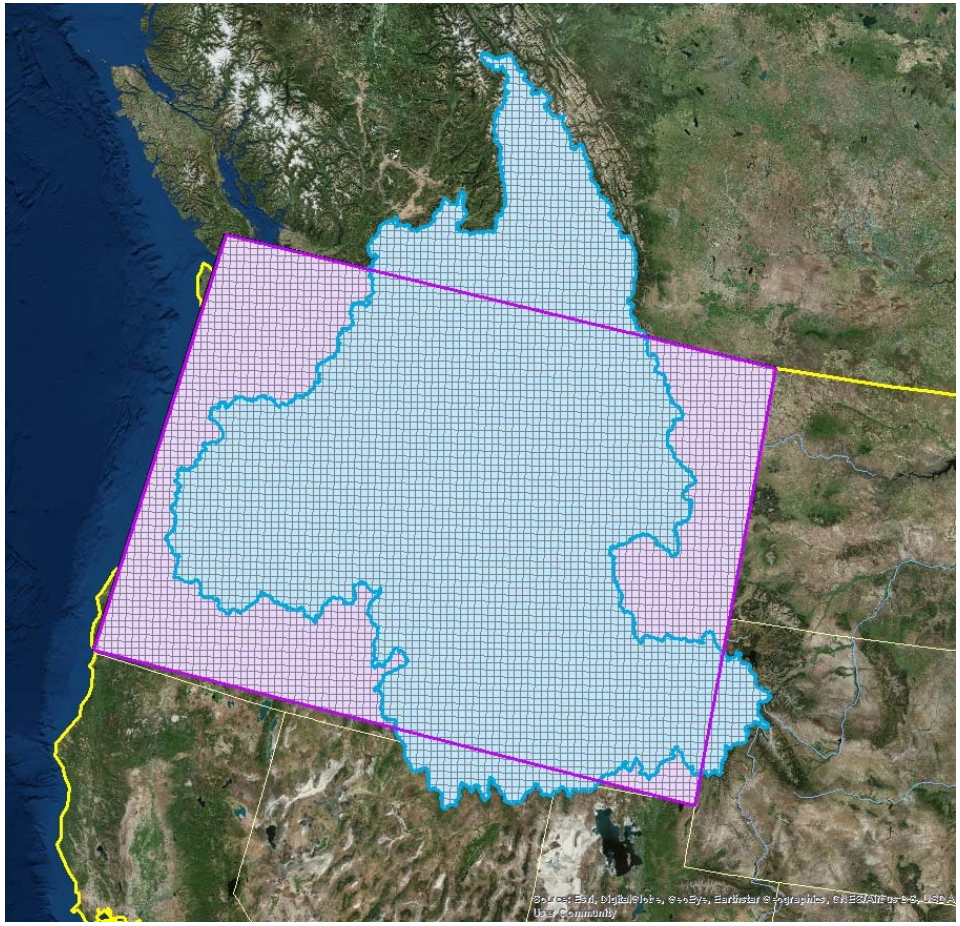
N Dynamics in the Pacific NW:

Insights from an integrated Earth system modeling approach

Why write this paper?

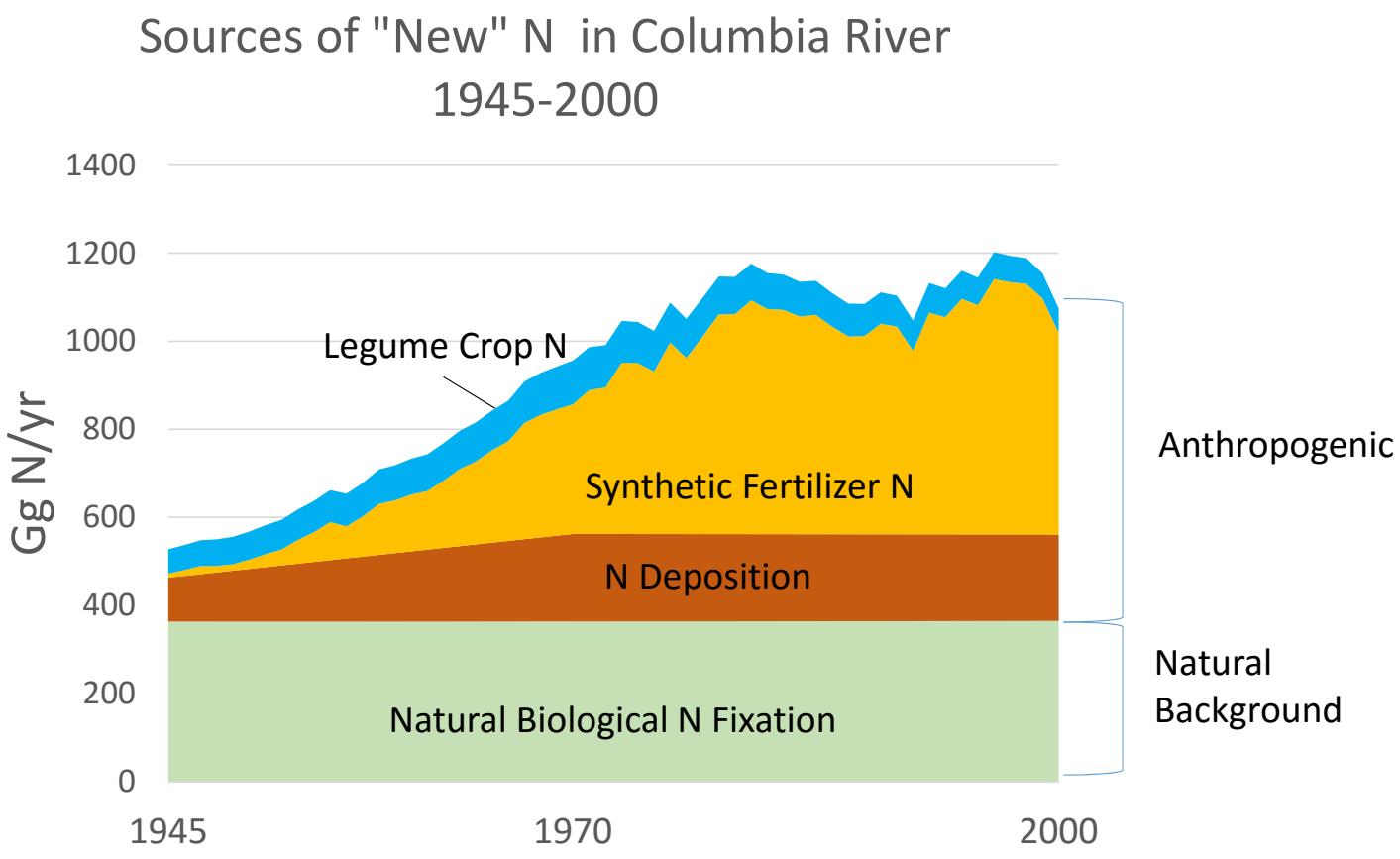
- Regional N budgets useful tools for gaining basic scientific understanding and management-relevant insight
- Have been carried out for many other systems, but not yet for the PNW
- N budgeting efforts rarely (if ever) linked to Earth System modeling efforts
- Provides framework to highlight collaborative nature of effort and novel insights that can be gained from a BioEarth-like approach

Study domain(s)

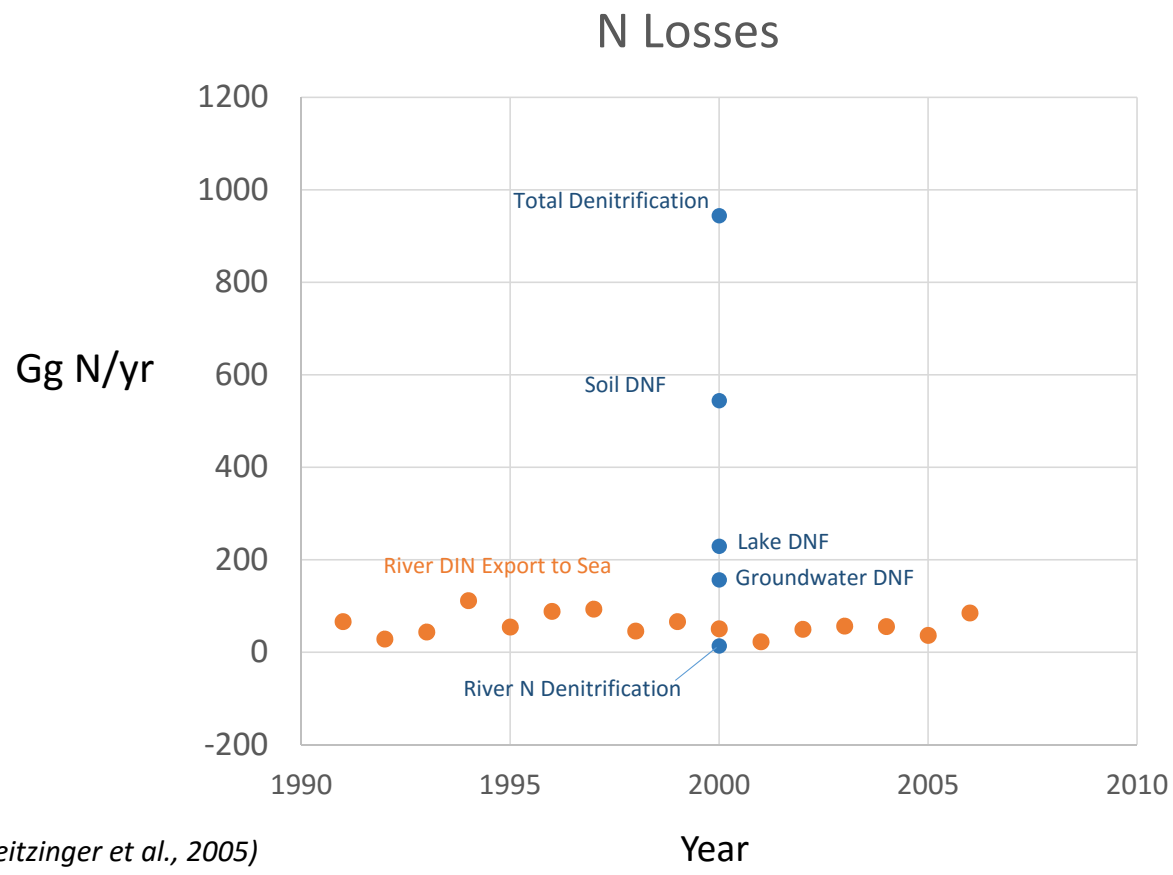


Domain (and resolution) for following several slides:

N Inputs

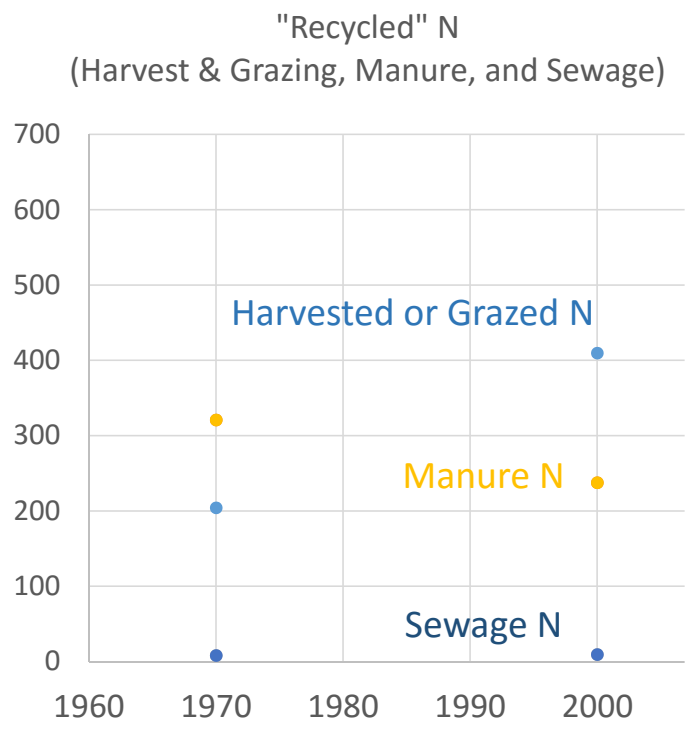

Sources of "New" N in Columbia River
1945-2000
Gg N/yr
1400
1200
1000
800
600
400
200
0
1945
1970
2000
Legume Crop N
Synthetic Fertilizer N
N Deposition
Natural Biological N Fixation
Anthropogenic
Natural
Background

N Outputs or Losses (Gg/yr)

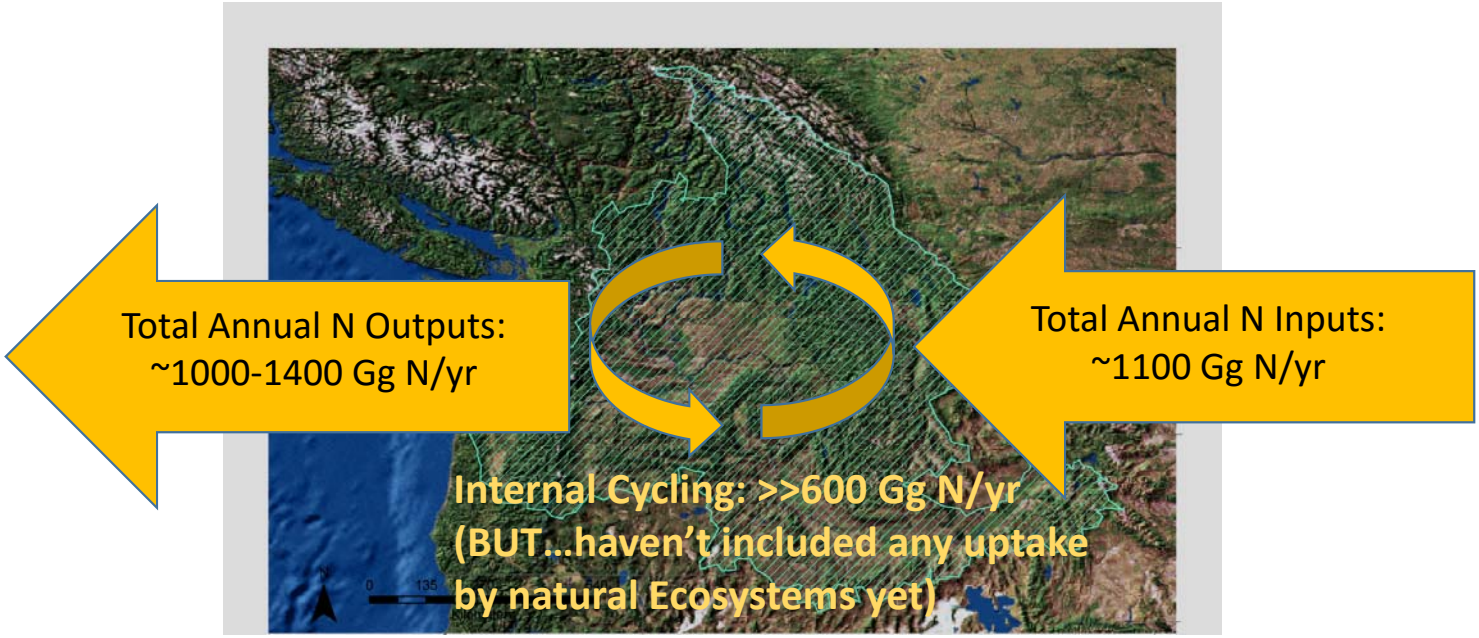


(Denitrification estimates from Seitzinger et al., 2005)
(River DIN export estimates from USGS NWIS system using Beaver Army Terminal Site)

Components of “Recycled” N in CRB (Gg/yr)

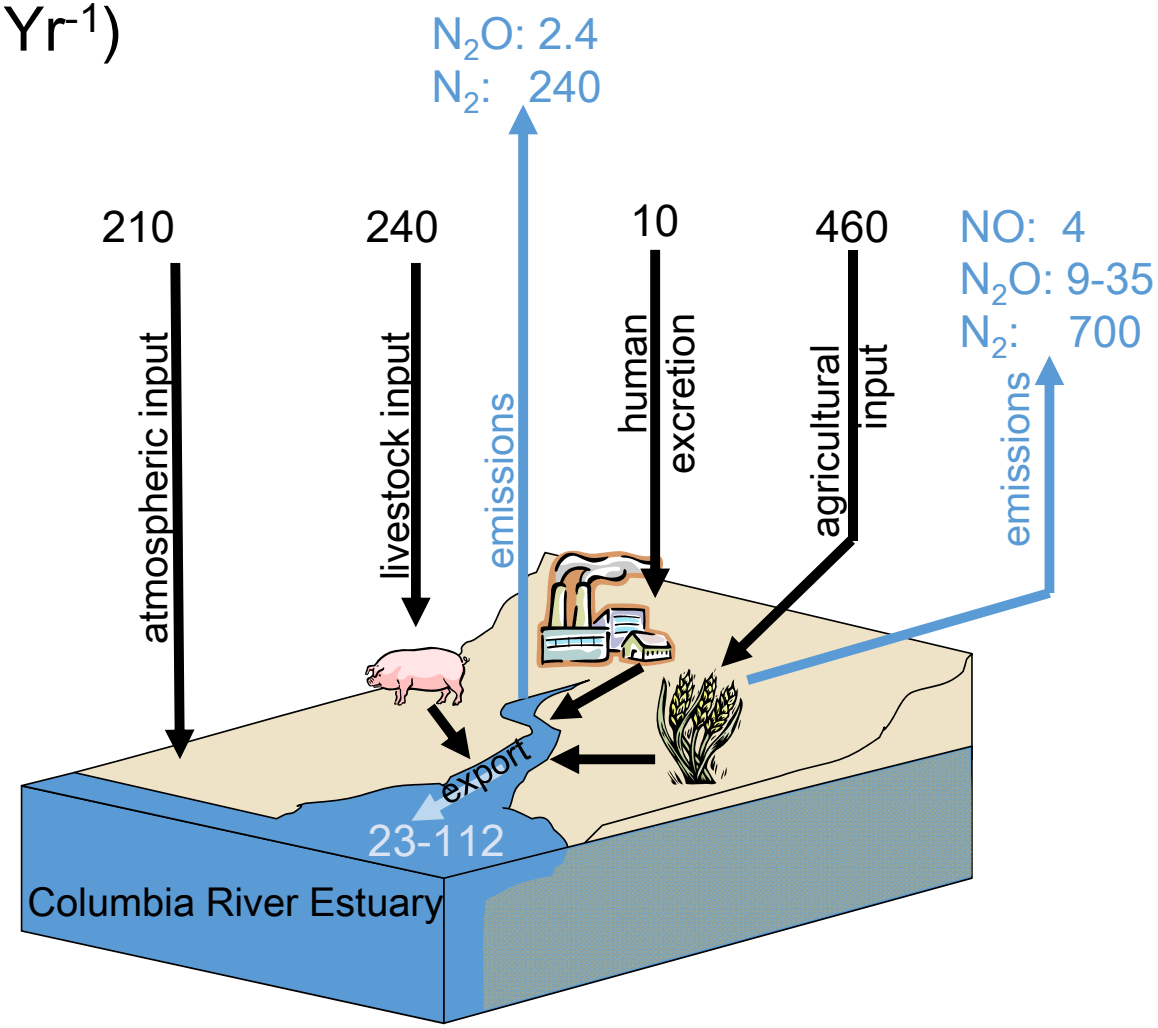


Putting Pieces Together



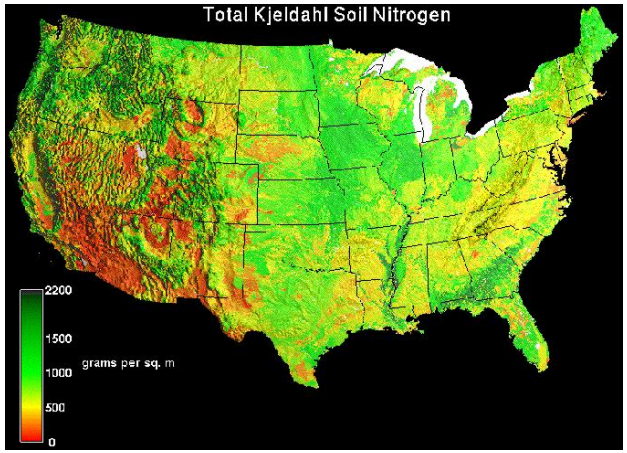
- Inputs and losses roughly in balance at regional scale (astoundingly!)

Columbia River Basin N Budget
(Gg N Yr^{-1})



N Stocks

How much N is in Soils? Sediments? Biomass?



???

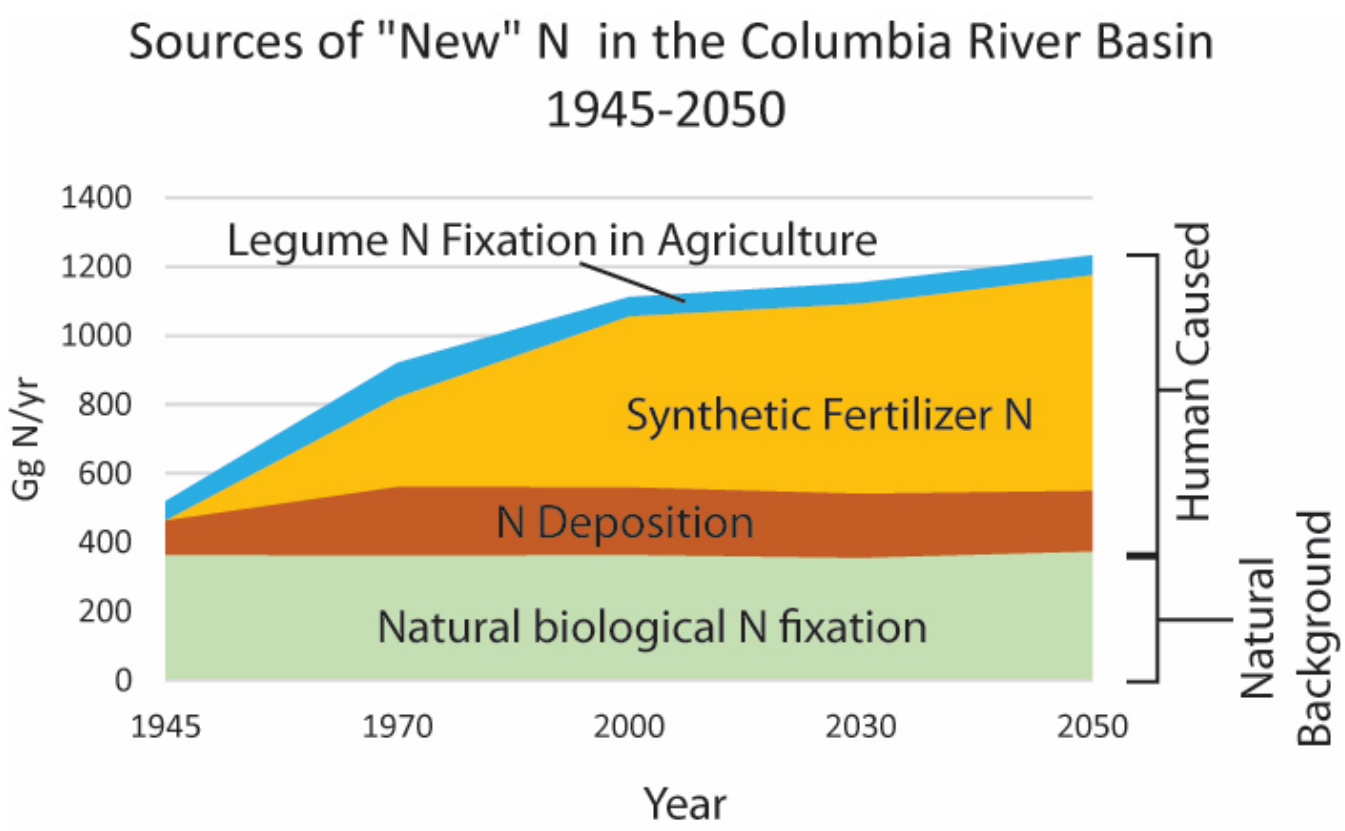
Is this something that RHESSys can help with?

Very rough estimate of soil N = 1,096,658 Gg N in CRB
Very rough estimate of veg N (assuming molar C:N = 50:1) = 35,958 Gg N in CRB
Net mineralization rate 10-120 kg N/km2/yr, scaled up this is ~730-8800 Gg N/year, so probably greater than inputs or outputs

Putting Pieces Together

- Inputs and outputs small in comparison to soil and vegetation stocks
- When soil N transformations are considered, internal cycling much greater than inputs or outputs

The future…


Sources of "New" N in the Columbia River Basin
1945-2050
Legume N Fixation in Agriculture
Synthetic Fertilizer N
N Deposition
Natural biological N fixation
Gg N/yr
1400
1200
1000
800
600
400
200
0
1945
1970
2000
2030
2050
Year
Human Caused
Natural Background

Big Fluxes

- Inputs
  - Synthetic Fertilizer
  - Natural N Fixation
- Losses
  - Denitrification (especially in soils, but lots of uncertainty here)
- Recycling
  - Harvest and export big and uncertain whether it is mostly a loss or mostly recycled locally at this point
  - Haven’t yet included what are likely the dominant pathways for N (re)cycling in the region (e.g. uptake and remineralization by natural ecosystems)

How Bio Earth could enhance this analysis (the path forward)

- Fill in holes/missing pieces
- More detail on fluxes
- Higher spatial resolution
- Higher temporal resolution
- Interactions between different sectors/systems???

Missing Pieces?

- Soil, sediment, and biomass stocks
- Industrial sources and sinks
- Crop and animal export via trade—how much of the harvested N is recycled locally?

Using Bio Earth to fill gaps and develop finer-grained understanding of N cycling

Bio Earth output and Atmospheric Deposition in the Columbia River Basin

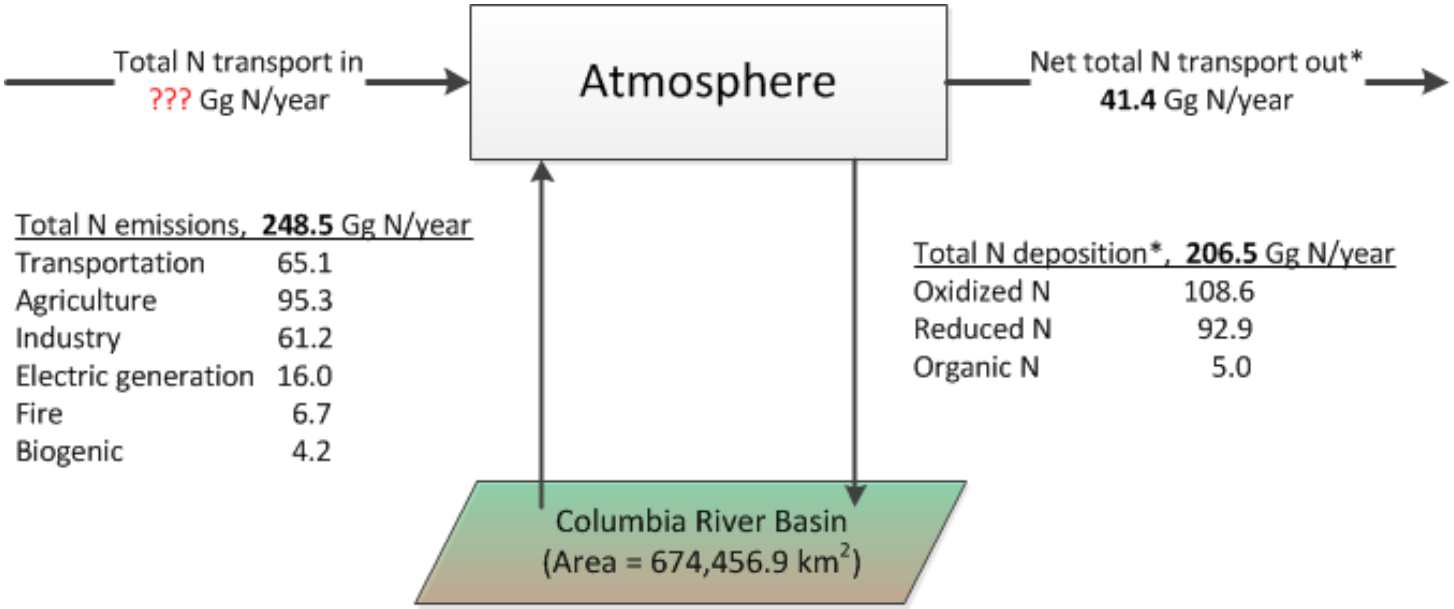
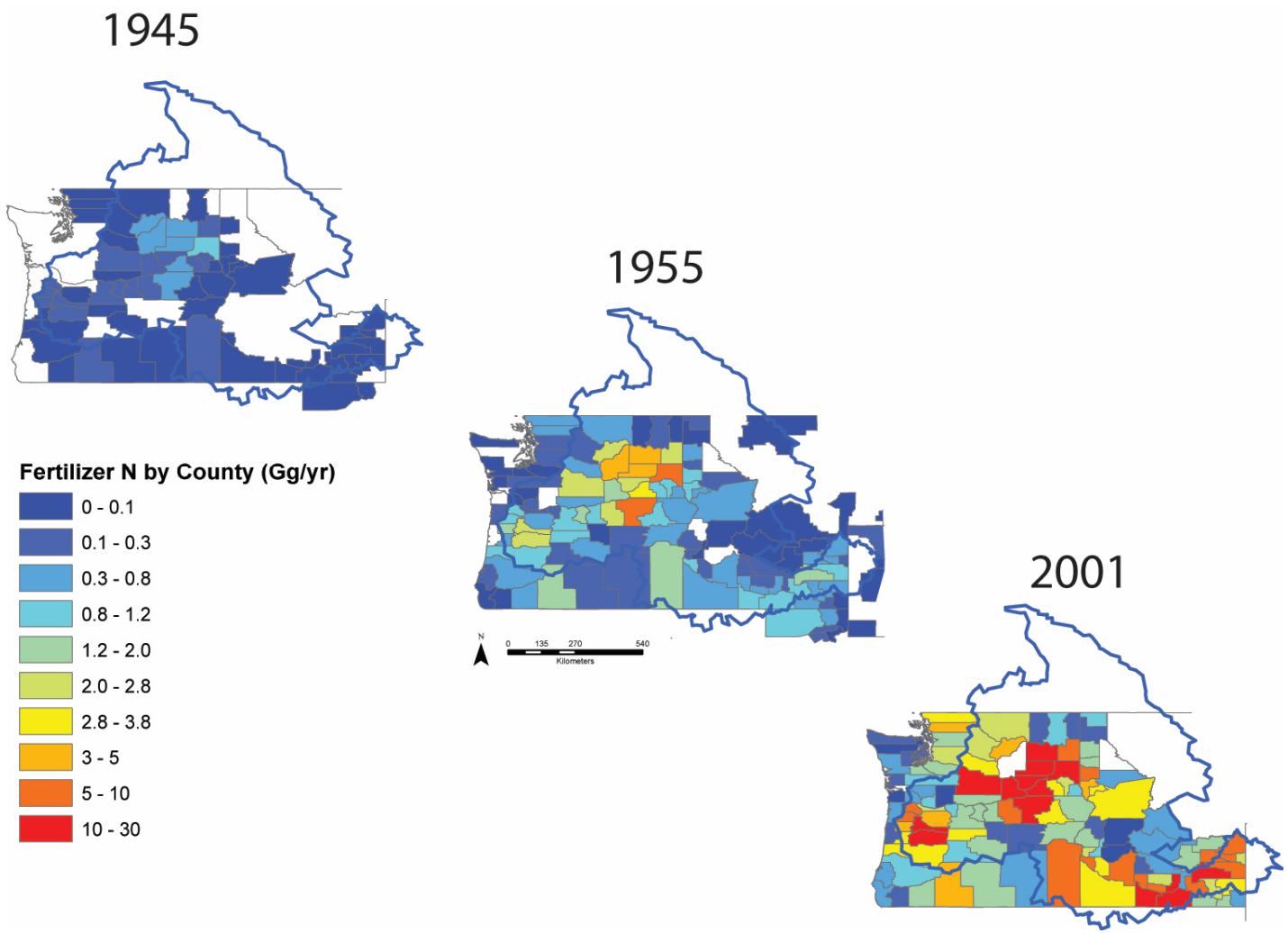


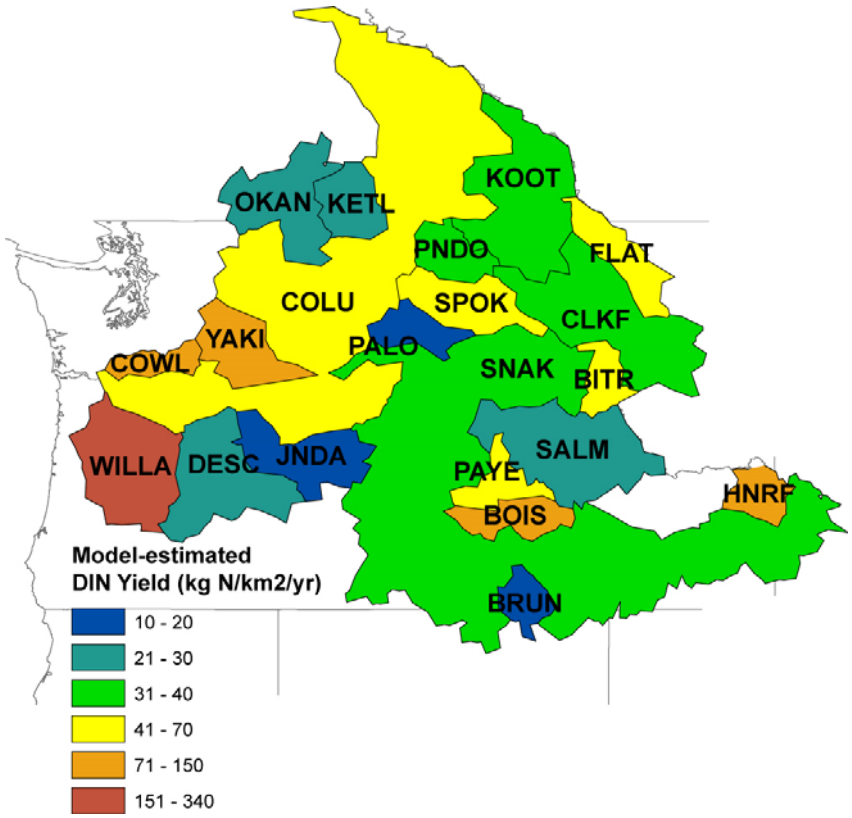
Figure 2. Atmospheric nitrogen budgets over the Columbia River Basin in 1998. Total N emissions of 357.4 Gg N/year is based on anthropogenic emissions from the 2002 National Emission Inventory, the MEGAN biogenic emission model, and the BlueSky modeling framework in combination with historical fire records. Total N deposition (256.9 Gg N/year) and net total N transport (99.7 Gg N/year) are based on the WRF-MEGAN-SMOKE-CMAQ simulations from Oct. 1997 to Sep. 1998. Considered N species are NO, NO2, NH3, HNO3, N2O5, HONO, PAN, ANO3, ANH4, and organic nitrate. Units are in Gg N/year.

Using Bio Earth to gain understanding at higher spatial resolution

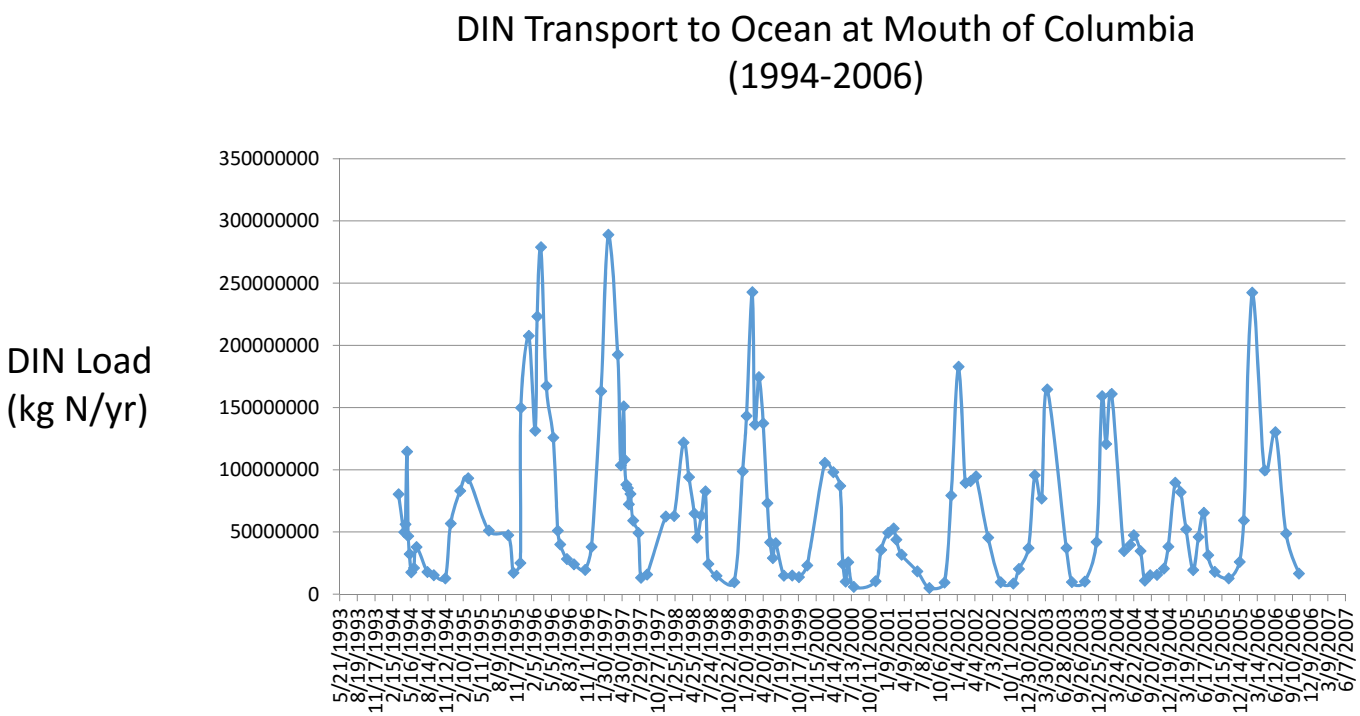
County-level Fertilizer Consumption (1945-2001)



NEWS-DIN-CRB Estimates of Sub-basin DIN yield (kg N/km^2/yr)

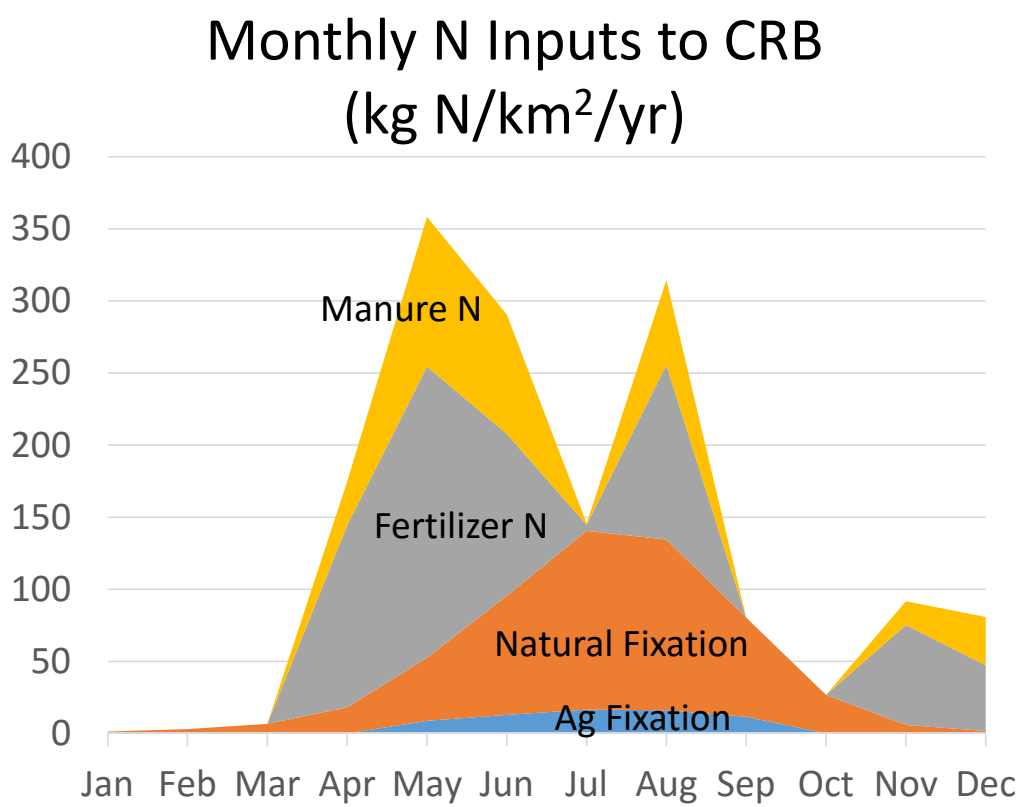


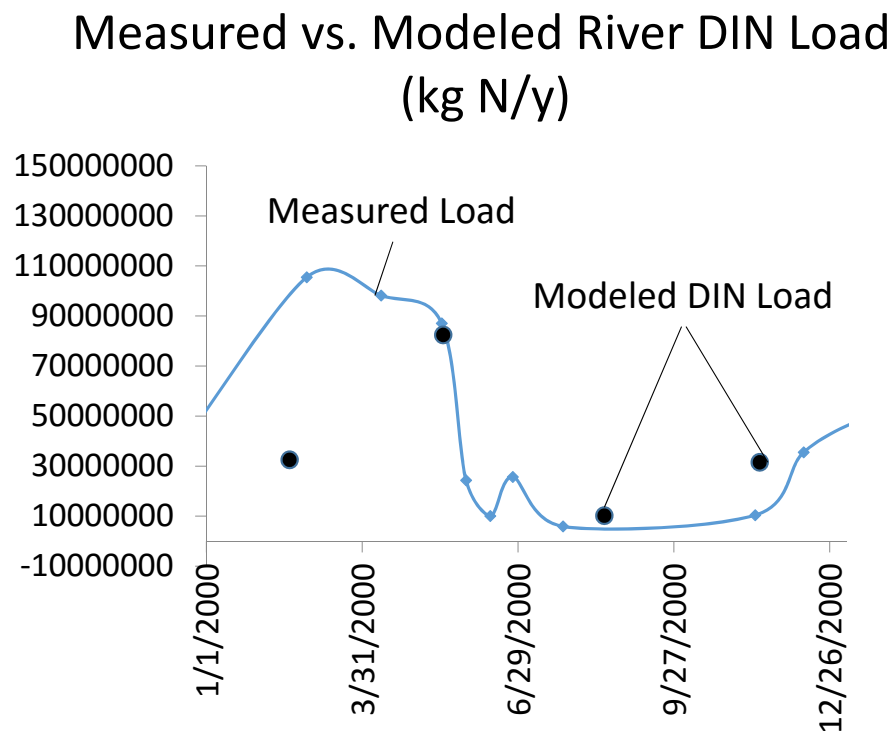
Using Bio Earth to gain understanding at higher temporal resolution



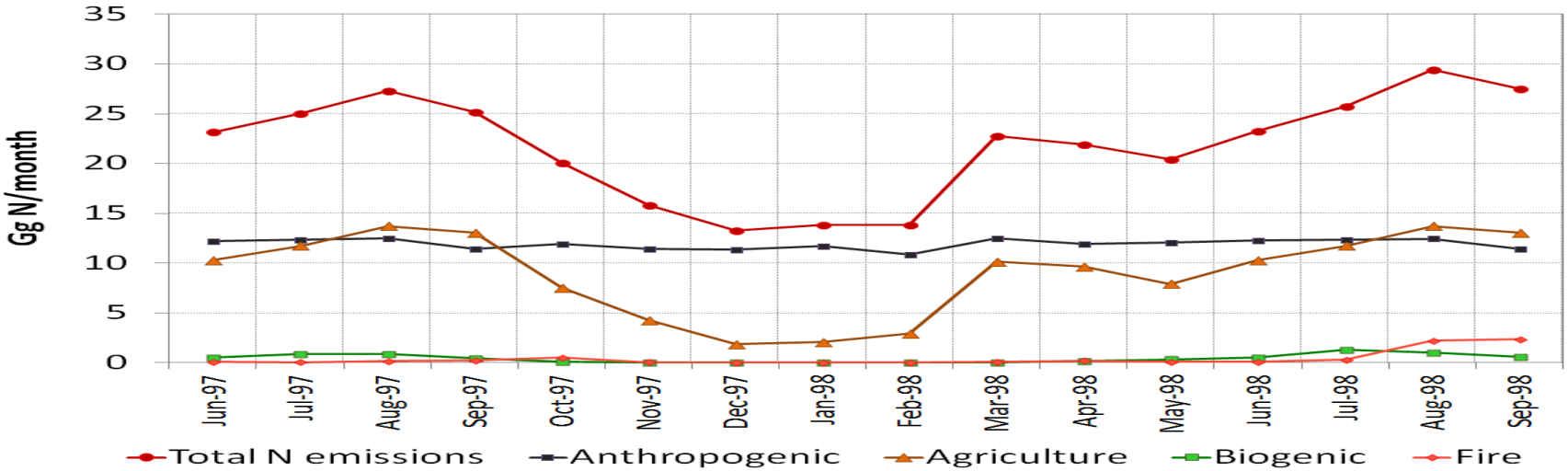
- 20 to 30-fold difference in N transport between seasons at mouth of Columbia River

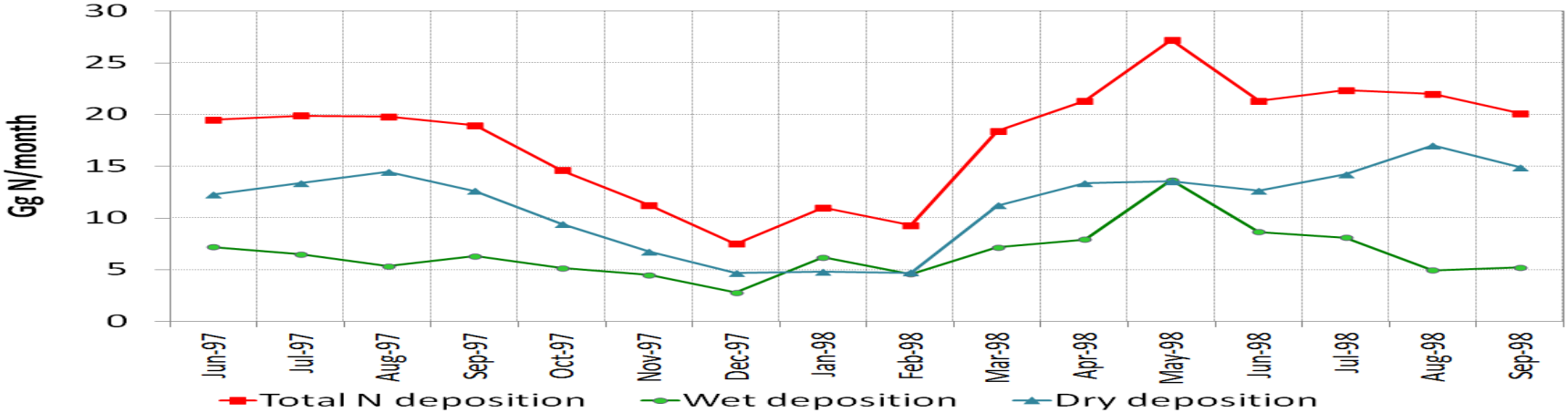
Use Bio Earth to gain understanding at higher temporal resolution

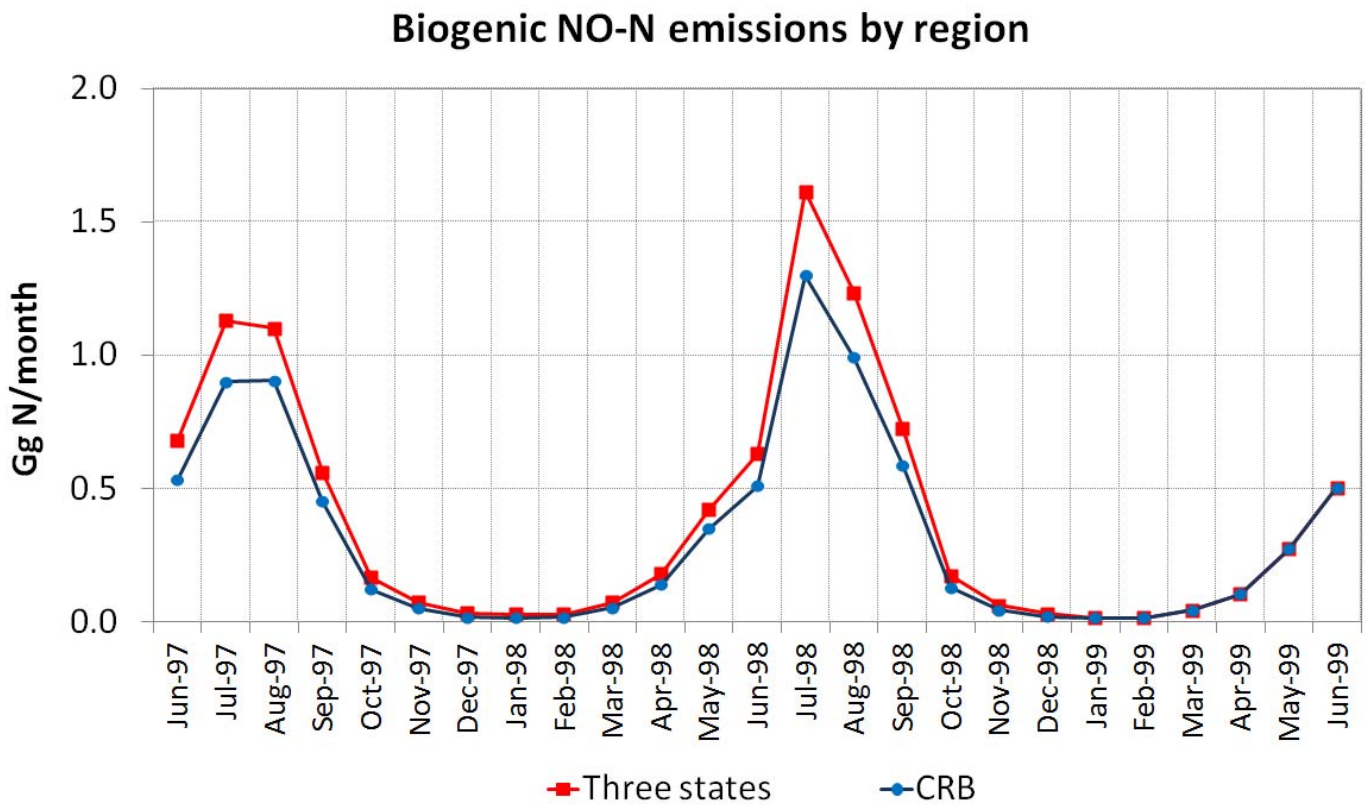




N Emissions and Deposition by Source and Type in the Columbia River Basin (1997-1998)






Biogenic NO-N emissions by region
Gg N/month
2.0
1.5
1.0
0.5
0.0
Jun-97
Jul-97
Aug-97
Sep-97
Oct-97
Nov-97
Dec-97
Jan-98
Feb-98
Mar-98
Apr-98
May-98
Jun-98
Jul-98
Aug-98
Sep-98
Oct-98
Nov-98
Dec-98
Jan-99
Feb-99
Mar-99
Apr-99
May-99
Jun-99
Three states
CRB

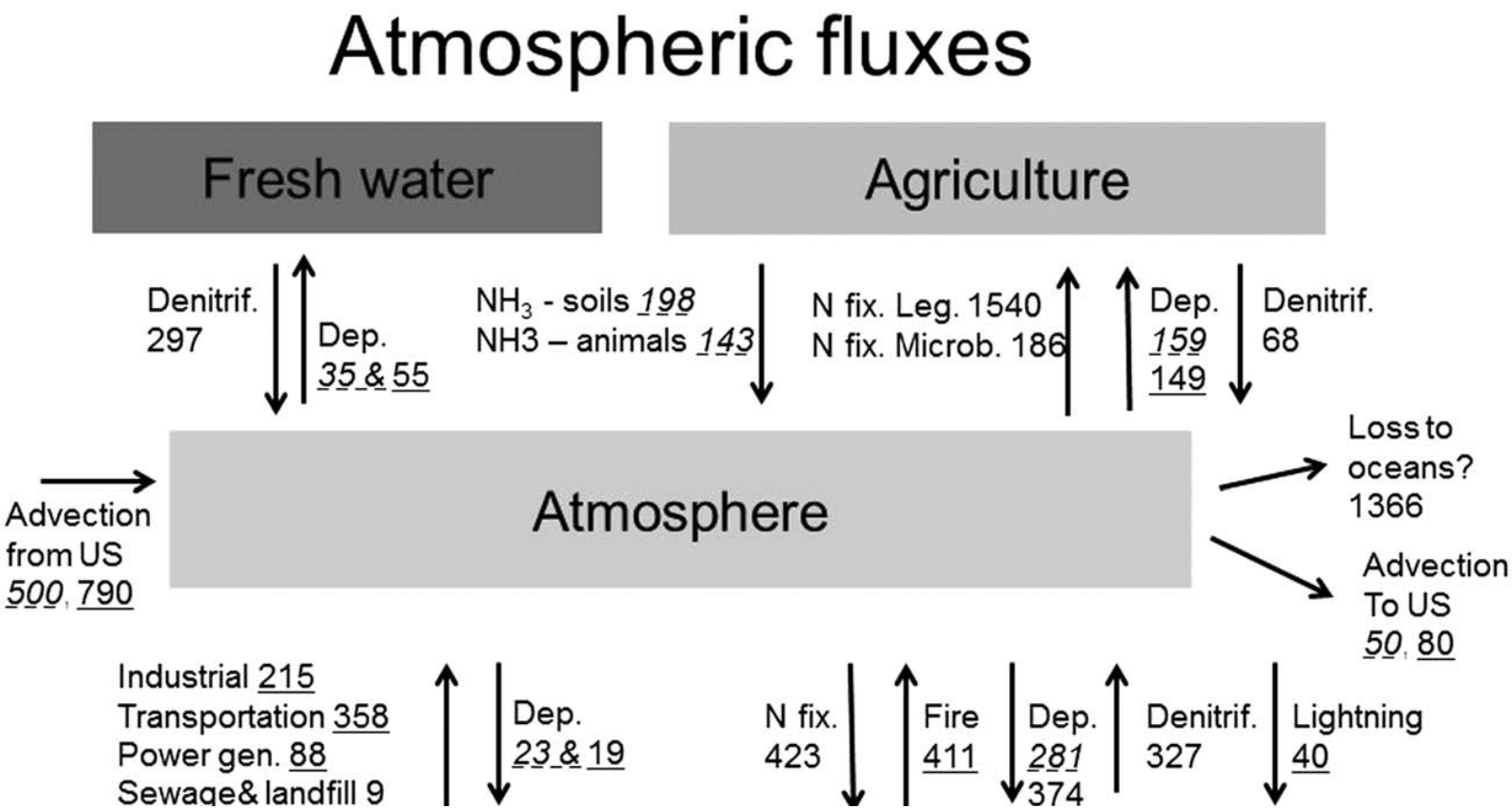
Use Bio Earth to demonstrate novel couplings between systems (potentially most compelling)…

- This seems like our central challenge
- How do we do this with respect to the regional N budget?
- Choose an example of an interaction/lever we think is a big deal for the N cycle that has a critical coupling mechanism that is missing from current analyses, but that we have the data and tools to address—and see how it scales up
- Use this case study as a “capstone” (or counterpoint) to the coarse-scale analysis

A few thoughts

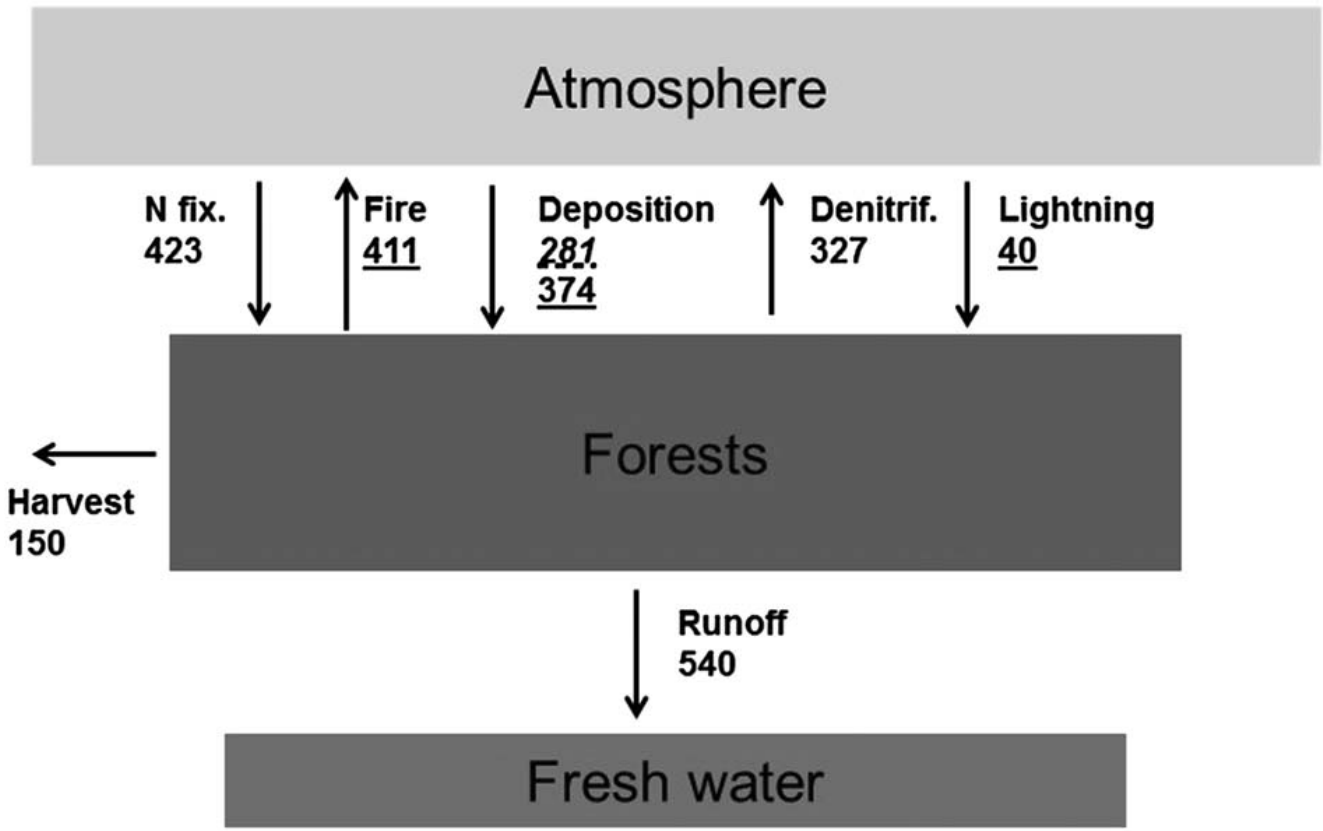
- N dep is an important input to natural ecosystems and we have detailed model results for N dep—how do we highlight that?—what is the relative role of managed vs natural ecosystems in the N budget?
- How much of the fertilizer is produced within the domain vs imported into the domain?
- Some (not all) of anthrogenic emissions may be deposited within a relatively short distance downwind such that there may be hotspots in the N budget within the domain that aren't totally reflected in the larger N budget or perhaps they dominate the larger budget? Similar to hotspots in N2O emissions, a few hotspots may account for a disportionate part of the N cycling. I don't know if this is true or important.
- As input to the atmospheric modeling, we have inputs from Asia and we will be able to document that. How much of a role in our regional budget do outside sources play? I suppose this also applies to the fertilizer question above.
- We can add slides from Tsengel on the monthly (high time resolution) atmospheric emissions and deposition (wet and dry) as examples of BioEarth outputs.

Composite Canadian N Budget
Clair et al.,2014

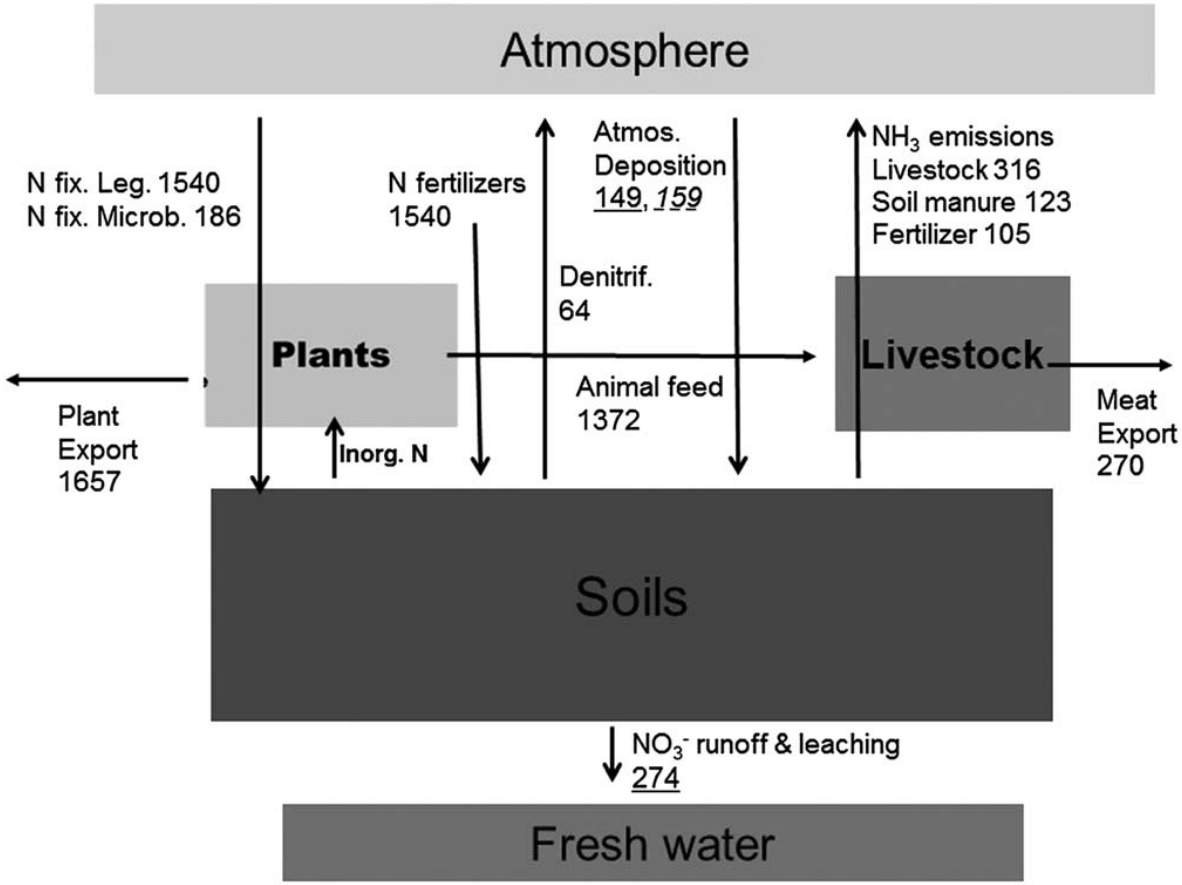


Clair et a., 2014
Canadian N Budget Components

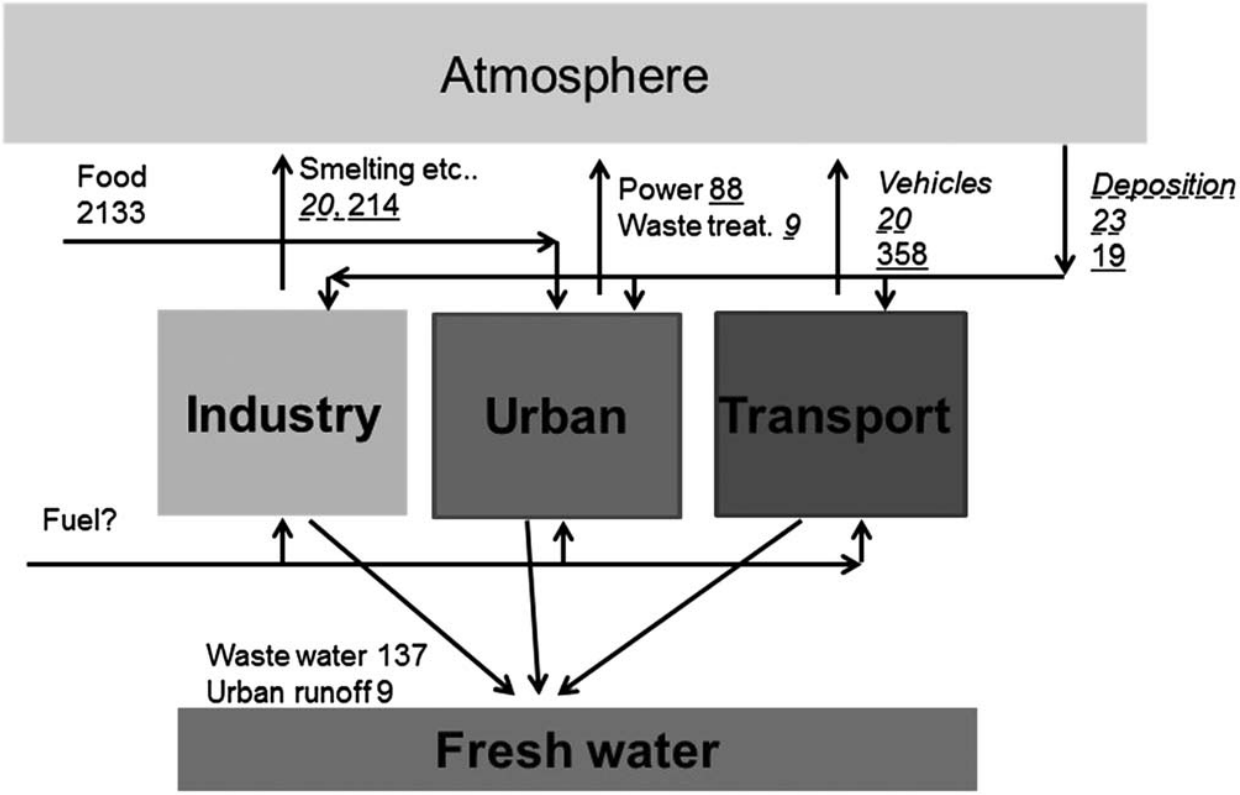
Forests and natural systems



Agricultural Systems



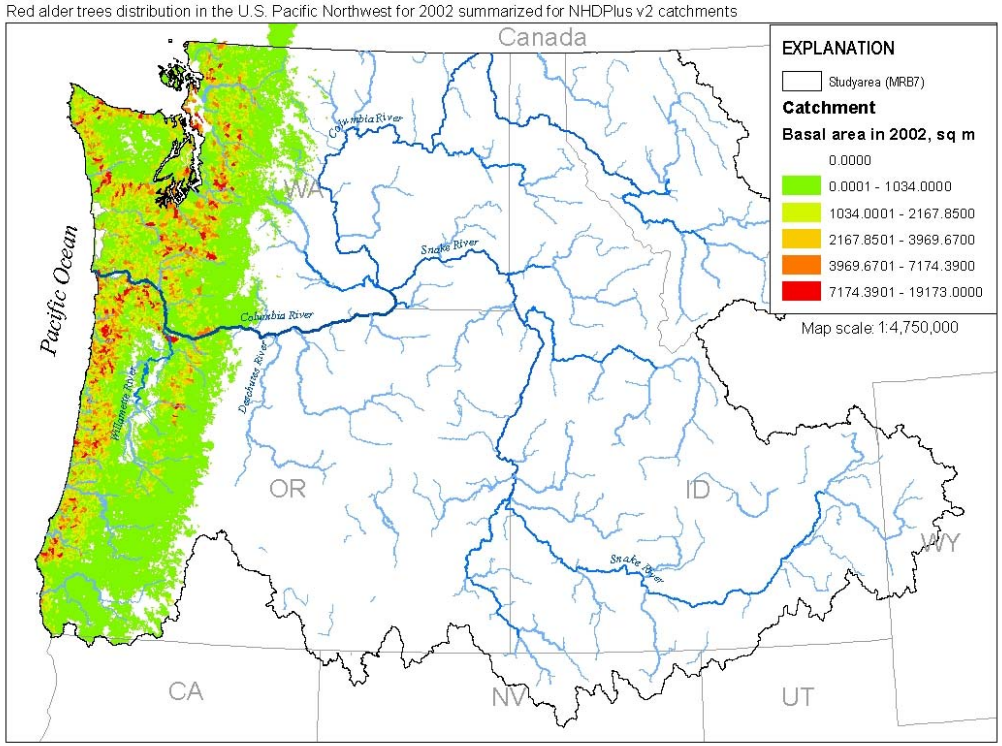
Urban/Industrial Component



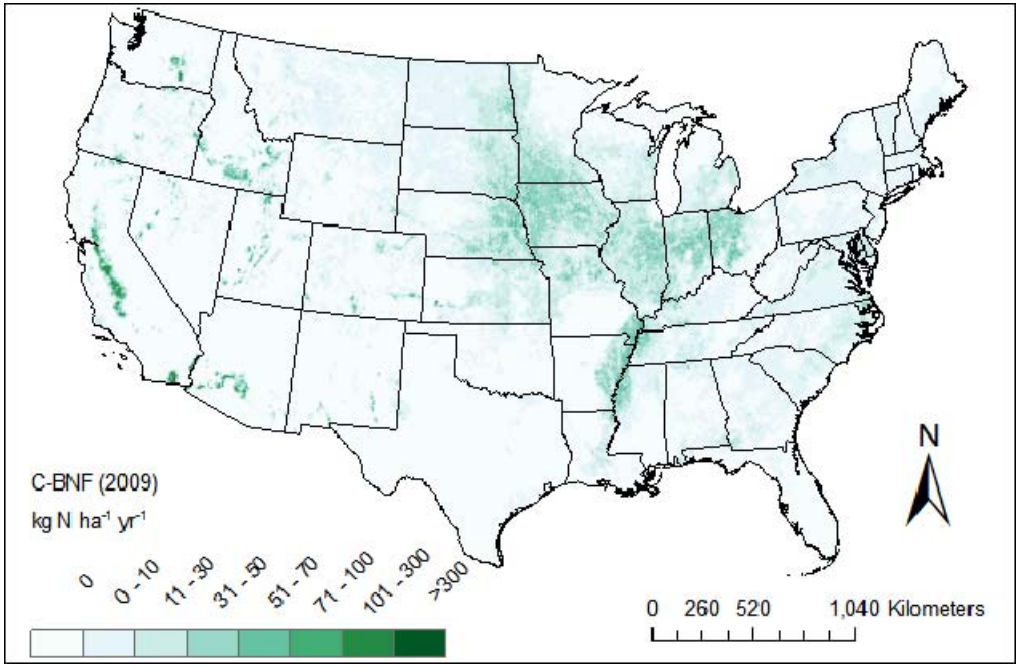
Things we can (and should) do better??

- Get the big fluxes as right as possible
  - Denitrification-Perhaps VIC Cropsyst can help here?
  - Crop Harvest
  - Export vs. internal recycling
  - N cycling in natural systems
  - Natural Biological N Fixation

Red Alder Distribution in PNW

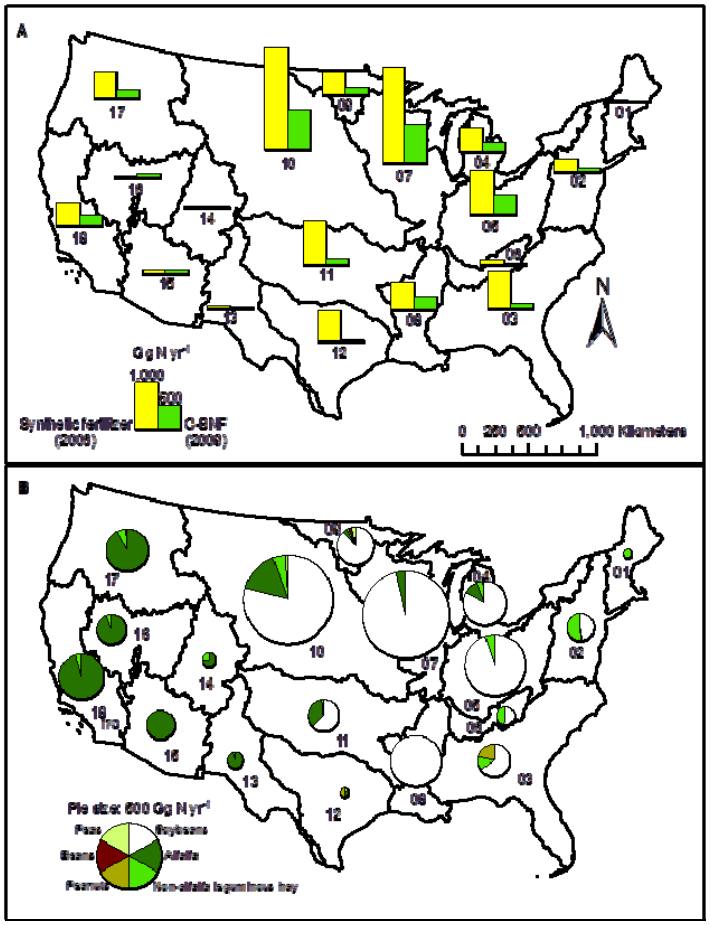


Crop Biological N Fixation in 2009



(Sobota et al., In prep.)

Crop Biological N fixation in US



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Domain 1: Three States

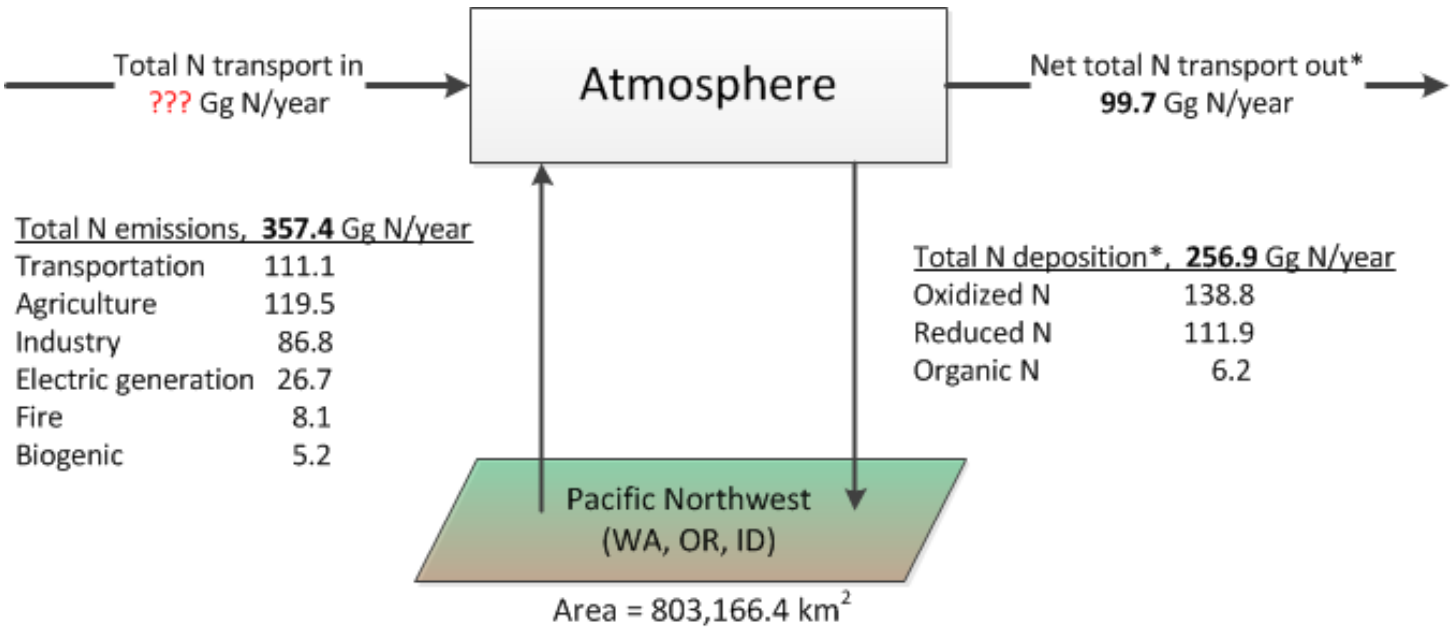
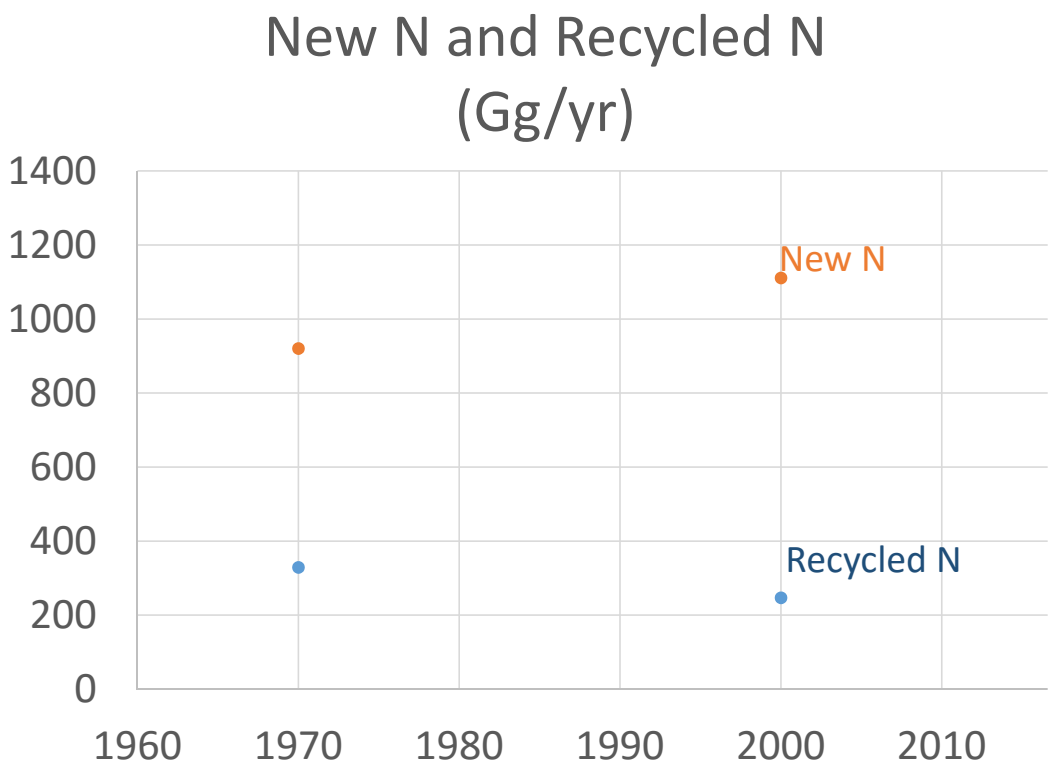
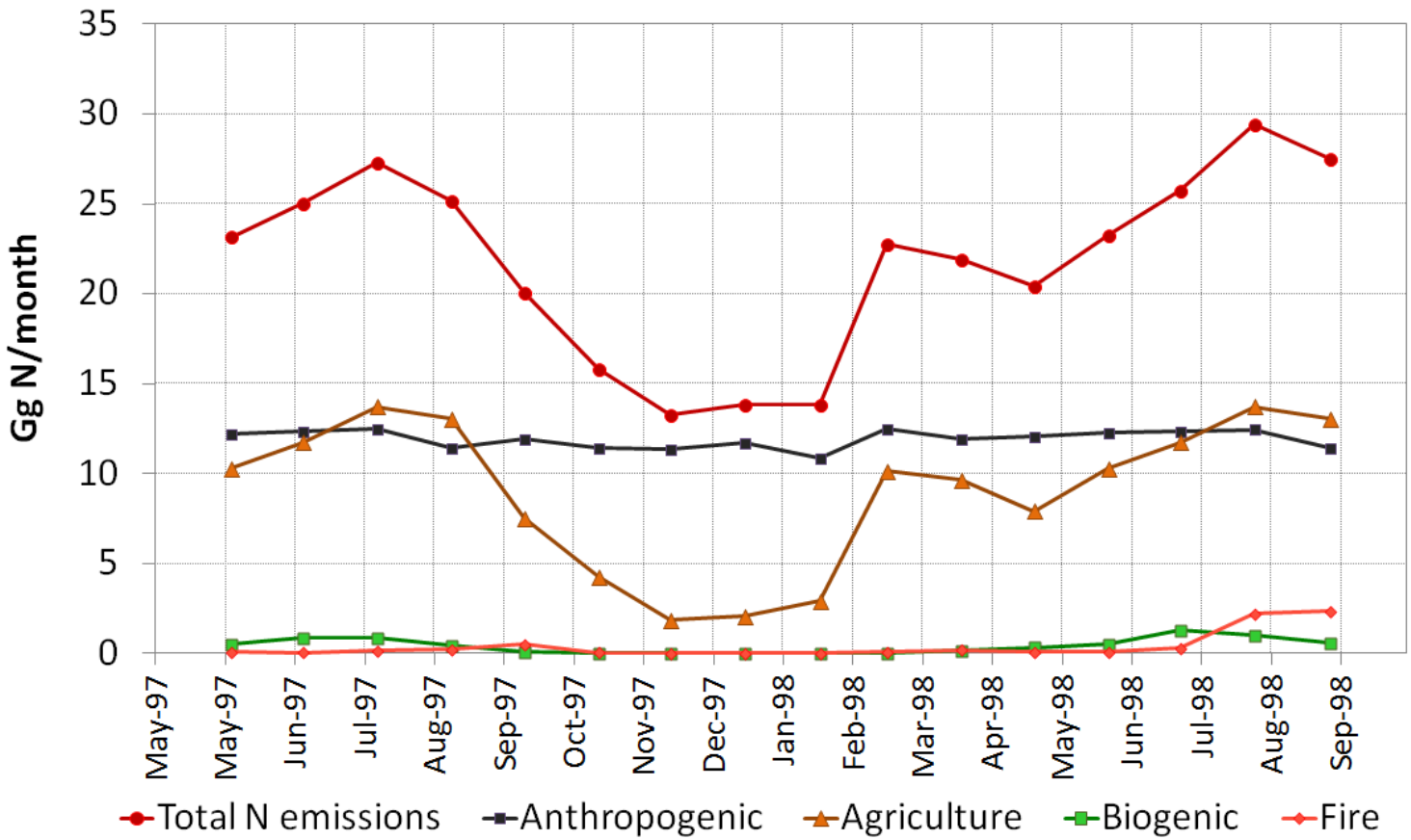


Figure 1. Atmospheric nitrogen budgets over the Pacific Northwest in 1998. Total N emissions of 357.4 Gg N/year is based on anthropogenic emissions from the 2002 National Emission Inventory, the MEGAN biogenic emission model, and the BlueSky modeling framework in combination with historical fire records. Total N deposition (256.9 Gg N/year) and net total N transport (99.7 Gg N/year) are based on the WRF-MEGAN-SMOKE-CMAQ simulations from Oct. 1997 to Sep. 1998. Considered N species are NO, NO2, NH3, HNO3, N2O5, HONO, PAN, ANO3, ANH4, and organic nitrate. Units are in Gg N/year.

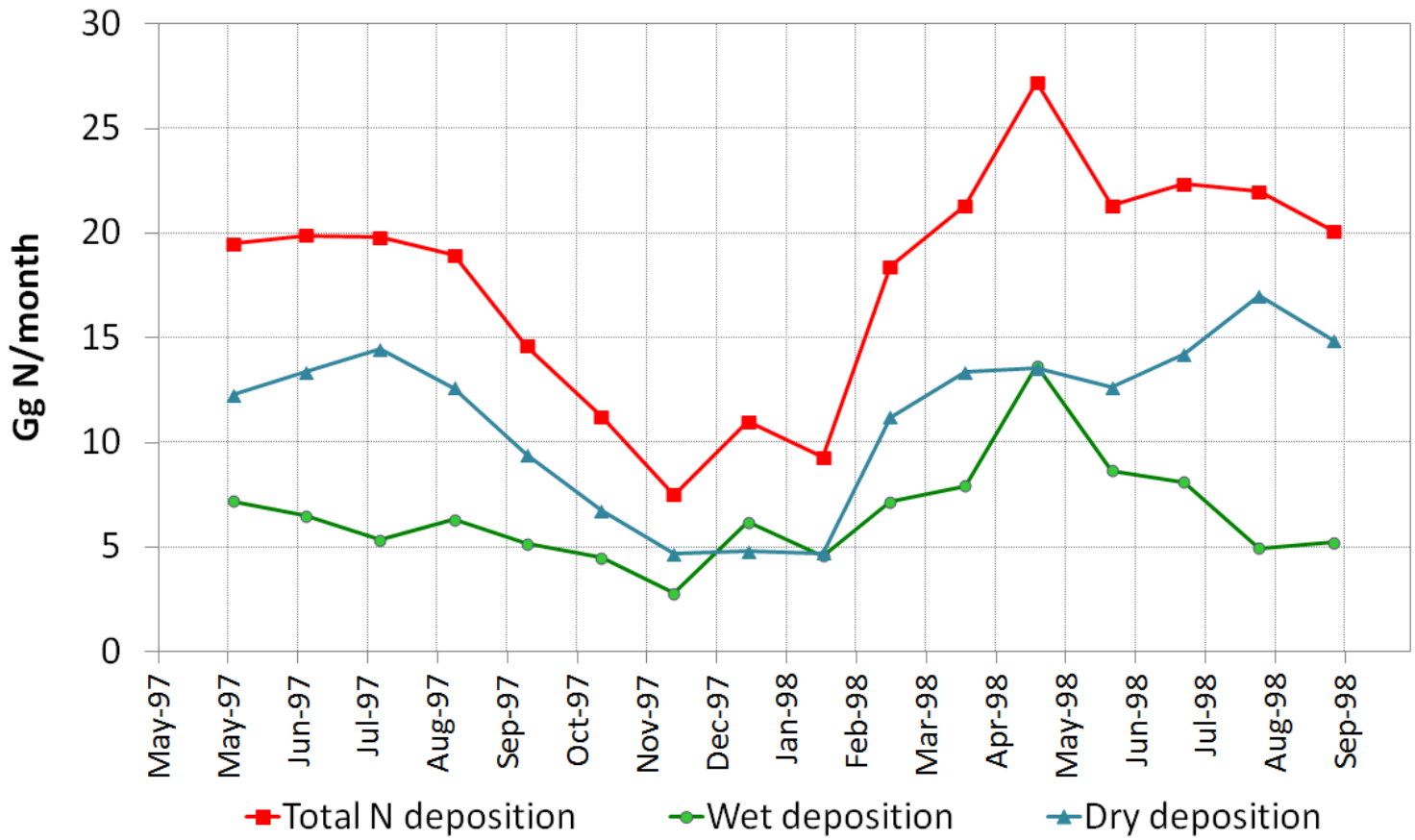
Recycled N


New N and Recycled N
(Gg/yr)
1400
1200
1000
800
600
400
200
0
1960
1970
1980
1990
2000
2010
New N
Recycled N

N Emissions by Source Type in the Columbia River Basin



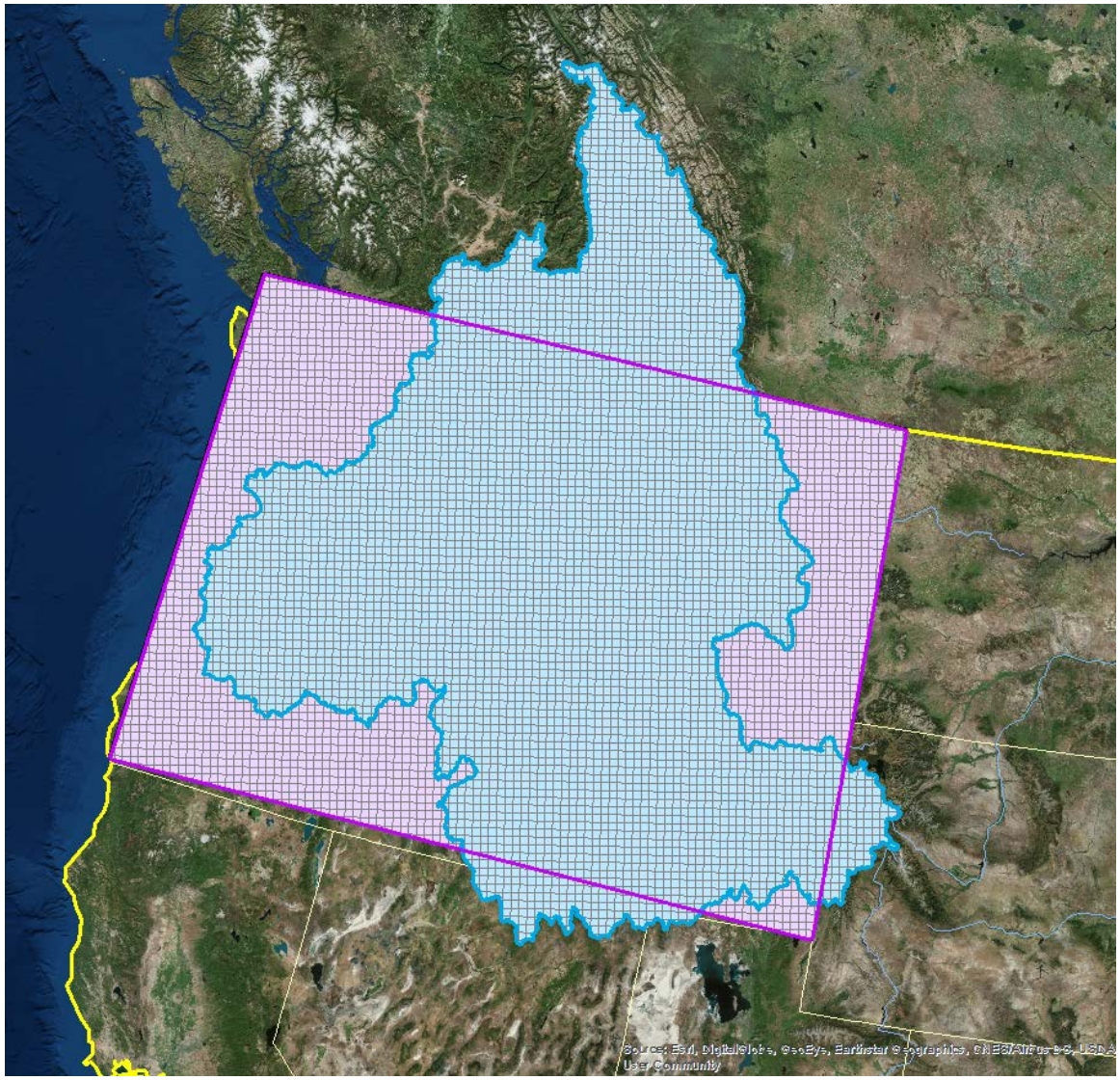
N Deposition in the Columbia River Basin



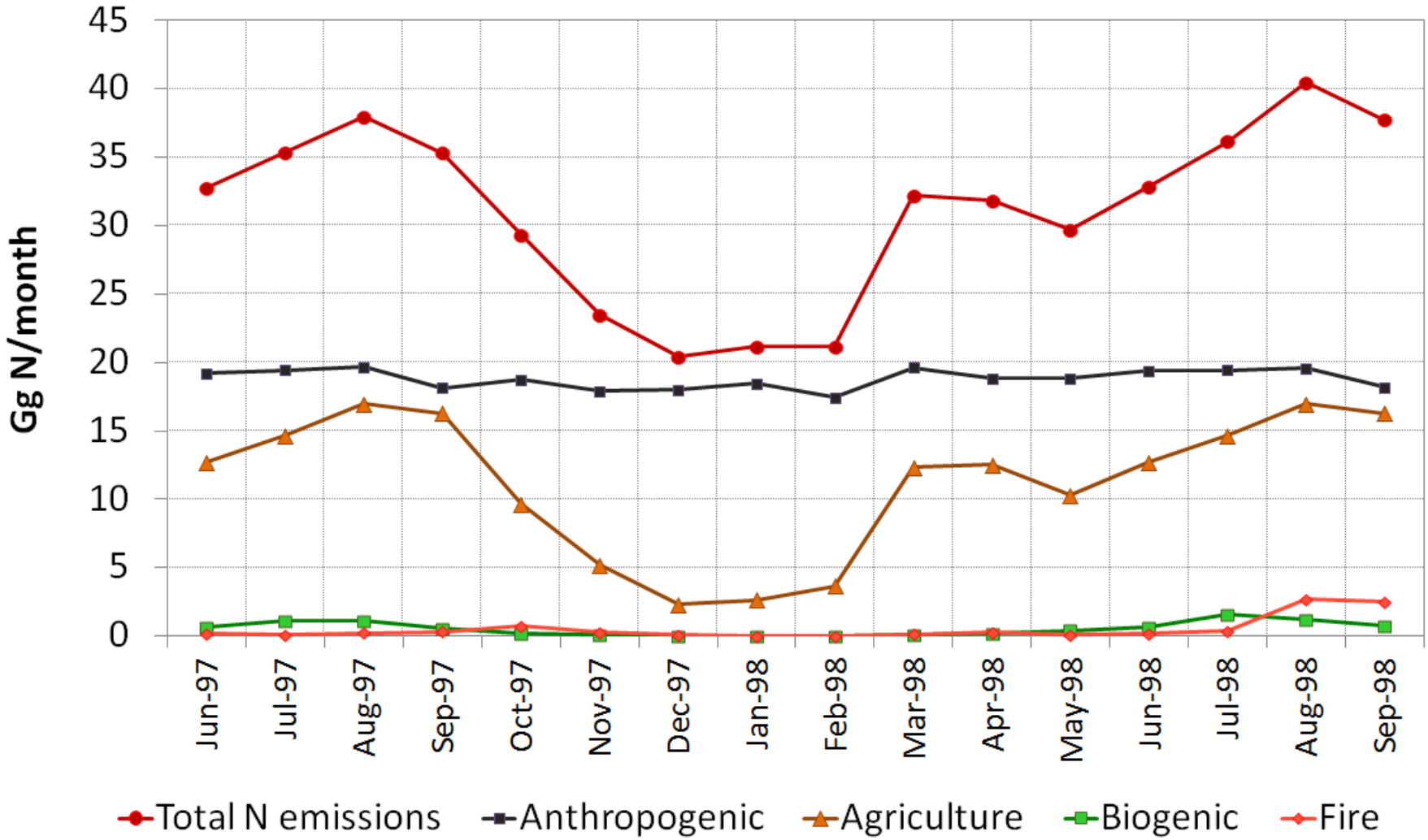
Atmos N fluxes

2016-02-22

Study domains



N Emissions by Source Type in the three states (WA, OR, ID)



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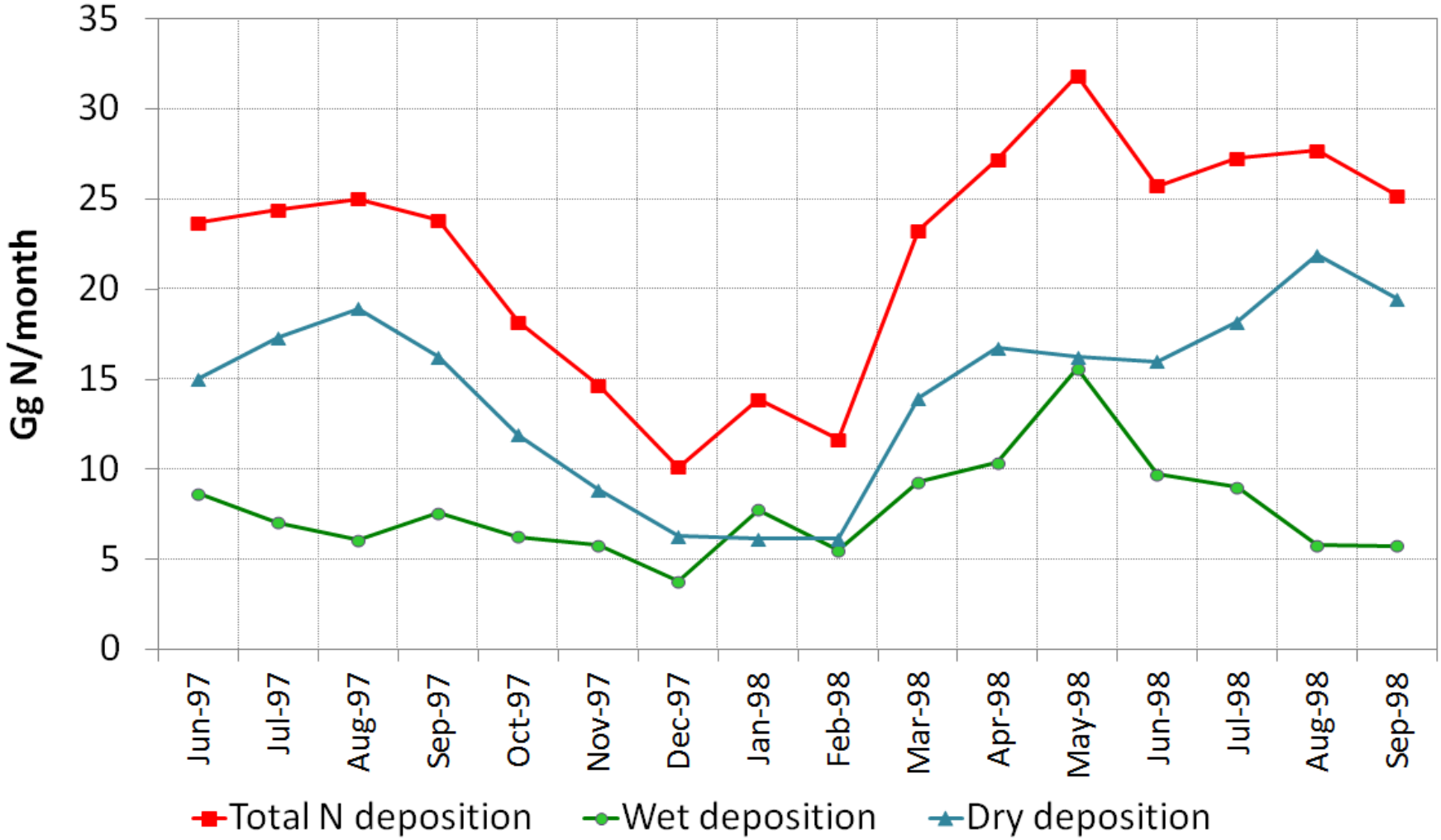

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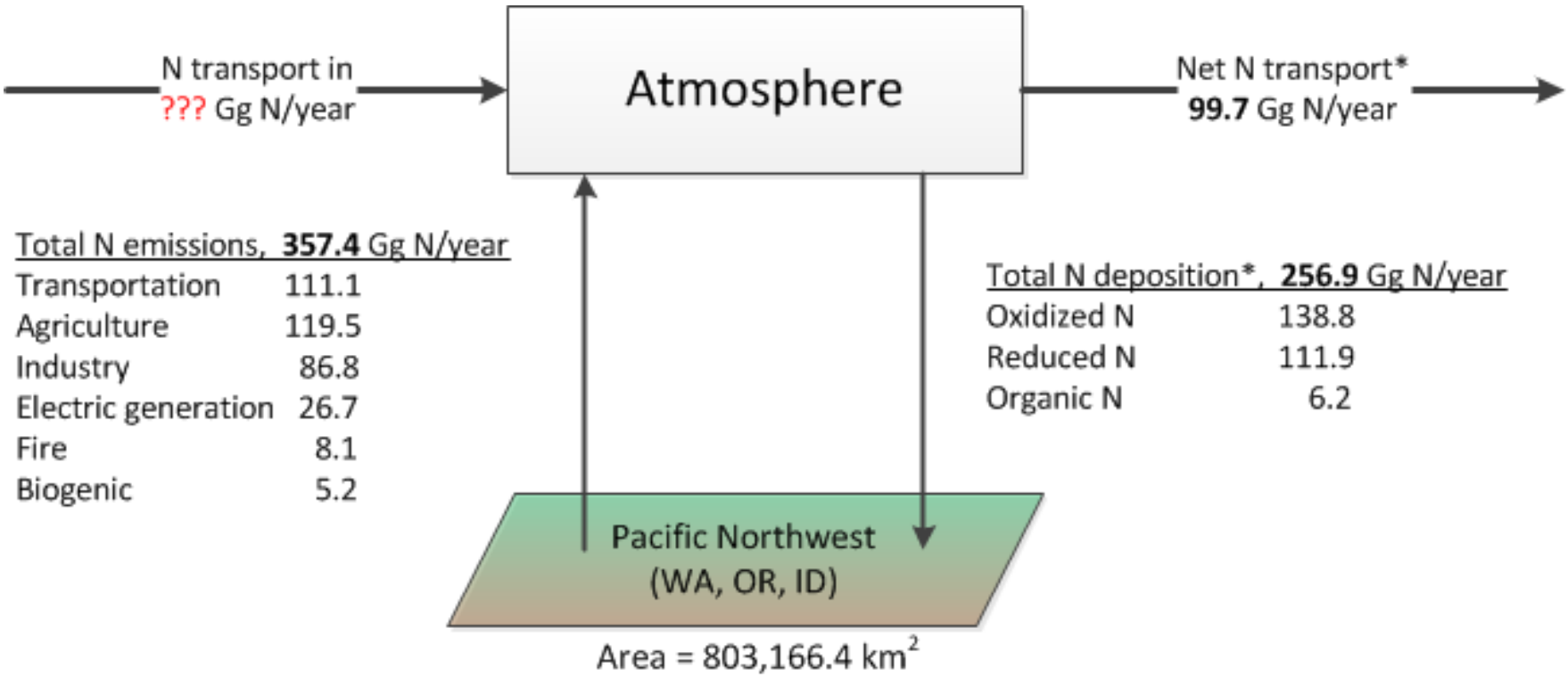

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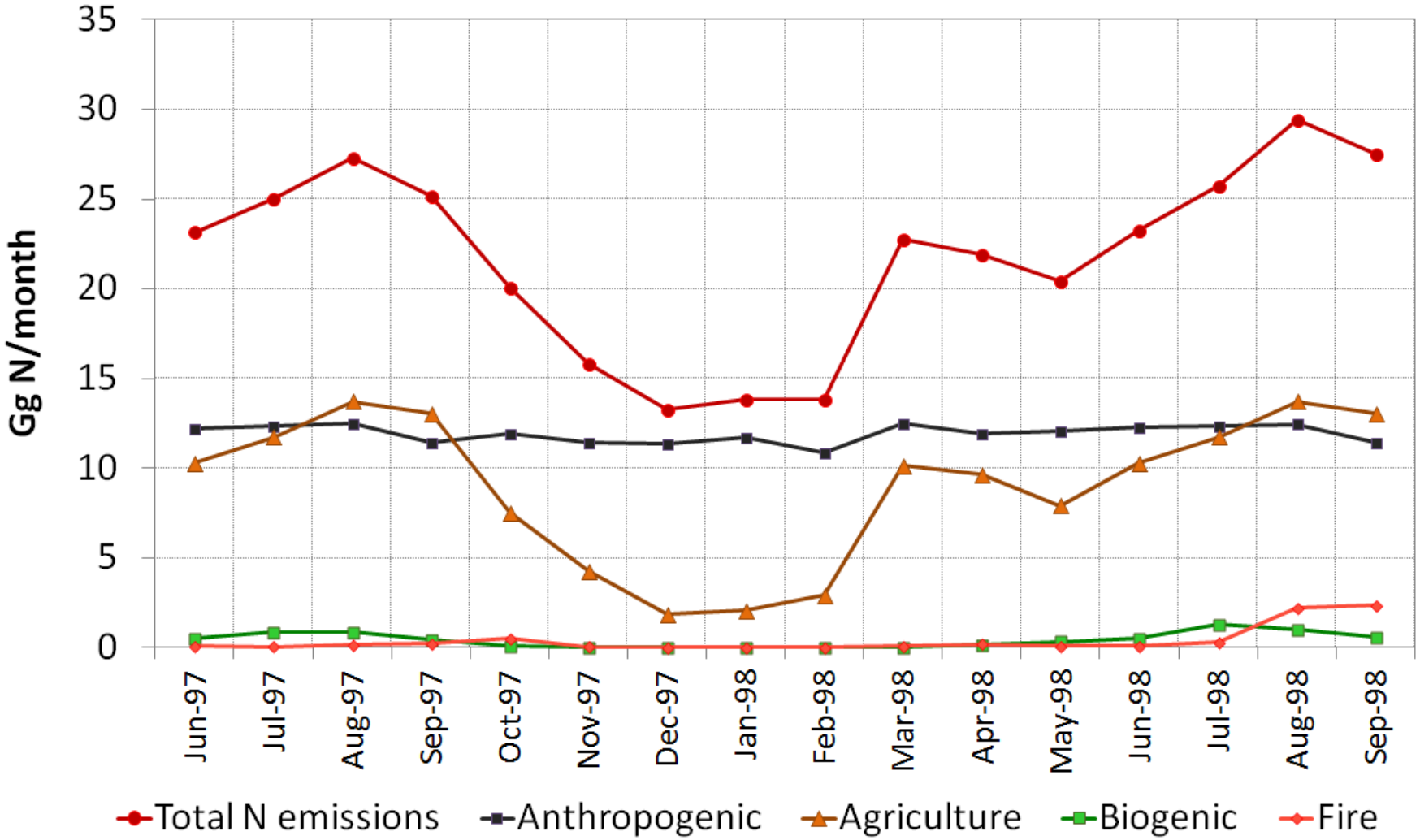
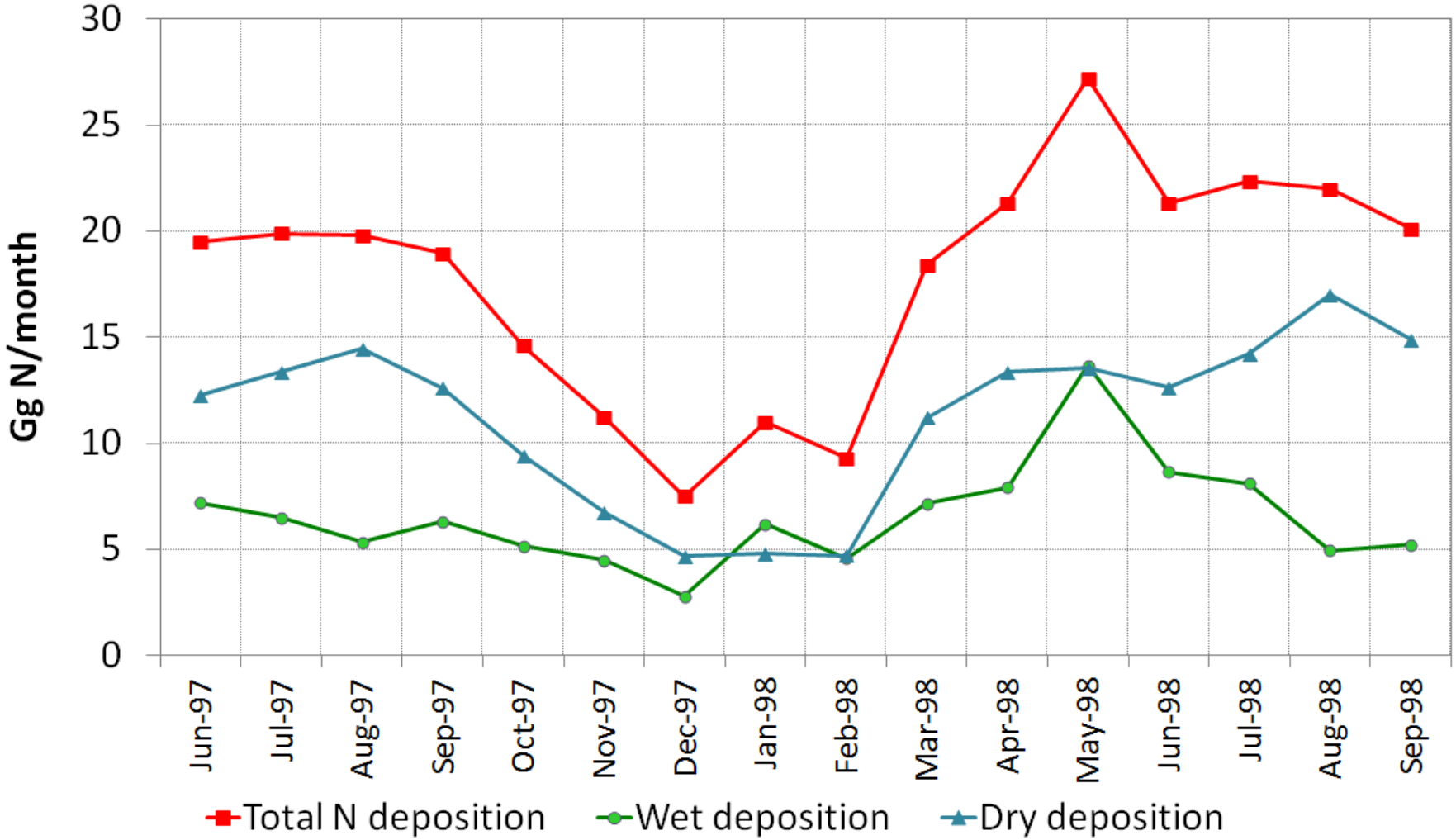


N Deposition in the Columbia River Basin



Domain 2: Columbia River Basin

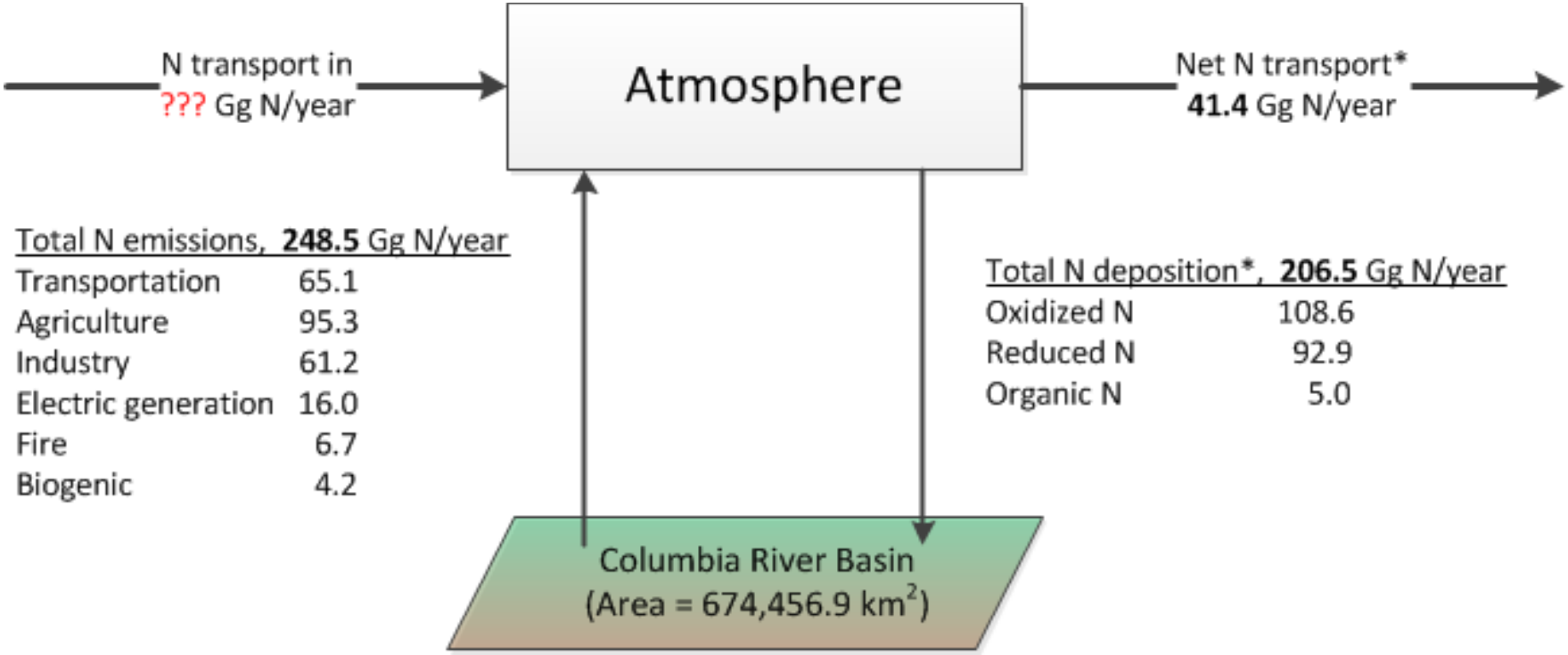
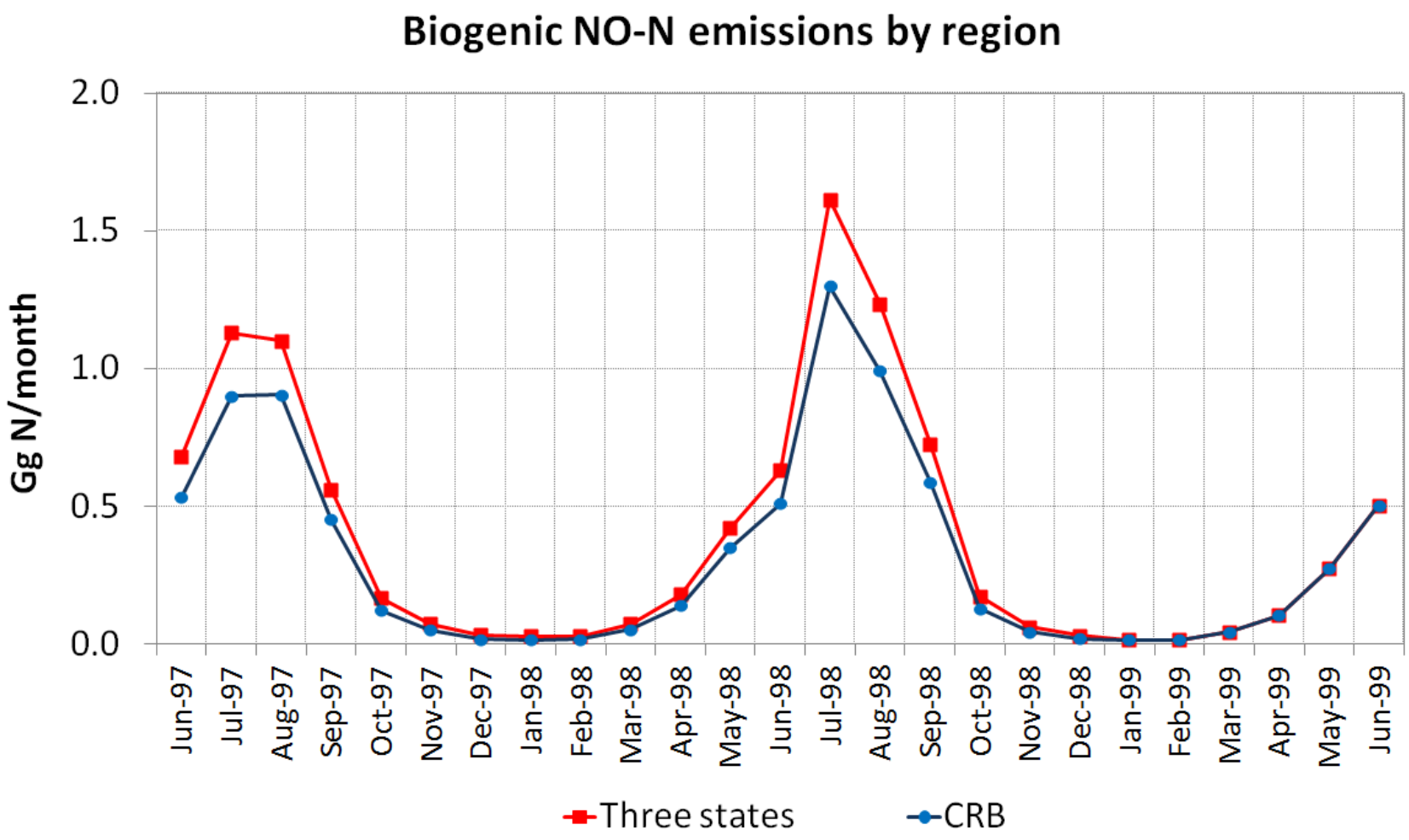


Figure 2. Same as Figure 1, but for the Columbia River Basin


Biogenic NO-N emissions by region
Gg N/month
2.0
1.5
1.0
0.5
0.0
Jun-97
Jul-97
Aug-97
Sep-97
Oct-97
Nov-97
Dec-97
Jan-98
Feb-98
Mar-98
Apr-98
May-98
Jun-98
Jul-98
Aug-98
Sep-98
Oct-98
Nov-98
Dec-98
Jan-99
Feb-99
Mar-99
Apr-99
May-99
Jun-99
Three states
CRB

EXTRA

Preliminary Results: atmospheric N fluxes

Domain 1: Three States

Year	1997						
Month	6	7	8	9	10	11	12
N Emission by sources, Mg N/month							
Transportation	9203.7	9274.8	9504.2	8975.4	9262.1	8868.2	9011.4
Electric generation	2216.6	2291.1	2291.1	2202.2	2276.1	2201.1	2215.5
Industry	7827.8	7879.0	7880.1	6967.8	7197.8	6876.0	6795.1
Agriculture	12715.6	14702.4	16976.8	16293.4	9680.8	5237.2	2298.2
Fire	151.8	100.0	236.6	325.0	746.3	247.1	72.5
Biogenic	680.6	1130.0	1101.5	562.0	167.1	75.5	33.2
Total	32796.2	35377.3	37990.2	35325.8	29330.1	23505.1	20425.8
N Deposition, Mg N/month							
Wet inorg. oxN	4084.94	3207.80	2727.42	3629.99	3884.49	3972.79	2927.46
Wet inorg. rdN	4574.07	3852.78	3361.79	3951.21	2382.56	1805.58	876.71
Wet org. N	0.06	0.07	0.05	0.05	0.02	0.02	0.01
Dry inorg. oxN	8167.73	9477.07	9987.97	7283.90	5845.80	4554.99	4245.69
Dry inorg. rdN	6337.00	6984.88	7952.57	8337.06	5753.49	4091.18	1906.31
Dry org. N	537.47	883.86	1007.06	628.12	332.10	250.65	179.86
Total	23701.29	24406.52	25036.85	23830.34	18198.45	14675.17	10136.03
Net N transport through the region, Mg N/month							
Nout - Nin = Nemis - Ndep	9094.9	10970.8	12953.3	11495.4	11131.7	8829.9	10289.8

Assumptions: no N accumulation in the atmosphere, no N exchange at the model top layer

Preliminary Results: atmospheric N fluxes

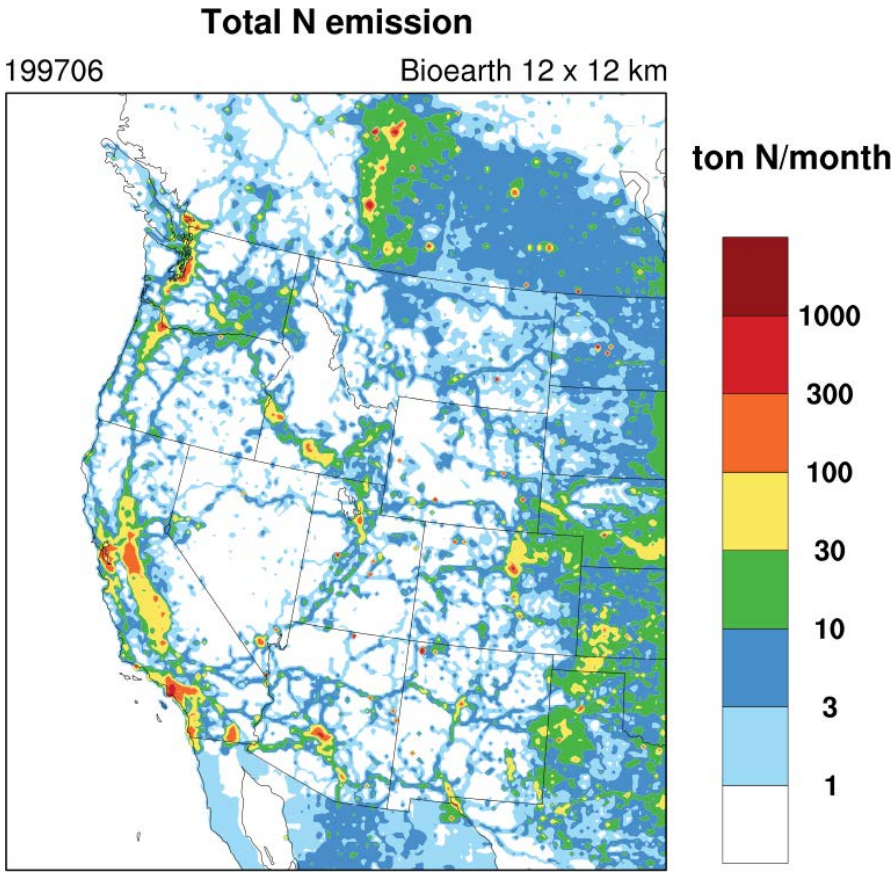
Domain 2: CRB

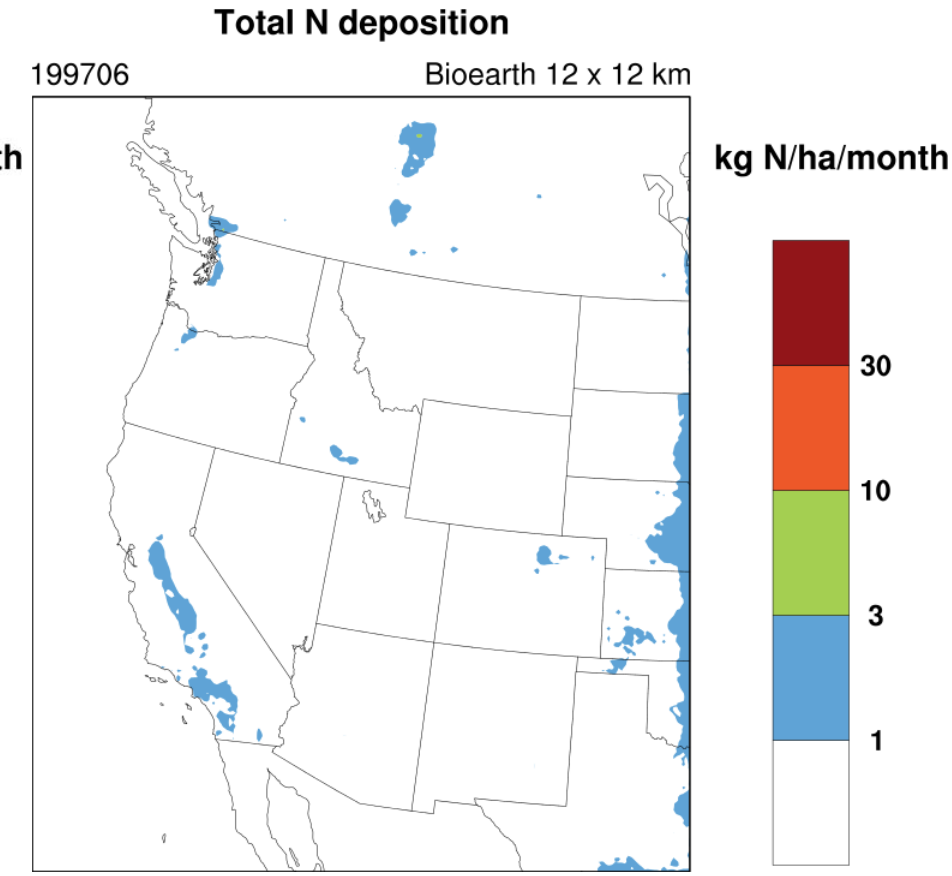
Year	1997						
Month	6	7	8	9	10	11	12
N Emission by sources, Mg N/month							
Transportation	5357.7	5430.3	5603.8	5216.7	5477.2	5280.9	5305.0
Electric generation	1309.1	1352.8	1352.8	1318.0	1362.2	1317.7	1349.4
Industry	5564.6	5561.6	5544.5	4901.1	5062.0	4830.5	4698.7
Agriculture	10308.6	11755.6	13739.1	13072.2	7553.6	4259.8	1876.5
Fire	80.4	57.8	175.3	226.8	498.0	62.6	21.1
Biogenic	532.7	900.3	905.0	453.0	123.2	51.3	19.7
Total	23153.0	25058.5	27320.6	25187.8	20076.1	15802.8	13270.4
N Deposition, Mg N/month							
Wet inorg. oxN	3306.35	2942.36	2375.34	2907.69	3145.79	3062.41	2136.16
Wet inorg. rdN	3917.16	3594.07	2991.57	3438.67	2039.07	1452.54	692.71
Wet org. N	0.06	0.07	0.05	0.05	0.02	0.02	0.01
Dry inorg. oxN	6526.46	7088.80	7308.38	5339.00	4439.90	3318.59	3049.14
Dry inorg. rdN	5304.58	5573.98	6335.69	6794.55	4730.85	3238.05	1515.24
Dry org. N	467.96	714.53	809.62	496.28	265.97	193.12	134.82
Total	19522.56	19913.83	19820.66	18976.28	14621.61	11264.71	7528.08
Net N transport through the region, Mg N/month							
Nout - Nin = Nemis - Ndep	3630.4	5144.6	7499.9	6211.5	5454.5	4538.1	5742.3

Assumptions: no N accumulation in the atmosphere, no N exchange at the model top layer

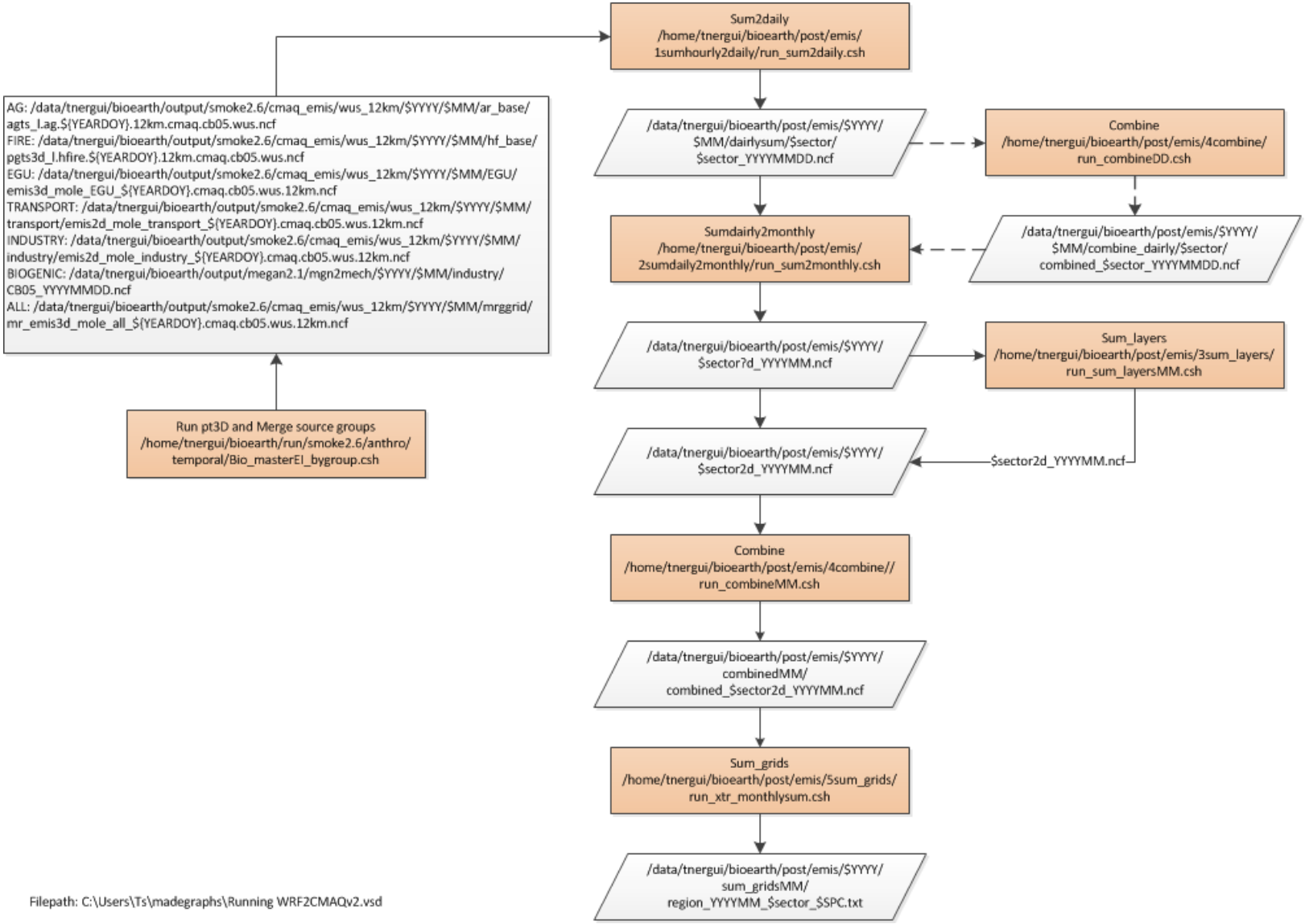
Example emission and deposition rates

June 1997





N emission calculation



Economic Factors Influencing N Fertilizer Use in the CRB

Mike Brady

Major Factors that Influence N Loading from Ag

- Long-run changes in crop mix
- Fertilizer prices
- Commodity prices
- Irrigation technology
  - Intensity
  - Efficiency
- Other information

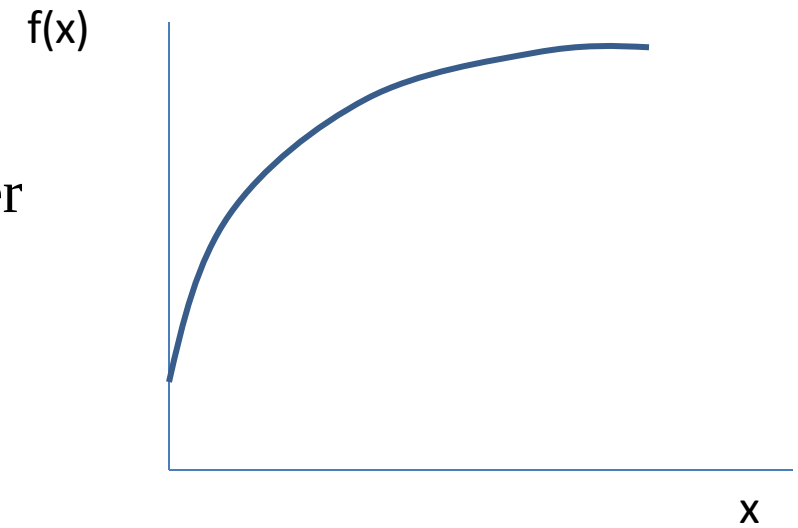
Own-price elasticity of fertilizer

- Obviously, higher N price should reduce use, ceterus paribus.

- How much fertilizer should be used?

$$p\frac{\partial f(\mathbf{x})}{\partial x} = r_x$$

$\mathbf{x}$: vector of inputs including fertilizer
p : commodity (crop) price
$f(\mathbf{x})$: production function
r_x : input price



Griliches (1958) Figures 1 and 3

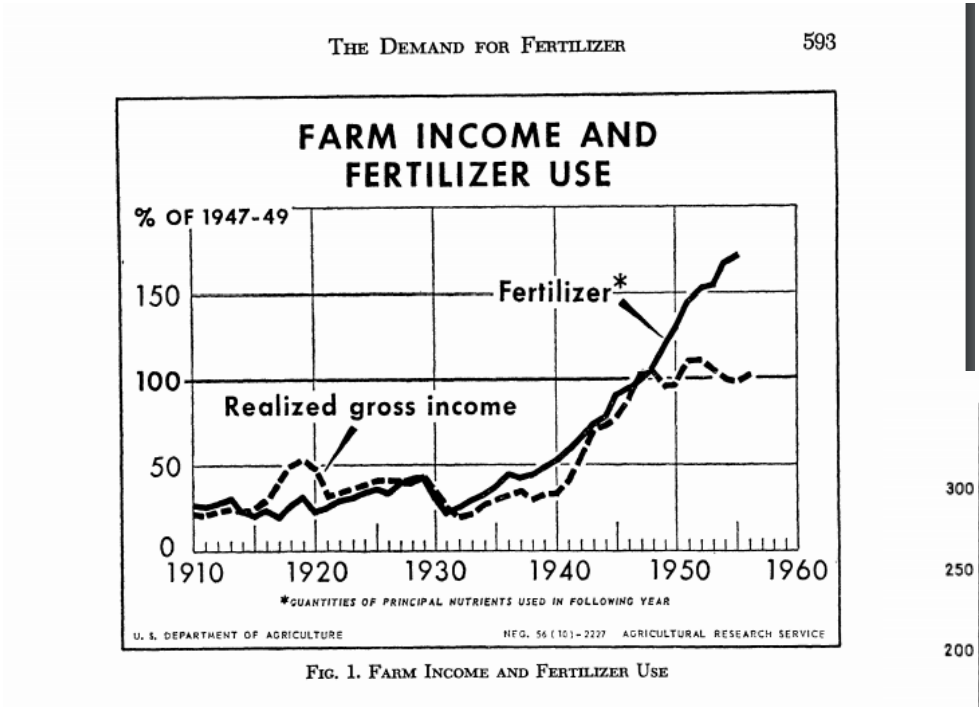


FIG. 1. FARM INCOME AND FERTILIZER USE

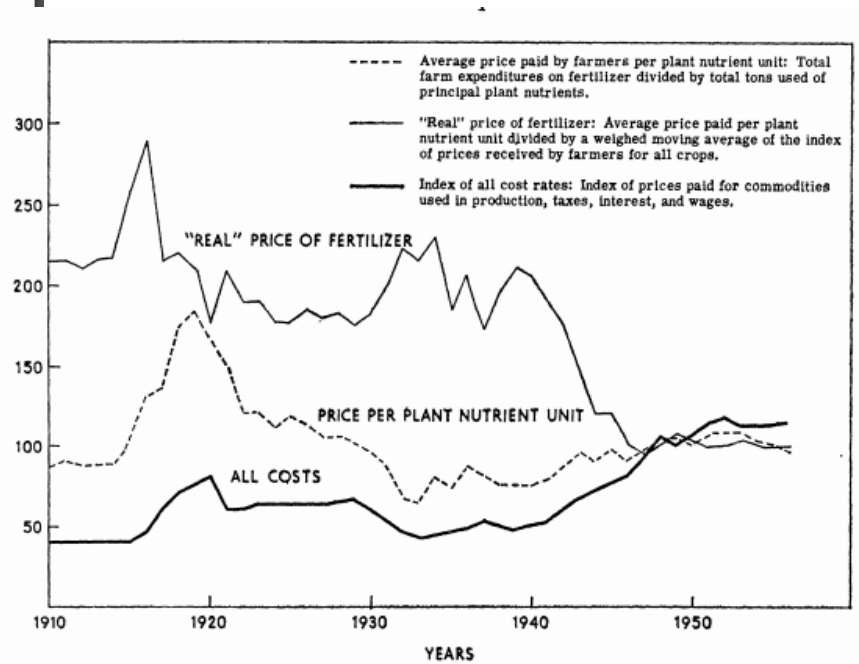


FIG. 3. FERTILIZER: INDEXES OF U. S. PRICE DEVELOPMENTS, 1947-49 = 100.

- Short-run price elasticity = -0.5
- Long-run price elasticity = -2.0

Soil Testing

- Williamson (2011)
  - Price elasticities between -1.67 and -1.87.
  - Soil testing: farmers who do soil testing reduce nitrogen use by up to 83 lbs/acre relative to the those that do not test (after controlling for other factors).
- Carman (1979)
  - Also finds fertilizer price elasticities range between -0.5 and -2.0.

Crop Mix

- Crop mix analysis would simply look at intensity of fertilizer use by crop from enterprise budgets.

- Backcast and forecast changes as crop mix changes.