Chesapeake Hypoxia Analysis and Modeling Program

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Long-term C and N biogeochemistry in the Chesapeake Bay watershed: Using the past to inform the future

Hanqin Tian, Yuanzhi Yao, Zihao Bian, Shufen Pan

(Auburn University)

Marjy Friedrichs (Virginia Institute of Marine Science)

Ray Najjar (Pennsylvania State University)

Eileen E. Hofmann (Old Dominion University)

Two recent papers published in April, 2021

JGR Biogeosciences

Research Article | Full Access

Impacts of Multiple Environmental Changes on Long-term Nitrogen Loading from the Chesapeake Bay Watershed

Shufen Pan, Zihao Bian, Hanqin Tian, Yuanzhi Yao, Raymond G. Najjar, Marjorie A. M. Friedrichs, Eileen E. Hofmann, Rongting Xu, Bowen Zhang

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Riverine carbon cycling over the past century in the Mid-Atlantic region of the United States

Yuanzi Yao, Hanqin Tian, Shufen Pan, Raymond G. Najjar, Marjorie A. M. Friedrichs, Zihao Bian, Hong-Yi Li, Eileen E. Hofmann

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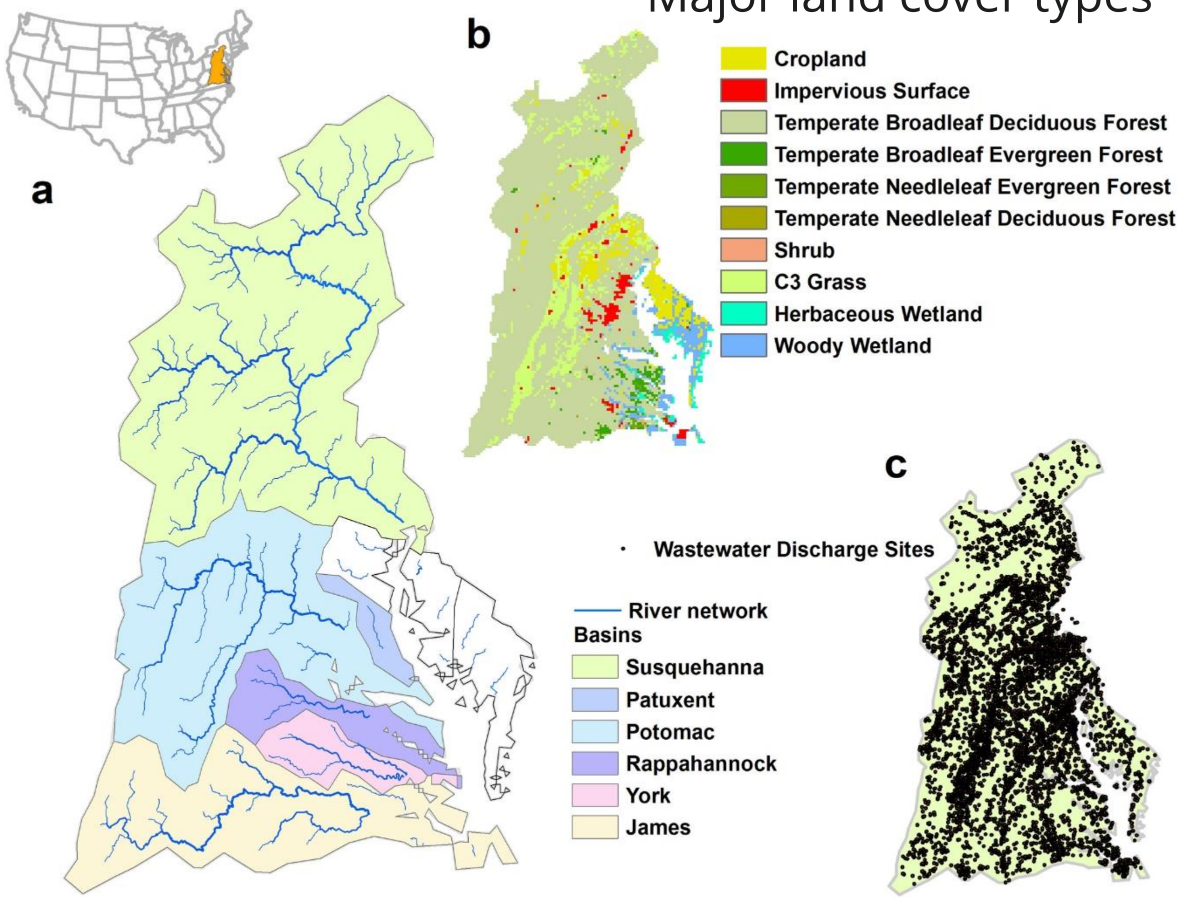
The Chesapeake Bay watershed

Major land cover types

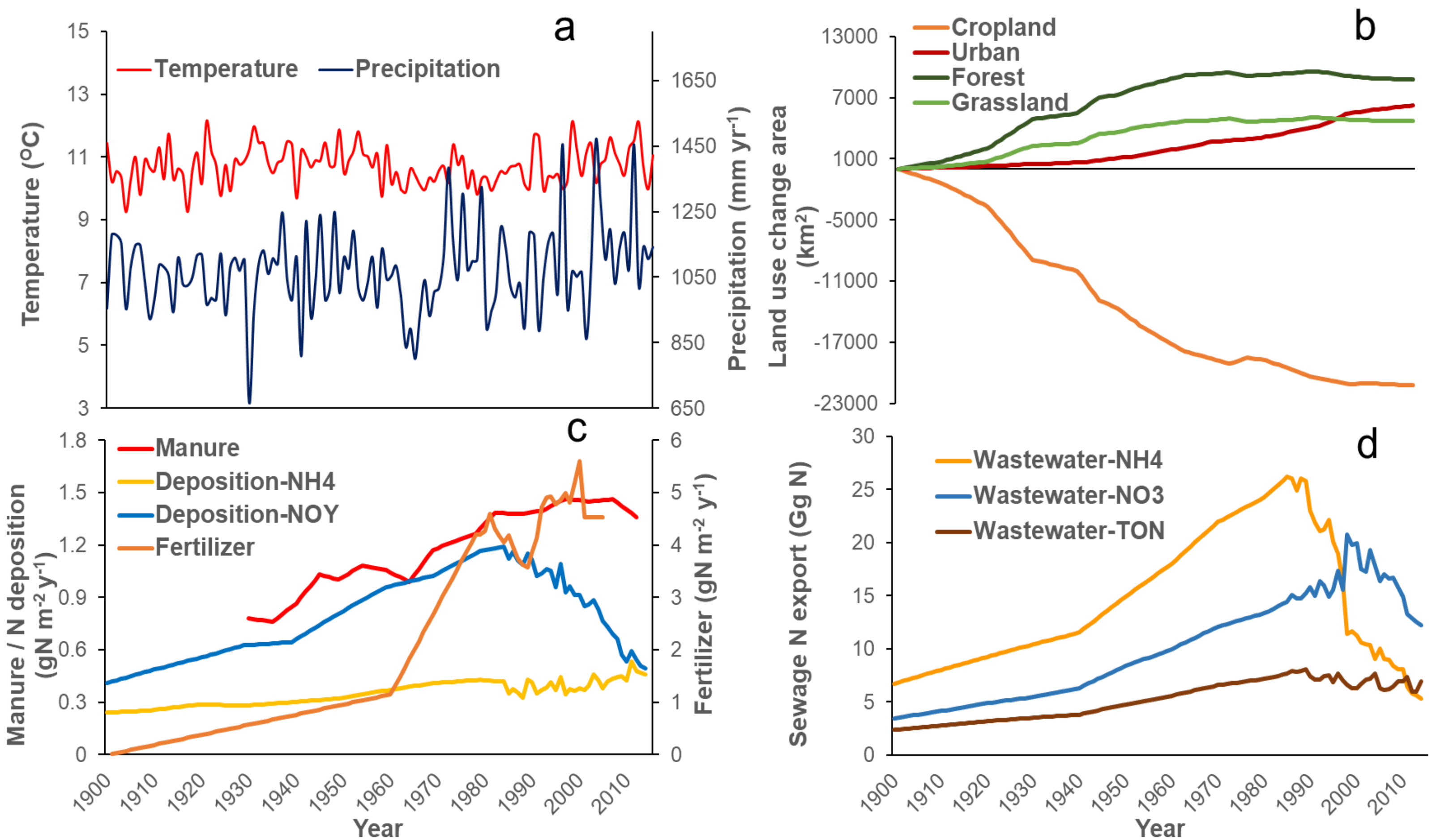


Sub-basins

Wastewater discharge sites

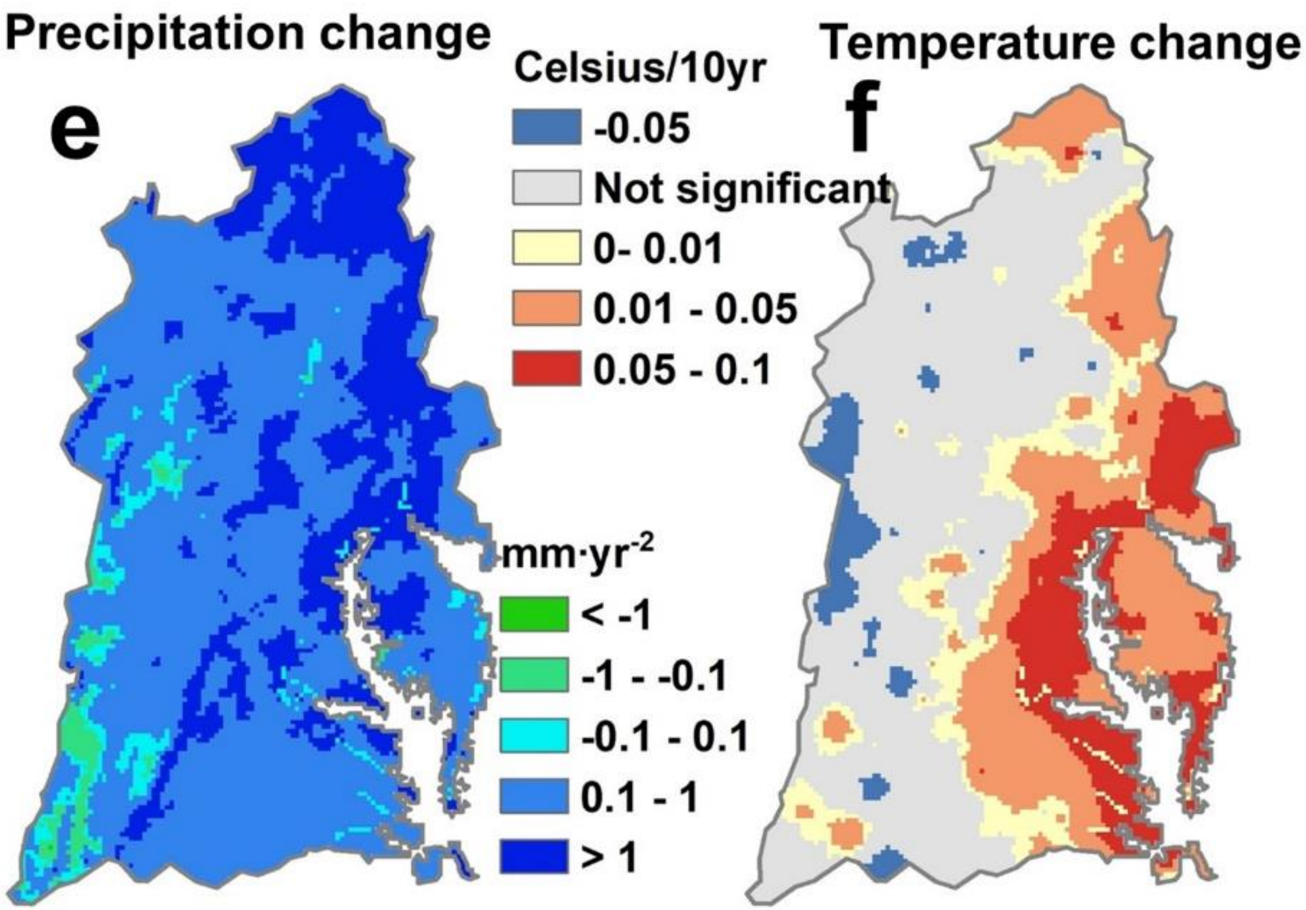
(from Pan et al. 2021. JGR)

Multiple Changes in climate, land use and nitrogen input in the Chesapeake Bay watershed during 1900-2015



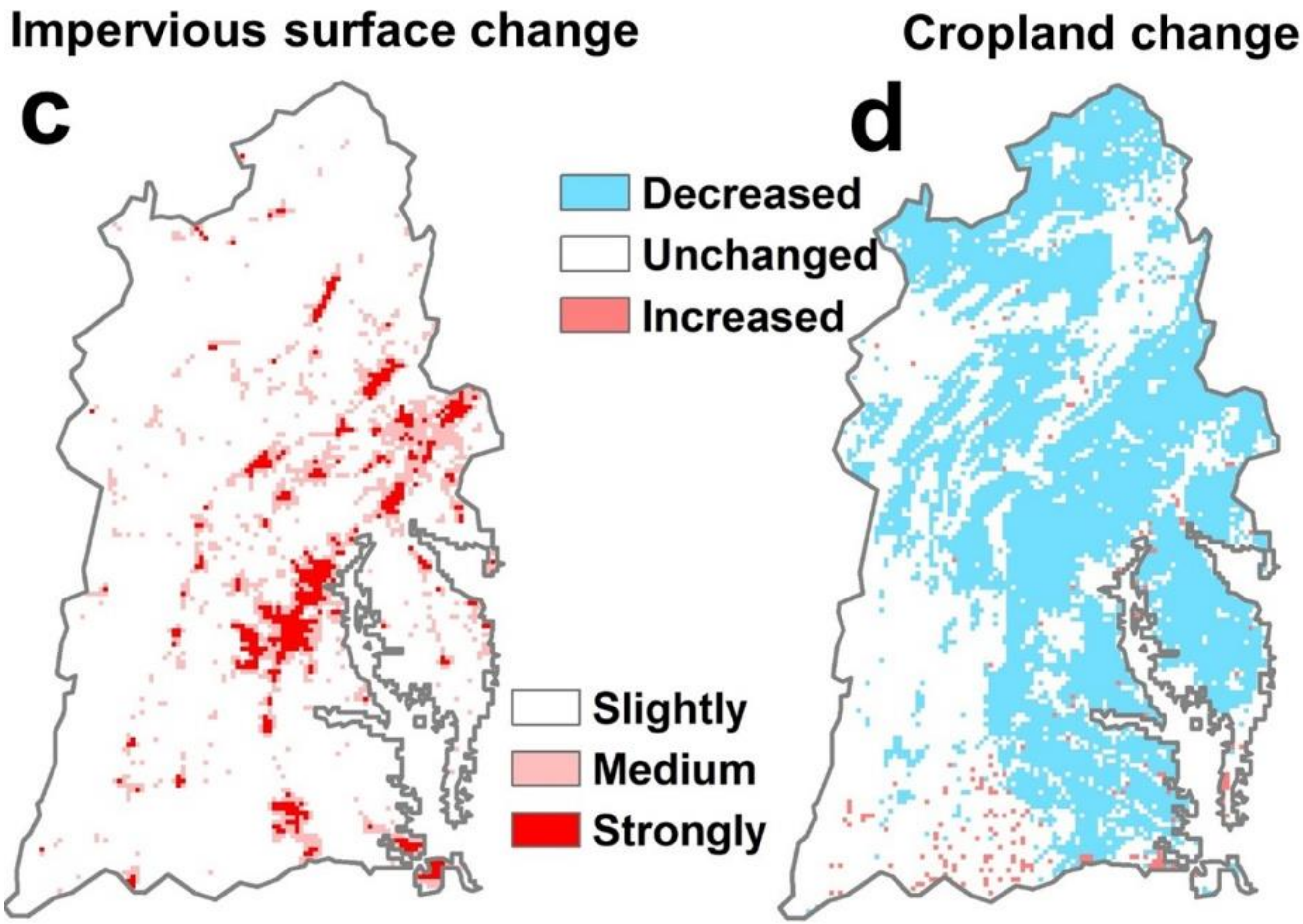
(from Pan et al. 2021. JGR)

A wetter and warmer climate, but varied spatially



(from Yao et al. 2021, JGR)

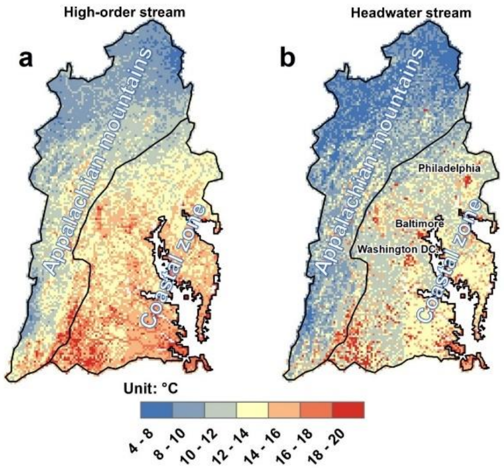
Widespread urbanization and cropland abandonment



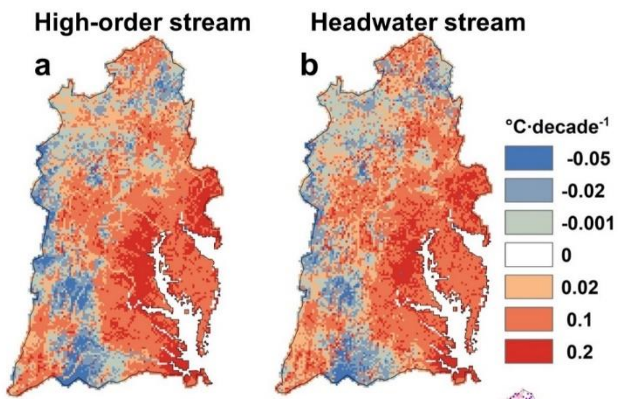
(from Yao et al. 2021, JGR)

Increased stream water temperature

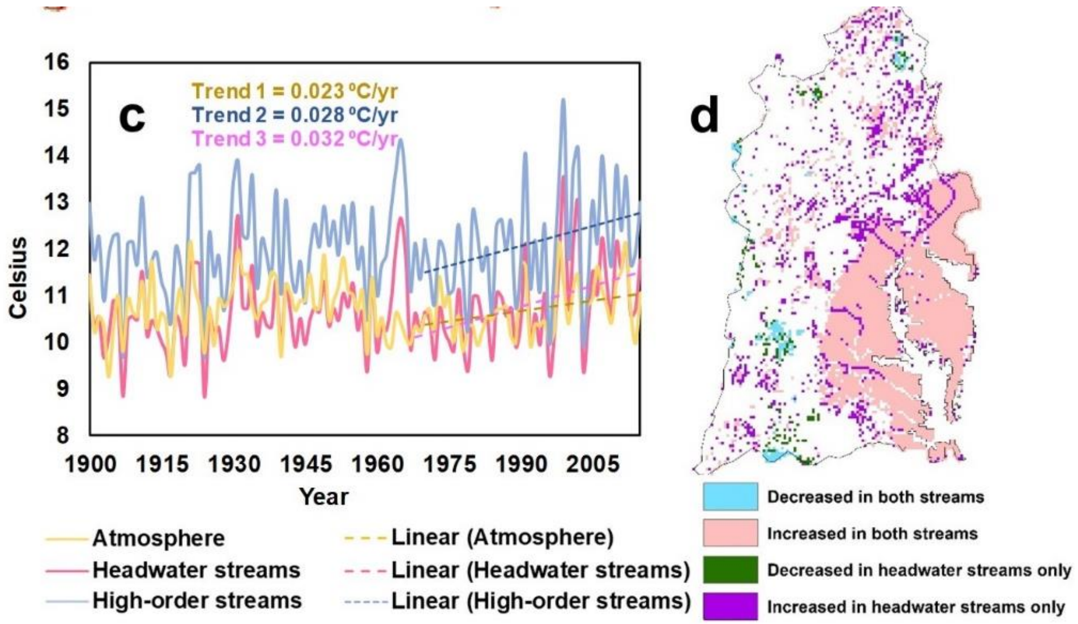
Water temperature



Changes in water temperature



Headwater stream temperature shows a higher increasing rate than that of high-order stream

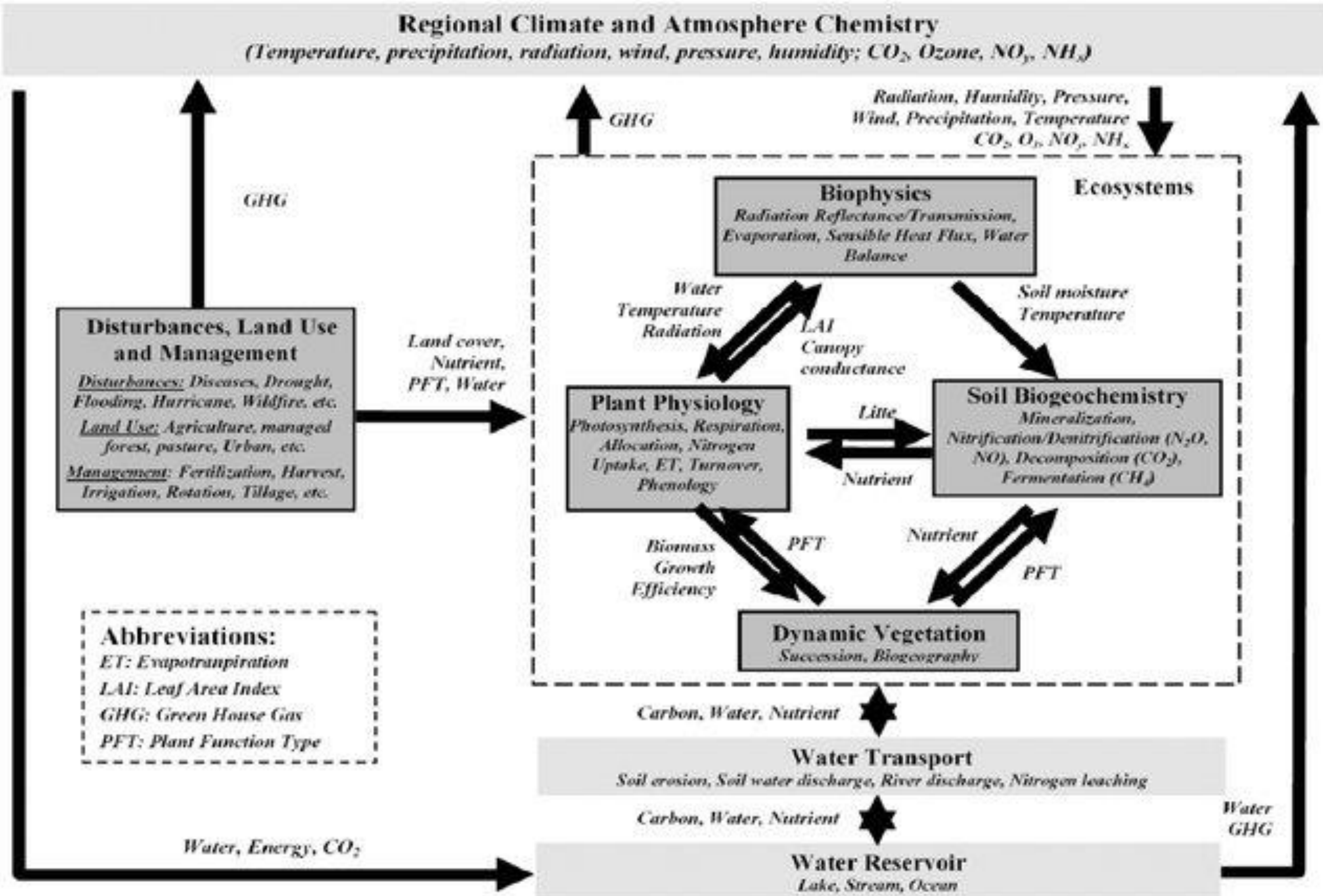


Yao et al. submitted

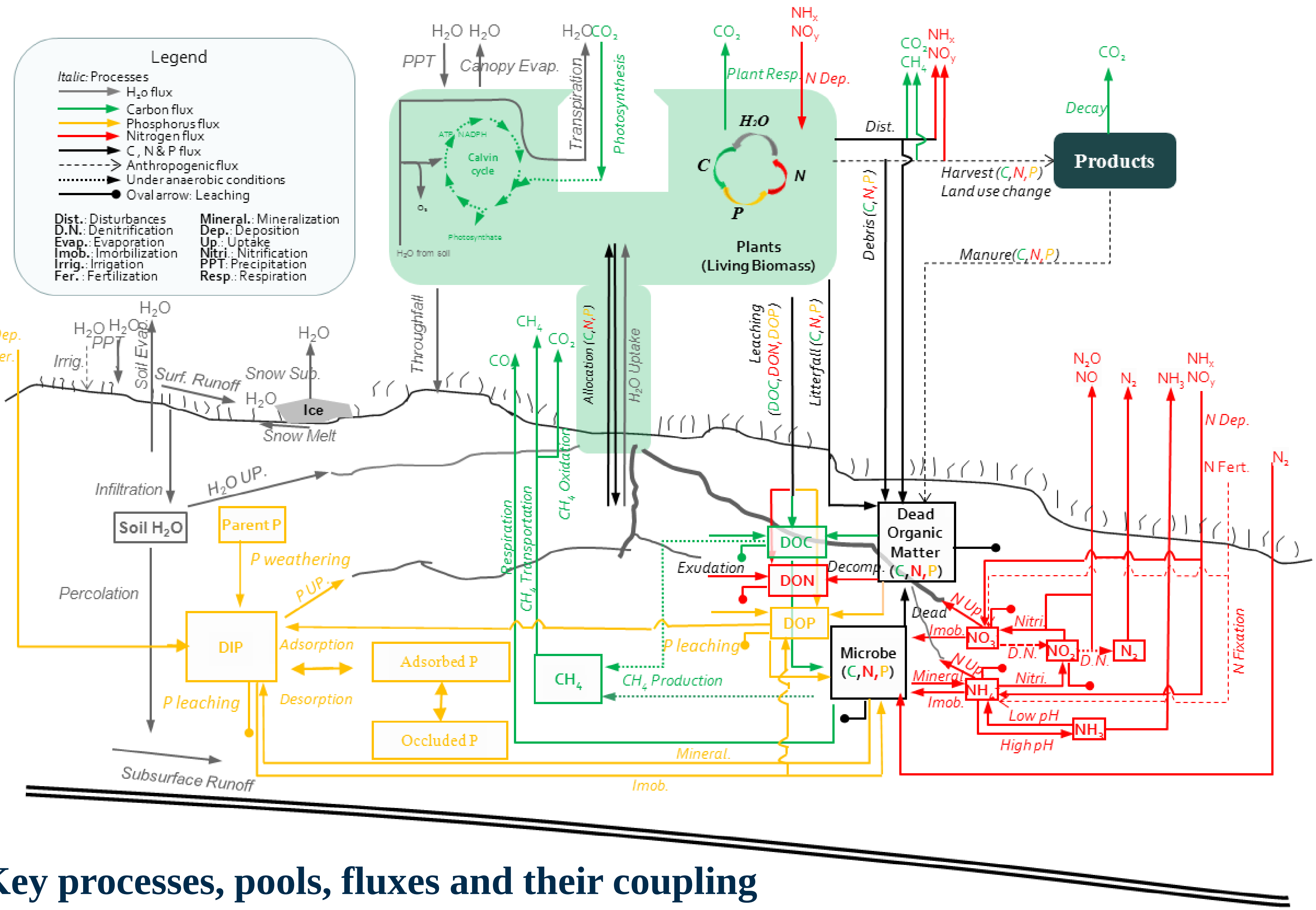
The question needs to be answered

How have multi-factor stresses in climate, atmospheric chemistry, land use and land management affected carbon and nitrogen cycling in the Chesapeake Bay watershed?

DLEM - The process-based modeling approach

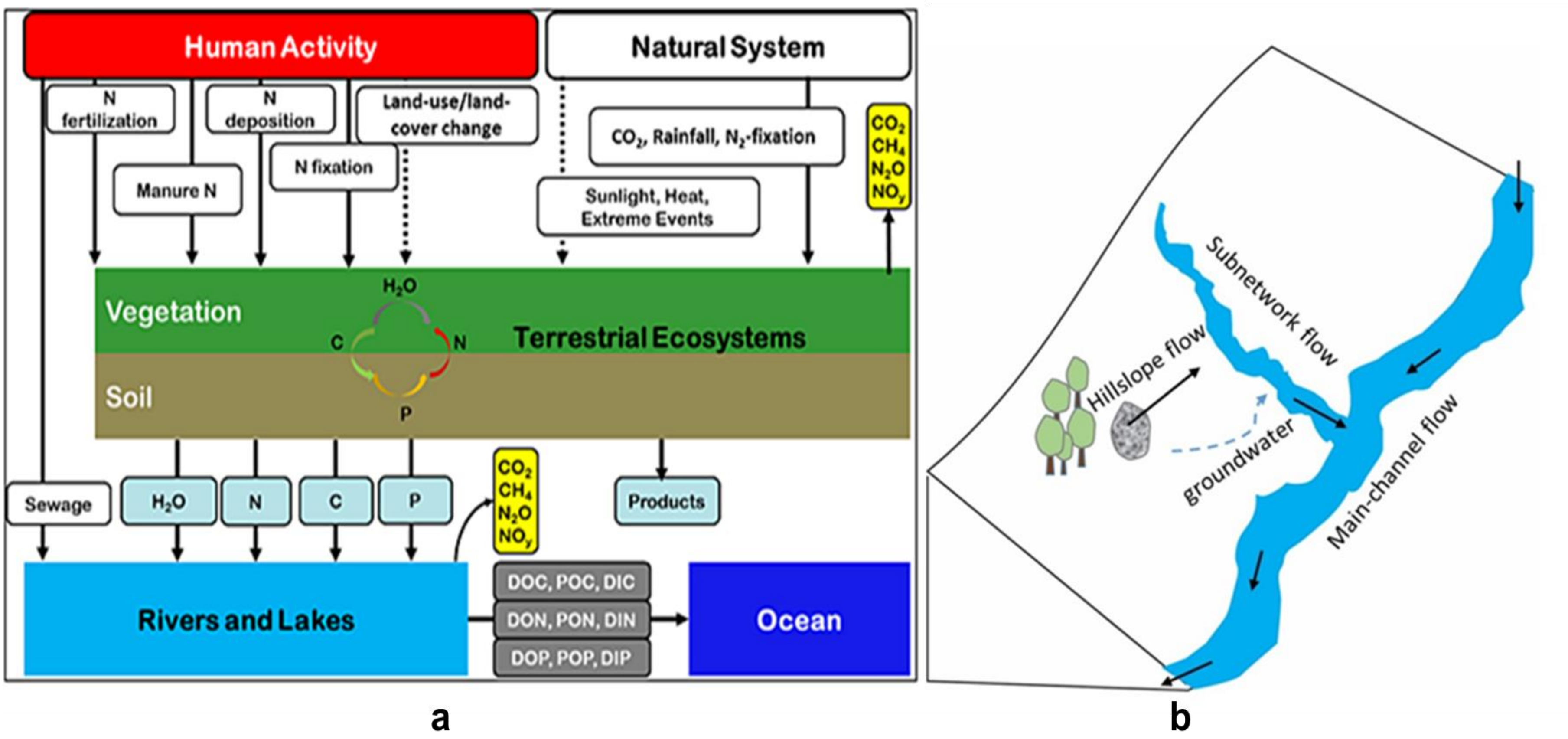


DLEM - A coupled biogeochemical/hydrological model



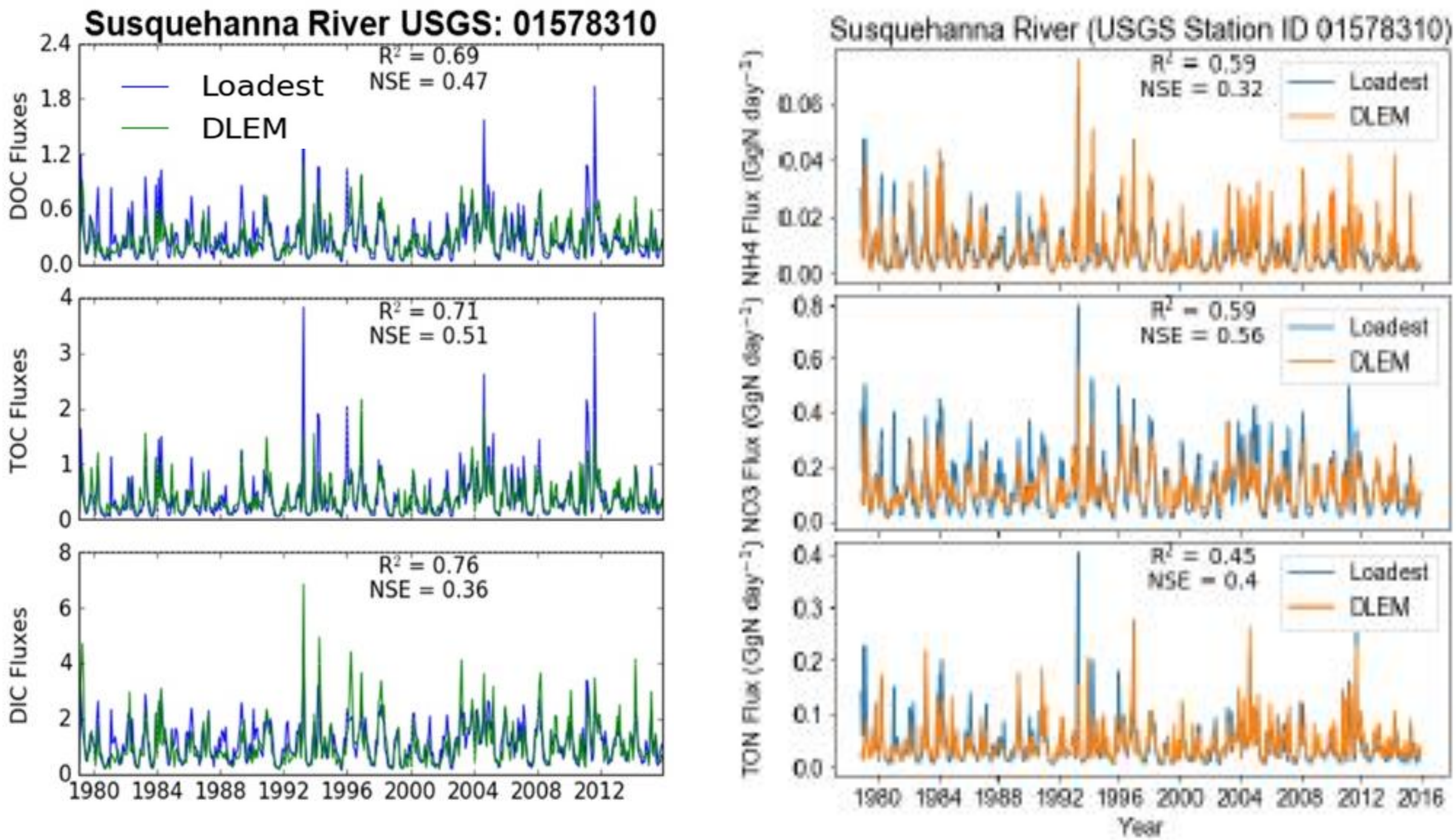
Key processes, pools, fluxes and their coupling

Framework of the terrestrial–aquatic interface (TAI) in the DLEM

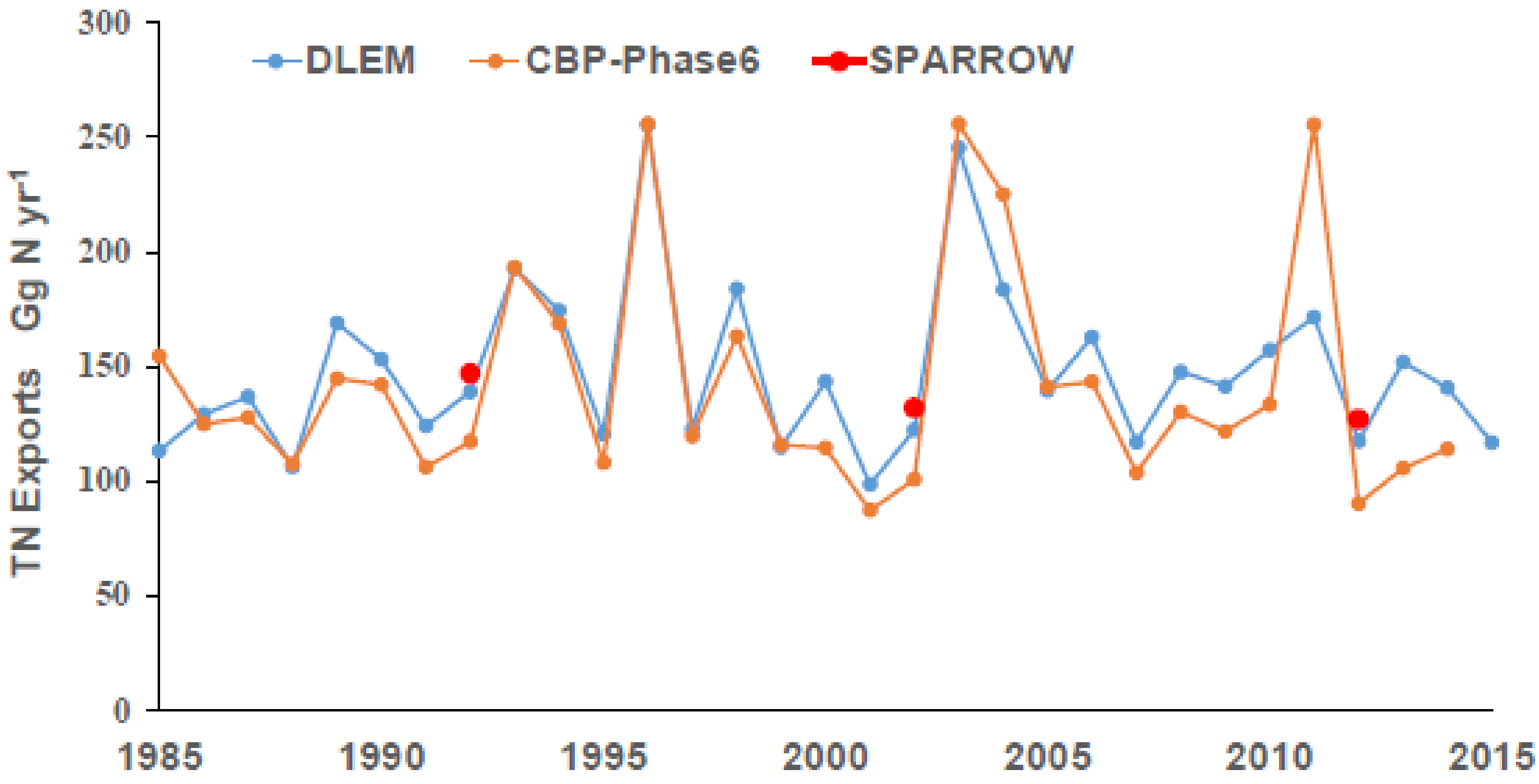


Tian et al. 2015, 2020; Yao et al. 2020, 2021, Pan et al. 2021

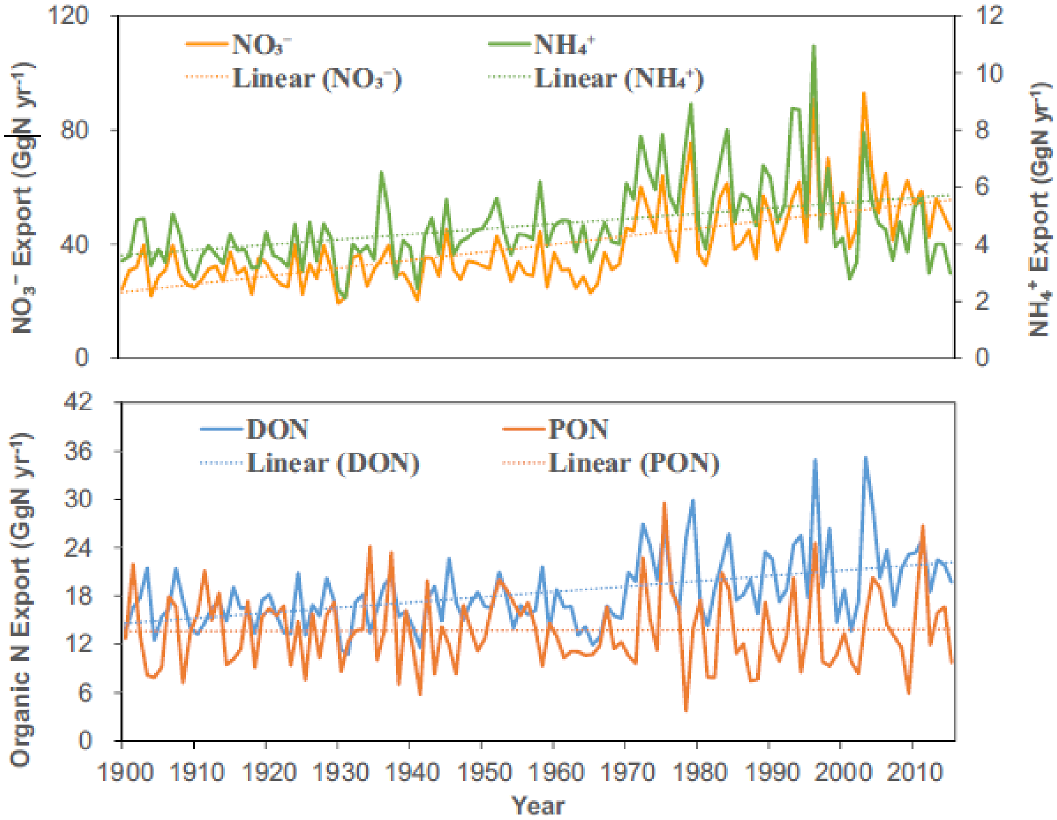
Comparison of DLEM simulated riverine N fluxes with the observations from USGS in six major rivers (e.g. Susquehanna River as an example)



Comparison of DLEM—simulated TN with CBP-Phase6 and SPARROW



Long-term change in N loading (1900-2015)



NH_4^+ 5.18±1.67 Gg yr^{-1}

NO_3^- 79.78±29.55 Gg yr^{-1}

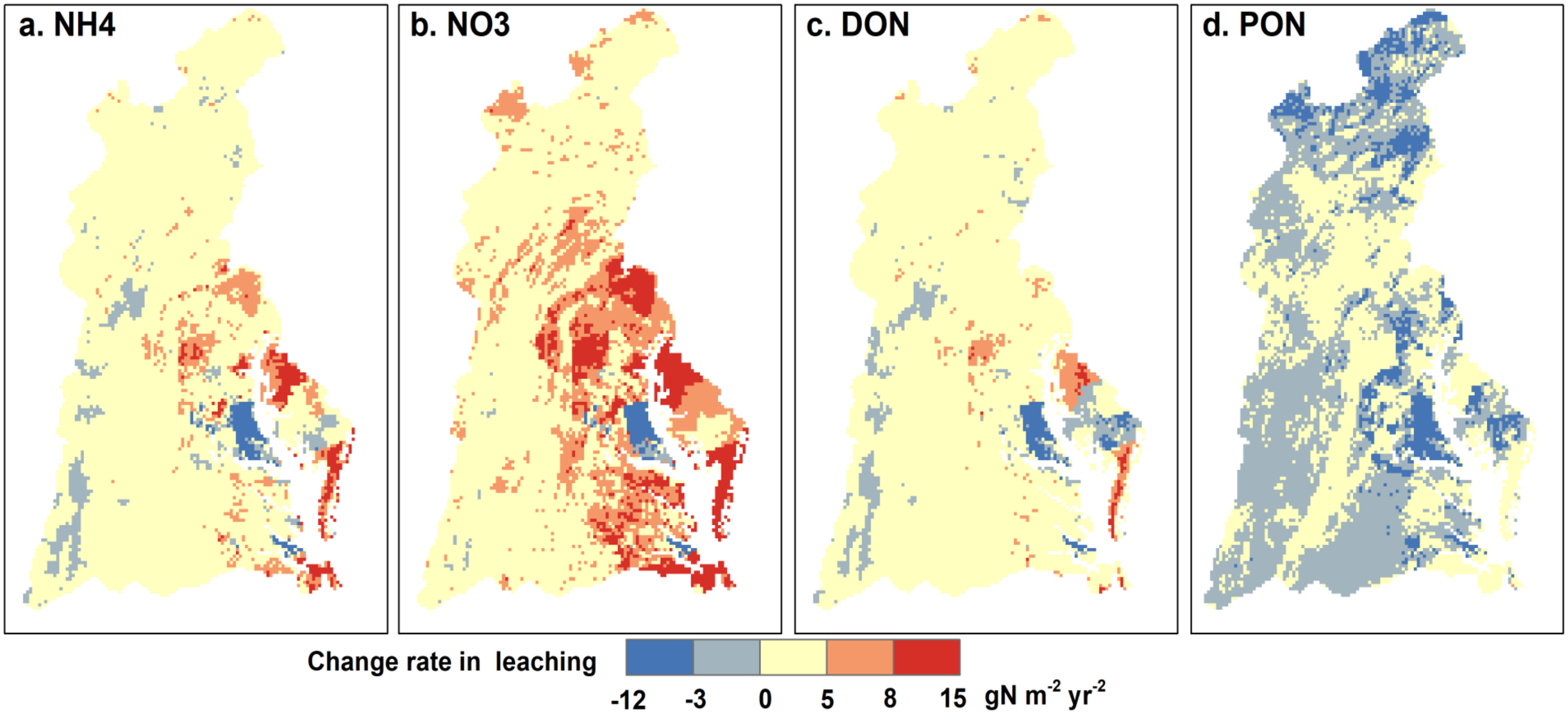
DON 19.11±4.82 Gg yr^{-1}

PON 14.22±4.85 Gg yr^{-1}

- NH_4^+, NO_3^- and DON export increased obviously (65.0% for NH4, 106.8% for NO3 and 40% for DON) from the 1900s to 1990s, and then declined due to pollution treatment in recent decades.
- PON exports kept relatively stable during the whole period.

Pan et al. 2021, JGR

Spatial Variability of N Export Changes (1900-2015)



- The leaching rate of NO_3^- increased during 1900-2015 almost in the whole watershed
- Enhanced NH_4^+ was found mainly in cropland, wetland, and grassland.
- Change rates of DON leaching were not significant.
- PON leaching rates demonstrated opposite patterns in different parts of the watershed.

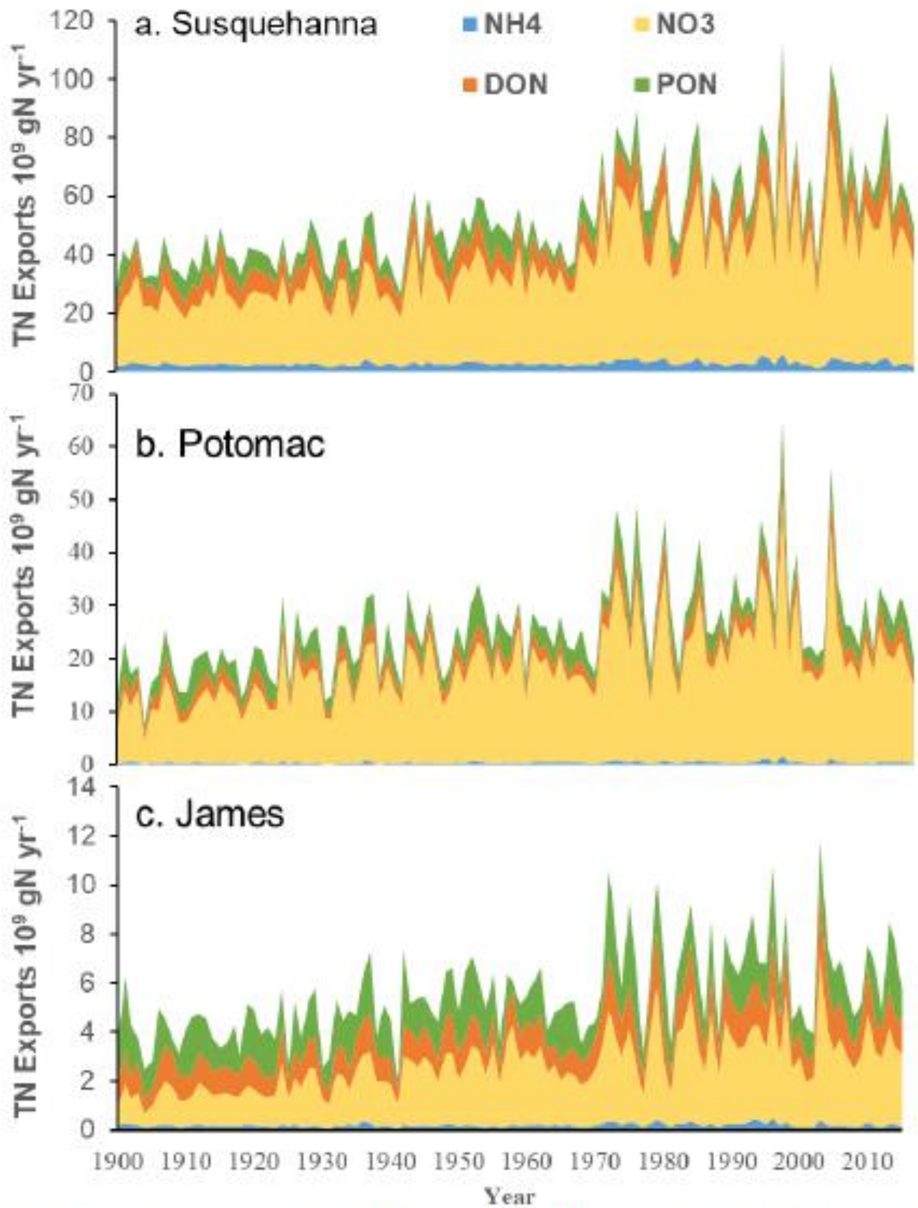
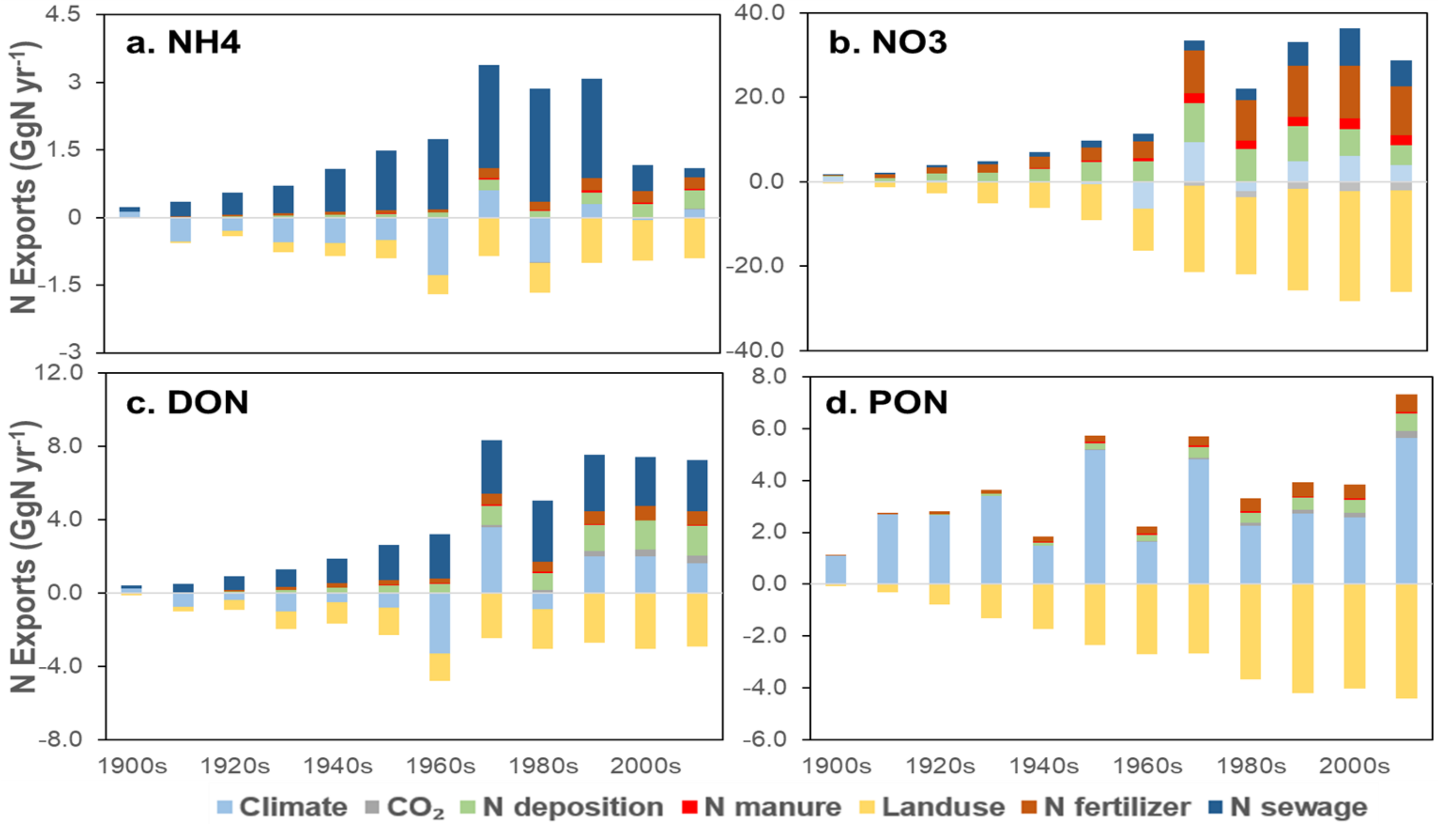


Figure S3. Annual averages of simulated riverine N exports in the (a) Susquehanna, (b) Potomac, and (c) James River sub-basins from 1900 to 2015.

The dominant controls on N loading are different among N species



<u>Major controlling factors for different N species:</u>

Riverine NH4+ : sewage.

Riverine NO3- : land use change, N fertilizer and N deposition change

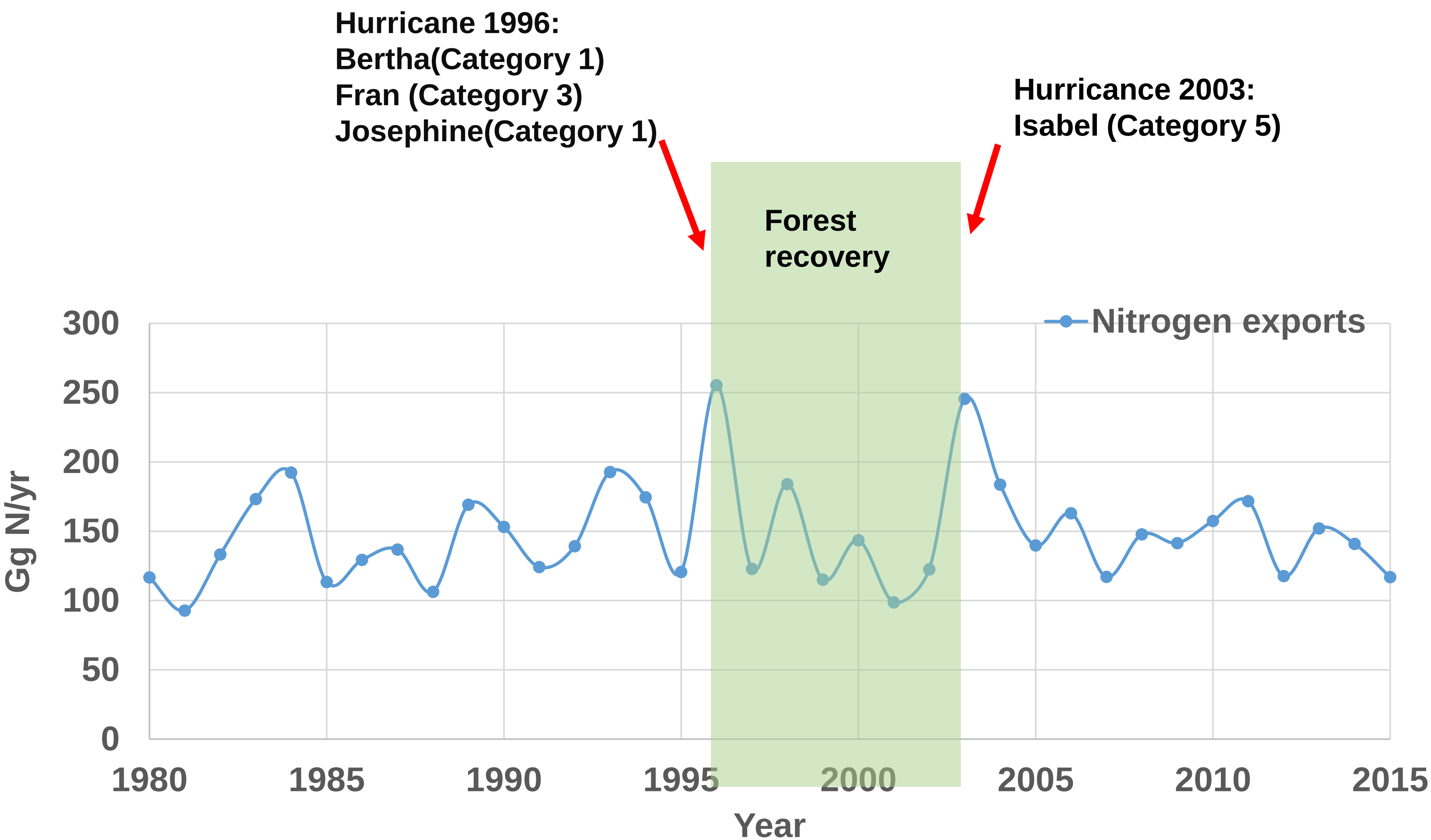
Riverine DON: urban sewage water

Riverine PON: land use change and climate change.

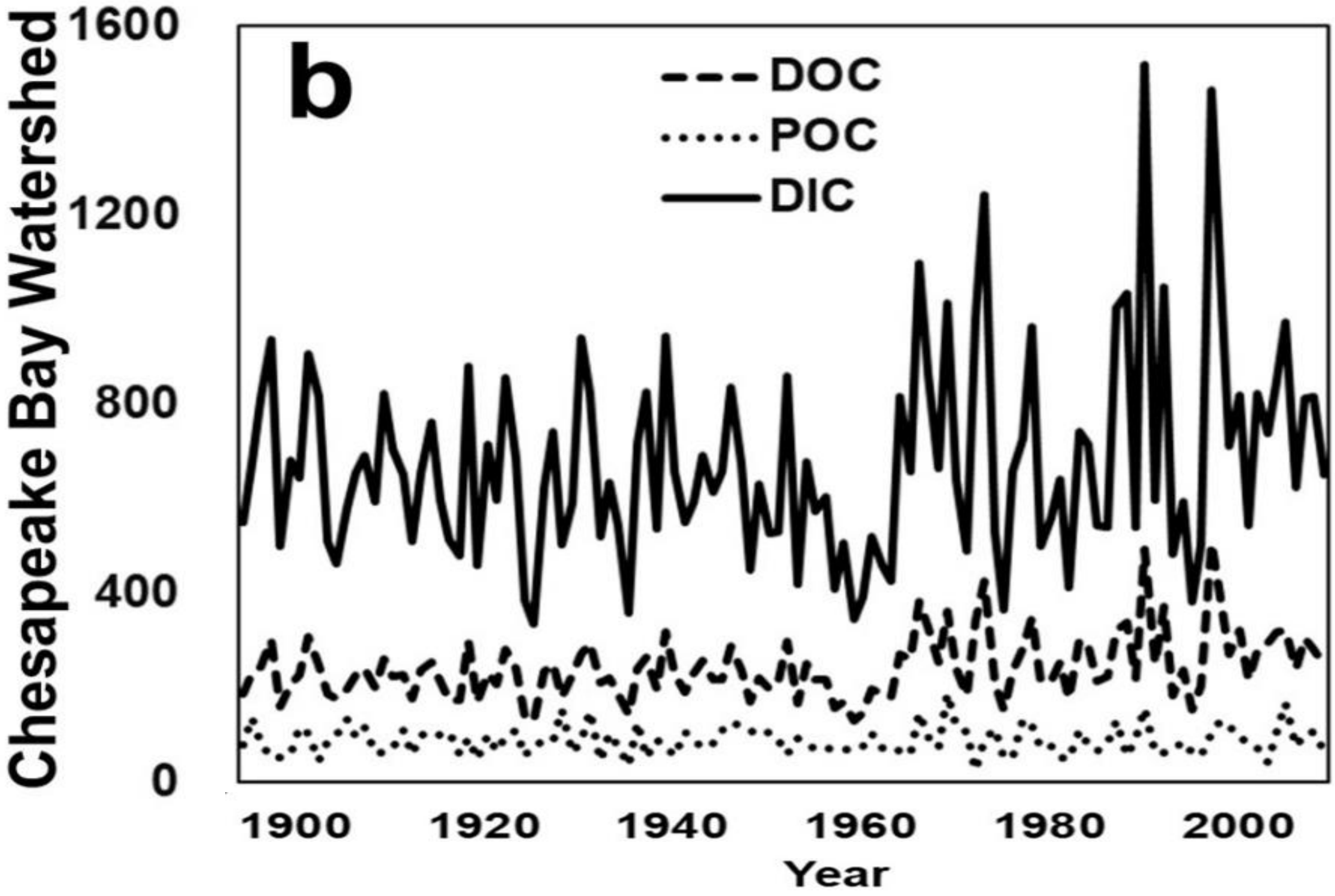
The relative importance of environmental Factors to N loading varied over time

decade	S1 (Climate)	S2 (CO_2)	S3 (N deposition)	S4 (N manure)	S5 (Land use)	S6 (N fertilizer)	S7 (N sewage)
1900s	2.7	0.0	0.1	0.0	-0.4	0.2	0.4
1910s	1.4	0.0	0.9	0.0	-1.8	0.9	1.1
1920s	2.3	0.0	1.8	0.0	-4.2	1.6	1.8
1930s	1.6	0.0	2.4	0.0	-7.3	2.4	2.3
1940s	0.2	0.1	3.5	0.3	-9.2	3.2	3.3
1950s	3.3	0.1	5.3	0.5	-12.9	3.8	4.7
1960s	-9.2	0.0	5.6	0.7	-14.6	4.5	5.9
1970s	18.4	-0.8	11.0	2.3	-26.3	11.3	7.6
1980s	-1.8	-1.2	9.2	2.2	-24.9	10.7	8.5
1990s	10.0	-1.3	10.3	2.5	-31.9	13.6	10.9
2000s	10.6	-1.7	8.7	2.7	-34.0	14.1	12.2
2010–2015	11.3	-1.3	7.4	2.6	-32.2	13.2	8.9

Heavy precipitation largely increased N export

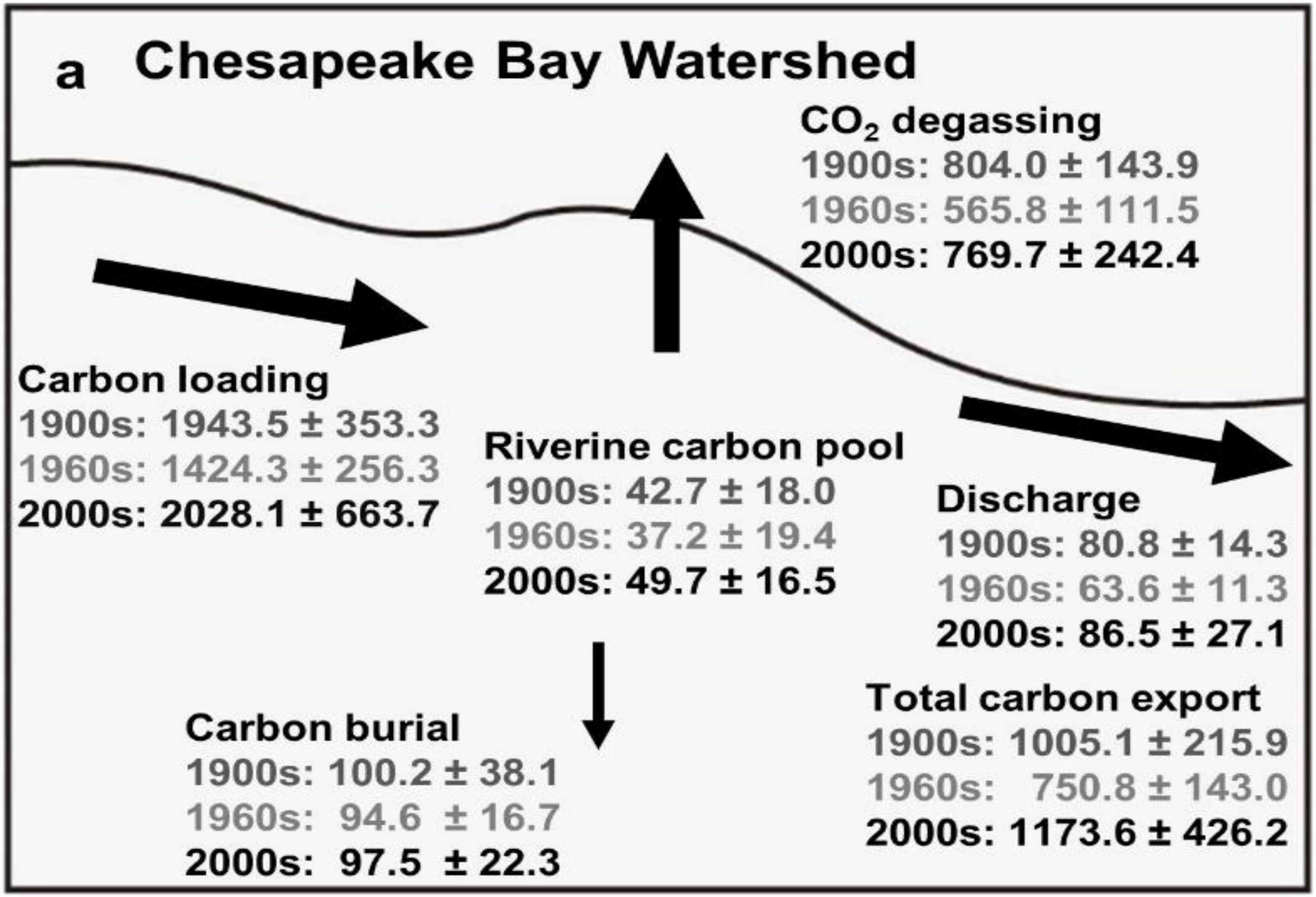


Century-long Carbon Export from land to the Chesapeake Bay



(Modified from Yao et al. 2021)

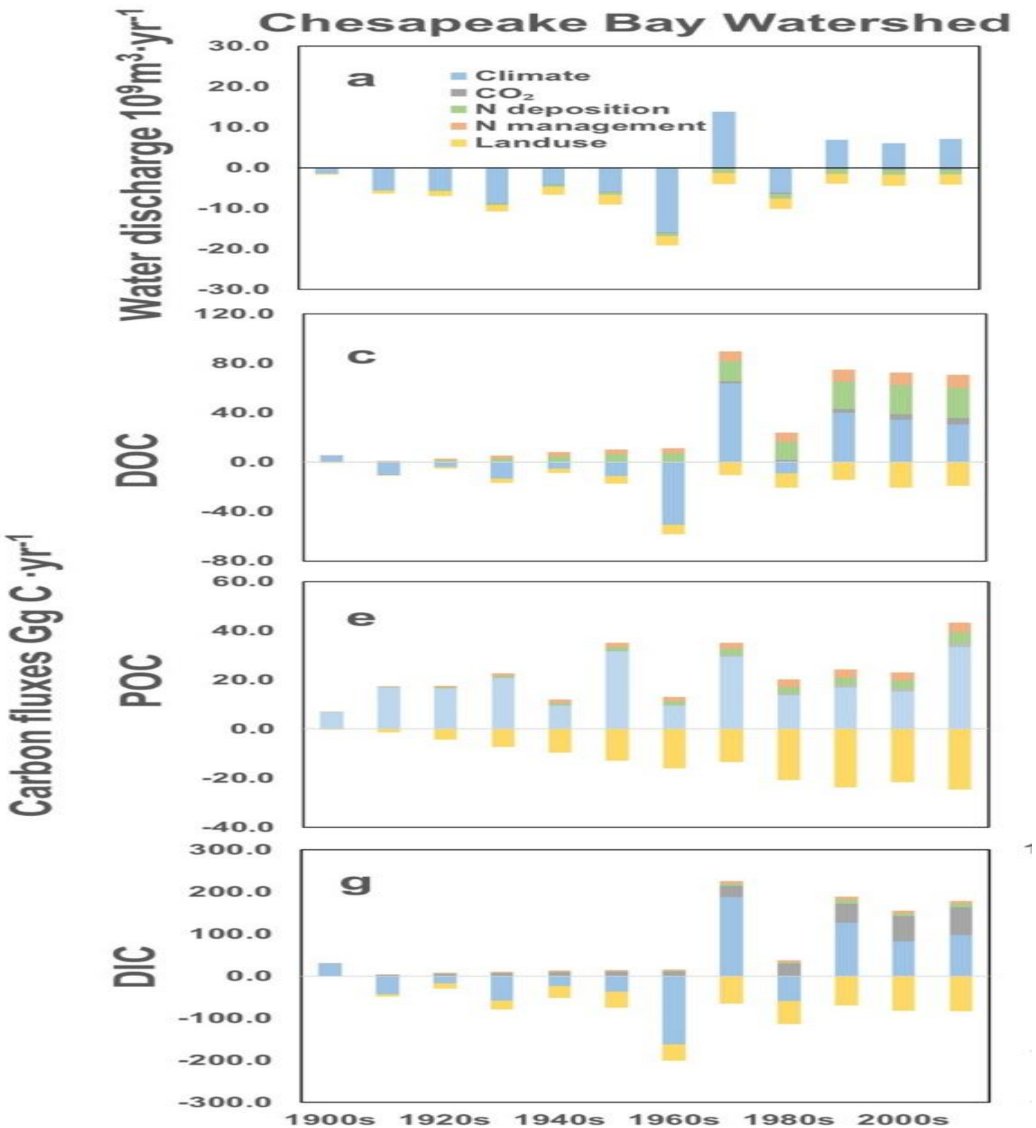
Riverine carbon budget in Chesapeake Bay watershed (1900s, 1960s and 2000s)



Discharge unit: $10^9\ m^3 \cdot yr^{-1}$
Carbon fluxes unit: $Gg\ C \cdot yr^{-1}$
Carbon pool unit: Gg C

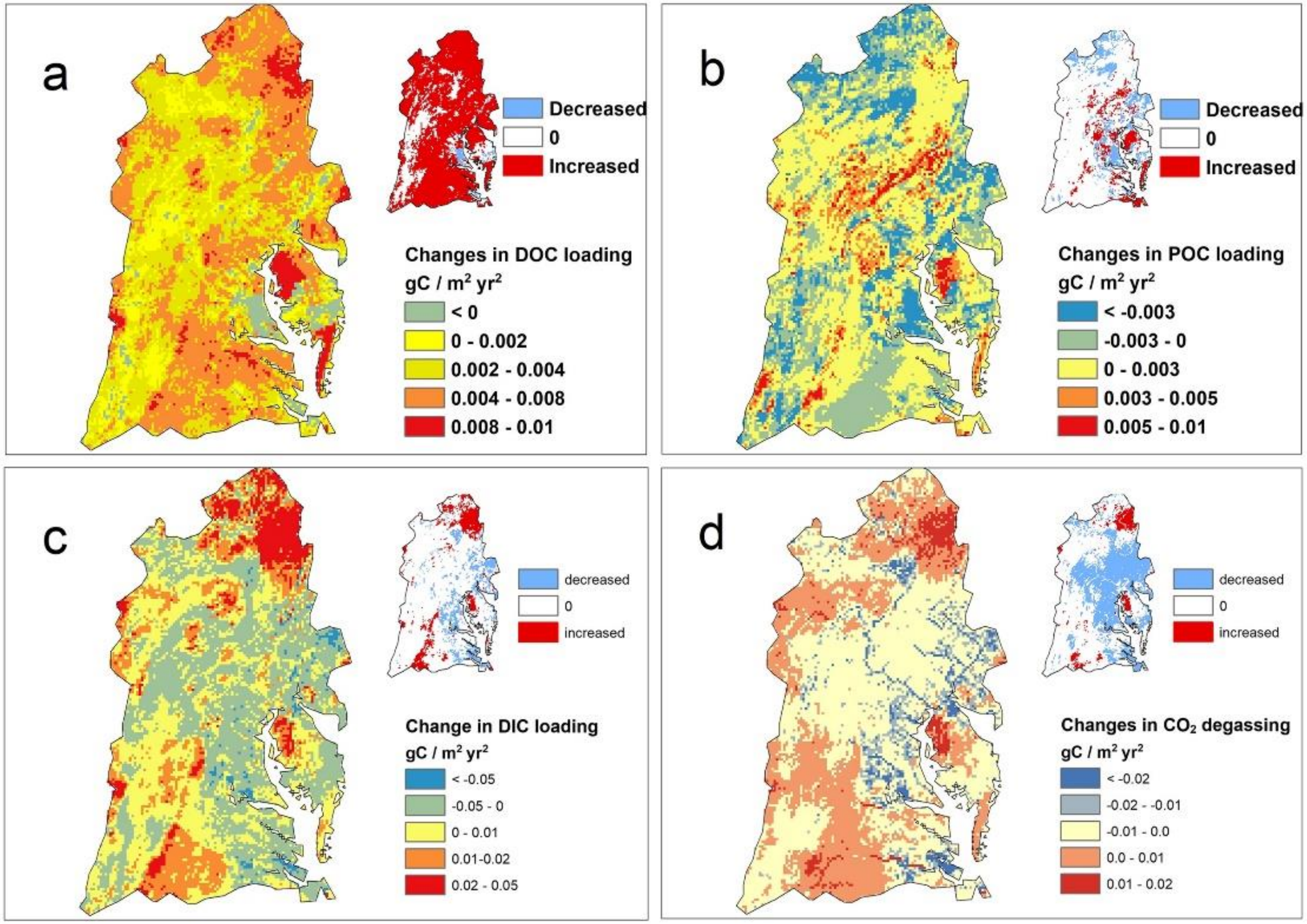
(Modified from Yao et al. 2021)

Relative contribution of environmental factors

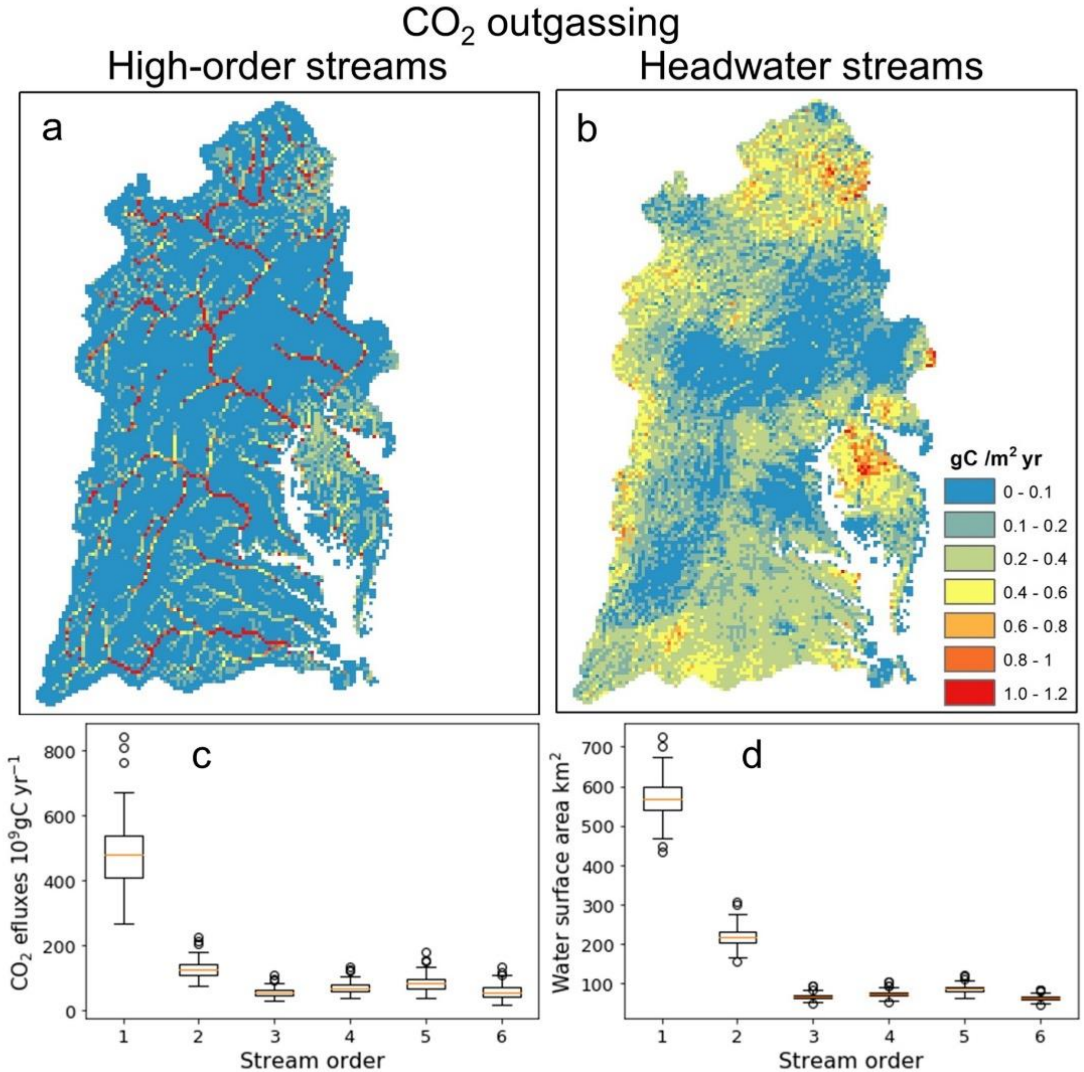


(Modified from Yao et al. 2021)

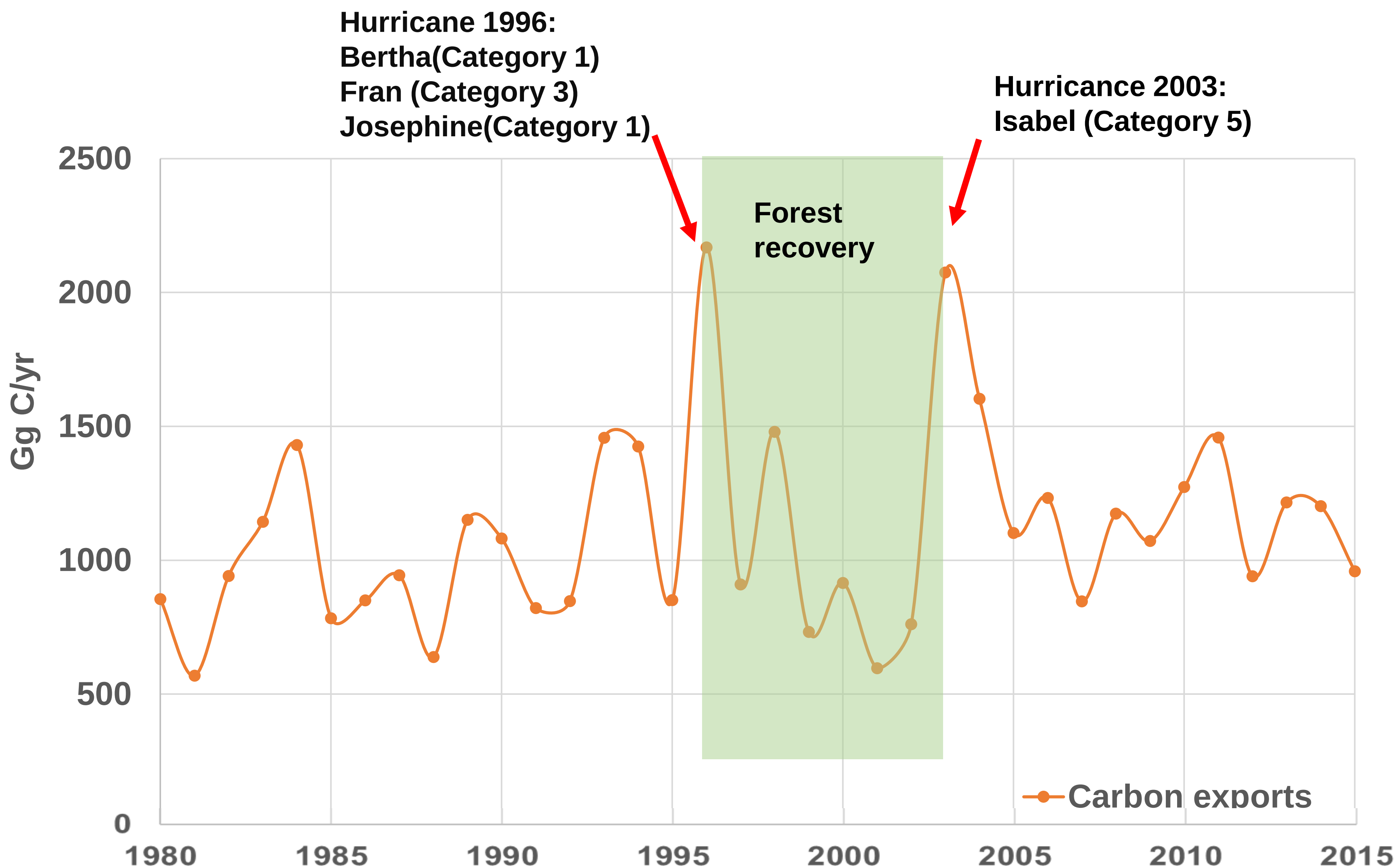
River CO_2 emissions are strongly associated with DOC and DIC loading



The 1st order stream released most of the CO_2



Heavy precipitation largely increased C export



Major conclusion (nitrogen fluxes)

- Nitrogen loading from Chesapeake Bay Watershed continually increased from the 1900s to the 1990s and has declined since then.

- Key contributors to total N export have changed over the past century from atmospheric N deposition to synthetic nitrogen fertilizer.

- Climate variability resulted in substantially interannual variation in N loading. Extreme precipitation events can lead to large increase in C export.

- More effective management of terrestrial non-point sources is required to achieve water quality goals.

Major conclusion (carbon fluxes)

- Over the past century, climate variability explains most of interannual and interdecadal variations in riverine carbon export to the Chesapeake Bay.
- Extreme precipitation events can lead to large increase in C export.
- Land conversion from cropland to forest decreased carbon export to the Chesapeake Bay.
- DIC and DOC loading and export are strongly associated with terrestrial processes such as soil respiration.

Implications and research needs

- A wetter and warmer world would likely increase both C and N exports from land to the Chesapeake Bay.
- More frequent hurricane events may lead to large C and N export to the Bay,
- From both scientific and policy perspectives, it’s of critical importance to improving our ability in predicting extreme climate events and their impacts.
- Process-based modeling approach is essential for predicting climate change impacts as well as multiple stressors' effects.
- Climate prediction needs to address management needs for climate information at fine spatial and temporal scales.

Acknowledgements

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Chesapeake Bay Program
Science. Restoration. Partnership.