Climate Effects on Biogeochemical and Hydrologic Processes in the Bay Watershed

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Appalachian Laboratory

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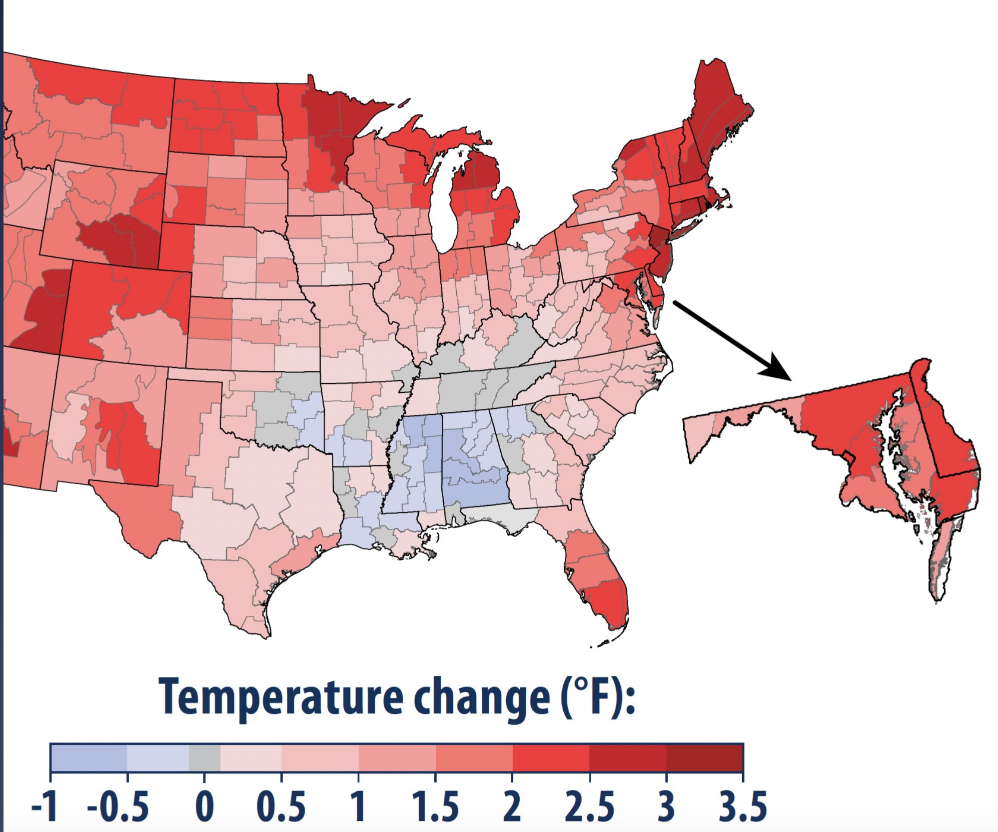
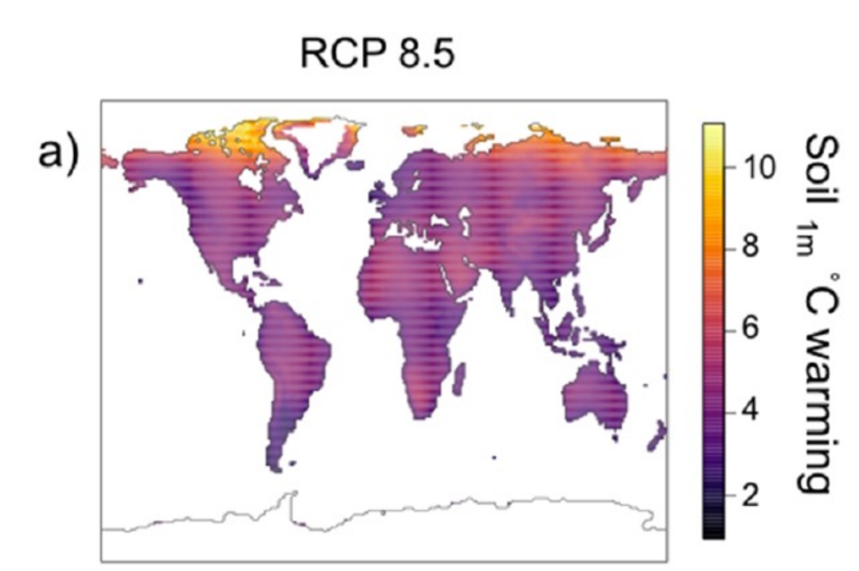
United States Environmental Protection Agency

Air temperature across most of the region has warmed one to two degrees (F) in the last century, soils and stream water have warmed, and heavy rainstorms are more frequent.

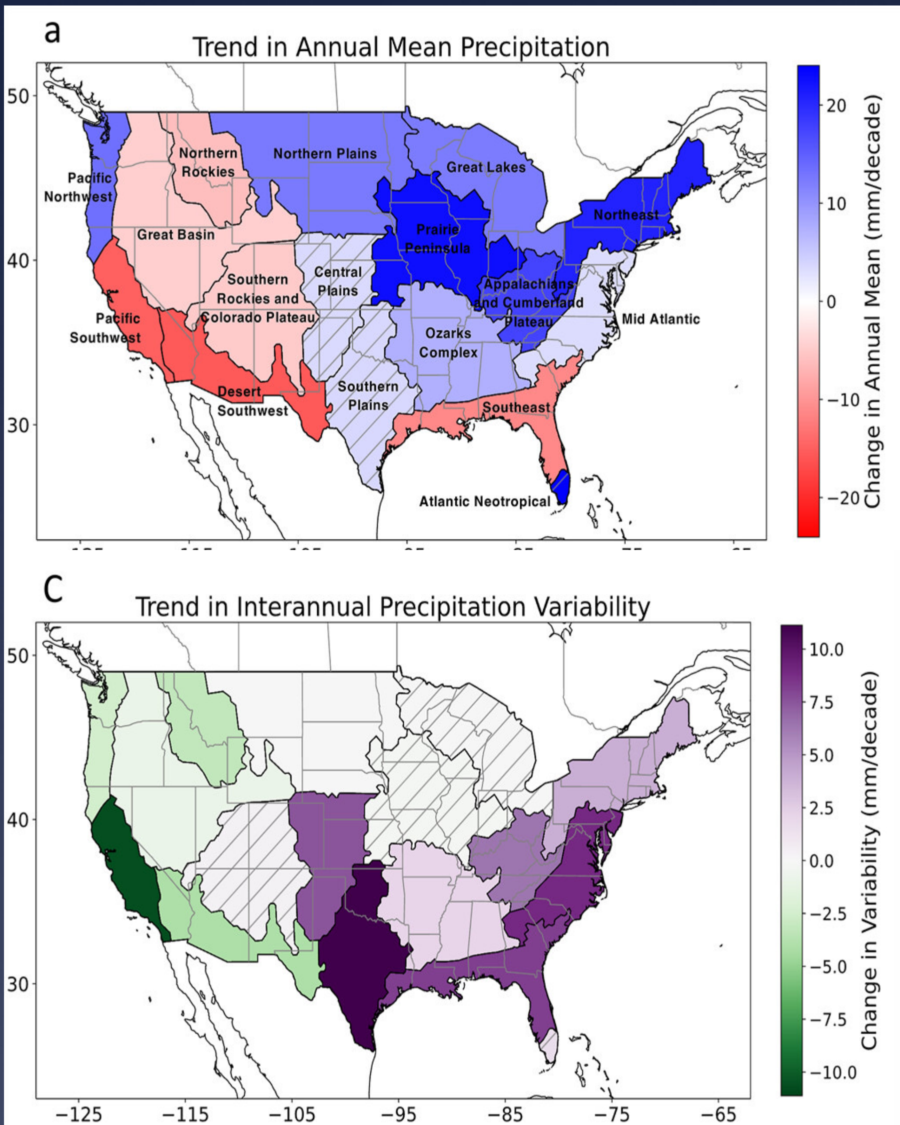


United States Environmental Protection Agency

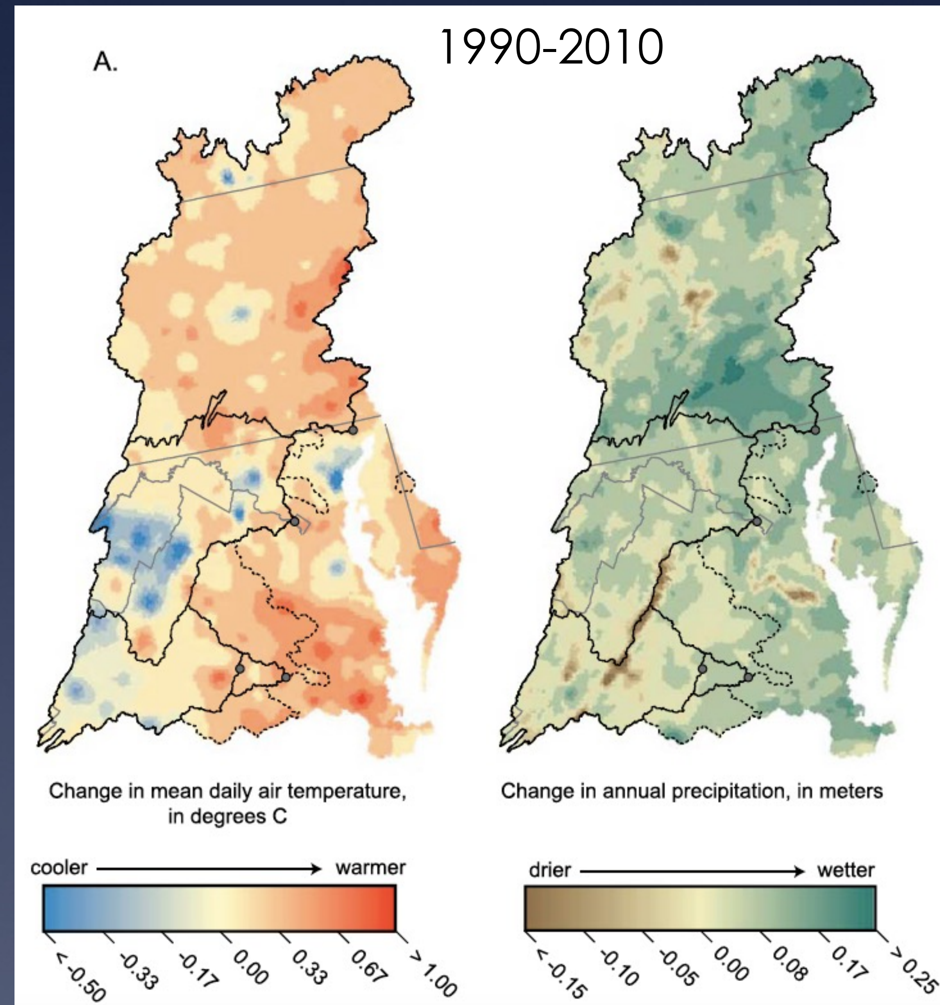


Soong, Phillips, Ledna, Koven, & Torn (2020) CMIP5 models predict rapid and deep soil warming over the 21st century. JGR: Biogeosciences, 125, e2019JG005266

Warmer, Wetter, and more precipitation variability in the Bay watershed

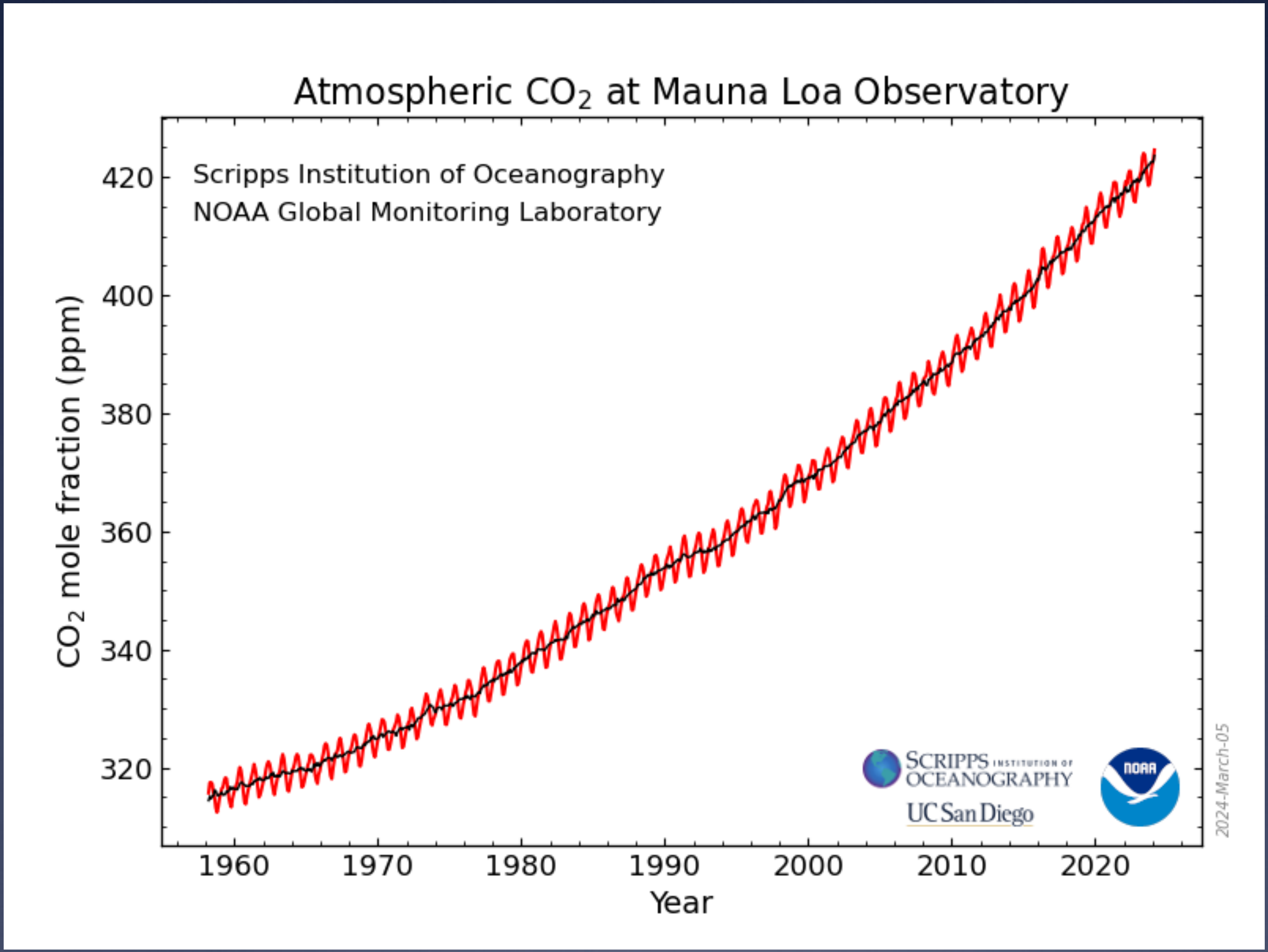


Harp & Horton (2023) GRL, Volume: 50, Issue: 13, e2023GL104533

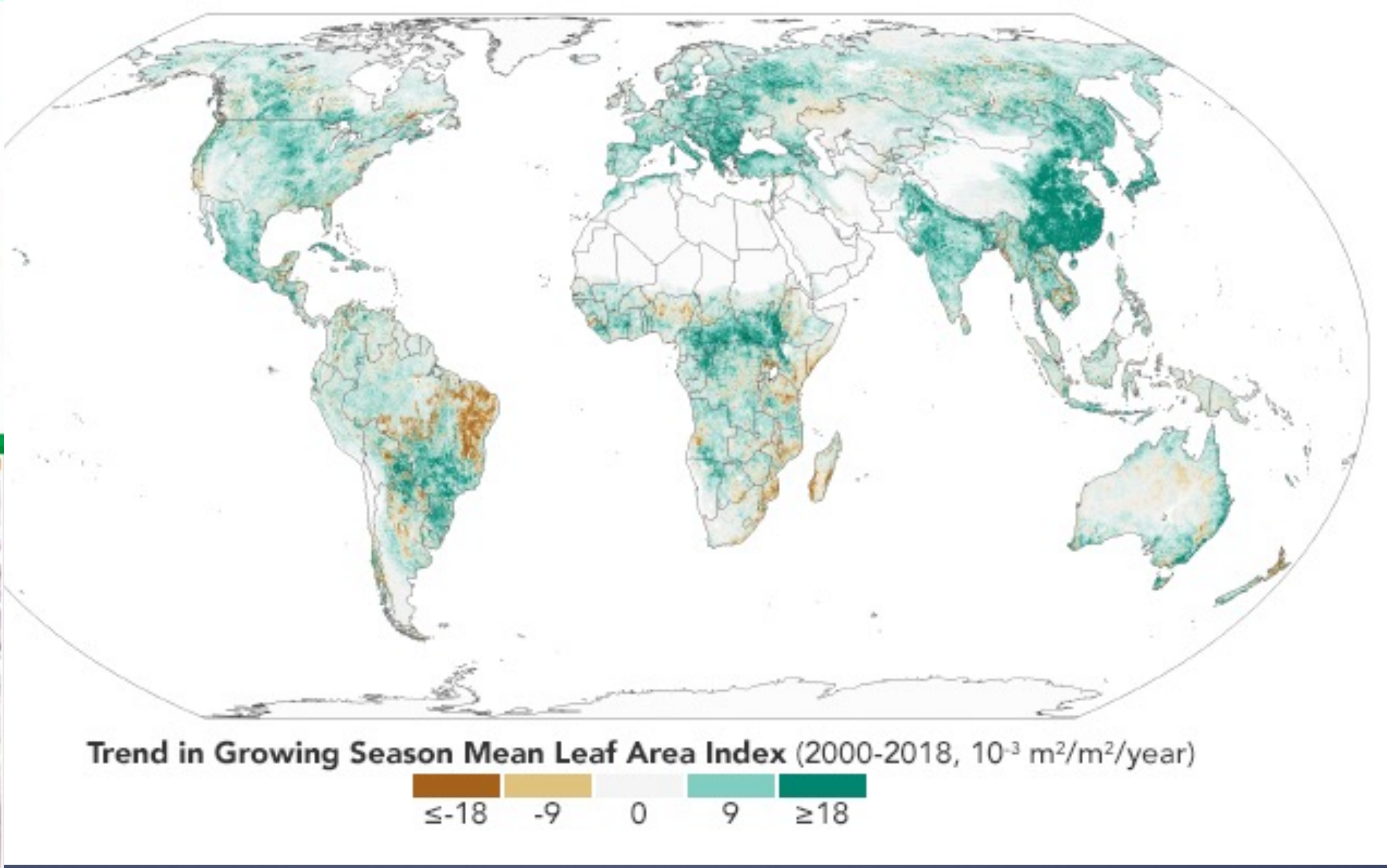


Chanat & Yang (2018) Water Resources Research, 54, 8120–8145.

Direct effect of eCO_2 on productivity



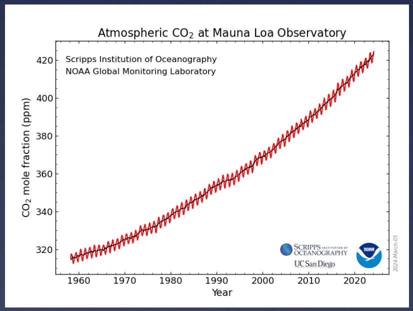
eCO_2 and Longer Growing Seasons

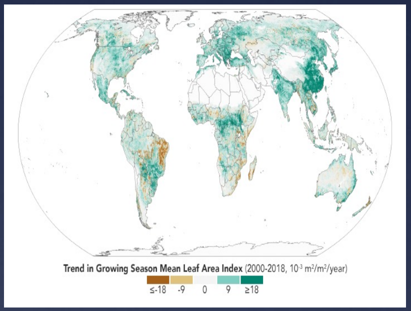


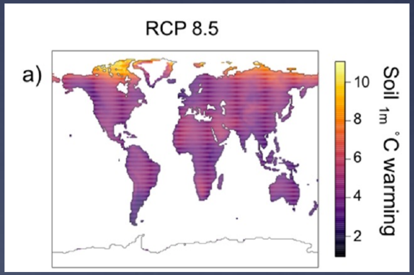
Piao, S., Wang, X., Park, T. et al. Characteristics, drivers and feedbacks of global greening. Nat Rev Earth Environ 1, 14–27 (2020). https://doi.org/10.1038/s43017-019-0001-x

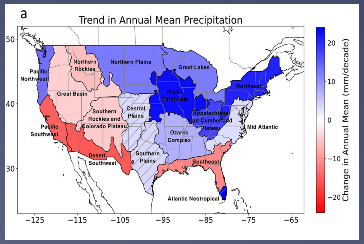
Summary of climate impacts on physical environment

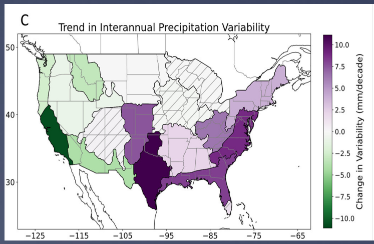
- Elevated atmospheric CO_2 and longer growing seasons result in greater carbon inputs to ecosystems, higher plant C:N
- Climate warming also leads to warmer soils
- Soil warming and eCO_2 balance out. Where precipitation increases, soil moisture increases
- However, precipitation is becoming more variable







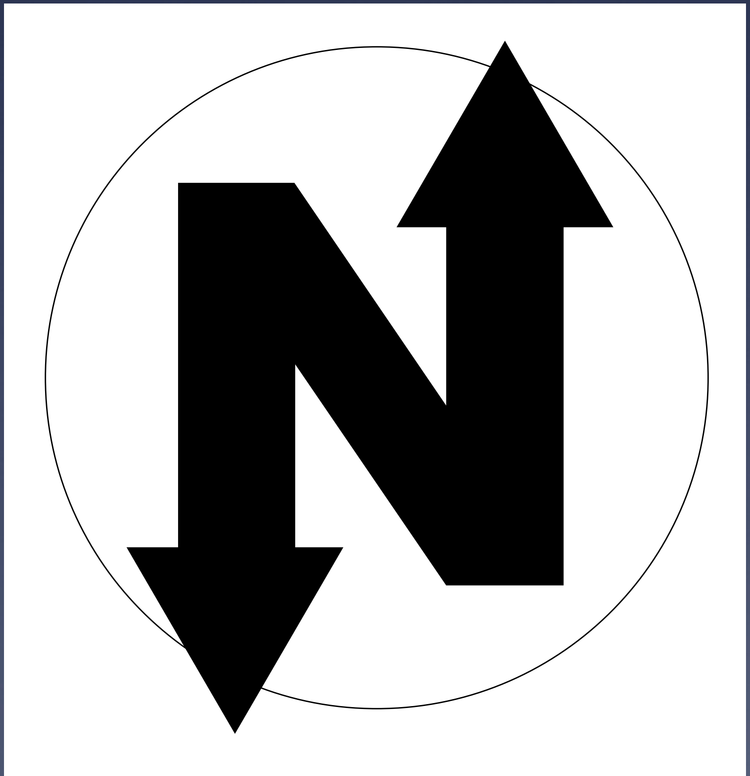




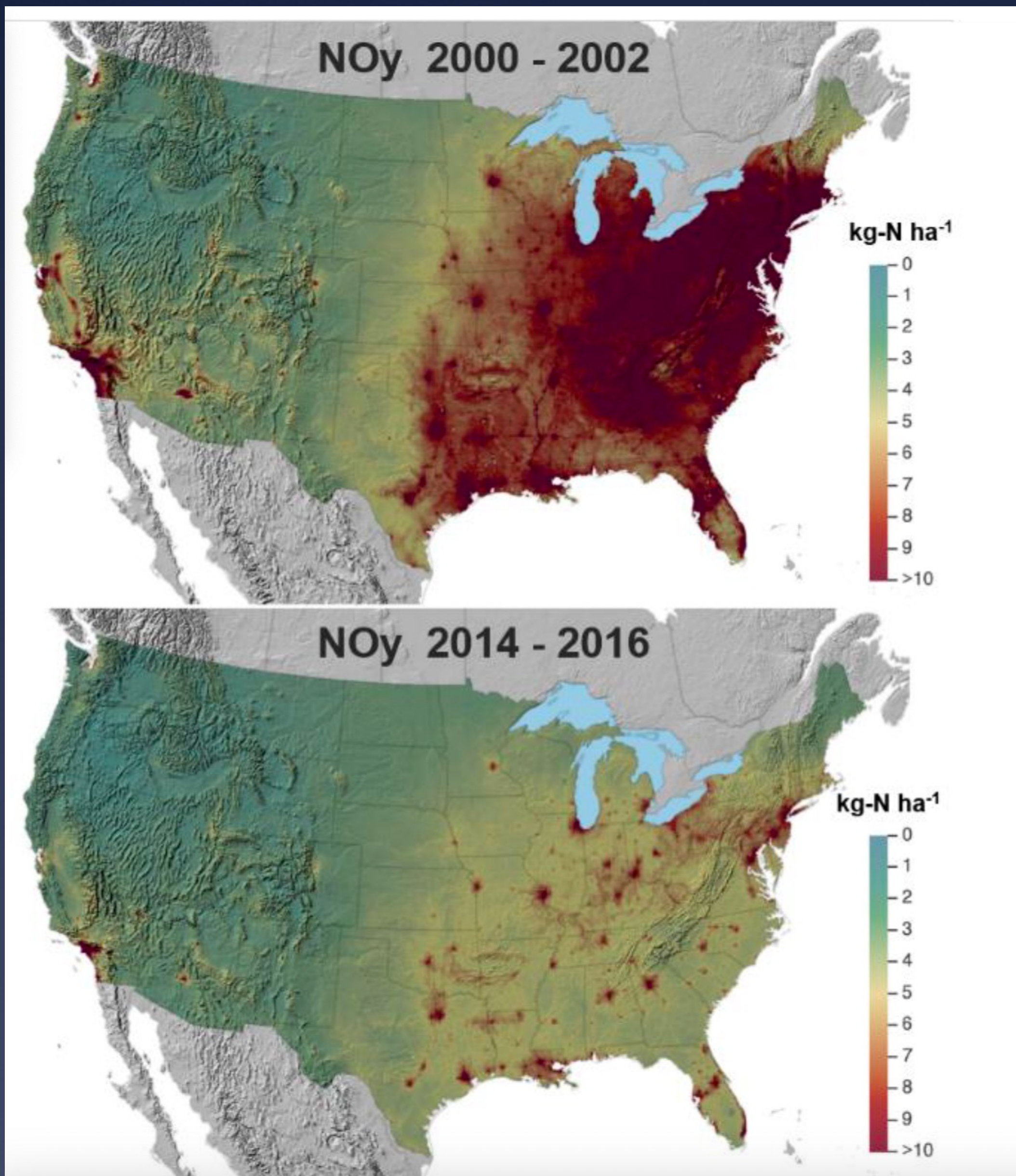
Impact on watershed load

$$I - dN_v/dt - dN_s/dt - G = L$$

Input | Vegetative Sink | Soil Sink | Gaseous Loss | Watershed Load



Declining N deposition in the US

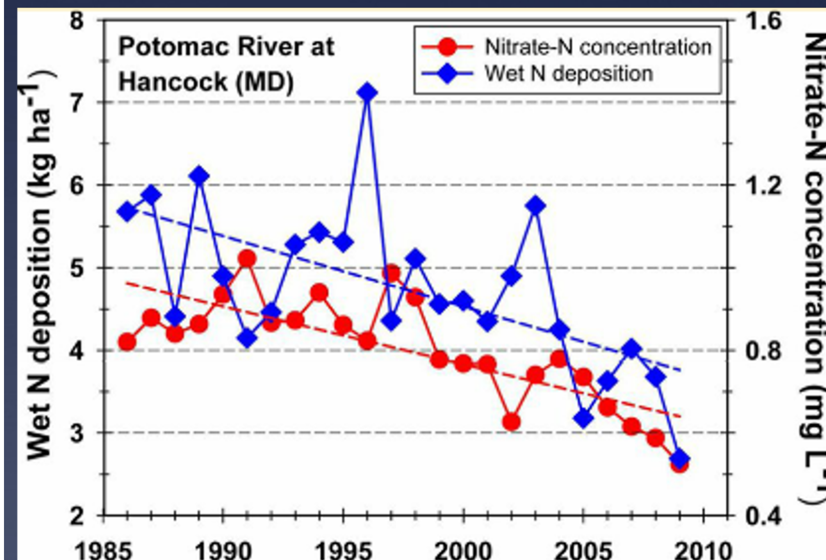


Environmental Science & Technology
Article
pubs.acs.org/est

Surface Water Quality Is Improving due to Declining Atmospheric N Deposition

Keith N. Eshleman,* Robert D. Sabo, and Kathleen M. Kline

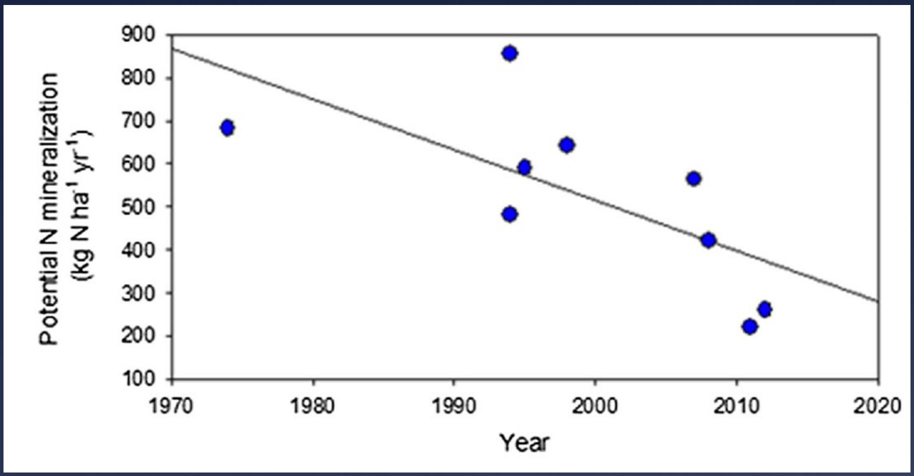
†University of Maryland Center for Environmental Science, Appalachian Laboratory, Frostburg, Maryland 21532, United States

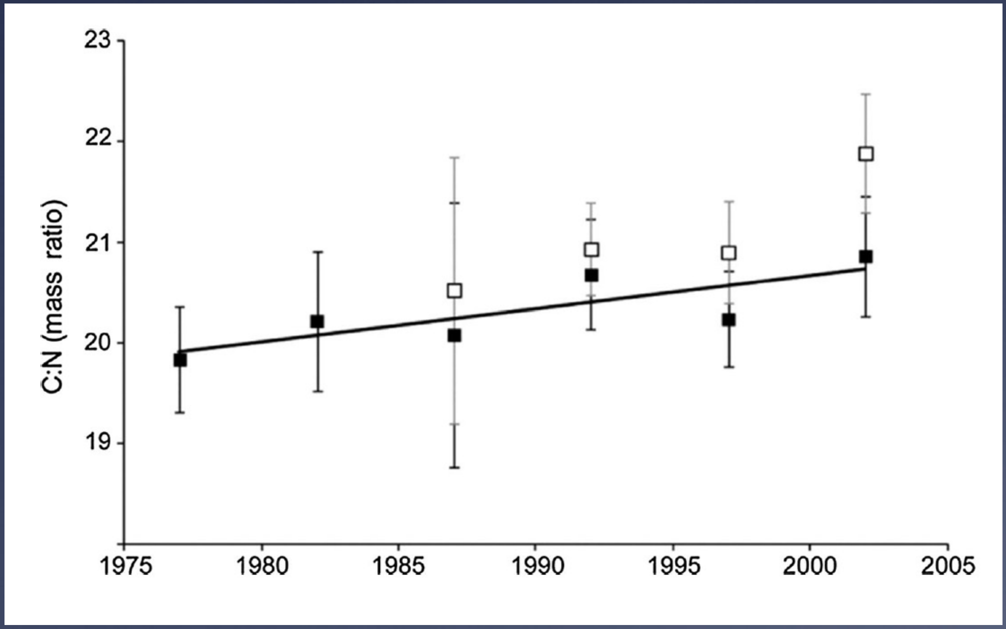


Caveats:

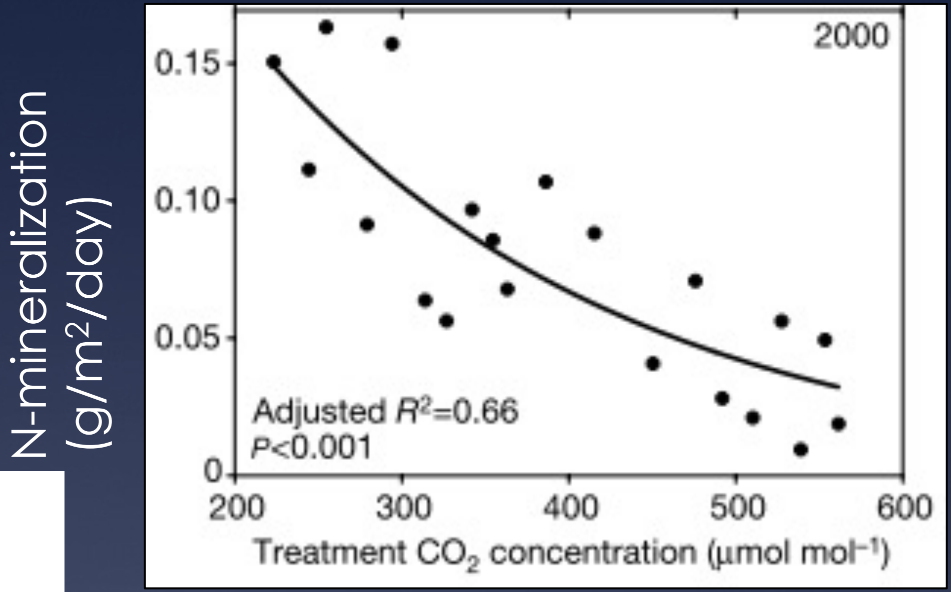
- Deposition of reduced forms of N has increased
- Mobile sources are still large

Natural sources of N supply are decreasing too



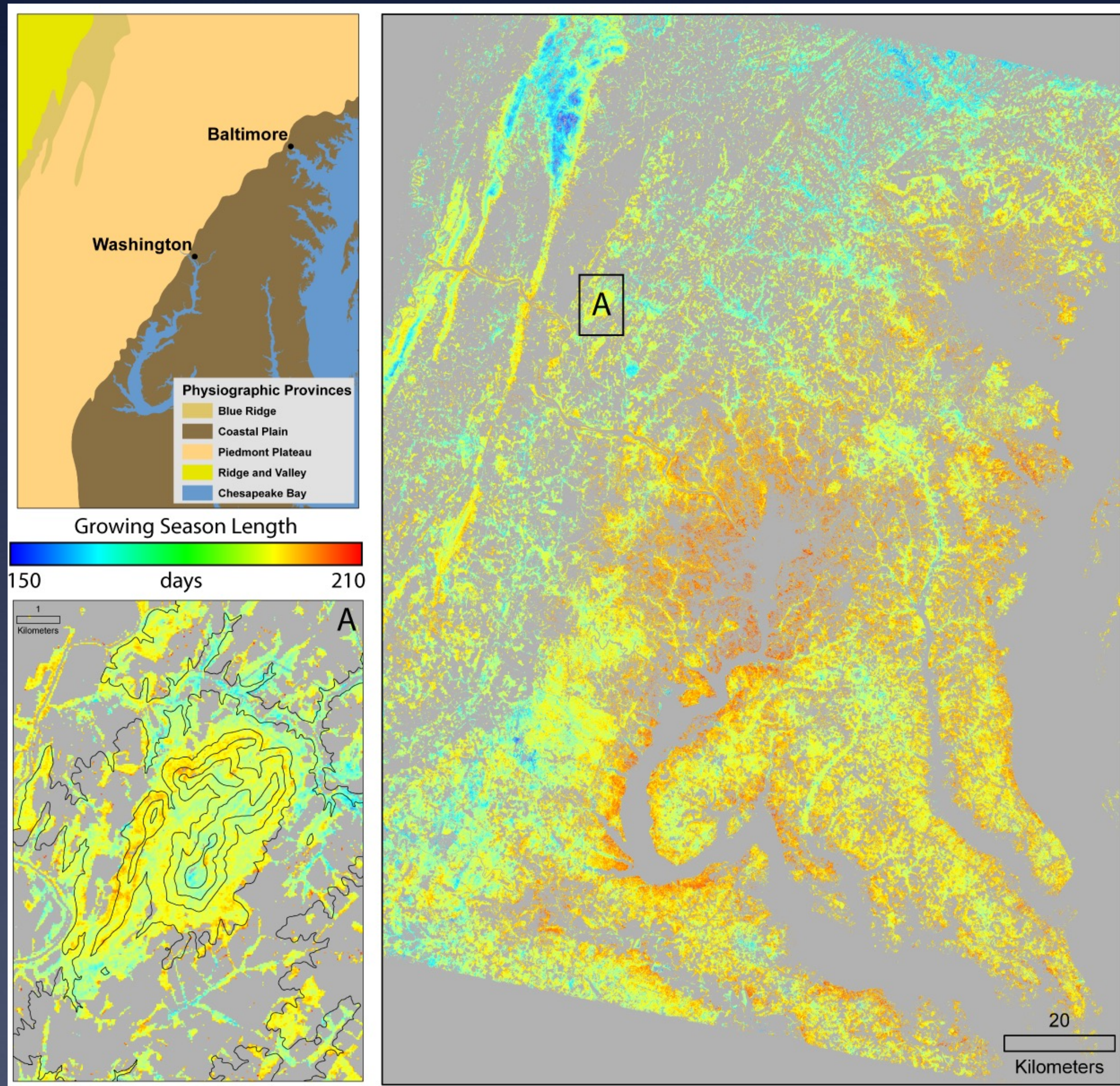


Groffman et al. Biogeochemistry (2018) 141:523–539)



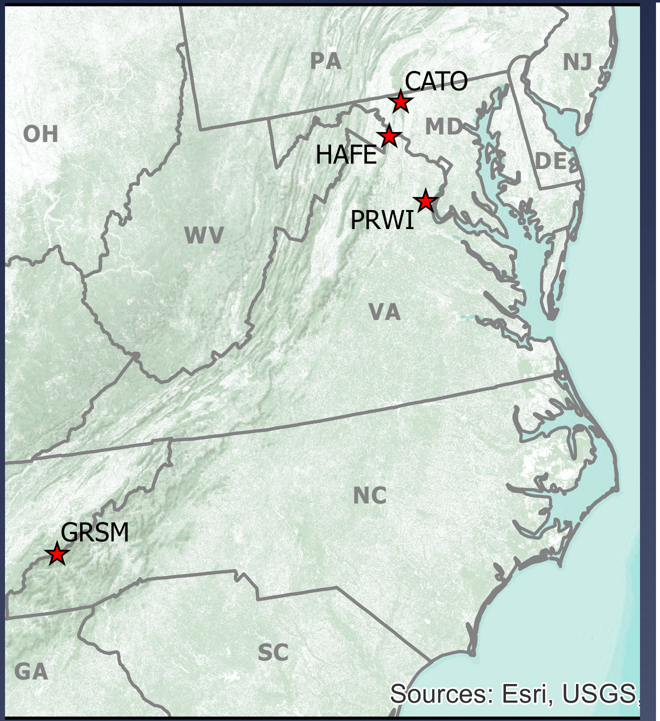
Gill et al. (2002)

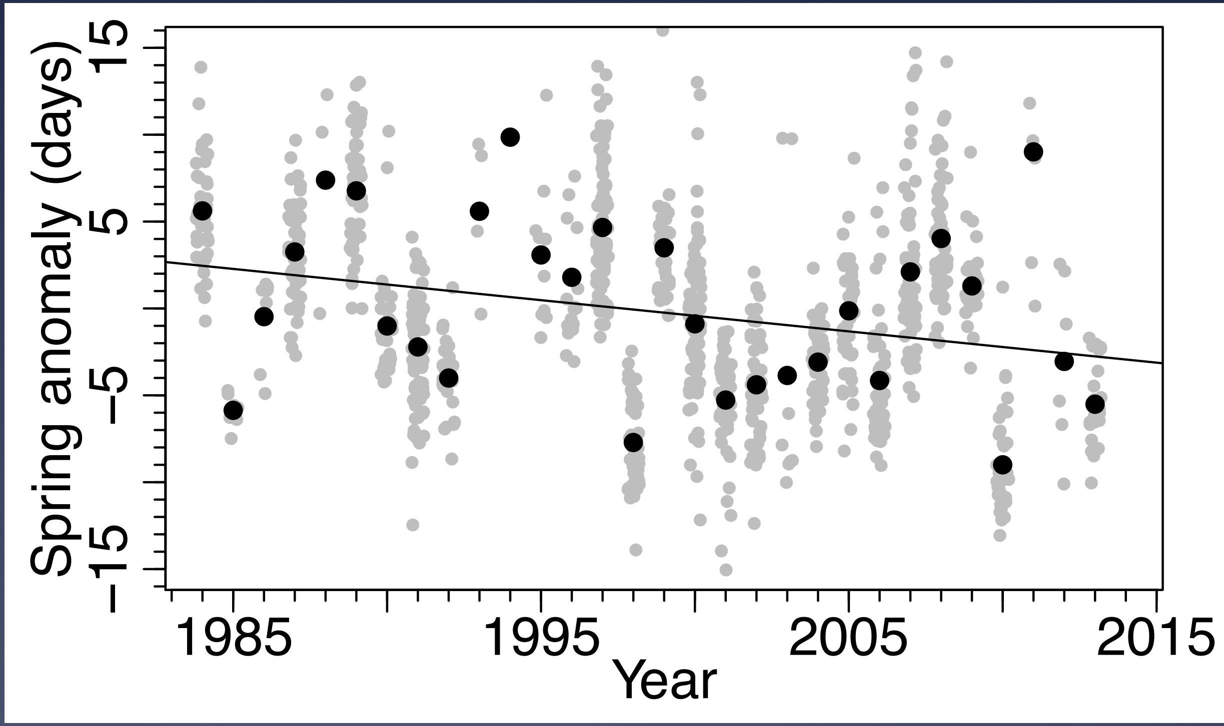
Longer growing seasons is another indicator of increasing demand



Elmore et al. 2012 GCB

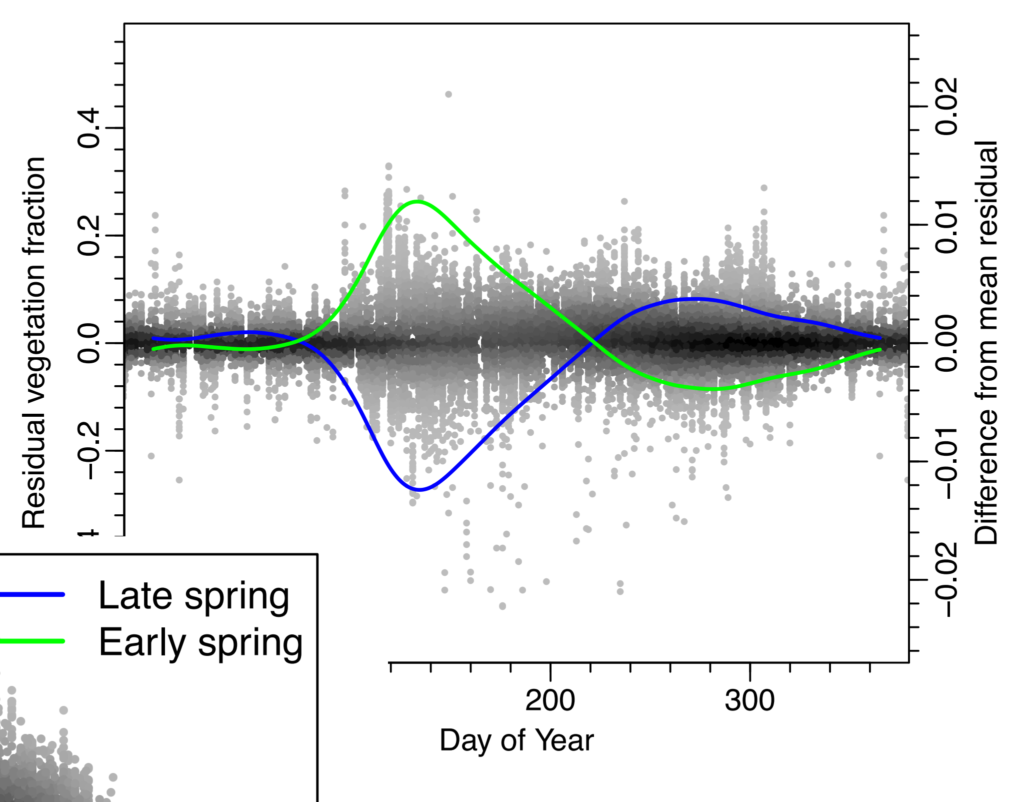
Earlier springs across 113 temperate forest sites

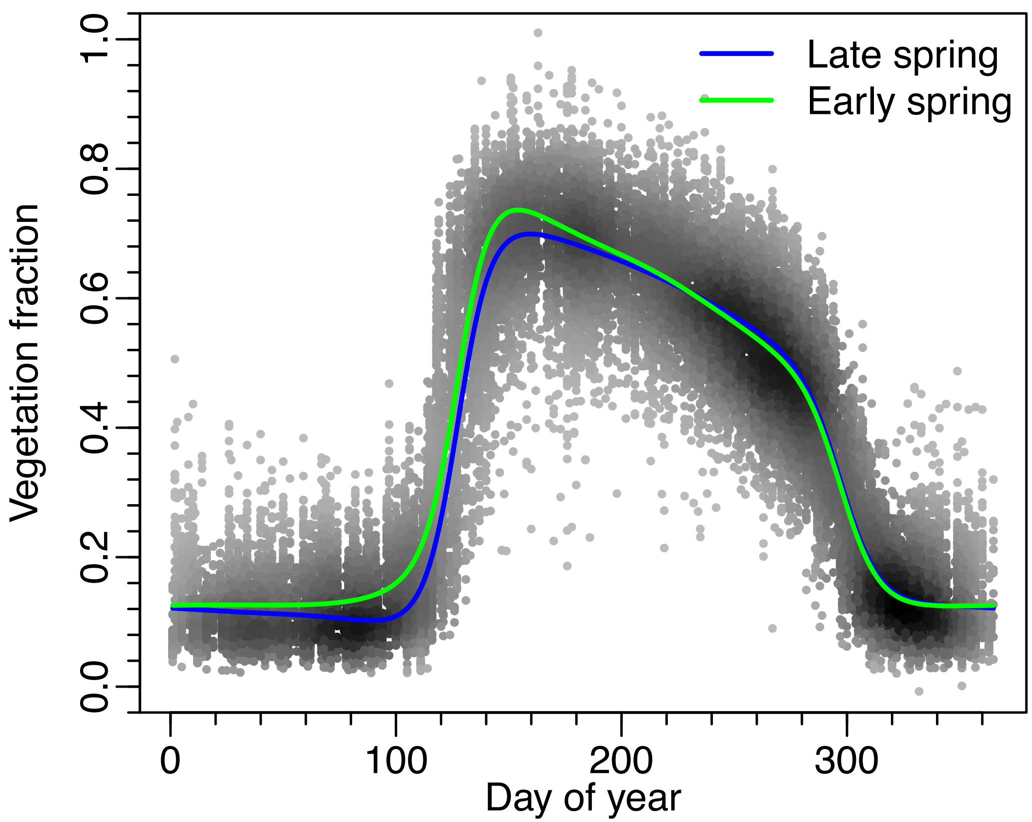




Elmore et al. (2016) Earlier springs are causing reduced nitrogen availability in North American eastern deciduous forests *Nature Plants 2: 16133*

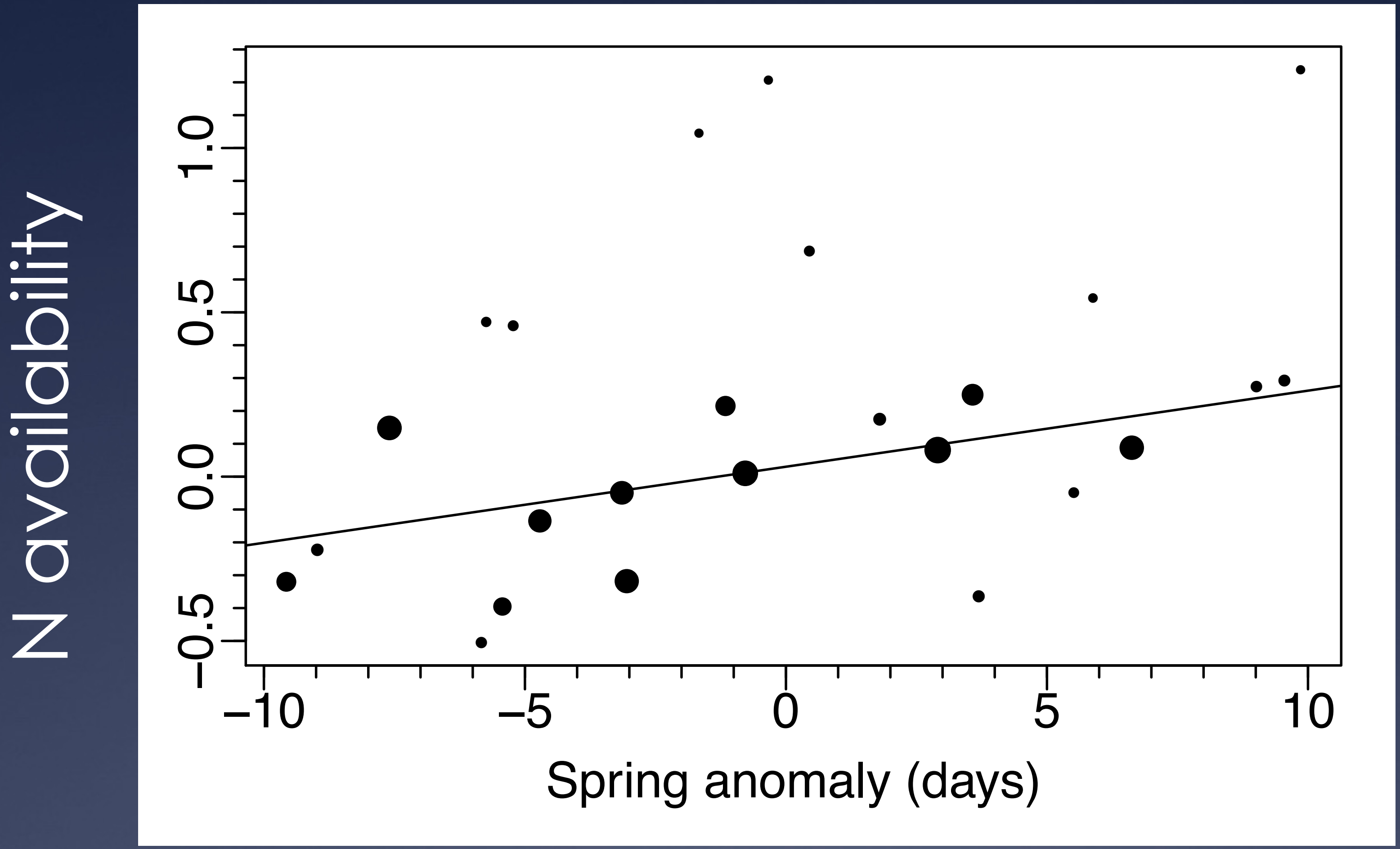
Early springs, early summer productivity

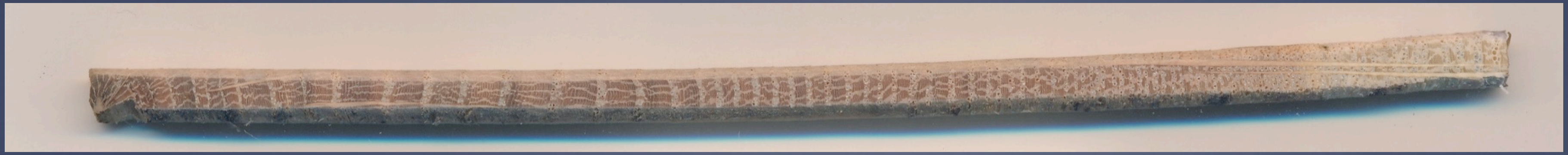




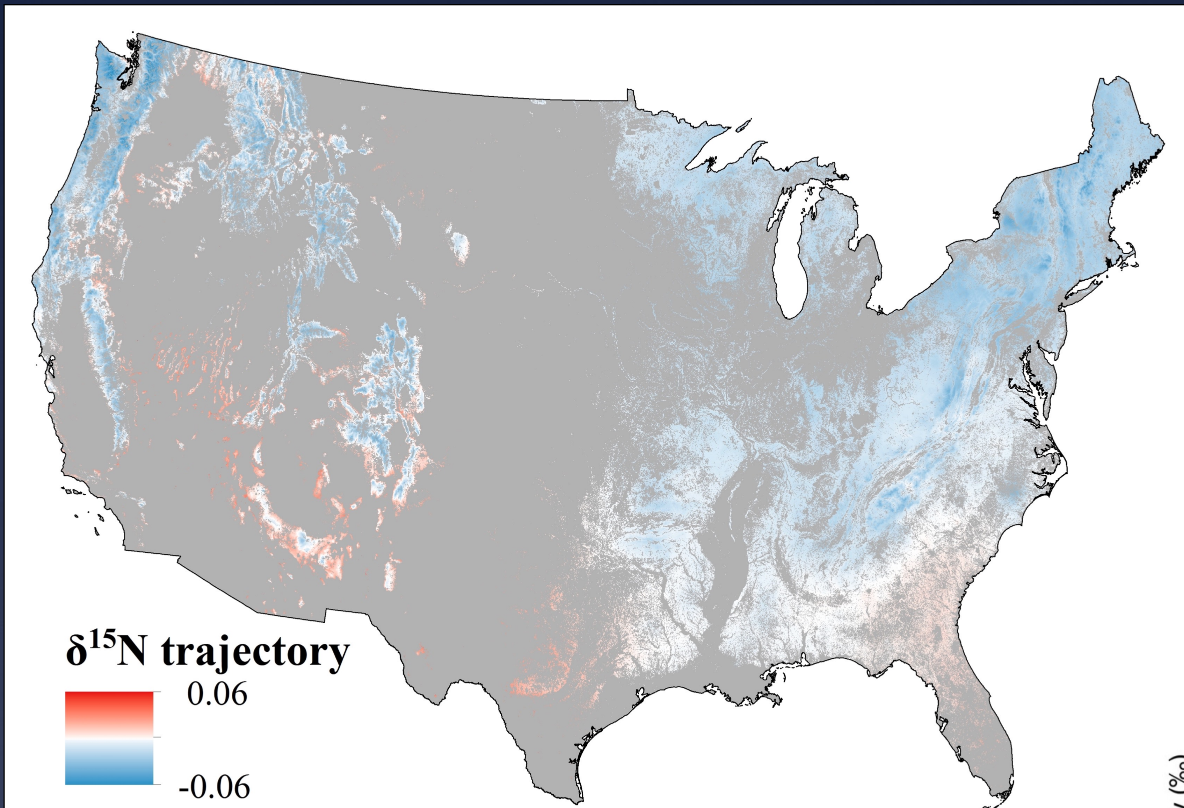
Late summer browning, early autumn

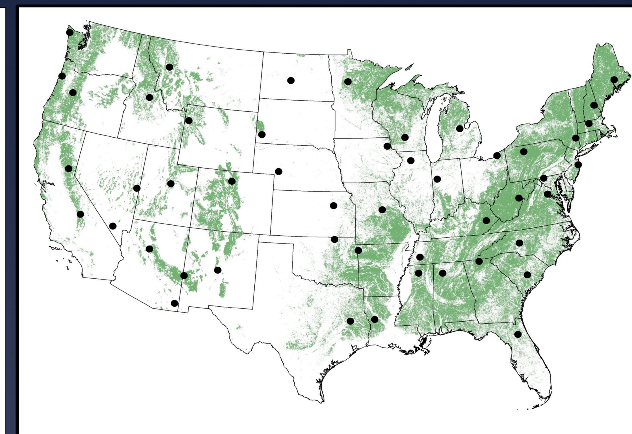
Effect of an earlier spring is to reduce N availability



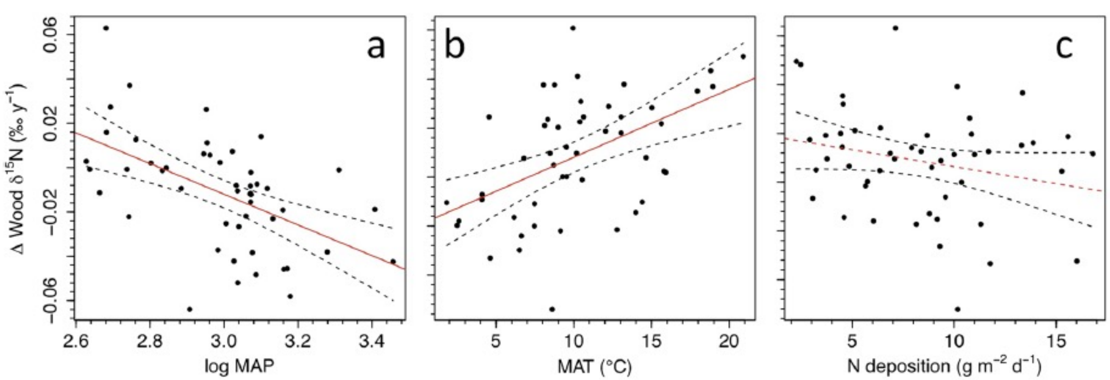


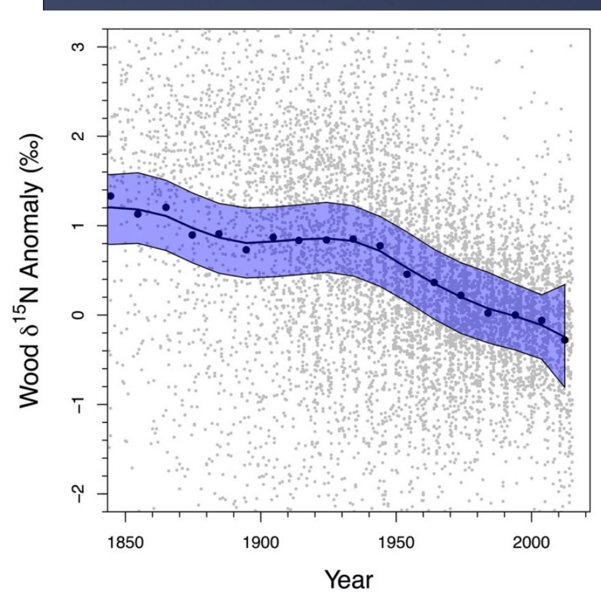
Tree rings: Wetter and cooler sites show strongest decline in N availability



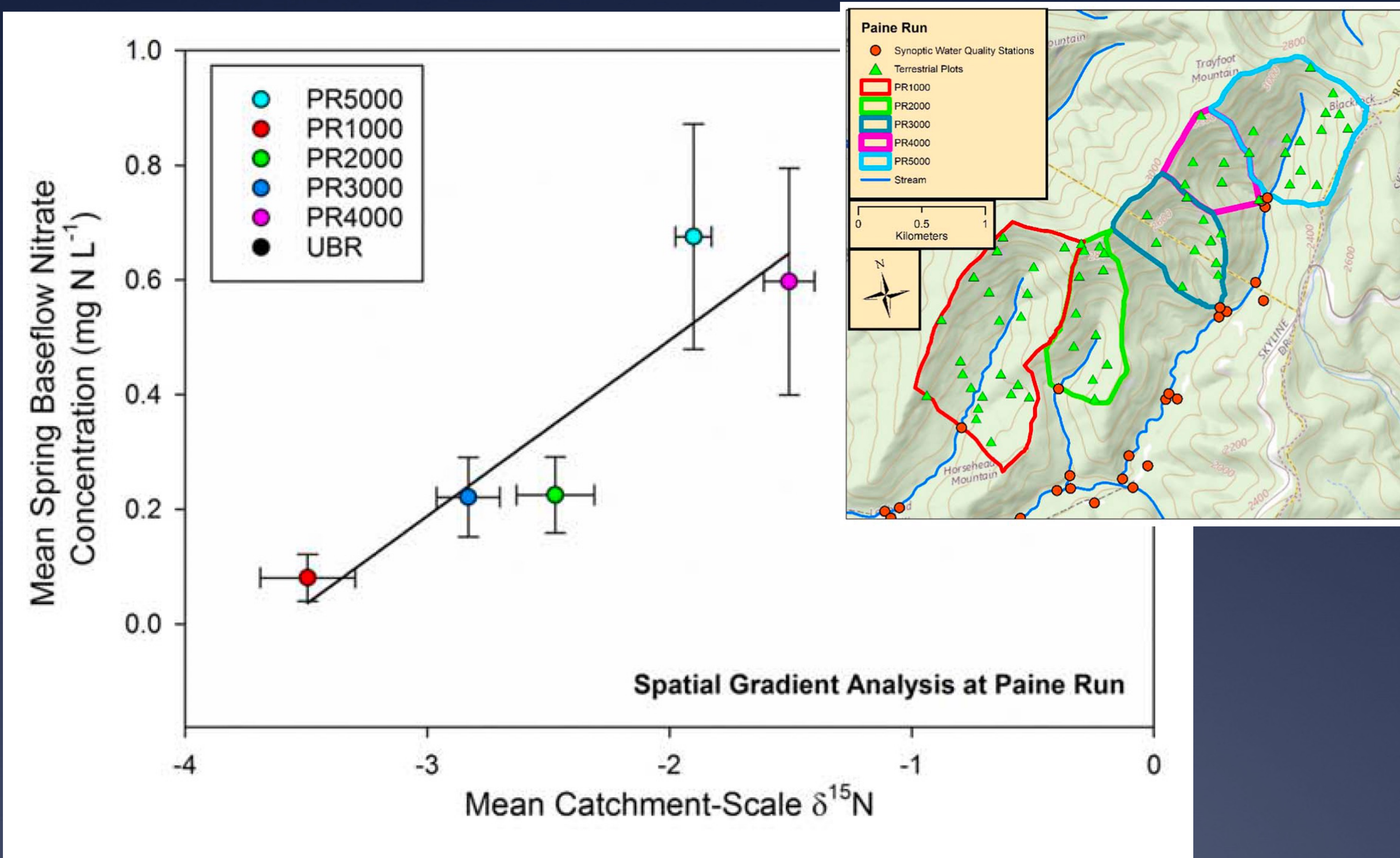


McLauchlan et al 2017
Scientific Reports





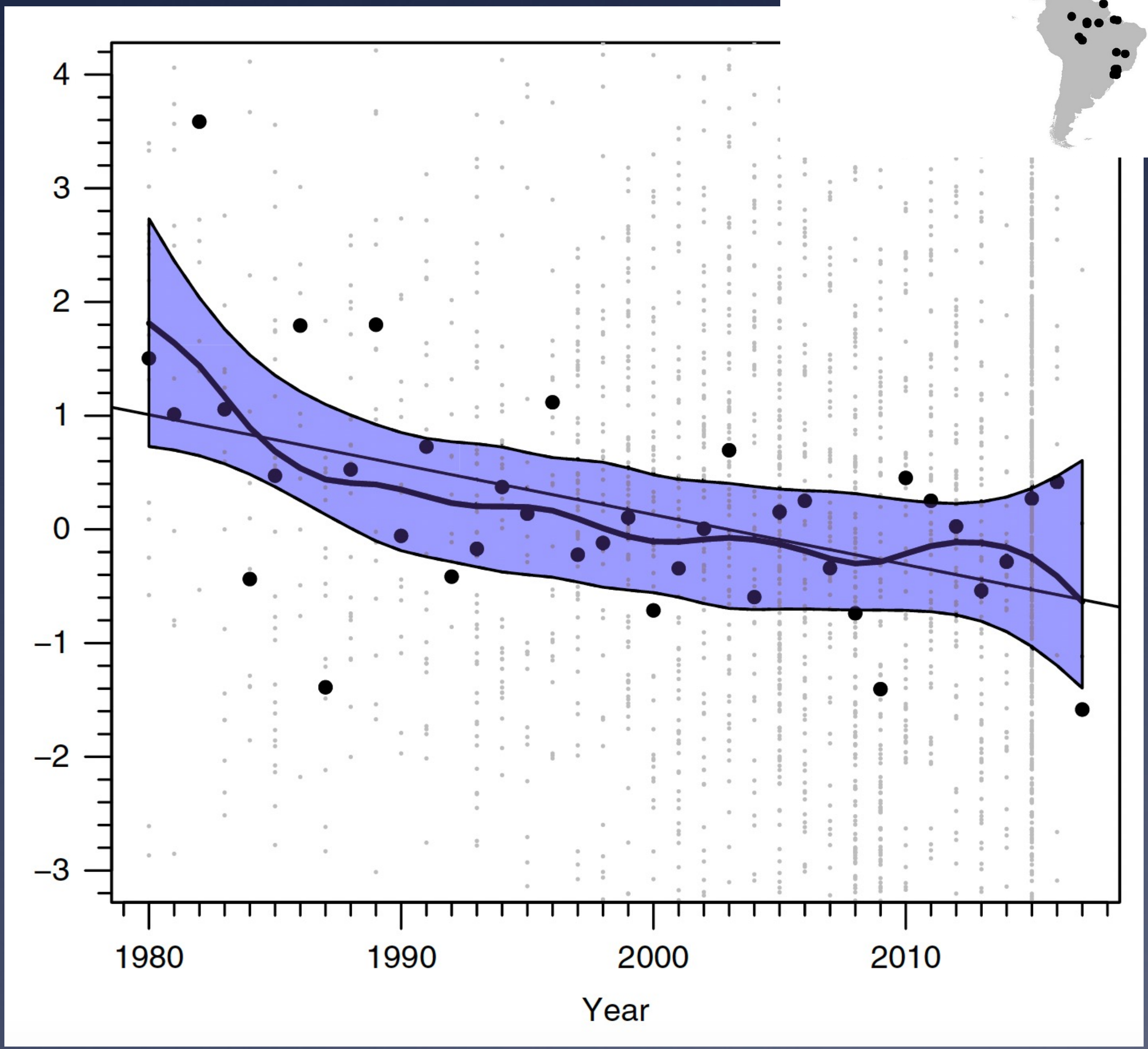
Tree ring N correlates with stream N

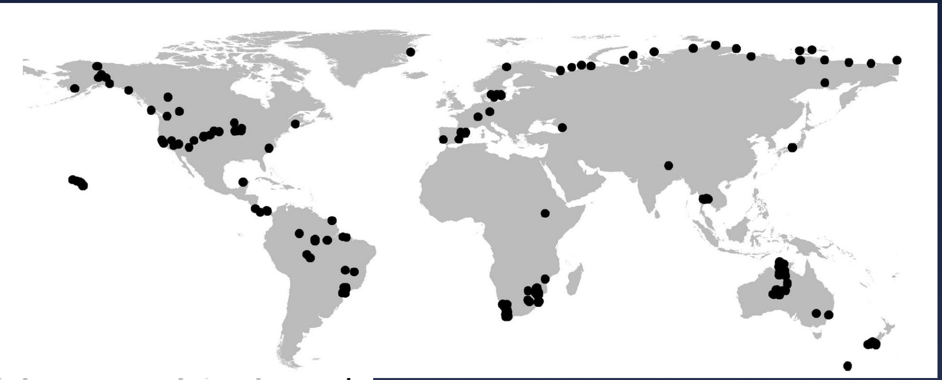


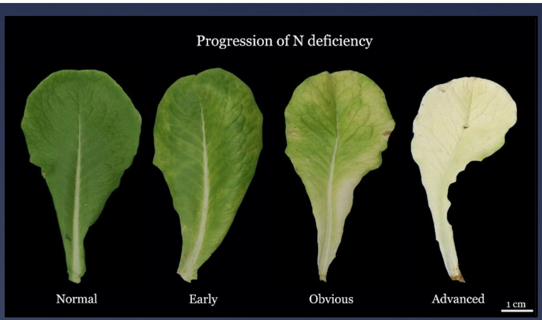
Sabo et al. 2020 *Environmental Research Letters*

Global observations of N availability

N availability

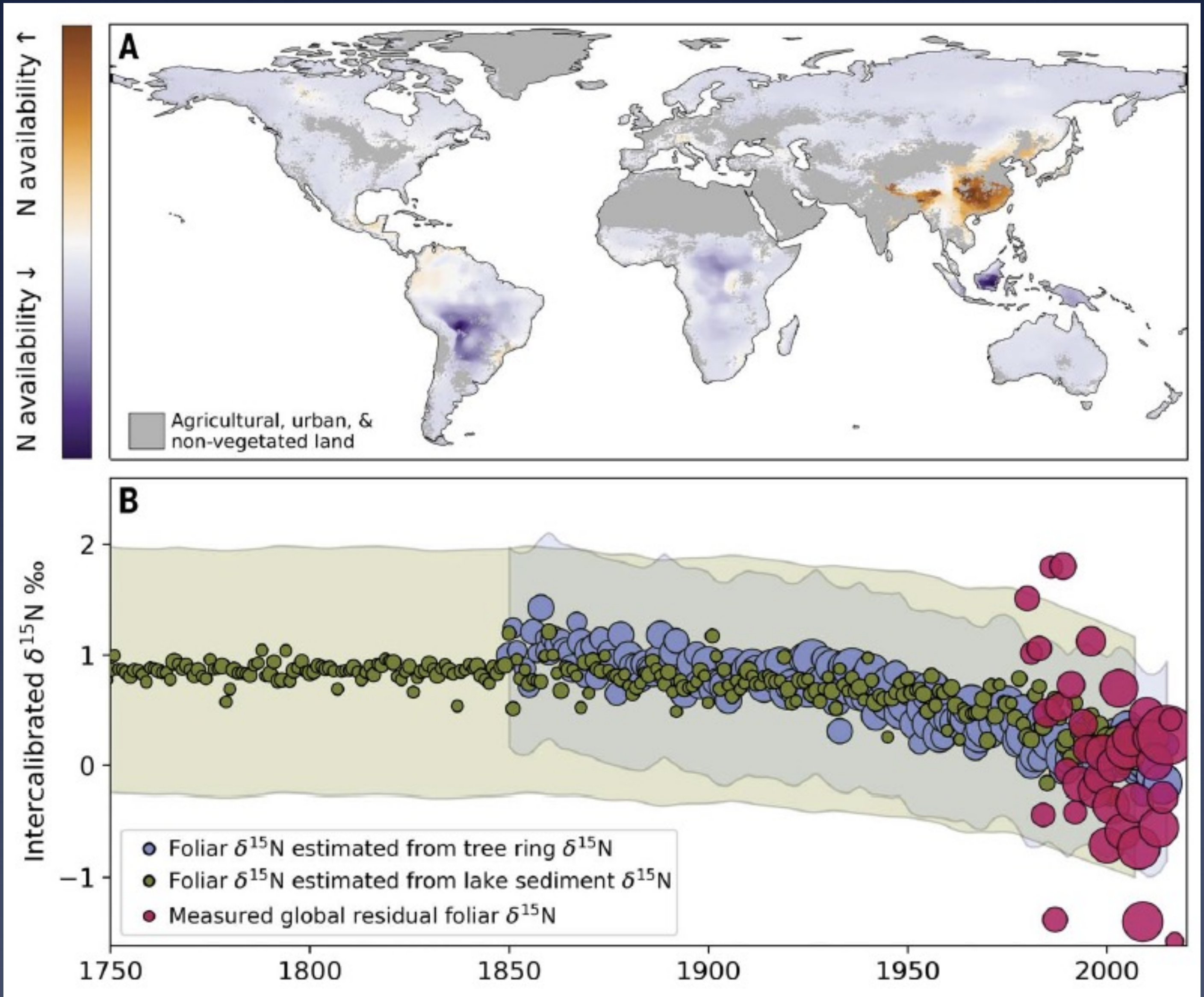






Craine JM, Elmore AJ, et al. Isotopic evidence for oligotrophication of terrestrial ecosystems. Nat Ecol Evol. 2018 Nov;2(11):1735-1744.

Long-term trends in N availability



Mason et al. (2022) Evidence, causes, and consequences of declining nitrogen availability in terrestrial ecosystems. *Science* Vol 376, Issue 6590

Impact on watershed load

$$I - dN_v/dt - dN_s/dt - G = L$$

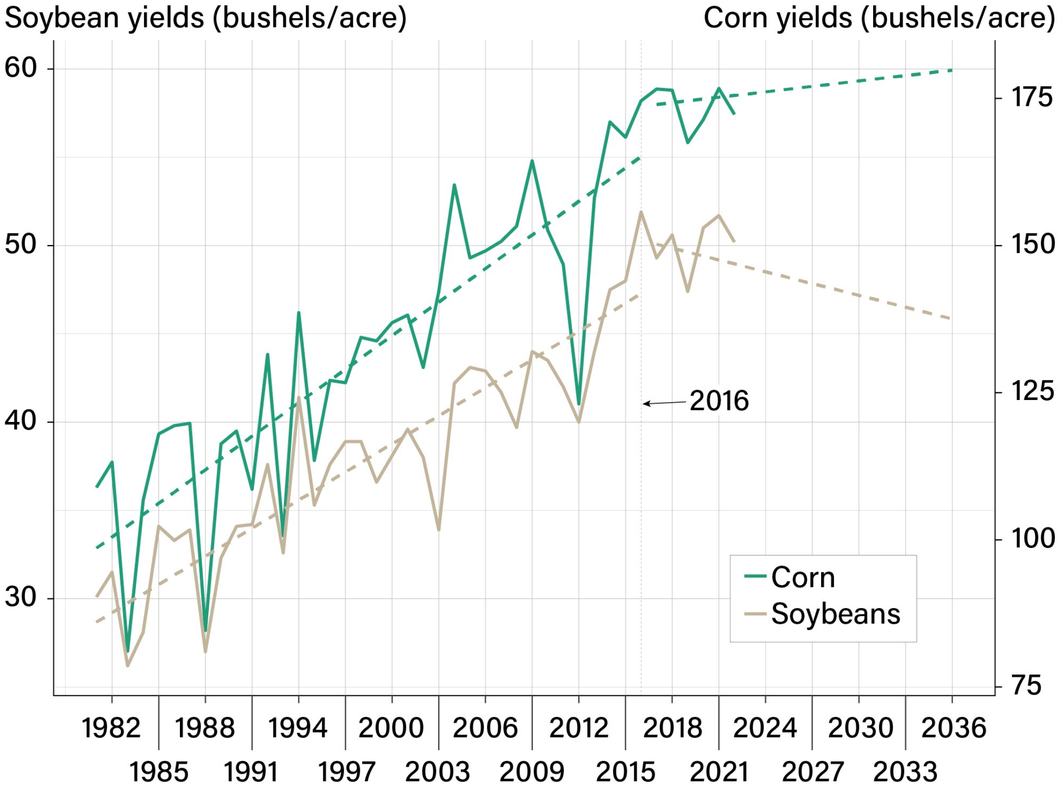
Input | Vegetative Sink | Soil Sink | Gaseous Loss | Watershed Load

Forest

Agriculture

Corn and soy yields have nearly doubled since early 1980s

U.S. soybean yields to decrease, corn yields to increase based on climate projections

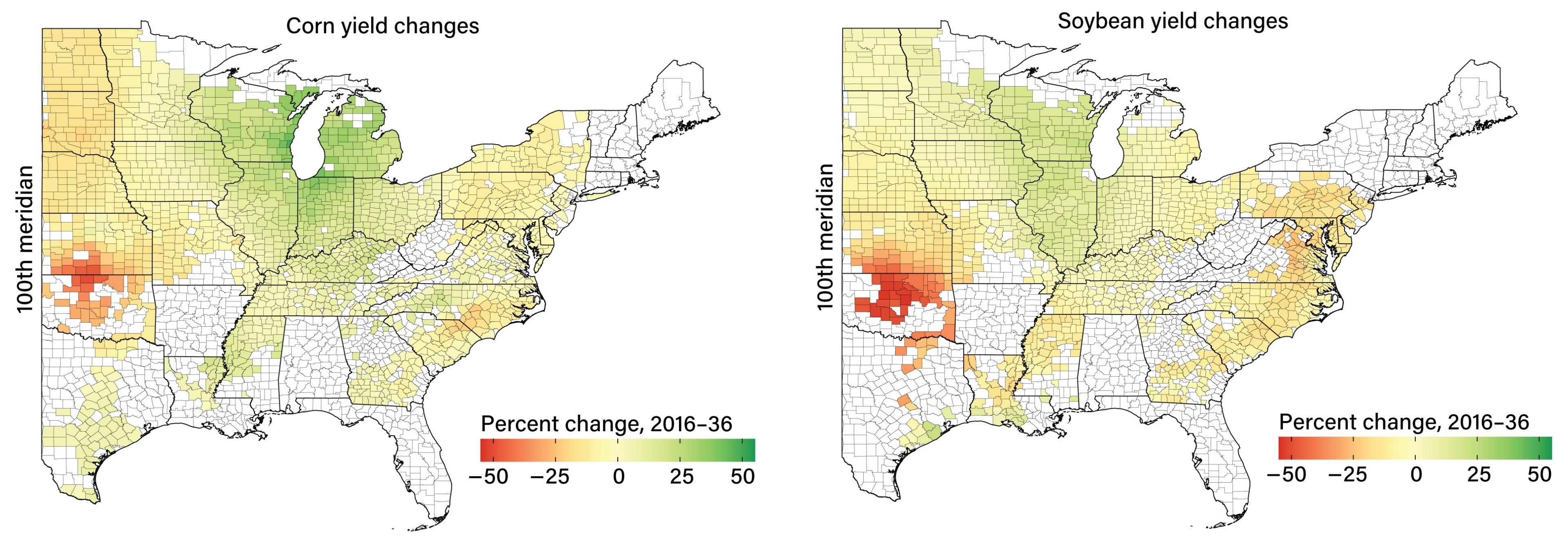


Note: Solid lines represent year-to-year changes, and dashed lines represent past and future trends. Researchers used 2016 as the base year to determine change in 2036.

Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service.

- Nutrient use efficiency increasing in the Chesapeake Bay and nationwide
- Coincides with improving water quality conditions in monitored agricultural watersheds (Sabo et al., 2022)

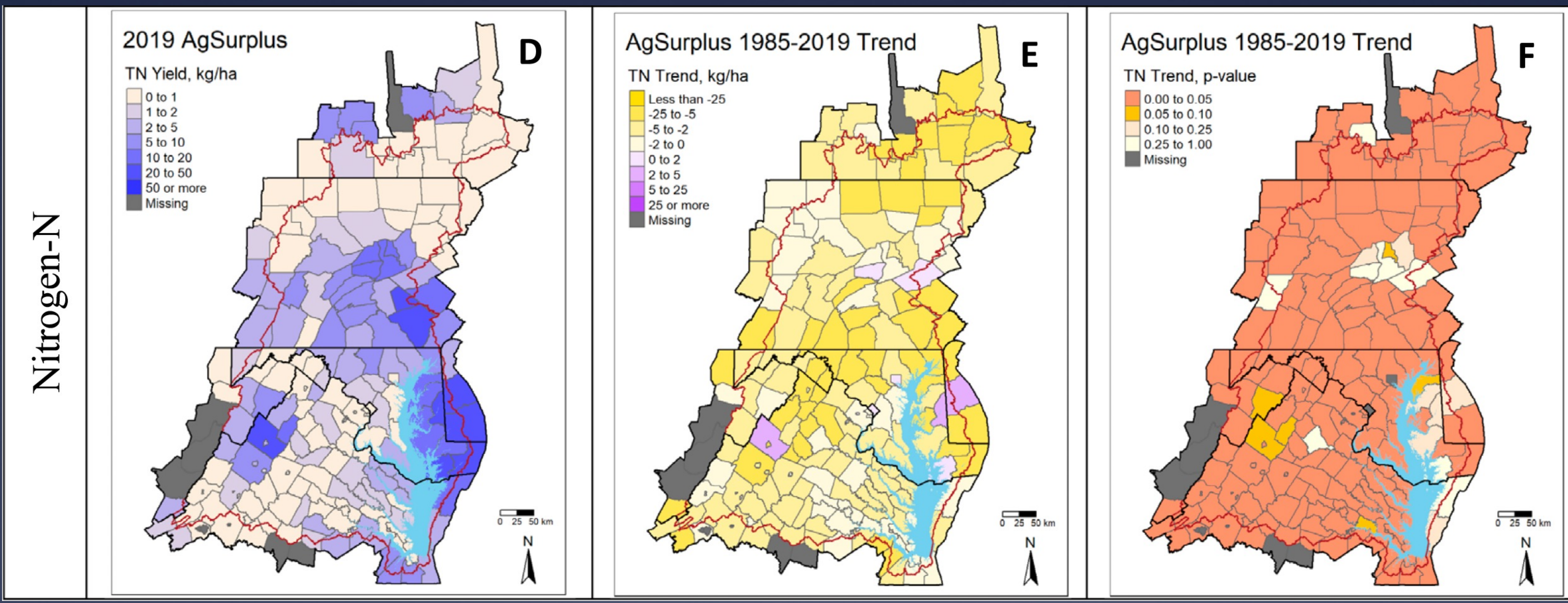
After decades of robust growth, corn and soy yields may stall or decline



- Crop yield one of the largest fluxes in the Bay watershed

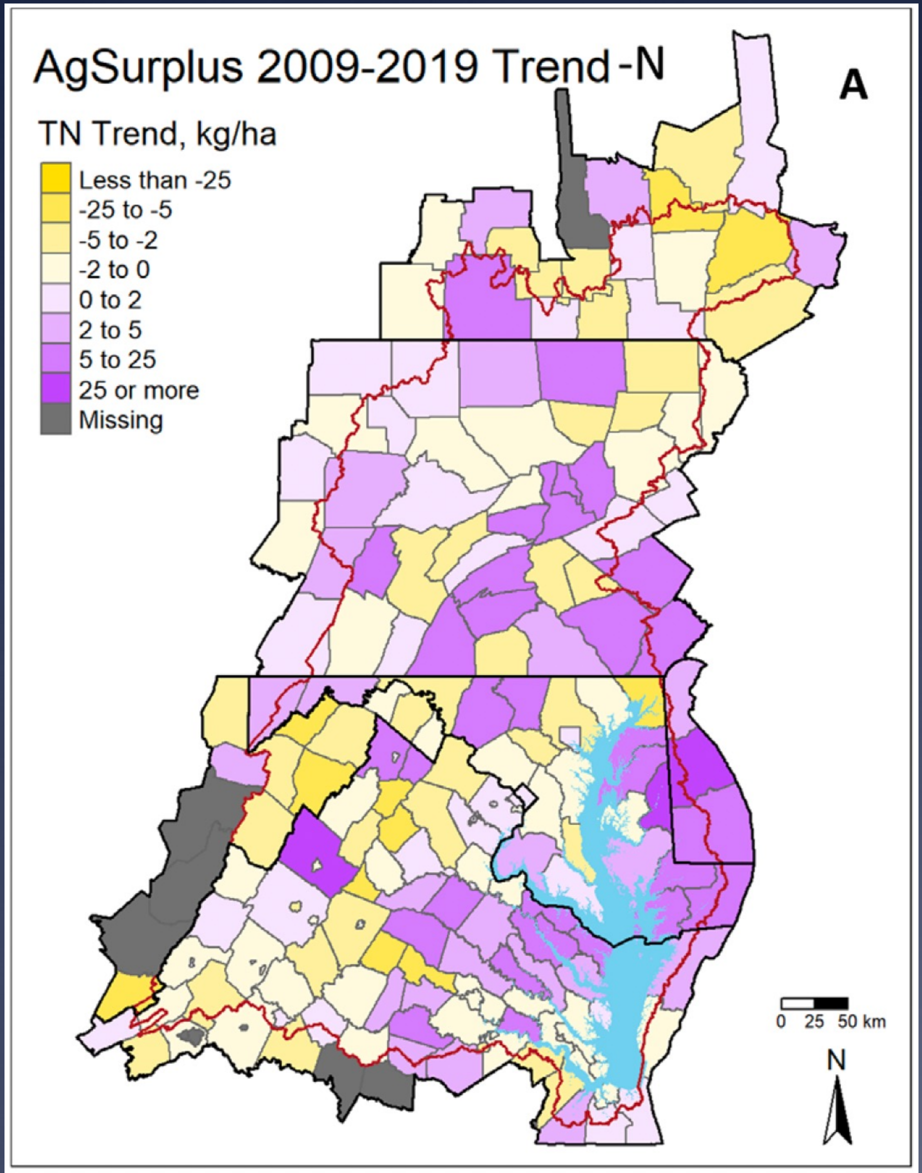
Beckman, Ivanic & Nava (2023) Estimating Market Implications From Corn and Soybean Yields Under Climate Change in the United States (No. 338944). United States Department of Agriculture, Economic Research Service.

N surplus (i.e., agricultural inputs minus crop removal) have declined due to yields outpacing inputs



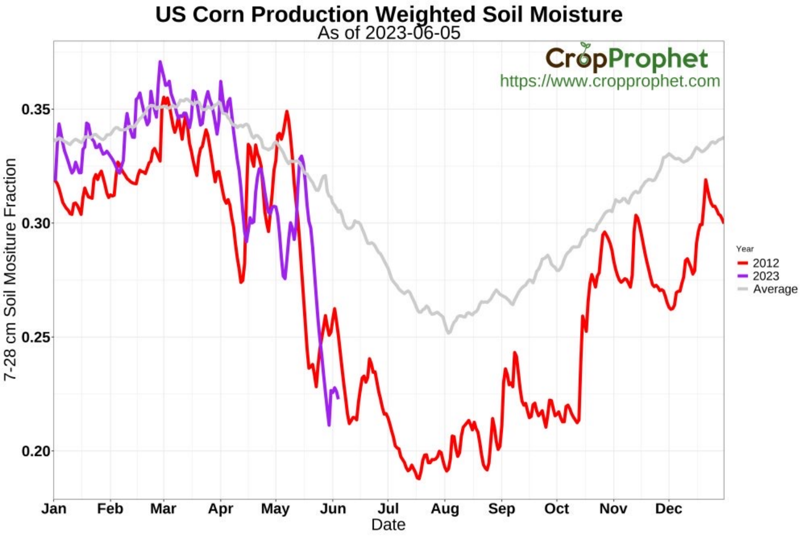
Sabo et al 2022 Environ. Res. Communications 4 045012

But the N surplus decline has slowed in recent years



- Increases in agricultural surplus in 2012 due to drought depressed crop yields 30 to 40% (Sabo et al., 2019, 2021)
- In general, yield increases have slowed while inputs have continued to increase

Yield is a tricky thing



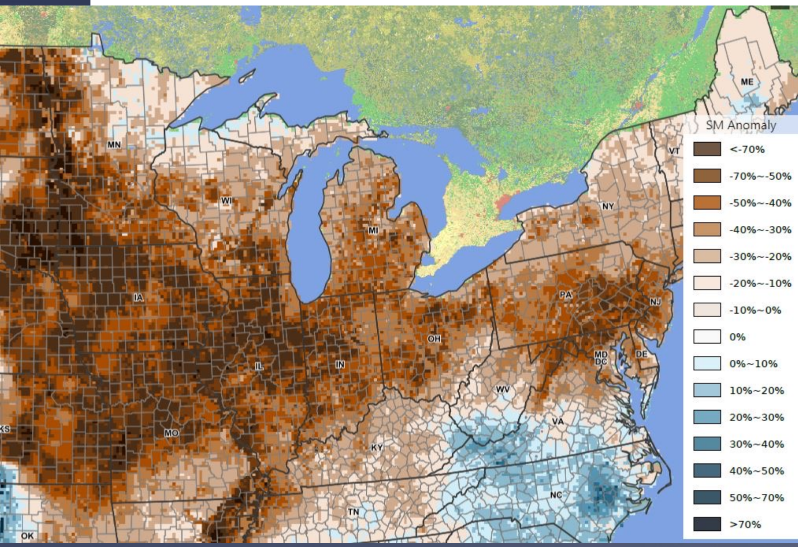
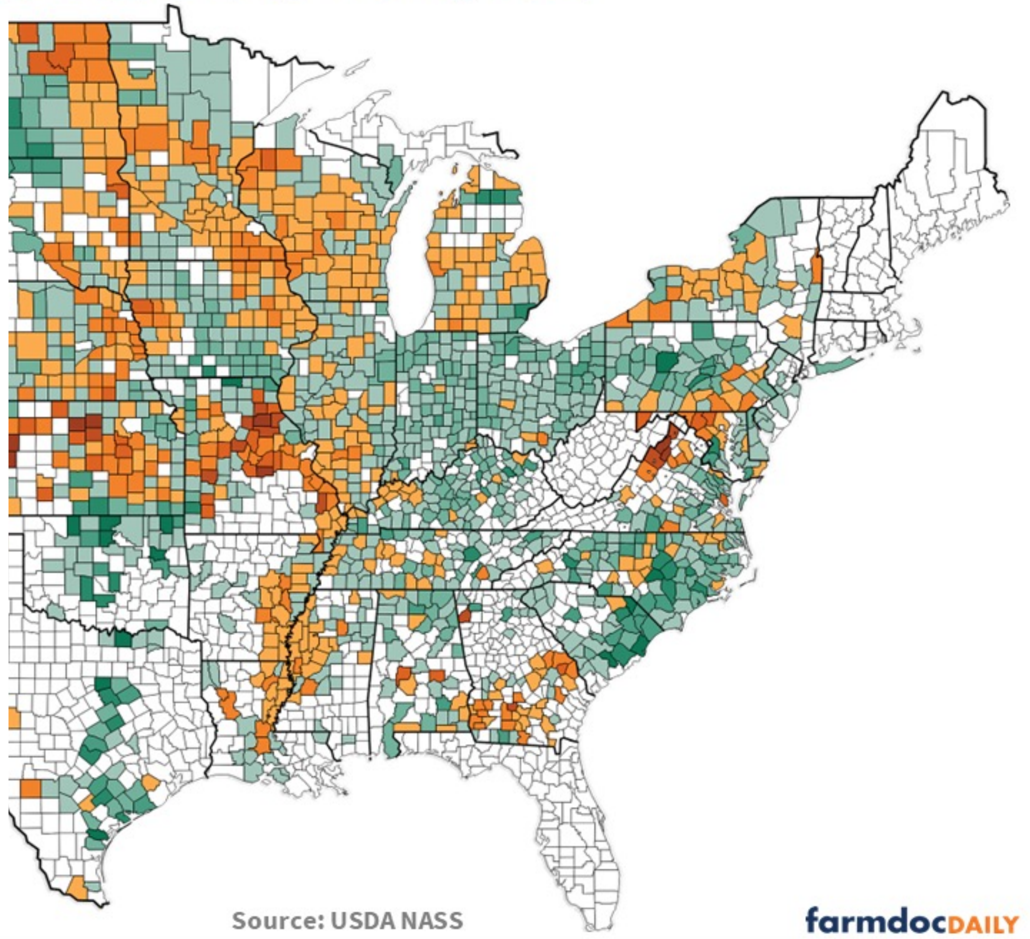
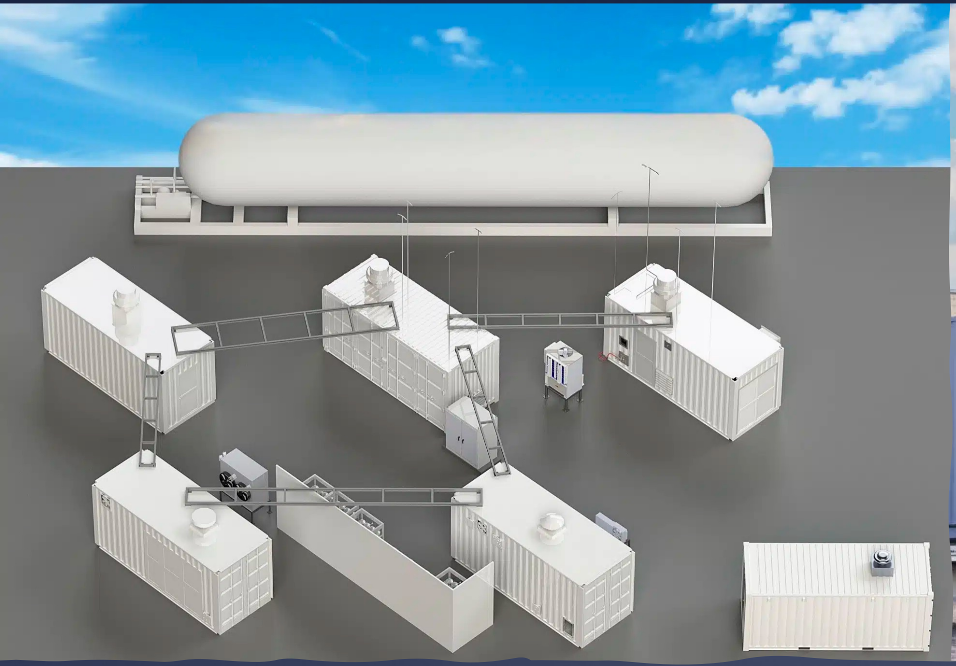


Figure 3. US County Corn Yields Relative to Trend, 2023



Wildcard: On-Farm Green Ammonia

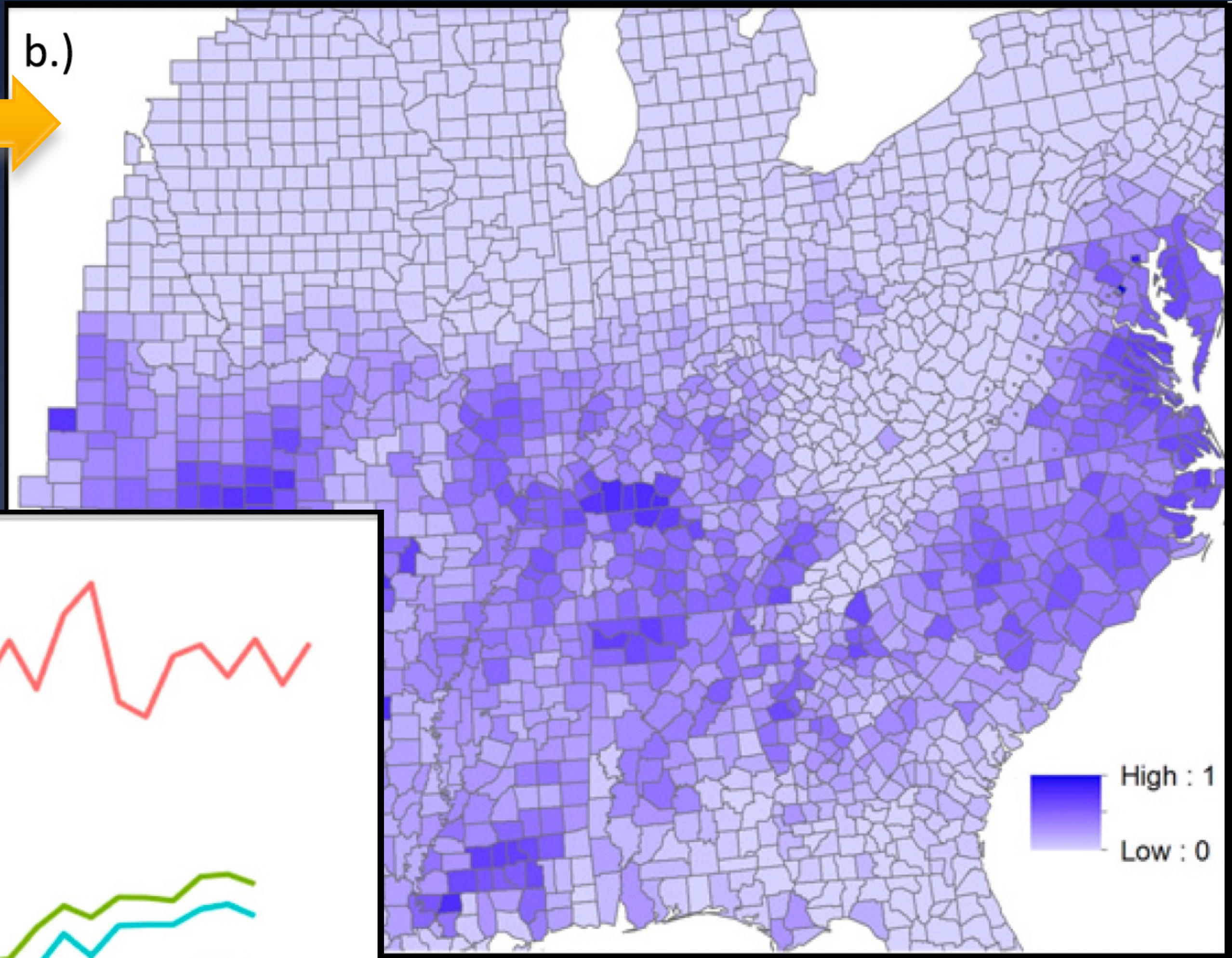


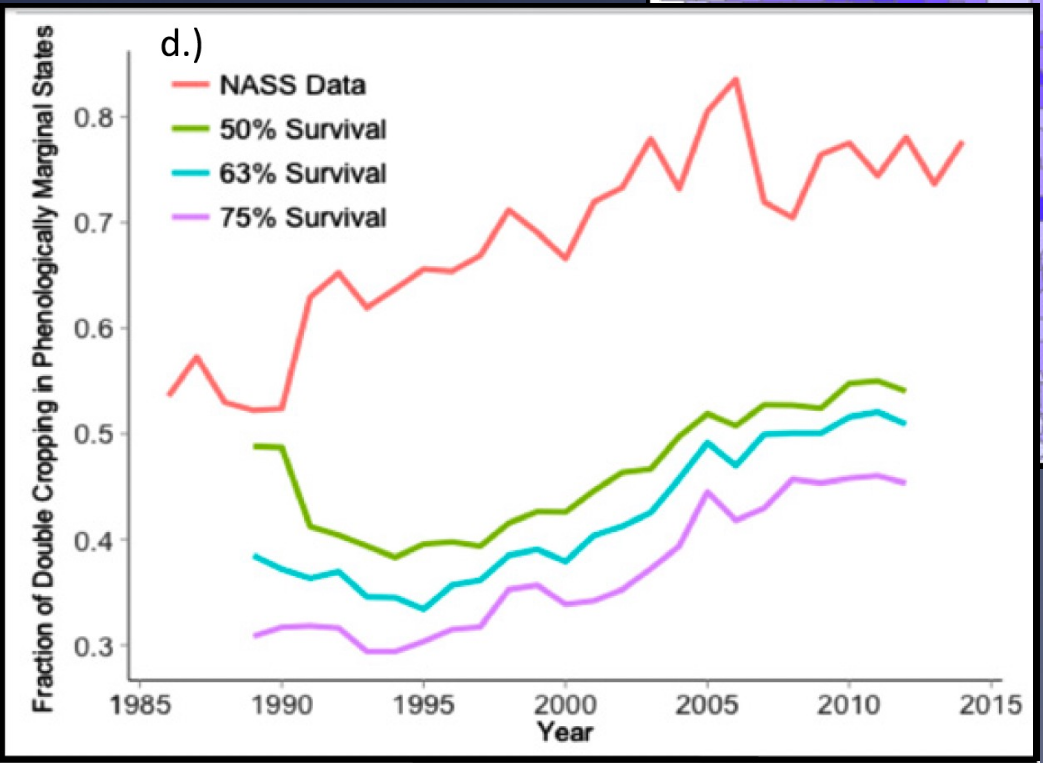
- System in which ammonia is made on-farm, ideally using renewable energy
- Can also be used as a fuel, particularly in the shipping industry
- How will fertilizer use change when farmers can make their own ammonia?

Xin Zhang at the Appalachian Lab directs an NSF-funded Center to investigate

Survival of double cropping systems

Fraction of Wheat-Soy double crop

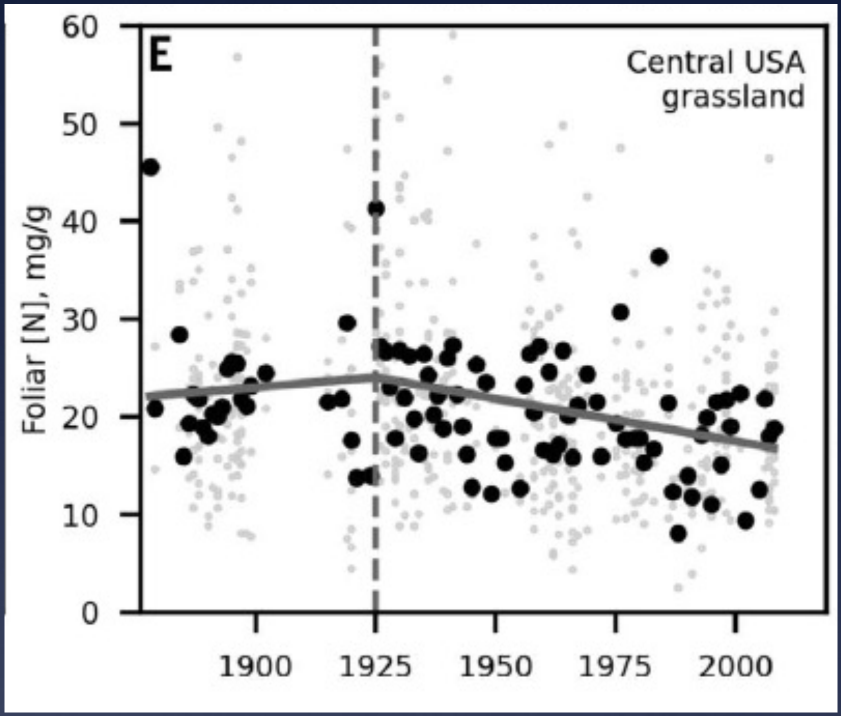




Seifert and Lobell (2015)
Environ. Res. Lett. 10 024002

2.4 million acres of pasture in the Bay watershed (~6%)

- Reductions in N availability due to rising CO_2 would be expected to reduce forage quality (e.g., elevate C:N ratios and reduce protein content)



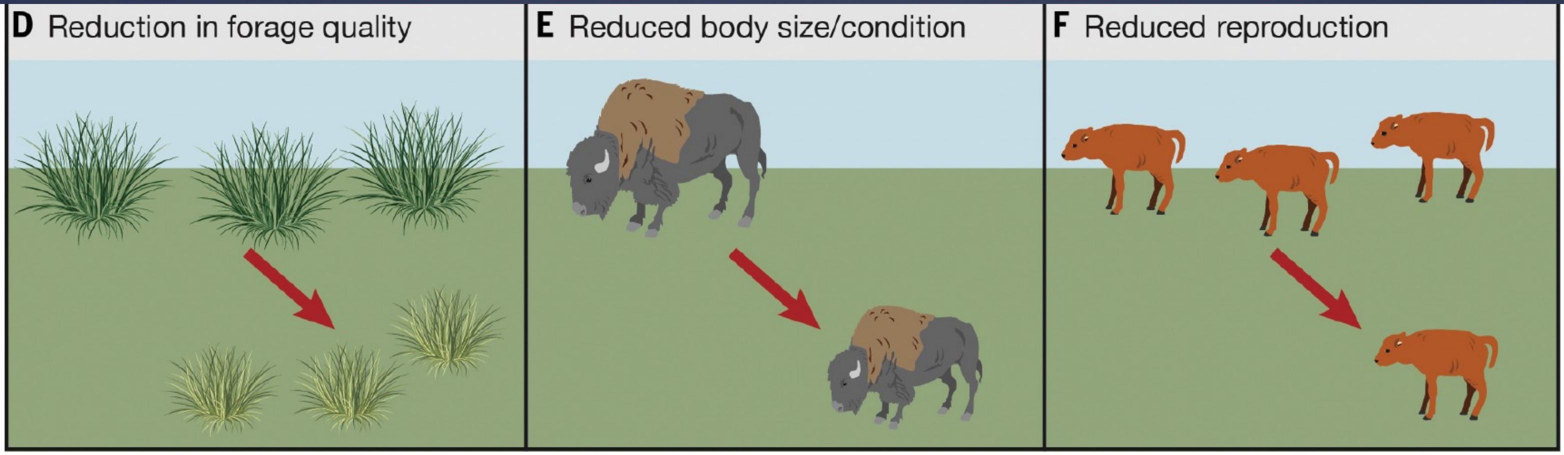
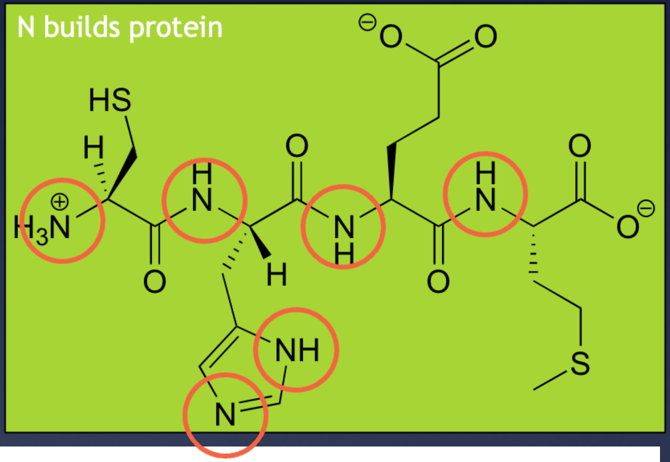
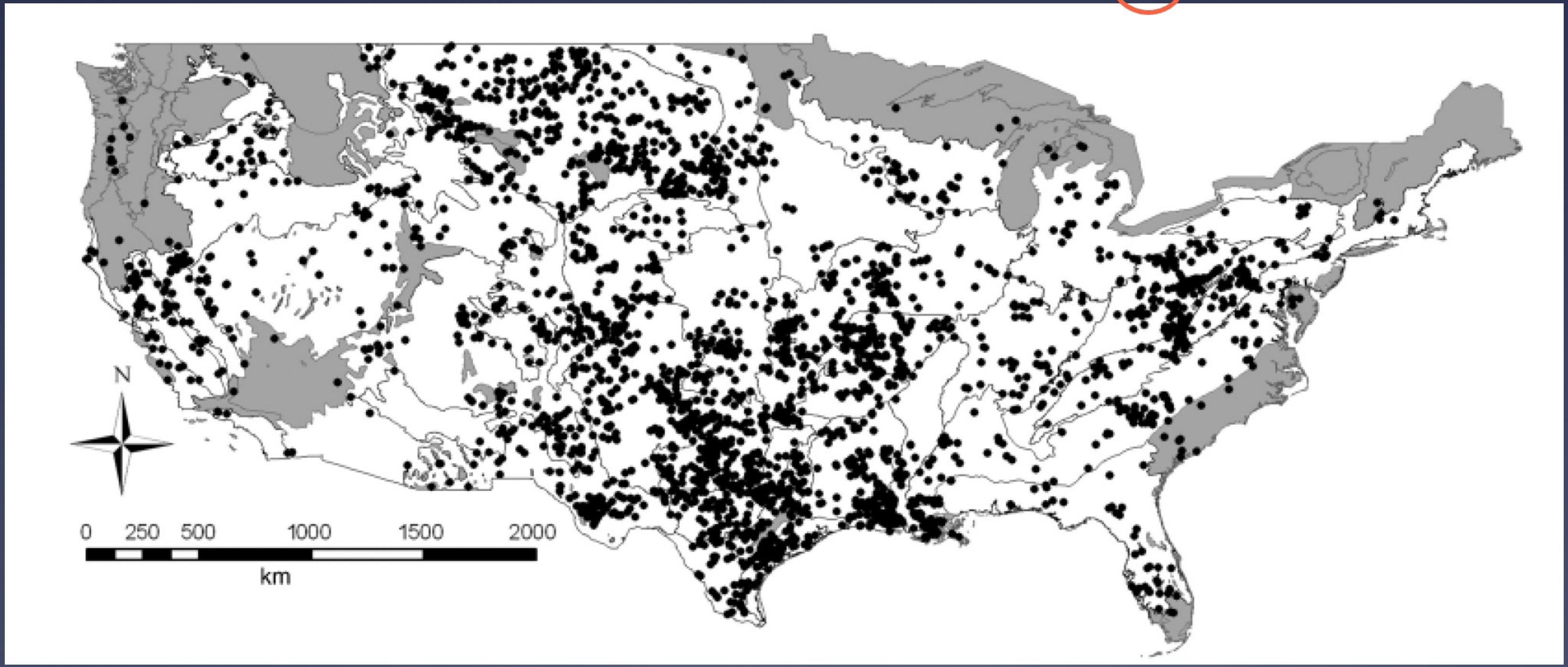


Fig. 4. Impacts of declines in foliar N concentrations on herbivore performance. Reduction in forage quality (**A** and **D**) may result in reduced herbivore body size and/or development rate (**B** and **E**) and reproduction (**C** and **F**) because herbivore growth rates and populations are often limited by protein availability.

Mason et al. (2022) Evidence, causes, and consequences of declining nitrogen availability in terrestrial ecosystems. *Science* Vol 376, Issue 6590

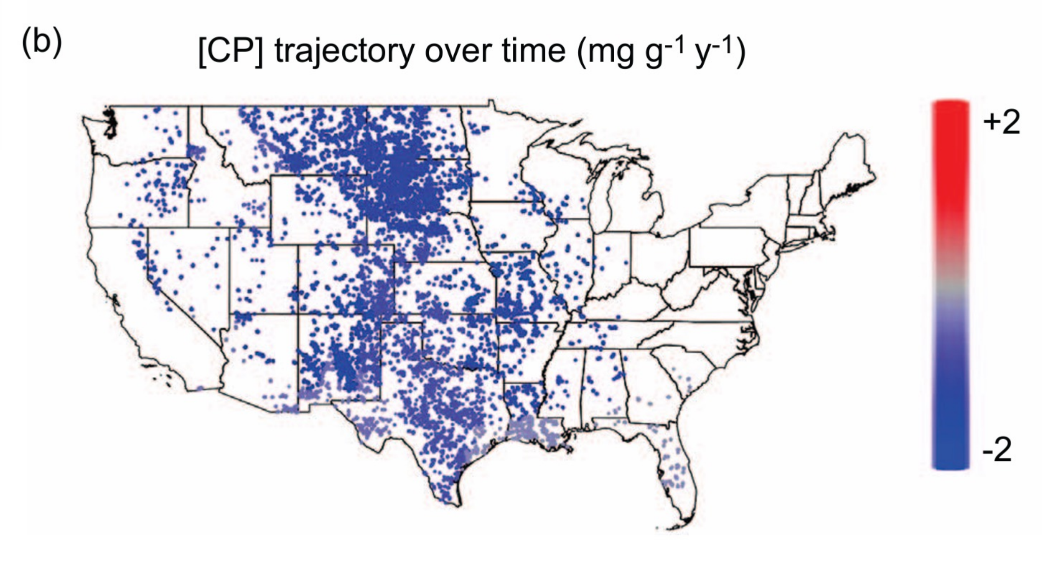
National network of samples

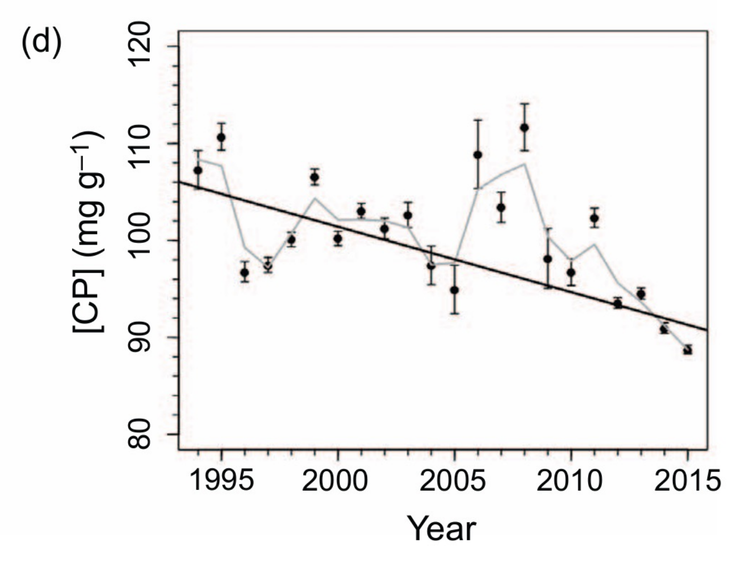


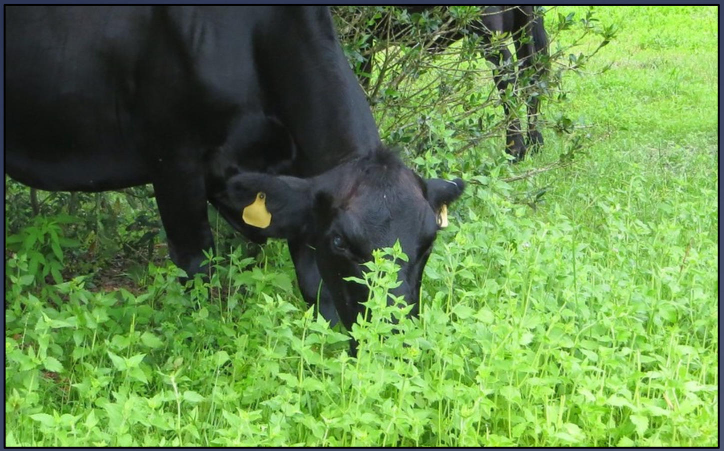


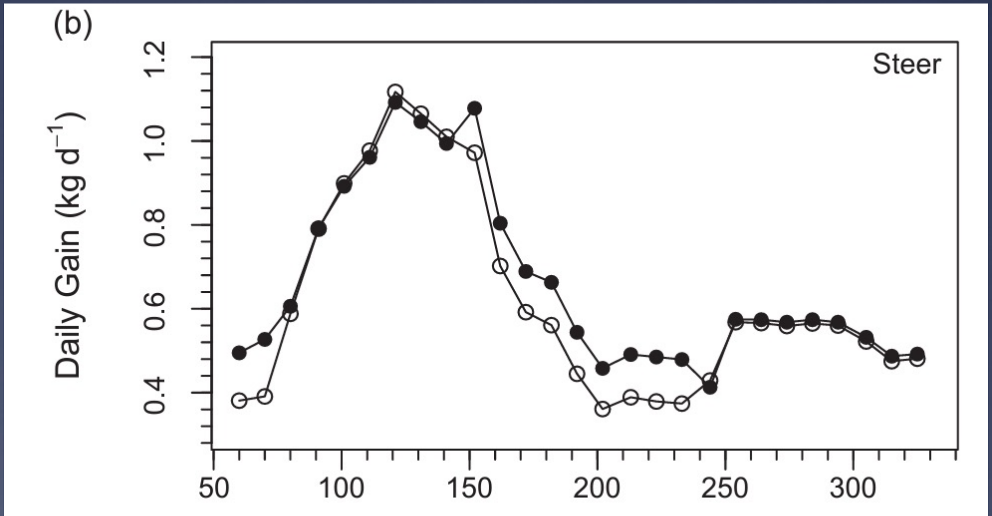
Craine, Elmore, and Angerer (2017) Environ. Res. Lett. 12 044019

Consequences of declining N





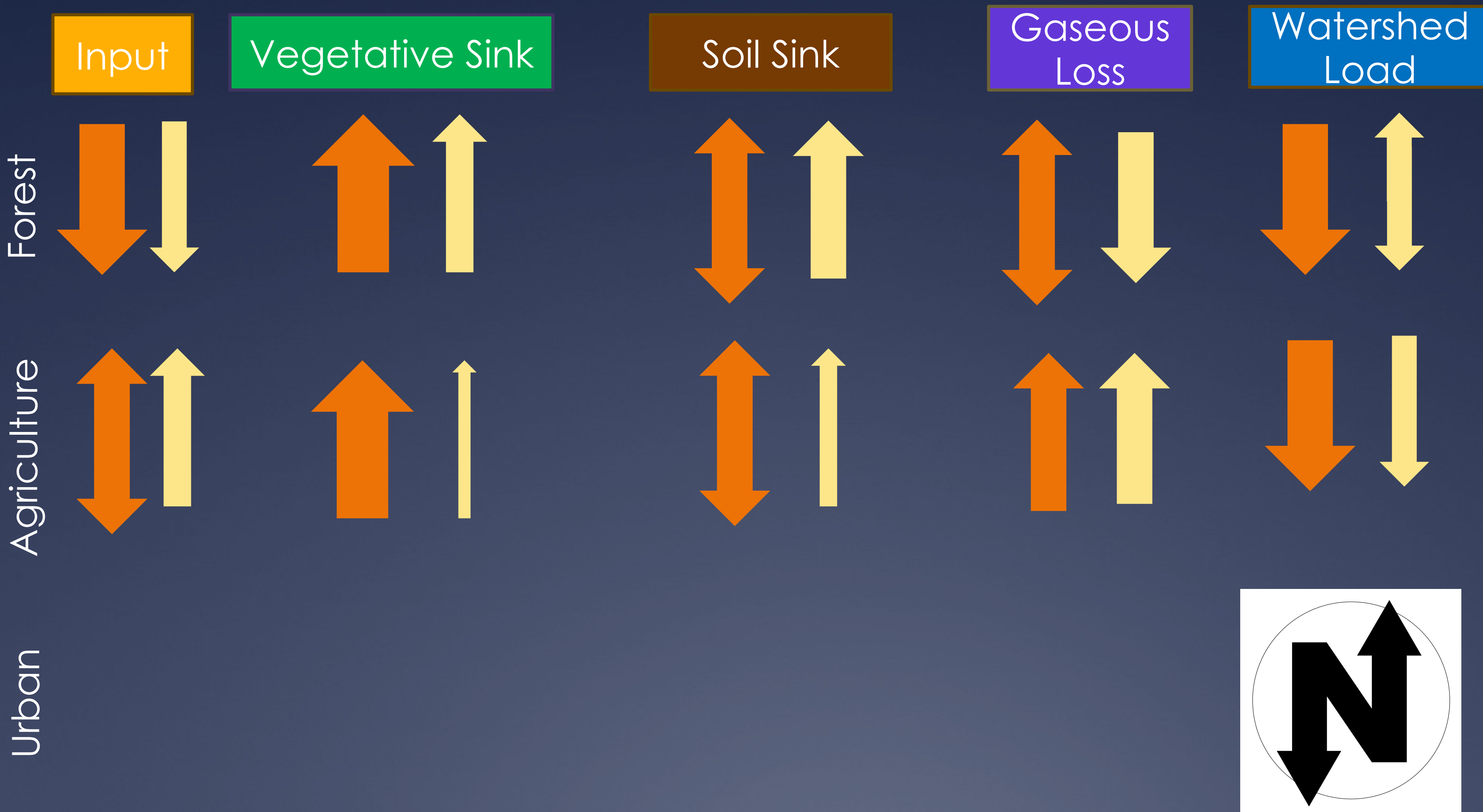




"At US$0.36/kg market price for soy meal, by 2015, the protein debt had increased to a US$1.9 billion annual reduction in protein provision."

Impact on watershed load

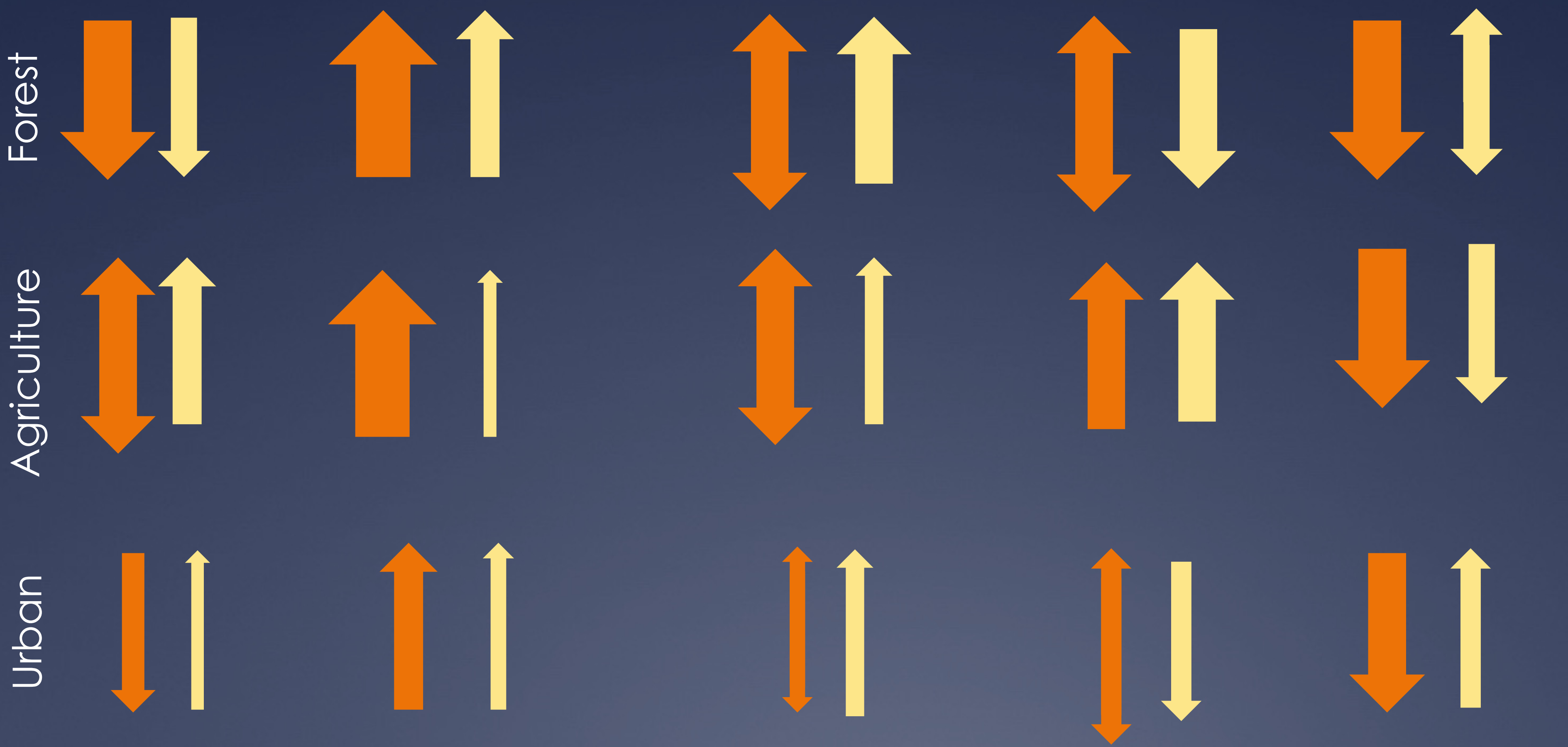
$$I - dN_v/dt - dN_s/dt - G = L$$



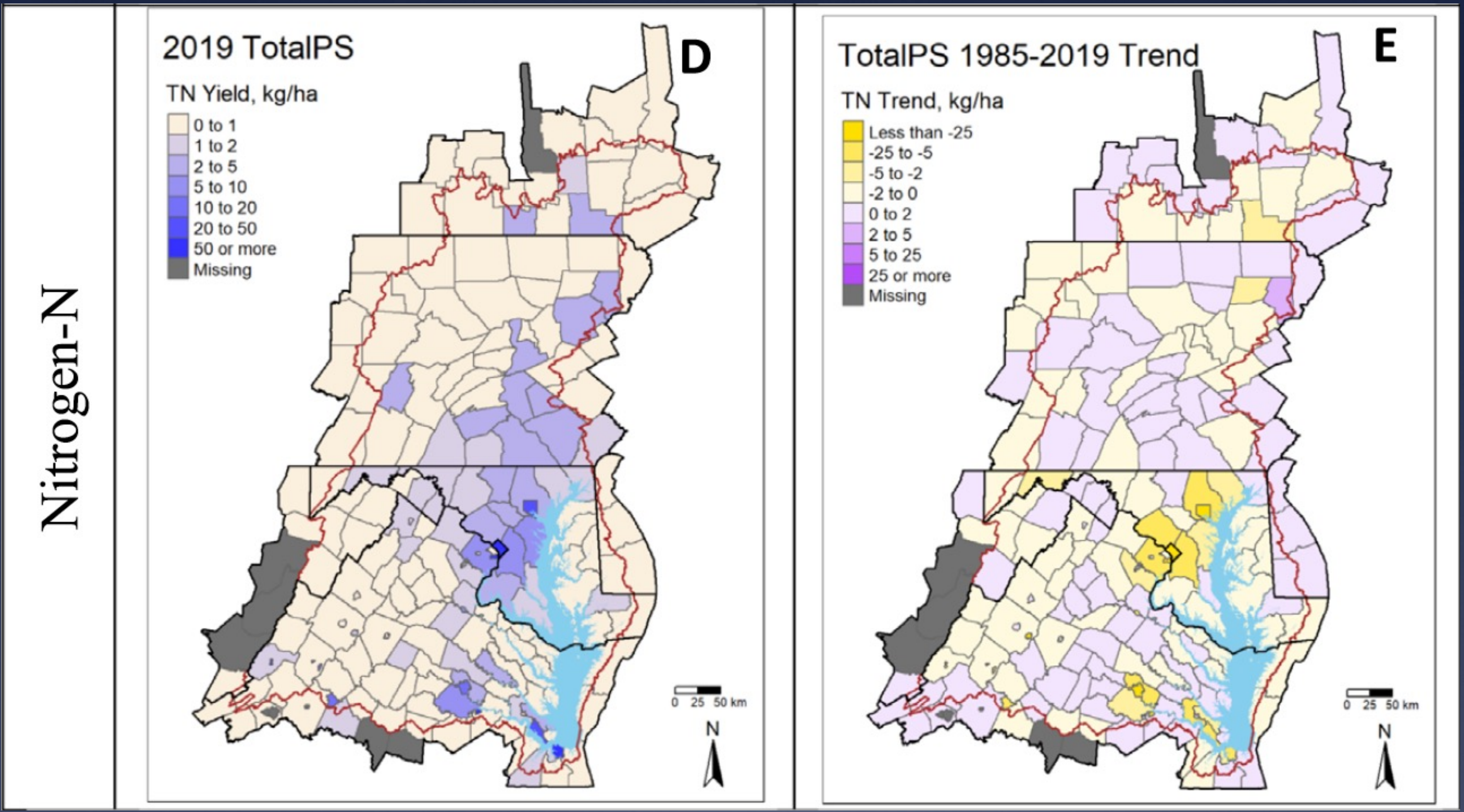
Impact on watershed load

$$I \;-\; dN_v/dt \;-\; dN_s/dt \;-\; G \;=\; L$$

Input | Vegetative Sink | Soil Sink | Gaseous Loss | Watershed Load



Urban loading: Point Source Trends



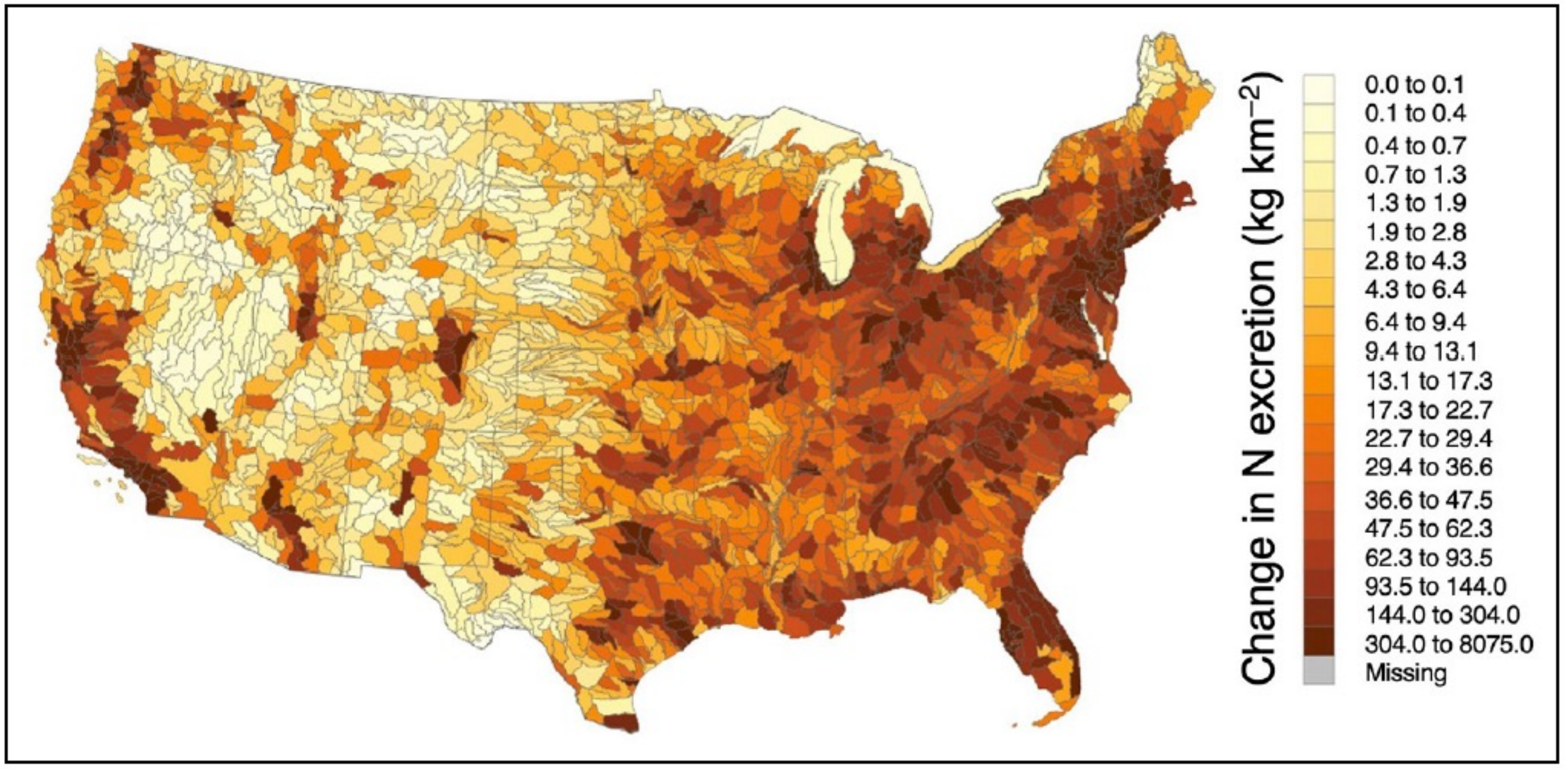
Sabo et al 2022 Environ. Res. Communications 4 045012

452 RESEARCH COMMUNICATIONS

The impact of excessive protein consumption on human wastewater nitrogen loading of US waters

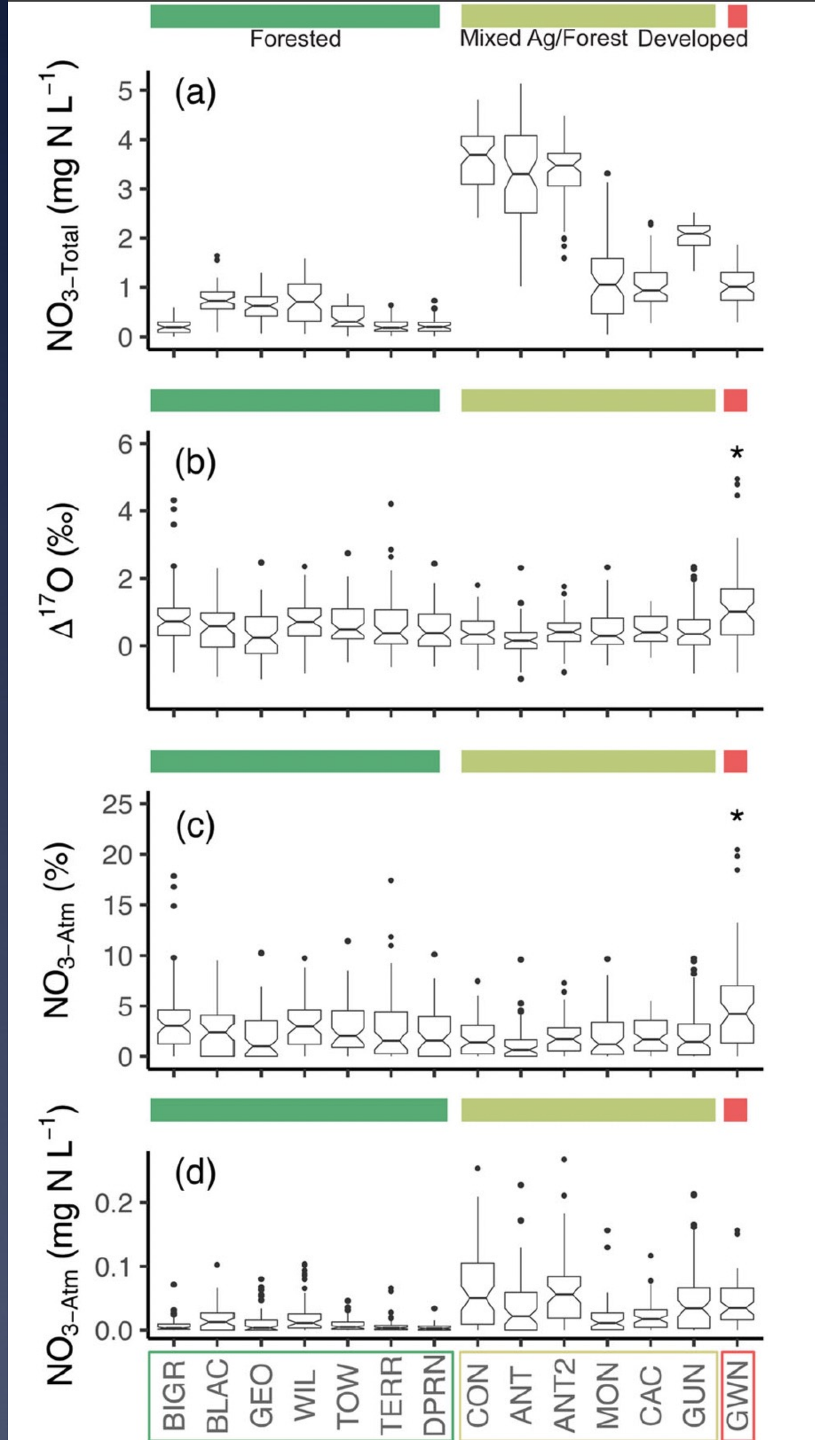
Maya Almaraz[1,2*], Caitlin D Kuempel[3], Andrew M Salter[4], and Benjamin S Halpern[2,5]

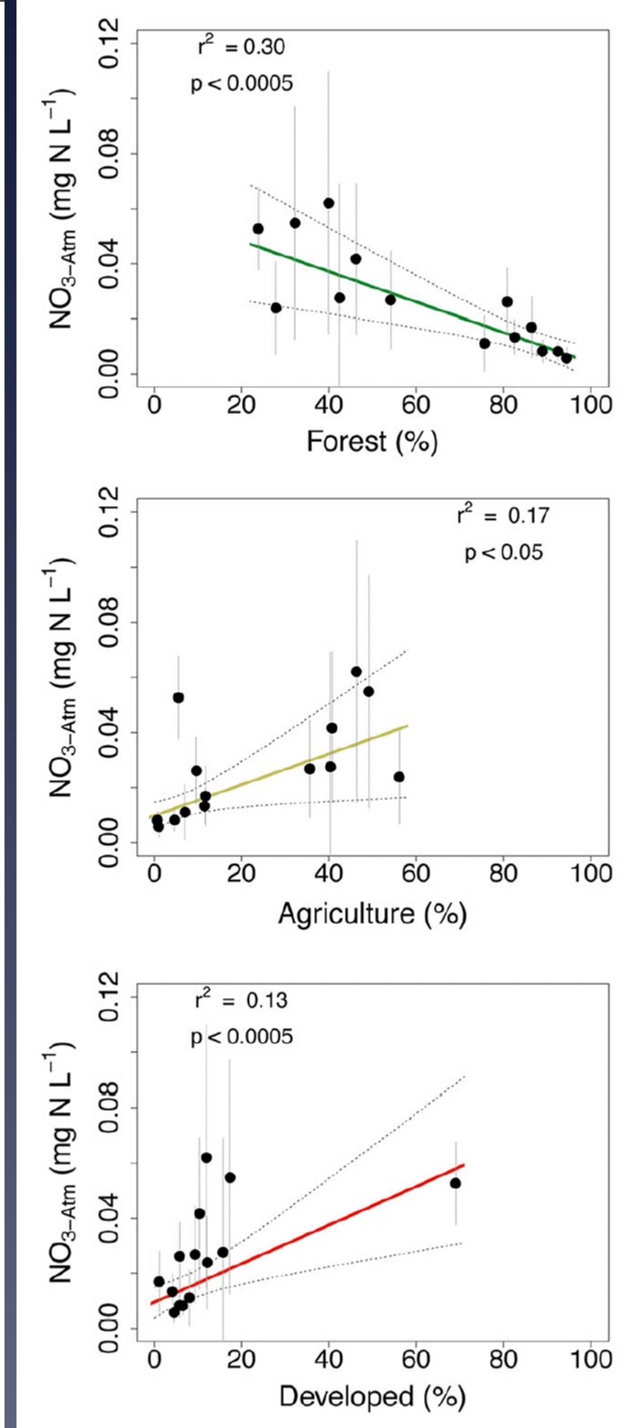
Front Ecol Environ 2022; 20(8): 452–458, doi:10.1002/fee.2531



Reduction in point source N if we ate the recommended diet

Atmospheric Nitrate increases in Urban landscapes

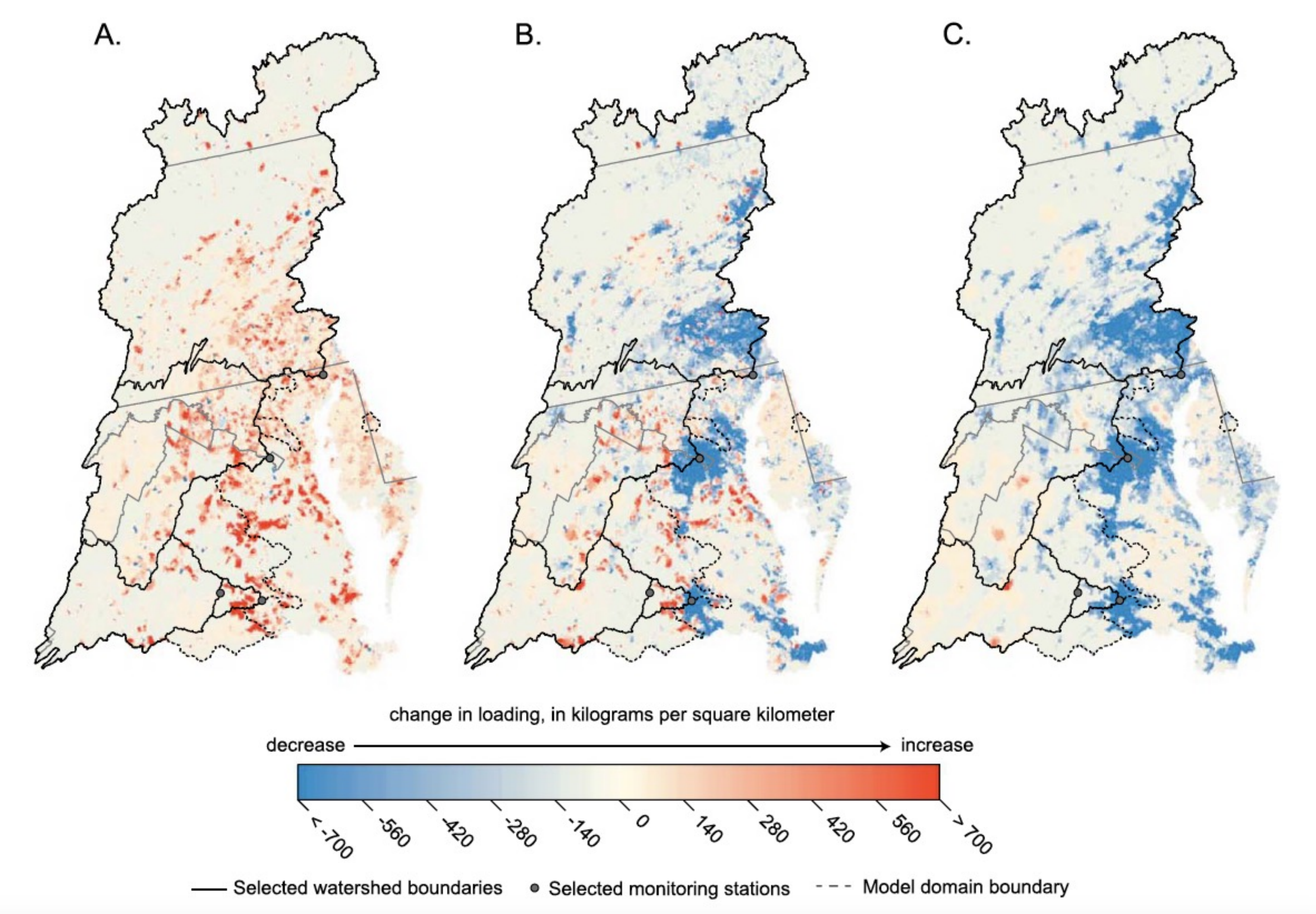




Bostic et al (2021) Ecosystems

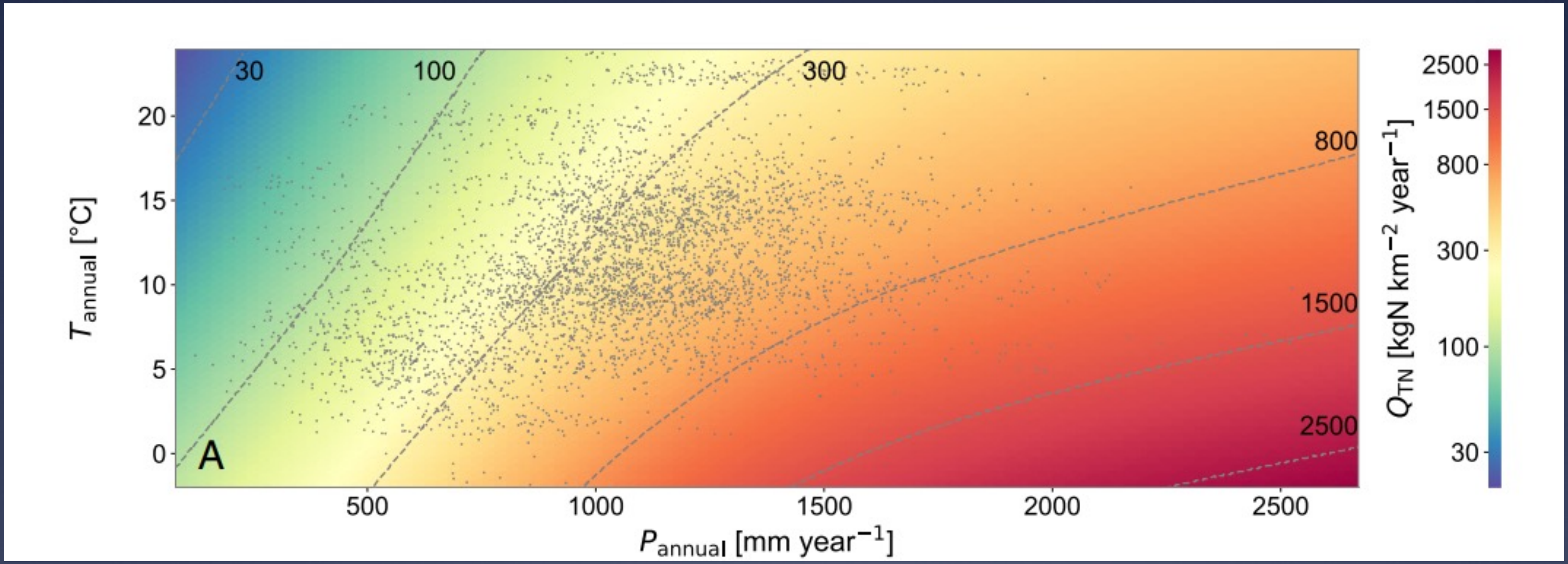
Evidence warming reduces loads

T & P Constant　　T & P Increasing　　Difference



Chanat & Yang (2018) Water Resources Research, 54, 8120–8145.

Warming may offset impact of precipitation changes on riverine nitrogen loading



Zhao, Merder, Ballard, and Michalak (2023) Warming may offset impact of precipitation changes on riverine nitrogen loading. *PNAS* 120:33, e2220616120