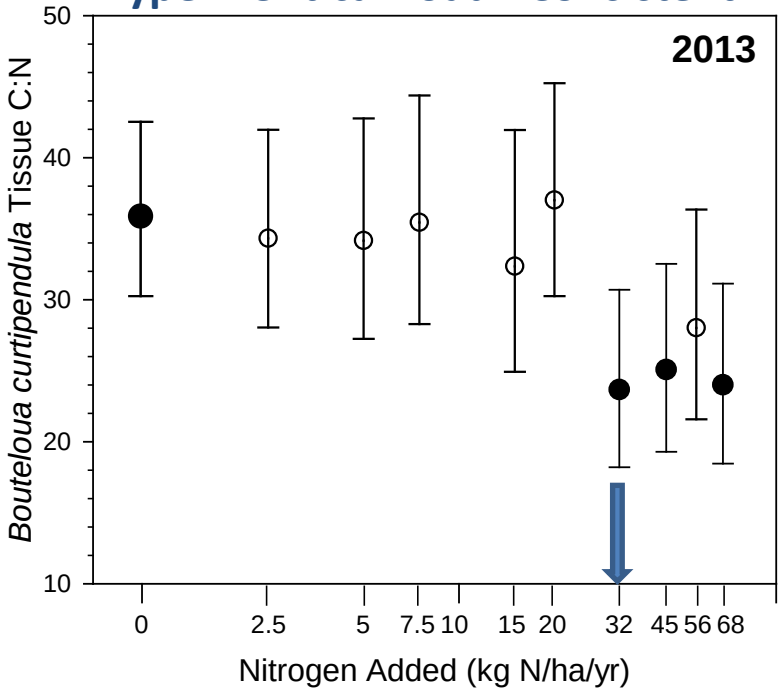
Results: Terrace site

A: 9.9 kg N/ha/yr
B: 38 kg N/ha/yr

Type A Critical Load: Lowest



Type B Critical Load: Consistent



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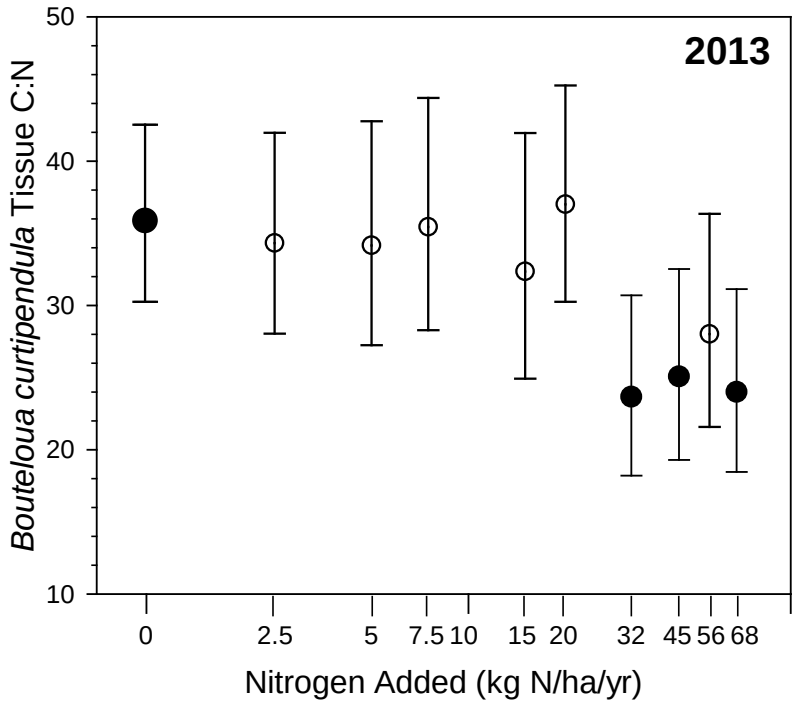
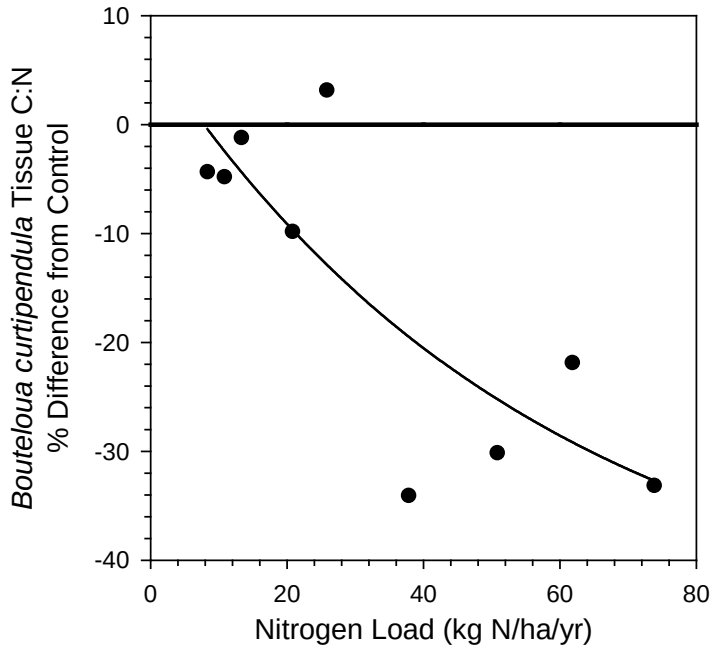
Results: Terrace site

A: 9.9 kg N/ha/yr
B: 38 kg N/ha/yr
C: 7.8 kg N/ha/yr



Type C Critical Load: Extrapolate



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Results: Hilltop site

Ecosystem characteristic	Response variable	Response			
		2010	2011	2012	2013
Soil N availability	Soil inorganic N	0	▲	--	--
Plant tissue N	*Pascopyrum smithii* C:N ratio	--	▼	--	0
	Andropogon gerardii C:N ratio	--	▼	--	0
	Bromus japonicus C:N ratio	--	▼	--	0
ANPP	Total herbaceous biomass	0	▲	▲	0
	Native herbaceous biomass	0	▼	0	0
Foliar cover	Total plant cover	0	0	0	0
Litter load	Litter biomass	--	0	0	0
Non-native species	Non-native proportion of cover	0	▲	0	▲
Biodiversity	Total species richness	0	0	0	0
	Native species richness	0	0	0	0
	Diversity	0	0	0	▼
Community composition	C3 proportion	0	0	0	0

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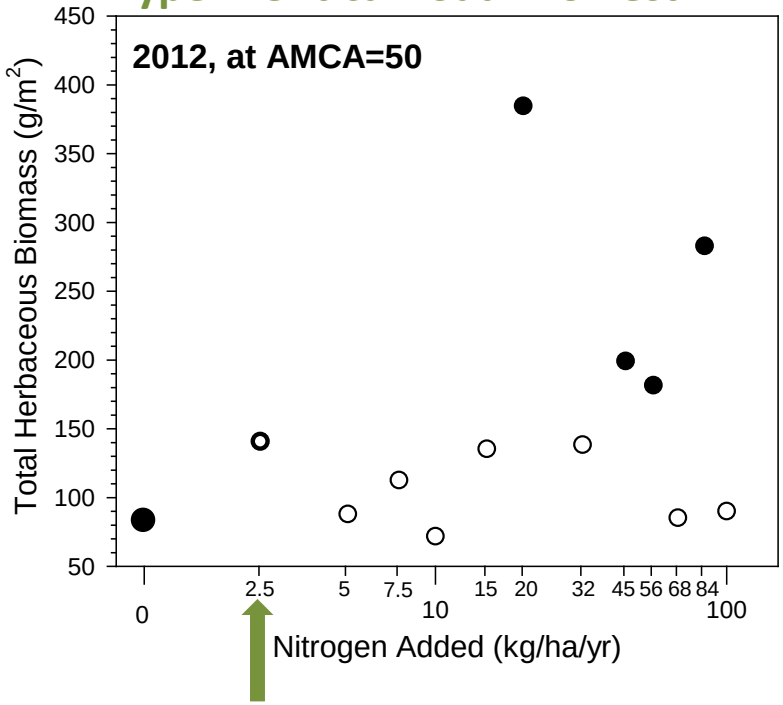
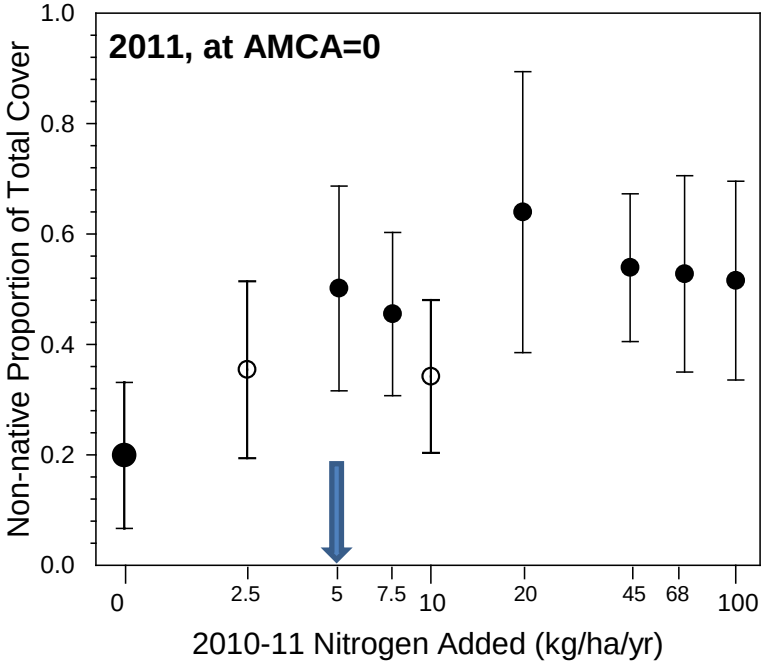
Results: Hilltop site

A: 6.4 kg N/ha/yr
B: 9.5 kg N/ha/yr

Type A Critical Load: Lowest



Type B Critical Load: Consistent



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Conclusions

Critical Load Type	BSV Site	Terrace Site	Hilltop Site
A	5.9	9.9	6.4 (high AMCA)
B	21	38	9.5 (low AMCA)
C	4.3	7.8	none

- Inconsistent responses complicate setting a definitive critical load.
- Precautionary critical loads are all below the range suggested by literature review and within or near the range of current deposition rates.

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Thanks to…

- NPS air resources division for funding and discussion about critical loads
- Field crews
  - 2010: Chelsea Kincheloe
  - 2011: Mark Visel & Christine Prins
  - 2012: Jessica Milby, Jessica Moran, Emily Meierindorf
  - 2013: Adam Fund & John Wendt
- Underpaid recruits: Jeff, Kassia, and Bengt Symstad
- Park support: Beth Burkhart, Milt Haar, WICA engine crew