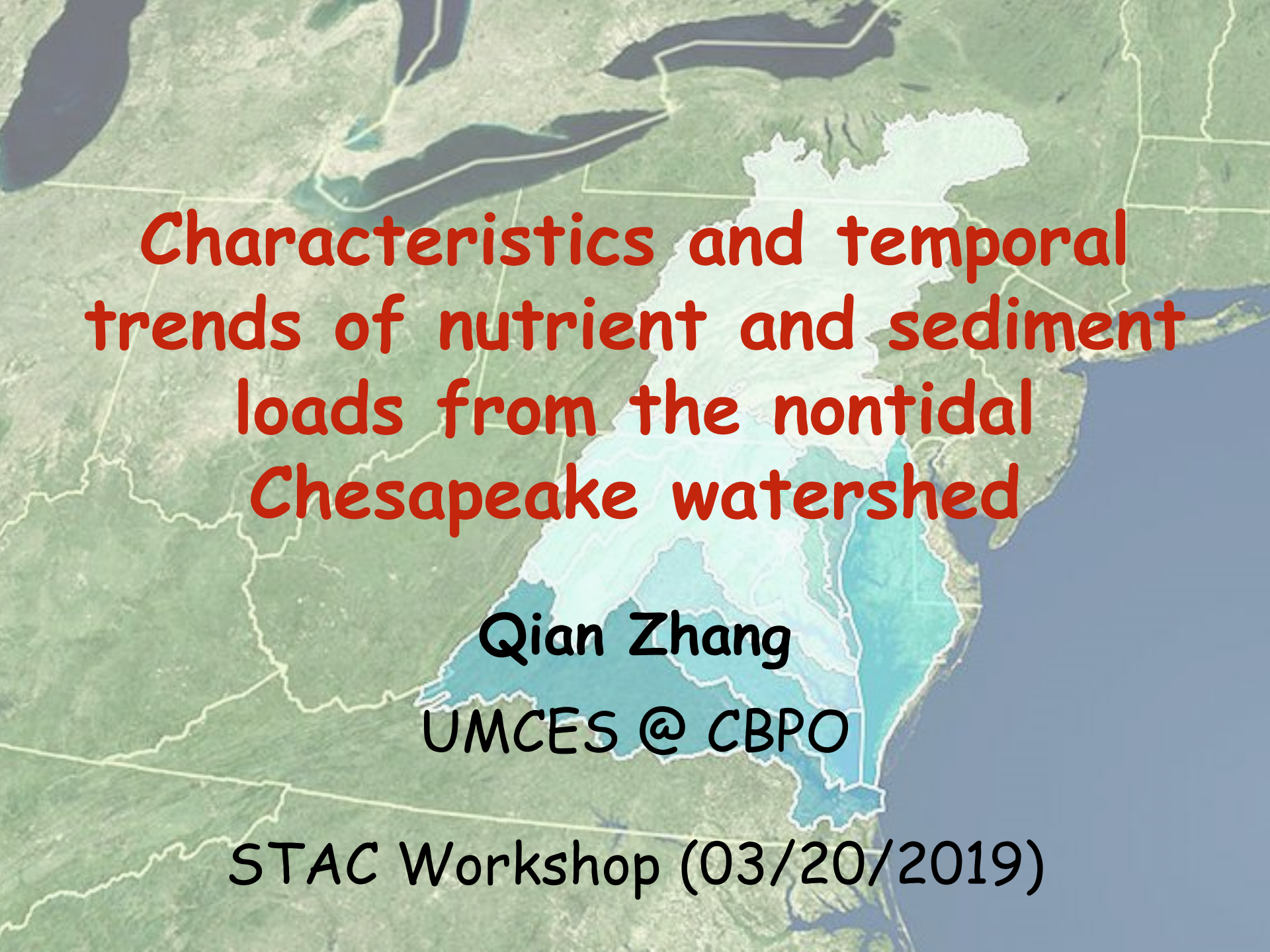


Characteristics and temporal trends of nutrient and sediment loads from the nontidal Chesapeake watershed

Qian Zhang

UMCES @ CBPO

STAC Workshop (03/20/2019)

Objectives

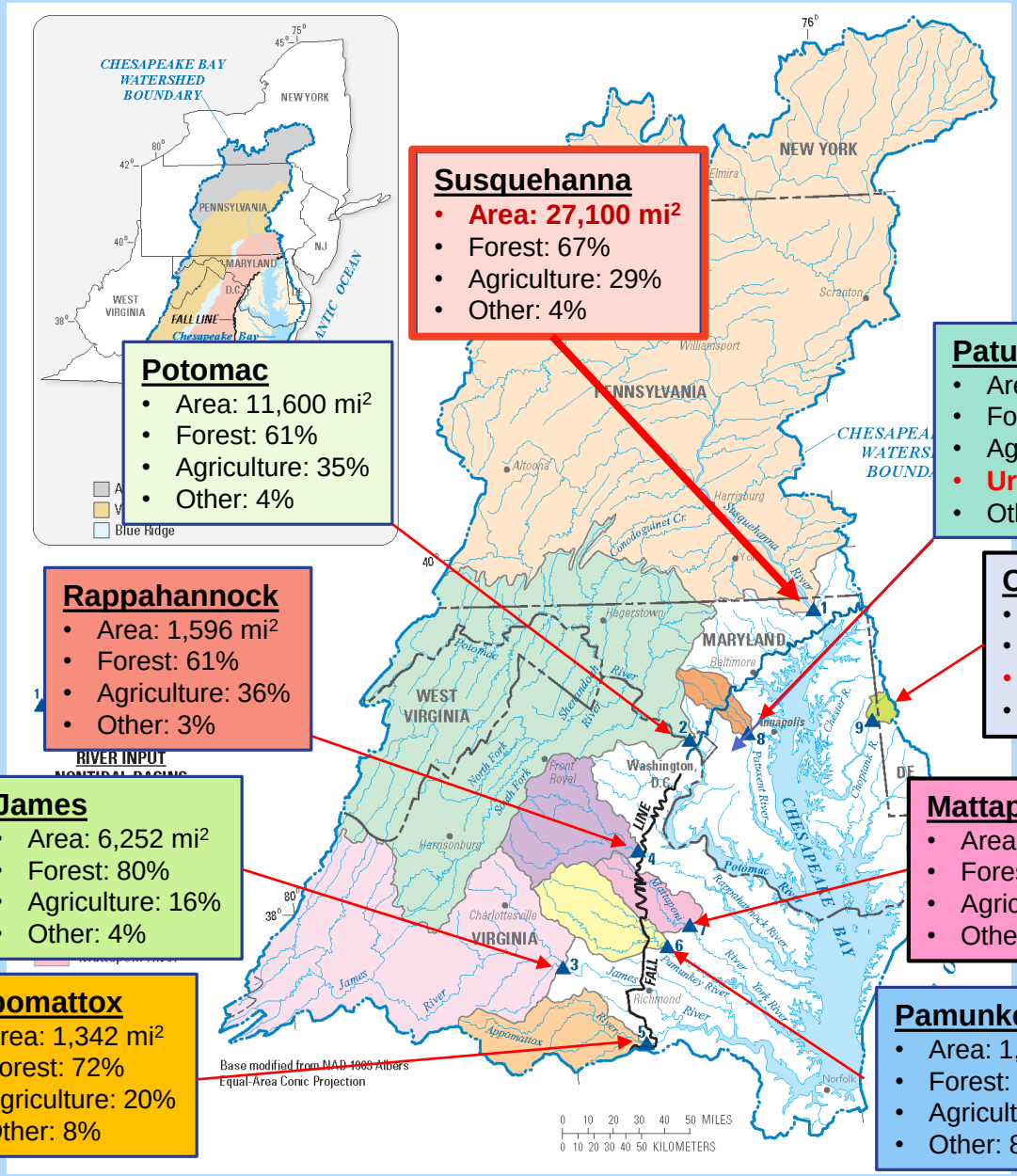
- **Explore the characteristics of riverine loads:**
  - By species: SS, TN, NOx, TP, PO4
    - 9 major tributaries
    - 4 seasons
    - 4 discharge quantiles

- **Explore the temporal trends of riverine loads:**
  - By species: SS, TN, NOx, TP, PO4

* Focused on the RIM watersheds (nontidal) in 1985-2016

* Used USGS R workspaces by Moyer et al. (2017)

River Input Monitoring (RIM) Sites



> 90% of NTCBW flow
~ 30-year daily flow
~ 20-30 samples/yr

Susquehanna
- **Area: 27,100 mi²**
- Forest: 67%
- Agriculture: 29%
- Other: 4%

Potomac
- Area: 11,600 mi²
- Forest: 61%
- Agriculture: 35%
- Other: 4%

Patuxent
- Area: 348 mi²
- Forest: 38%
- Agriculture: 41%
- **Urban: 13%**
- Other: 8%

Choptank
- Area: 113 mi²
- Forest: 29%
- **Agriculture: 50%**
- Other: 21%

Rappahannock
- Area: 1,596 mi²
- Forest: 61%
- Agriculture: 36%
- Other: 3%

James
- Area: 6,252 mi²
- Forest: 80%
- Agriculture: 16%
- Other: 4%

Mattaponi
- Area: 603 mi²
- Forest: 69%
- Agriculture: 19%
- Other: 12%

Appomattox
- Area: 1,342 mi²
- Forest: 72%
- Agriculture: 20%
- Other: 8%

Pamunkey
- Area: 1,078 mi²
- Forest: 68%
- Agriculture: 24%
- Other: 8%

WRTDS: Trend Analysis

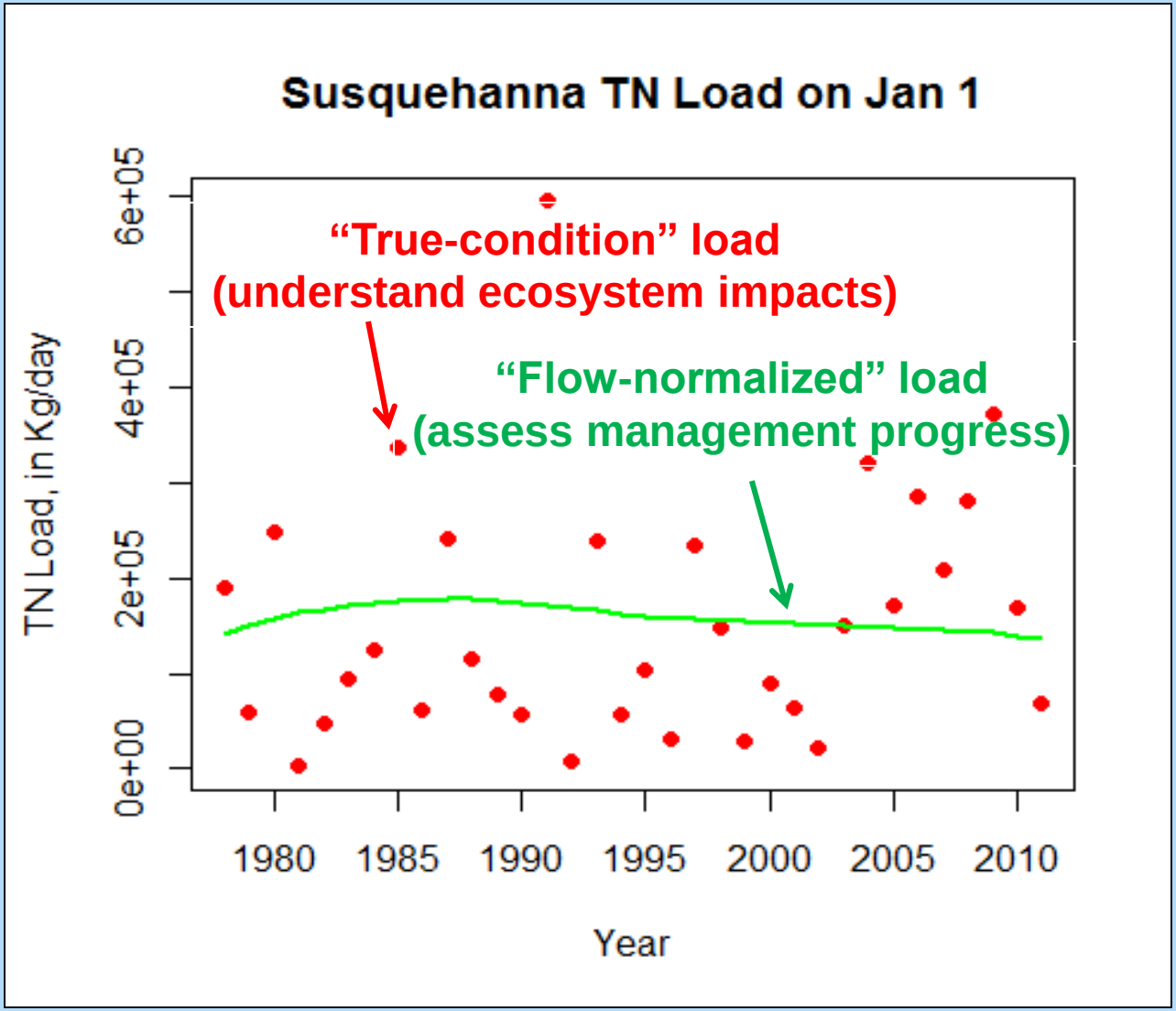
Daily flow & discretely-sampled concentration data at a sampling site

↓

WRTDS
(Hirsch et al. 2010)

↓

Daily conc. and load estimates



For the latest load estimates, see Moyer et al. (2017); https://doi.org/10.5066/F7RR1X68.

❖ **Explore the characteristics of riverine loads:**

- By species: SS, TN, NOx, TP, PO4
  - ❑ 9 major tributaries
  - ❑ 4 seasons
  - ❑ 4 discharge quantiles

True-condition Estimates (w/o TIME) 1985-2016 total

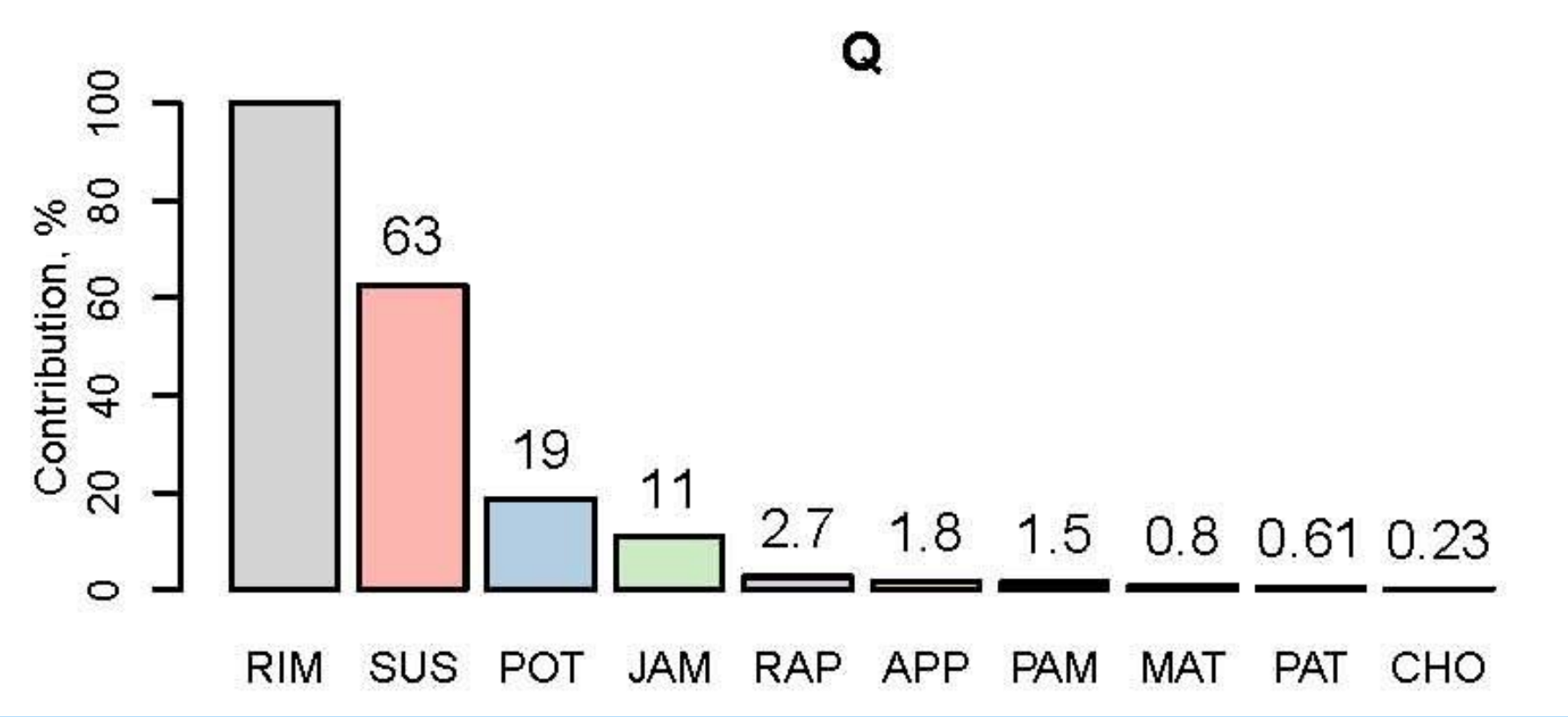
❖ **Explore the temporal trends of riverine loads:**

- By species: SS, TN, NOx, TP, PO4

* Focused on the RIM watersheds (nontidal) in 1985-2016

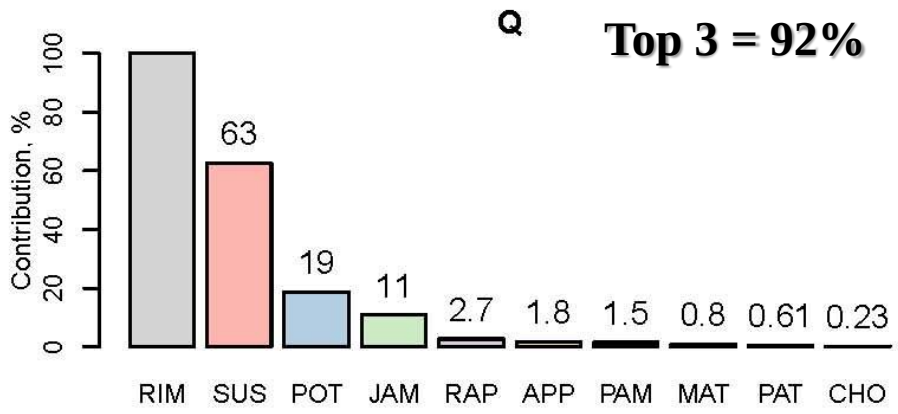
* Used USGS R workspaces by Moyer et al. (2017)

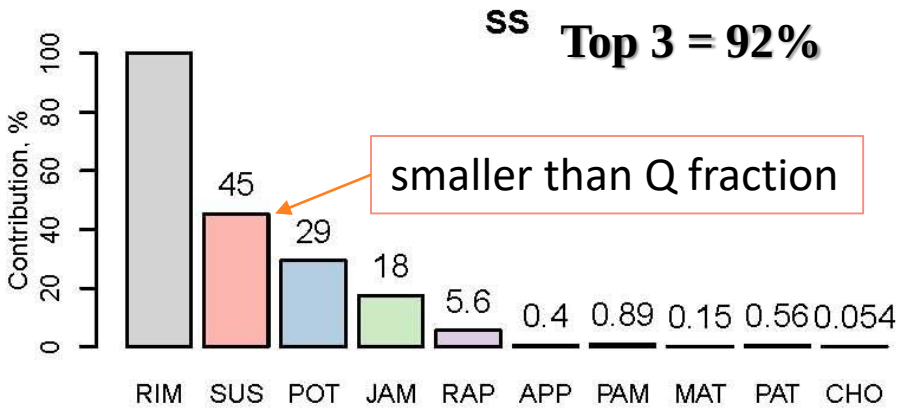
Distribution by Tributary

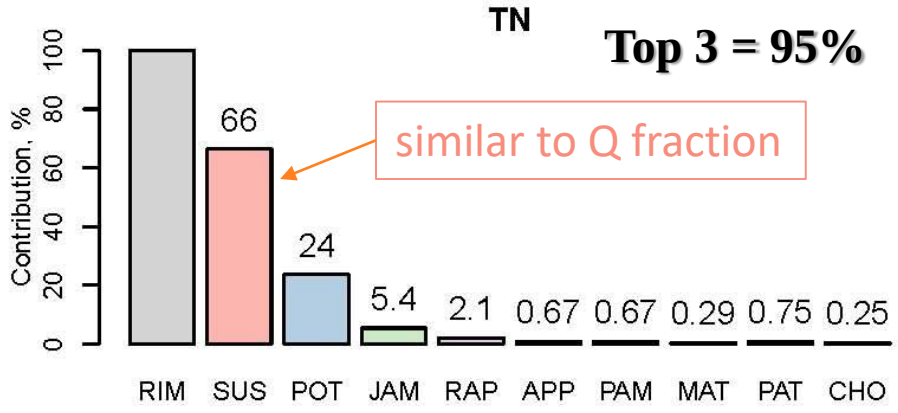


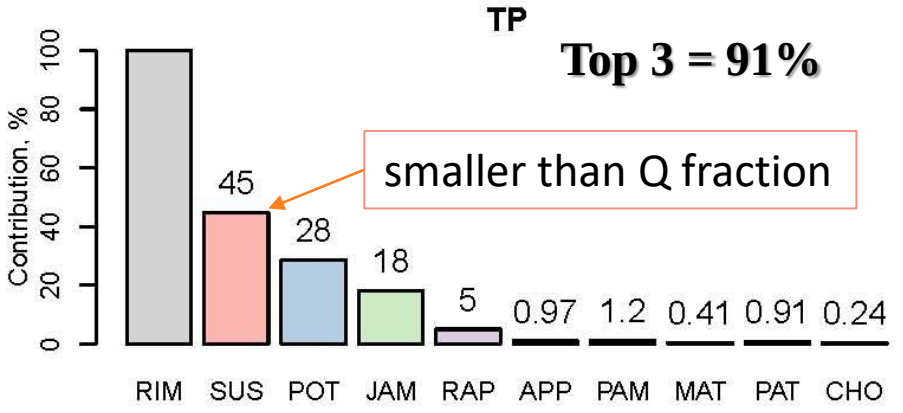
ordered by watershed size

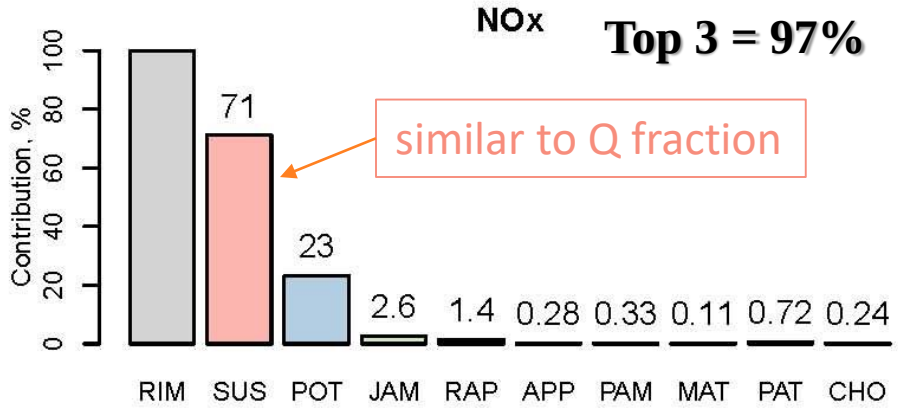
Distribution by Tributary (% Load)

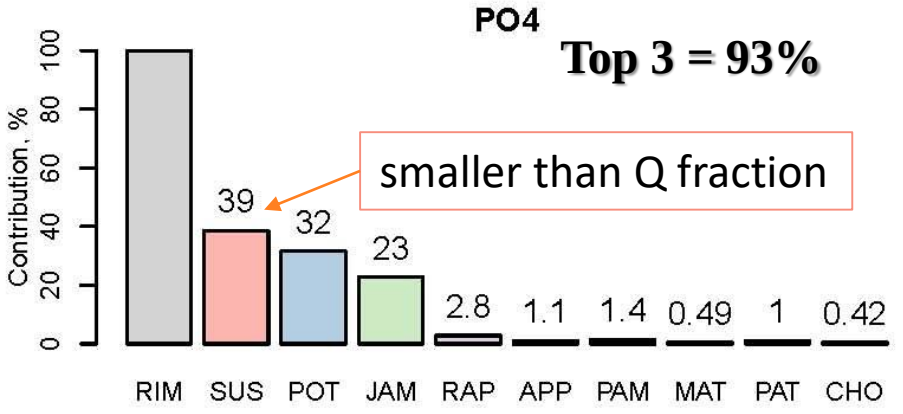






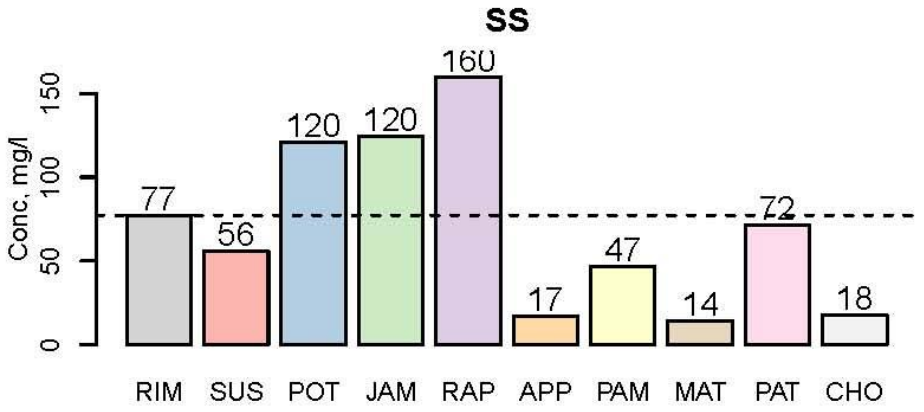


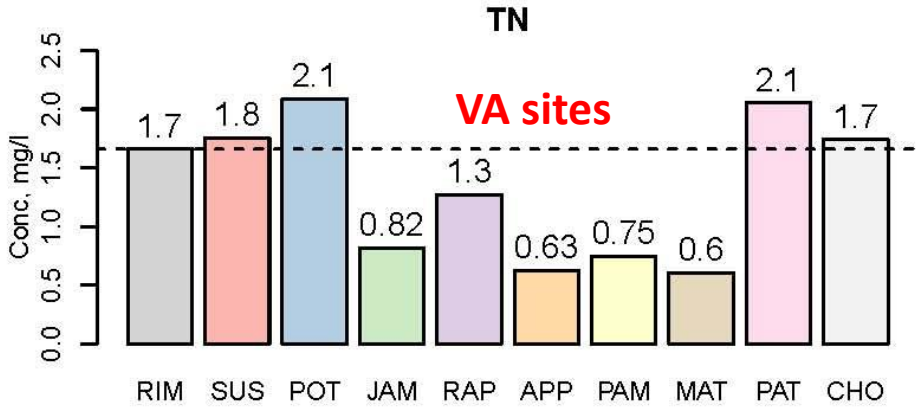


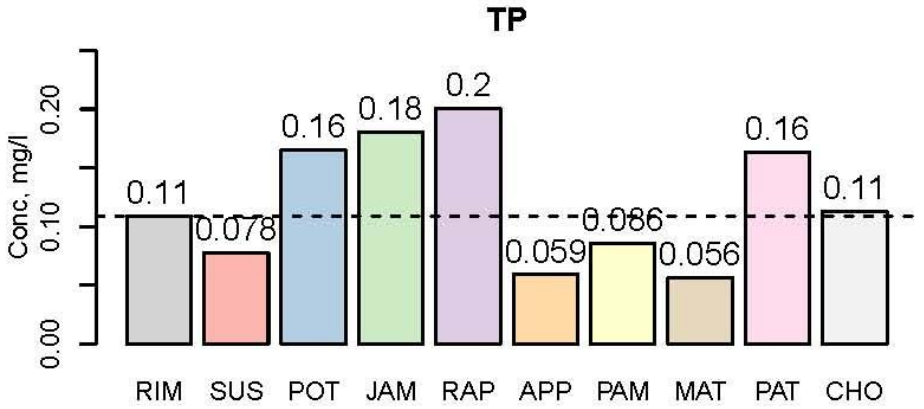


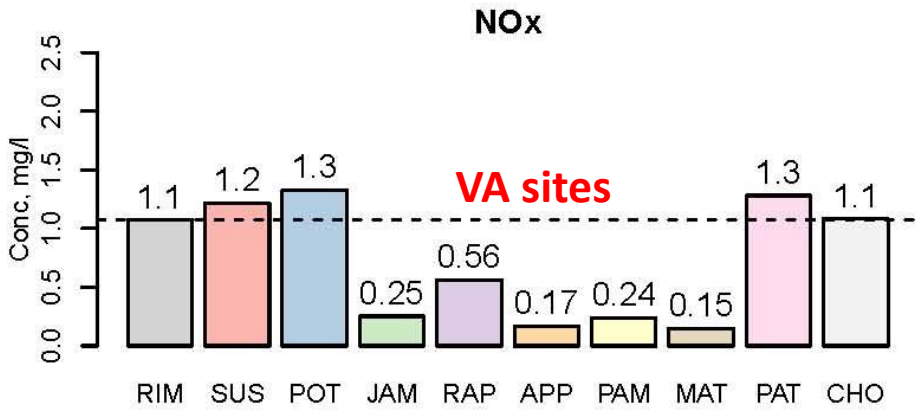
Distribution by Tributary (FWC)

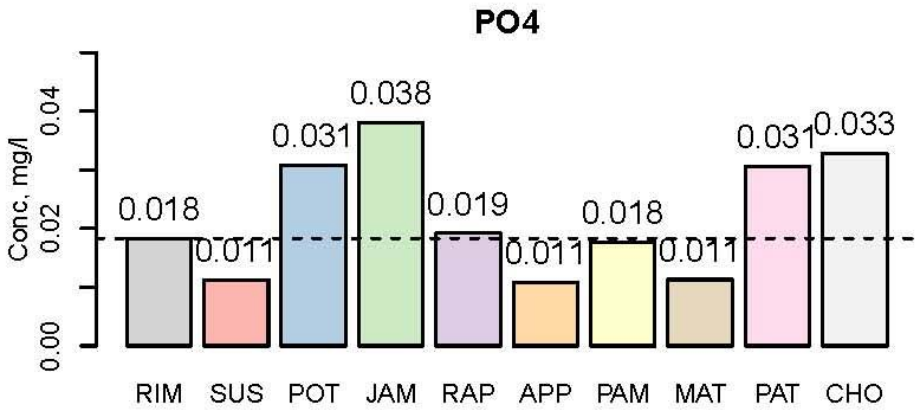
Range in average concentration:
SS: 14-160 mg/L (**x11**)
TN: 0.6-2.1 mg/L (**x3.5**)
TP: 0.056-0.2 mg/L (**x3.6**)
NOx: 0.15-1.33 mg/L (**x8.8**)
PO4: 0.011-0.038 mg/L (**x3.5**)



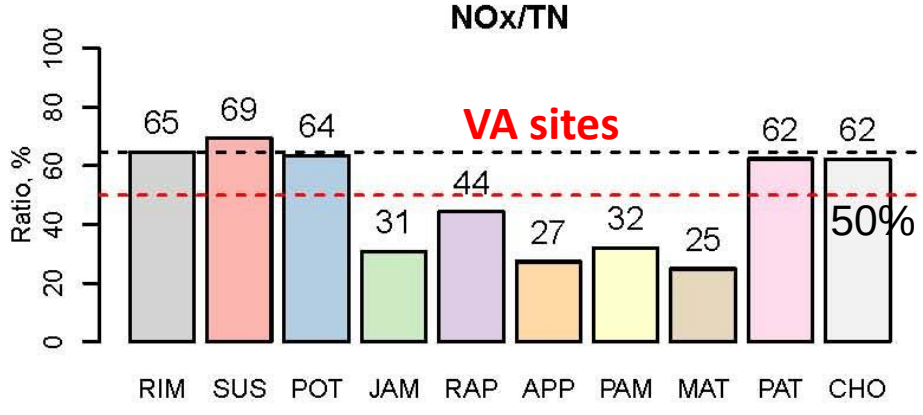


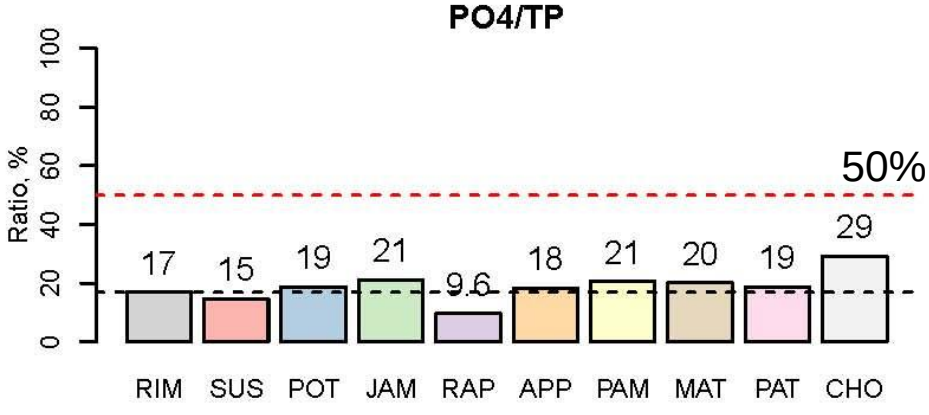






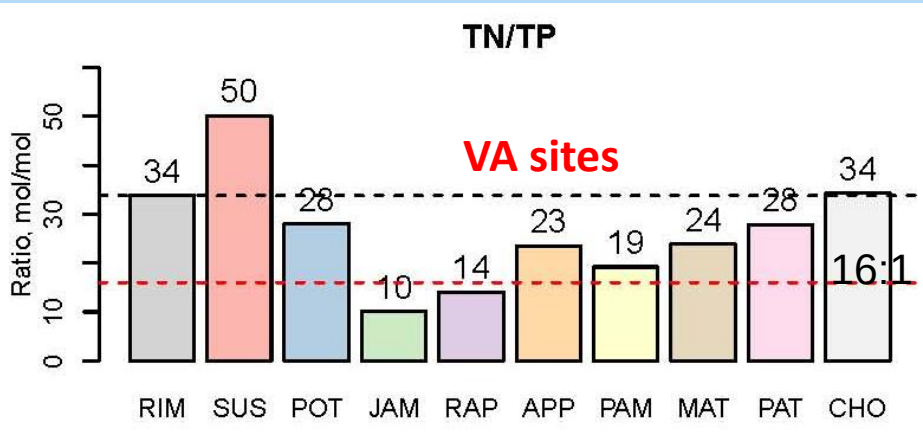
Distribution by Tributary (Ratio)

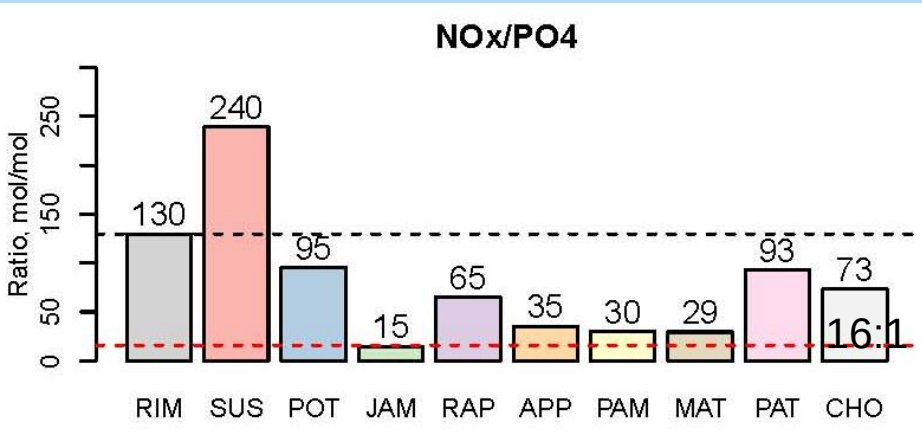




NOx/TN ranged in 25%-70%
(contrast between MD and VA rivers)

PO4/TP ranged in 9.6%-29%
(most rivers in the range of 15%-21%)





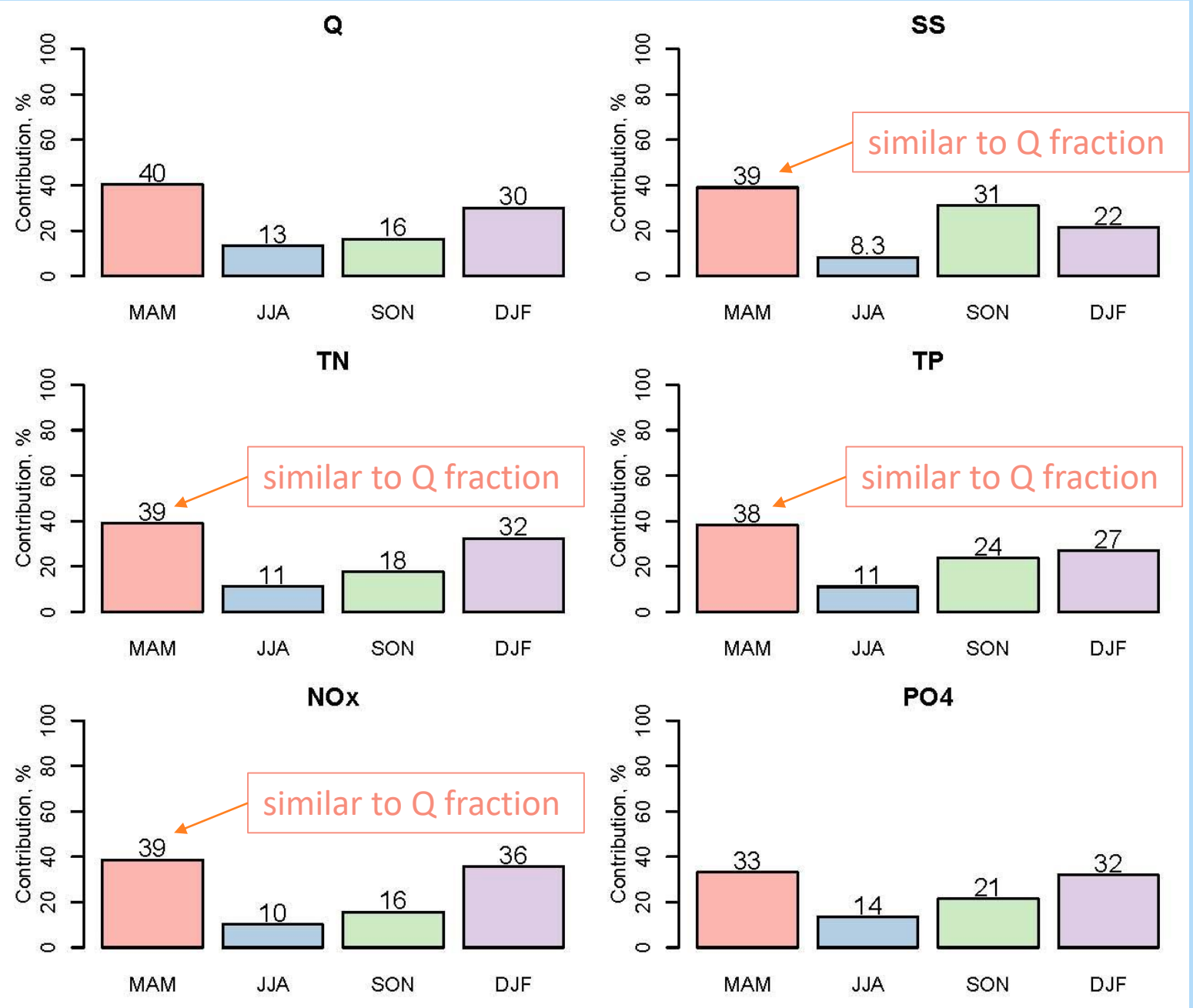
TN/TP ranged in 10-50 mol/mol
(Susquehanna: the only river > mean)
(James and Rap: two rivers <16:1)

NOx/PO4 ranged in 15-240 mol/mol
(Susquehanna: the only river > mean)
(James: the only river <16:1)

Summary (Patterns by Tributaries)

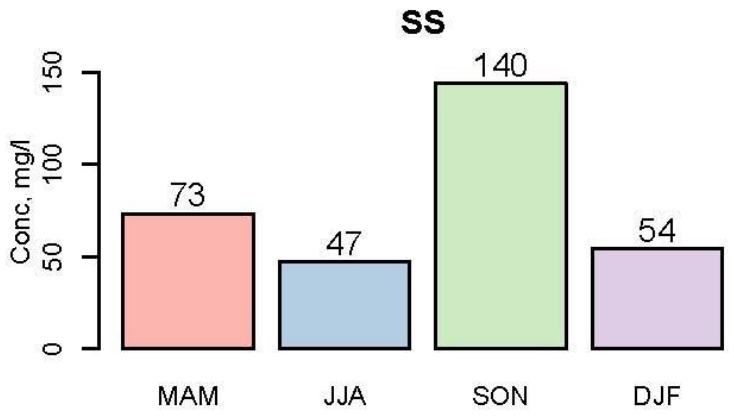
- The three largest tributaries (SUS, POT, and JAM) represent > 90% of total flow and total load.
- Average concentration is more variable for SS (x11) and NOx (x8.8) than the other species (x3-x4).
- NOx is a major fraction of TN in MD rivers but a minor fraction in VA rivers; PO4 is consistently a minor fraction of TP in MD and VA rivers.
- For both TN:TP and NOx:PO4 molar ratios, Susquehanna is the only river that exceeds the RIM average; James is the only river that is < 16:1.

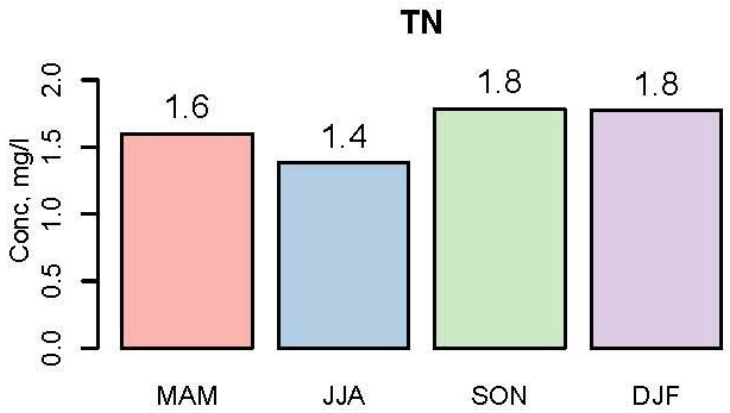
Distribution by Season (% Load)

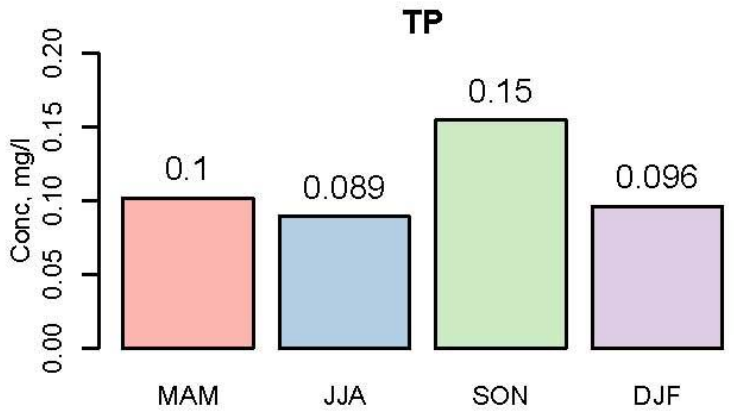


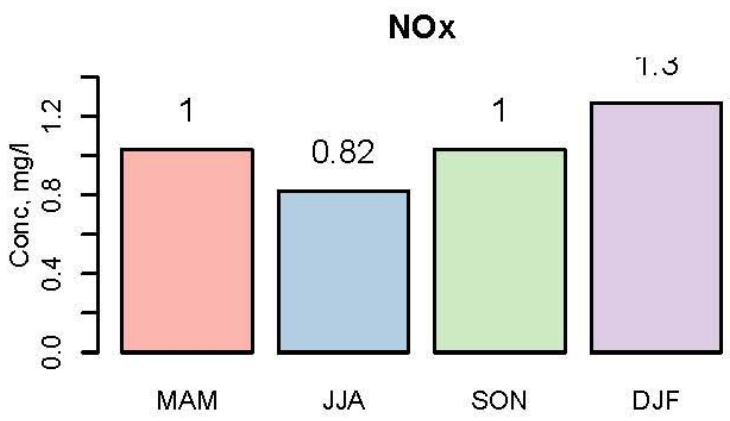
Distribution by Season (FWC)

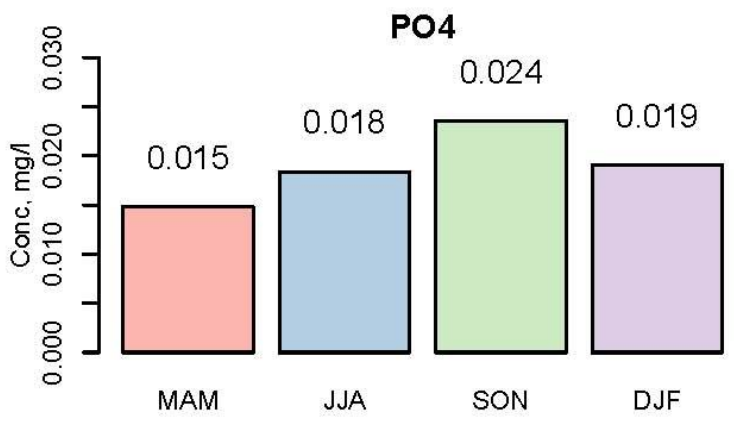
Largest seasonal concentration:
SS: Sep-Nov
TN: Sep-Nov and Dec-Feb
TP: Sep-Nov
NOx: Dec-Feb
PO4: Sep-Nov



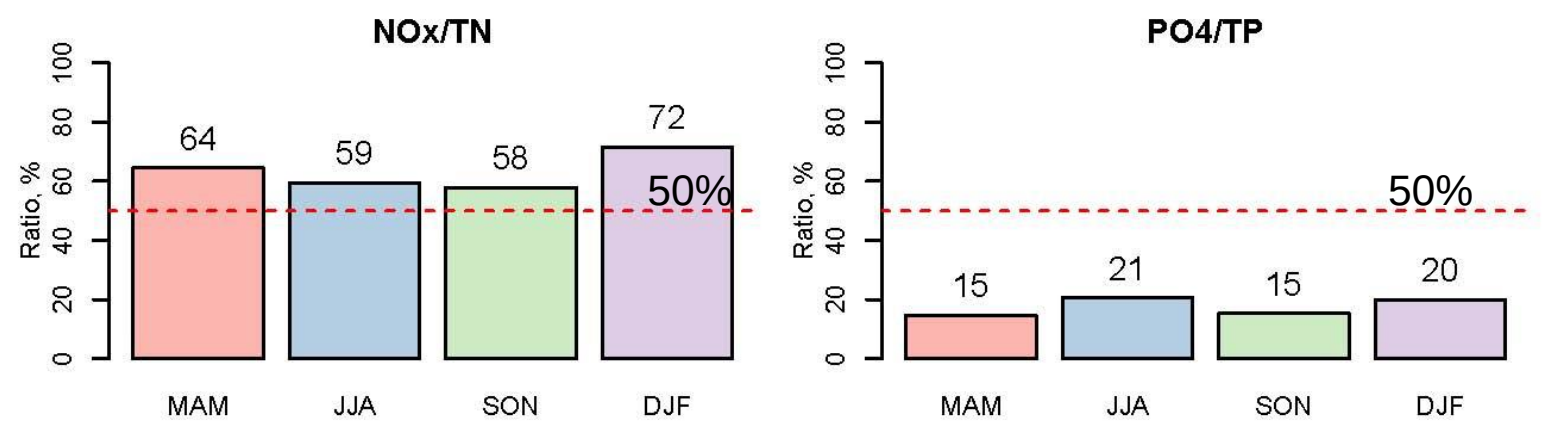






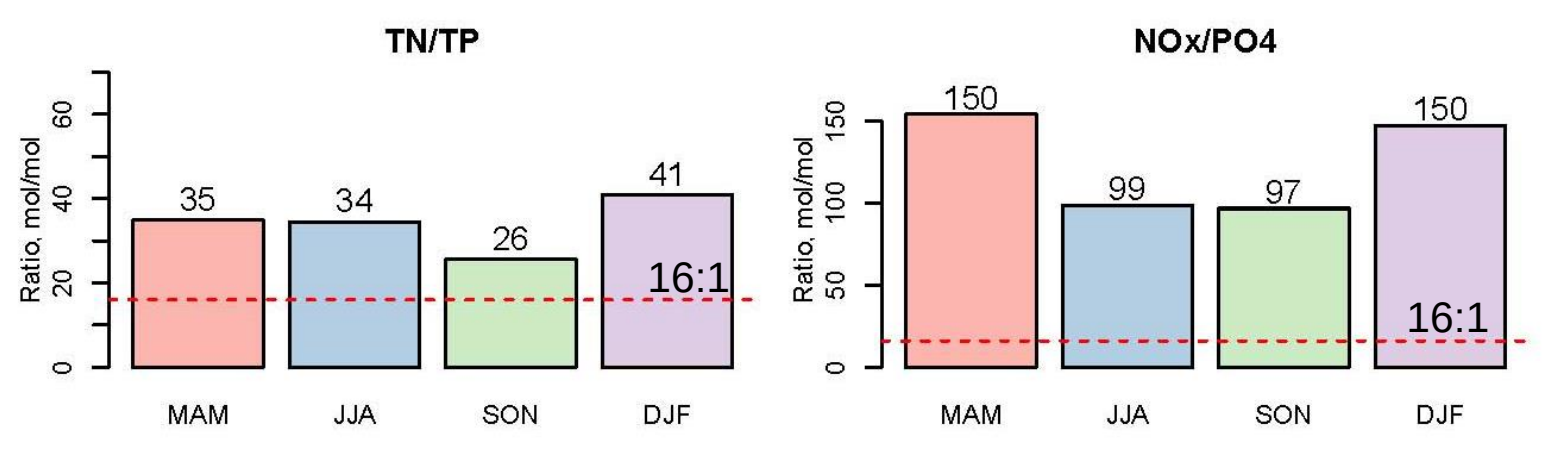


Distribution by Season (Ratio)



NOx is always the dominant fraction of TN

PO4 is is always the less dominant fraction of TP



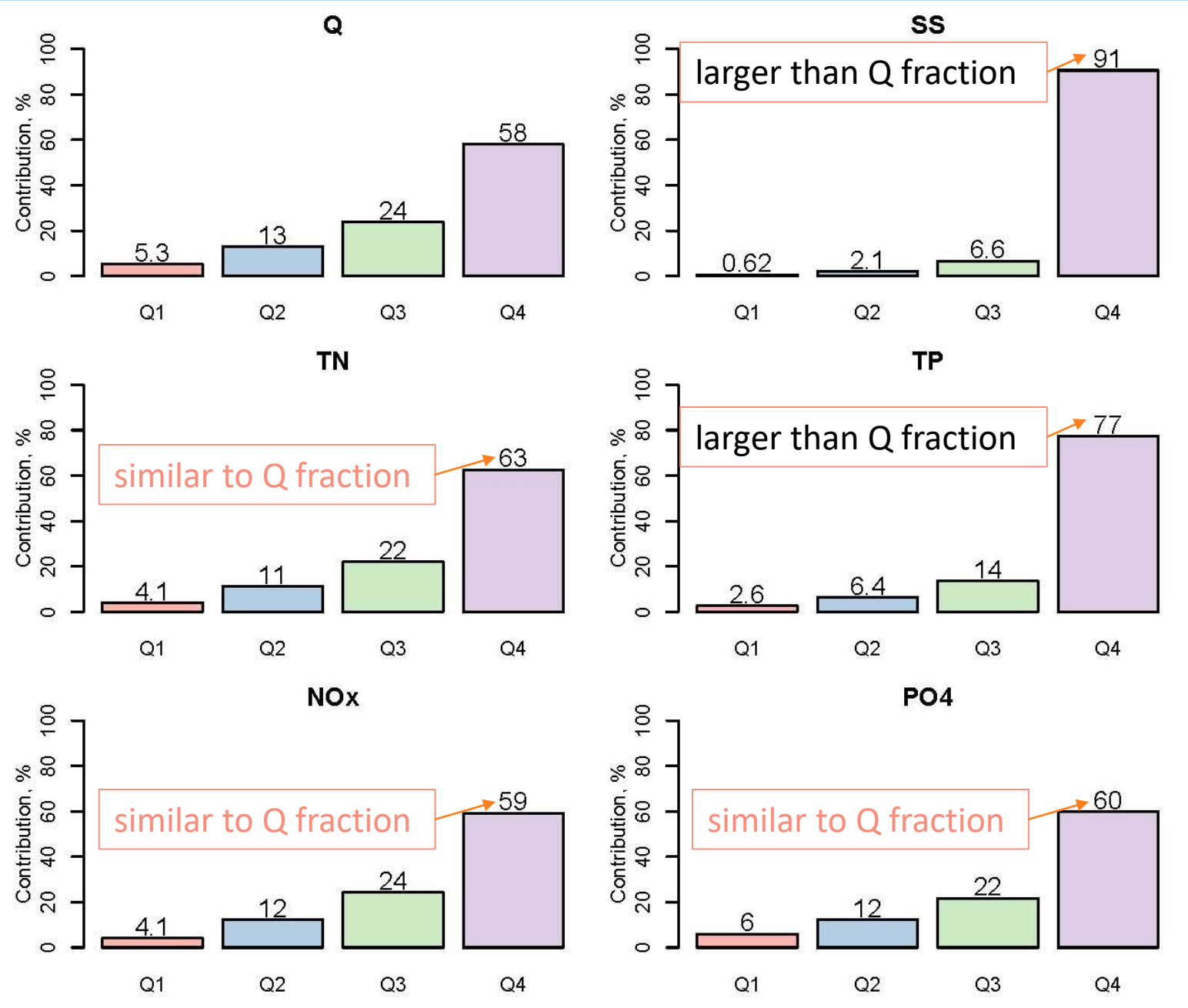
TN:TP ratio always > 16

NOx/PO4 ratio always > 16

Summary (Patterns by Seasons)

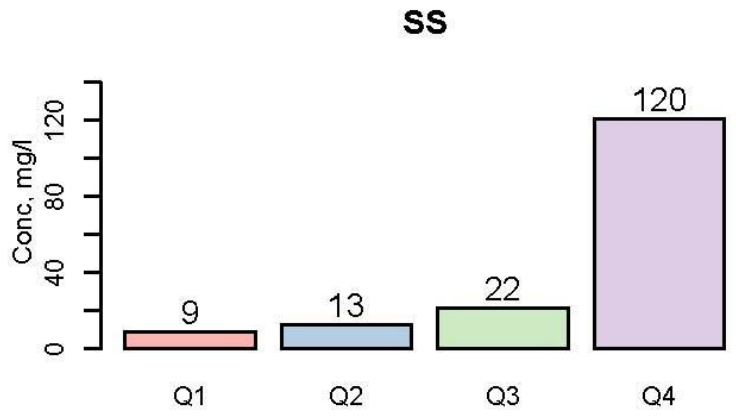
- Contributions of load by the four seasons are generally similar to their contributions of flow.
- Average seasonal concentration is at the highest in Sep-Nov (SS, TN, TP, PO4) and Dec-Feb (TN, NOx).
- NOx is a major fraction of TN in all four seasons, whereas PO4 is consistently a minor fraction of TP.
- For both TN:TP and NOx:PO4 molar ratios, all four seasons are > 16:1.

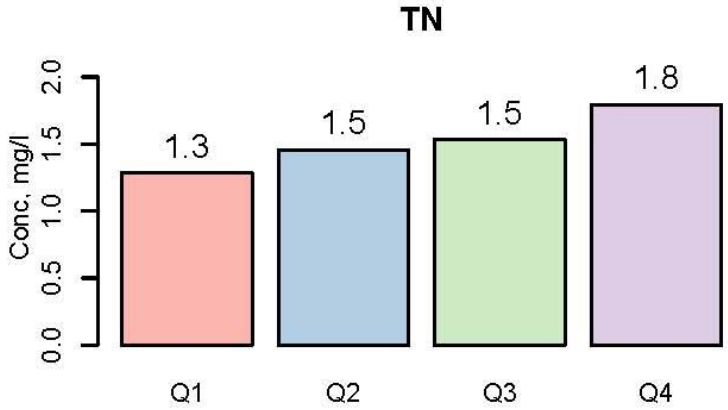
Distribution by Flow (% Load)

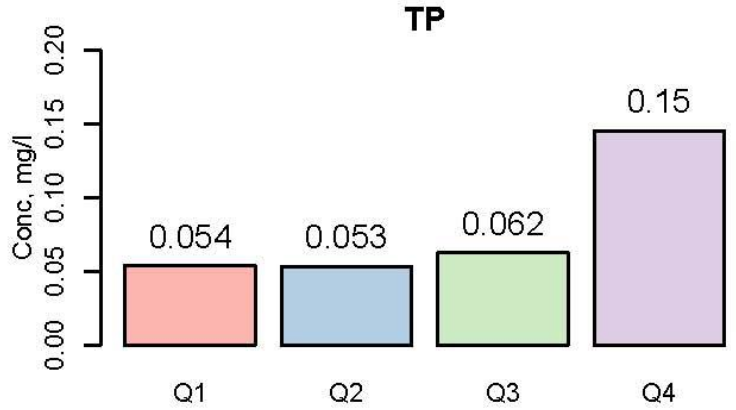


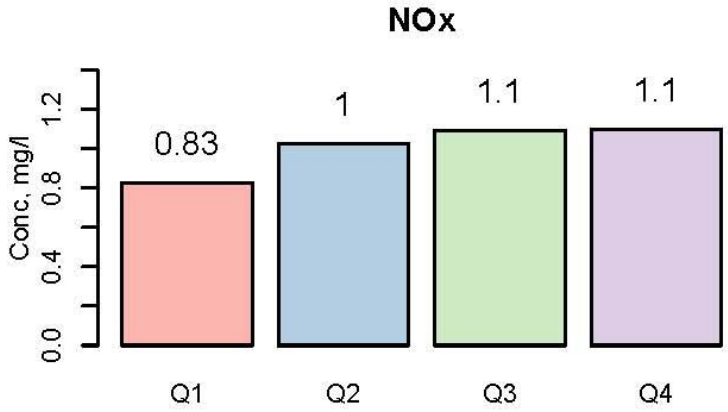
Distribution by Flow (FWC)

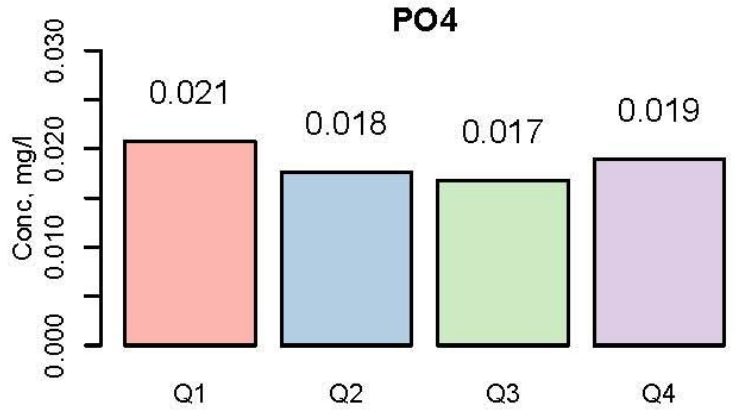
Flow-weighted concentration:
SS: Q4 >> Q1, Q2, Q3
TN: similar
TP: Q4 > Q1, Q2, Q3
NOx: similar
PO4: similar



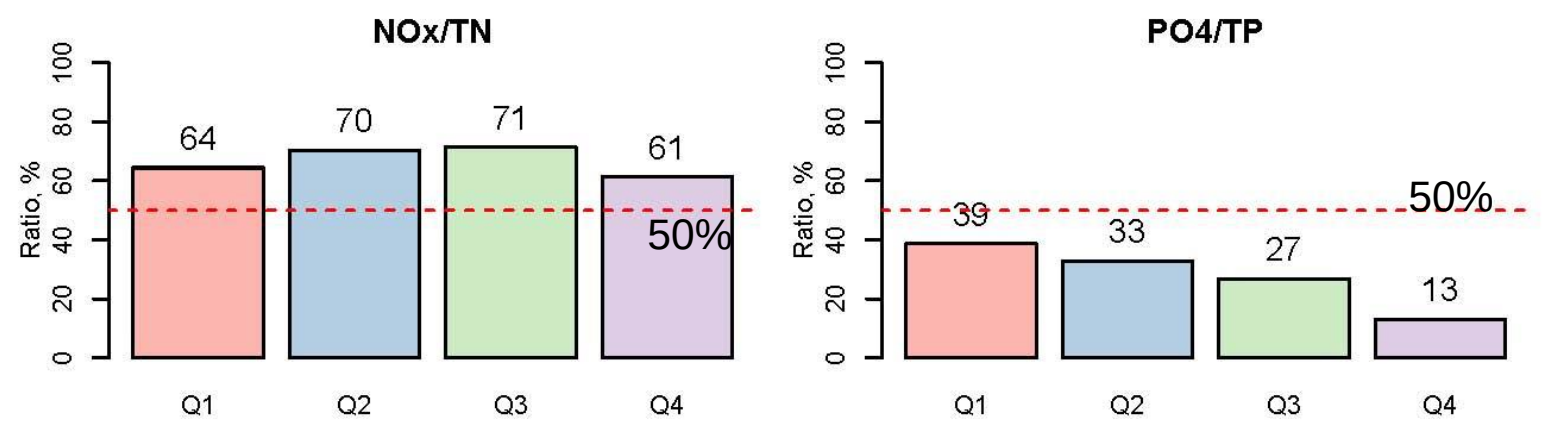






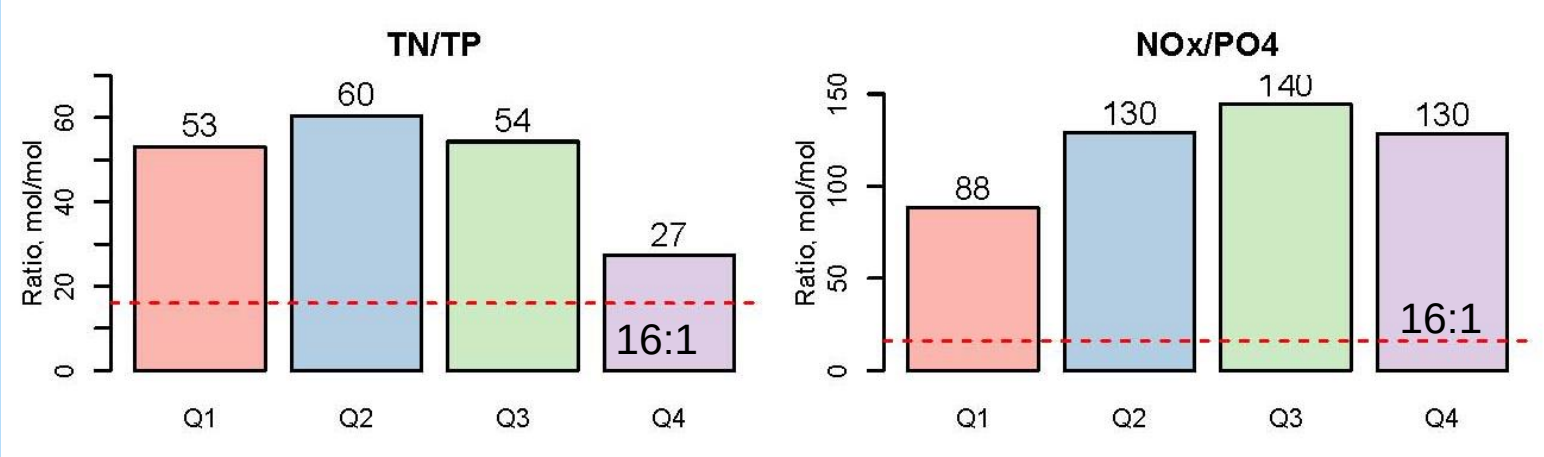


Distribution by Flow (Ratio)



NOx is always the dominant fraction of TN

PO4 is is always the less dominant fraction of TP



TN:TP ratio always > 16

NOx/PO4 ratio always > 16

Summary (Patterns by Flow Quantiles)

- Q4 represents 58% of flow among four quantiles. Q4 represents a similar % for TN, NOx, and PO4 but a much higher % for SS (91%) and TP (77%).
- Average flow-weighted concentration is similar among the four flow quantiles for TN, NOx, and PO4; it is much higher in Q4 than the other quantiles for SS and TP.
- NOx is a major fraction of TN in all four flow quantiles, whereas PO4 is a minor fraction of TP.
- For both TN:TP and NOx:PO4 molar ratios, all four flow quantiles are > 16:1.

❖ Explore the characteristics of riverine loads:

- By species: SS, TN, NOx, TP, PO4
  - ❑ 9 major tributaries
  - ❑ 4 seasons
  - ❑ 4 discharge quantiles

❖ **Explore the temporal trends of riverine loads:**

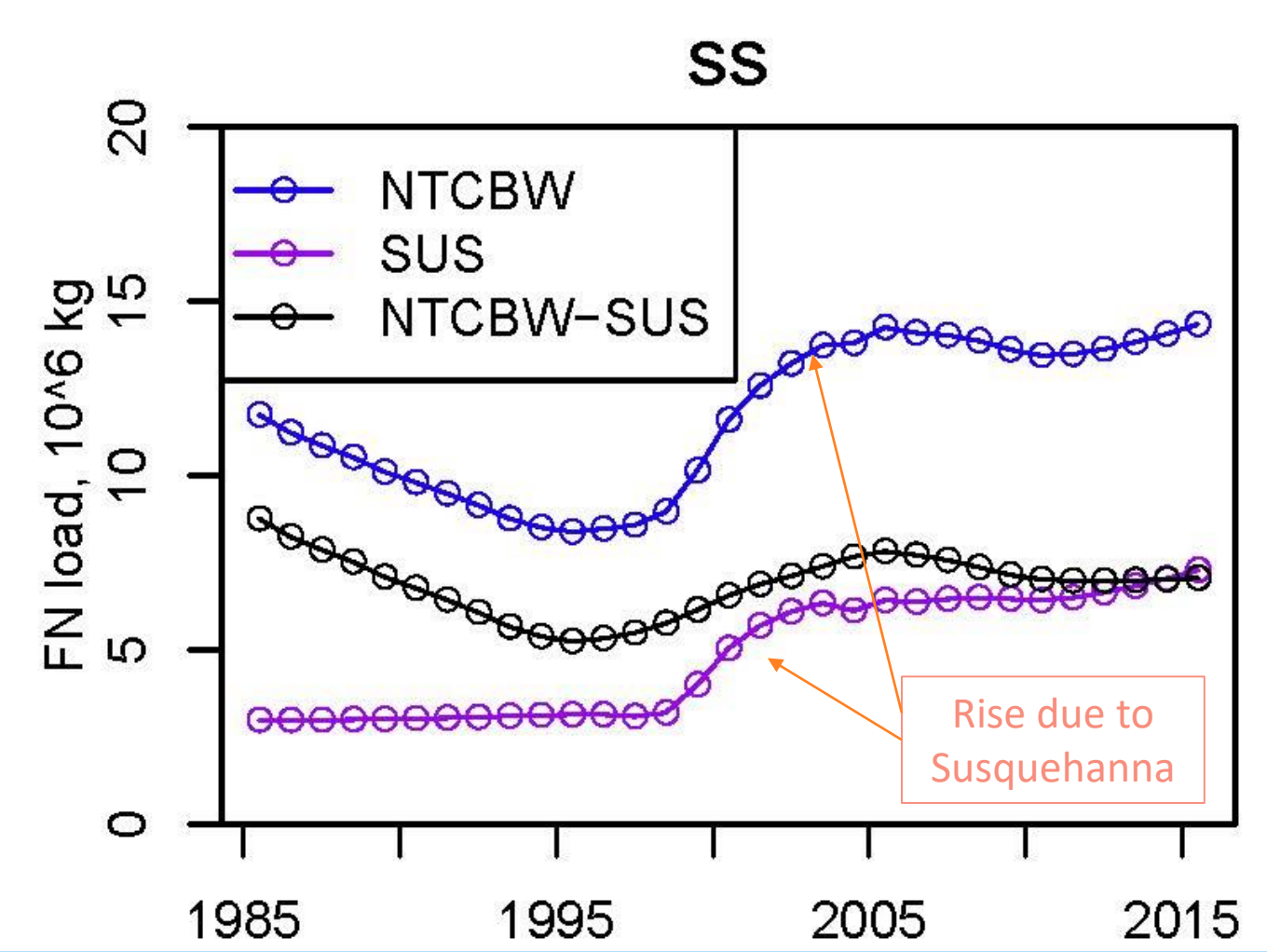
- By species: SS, TN, NOx, TP, PO4

Flow-normalized Estimates (w/ TIME)

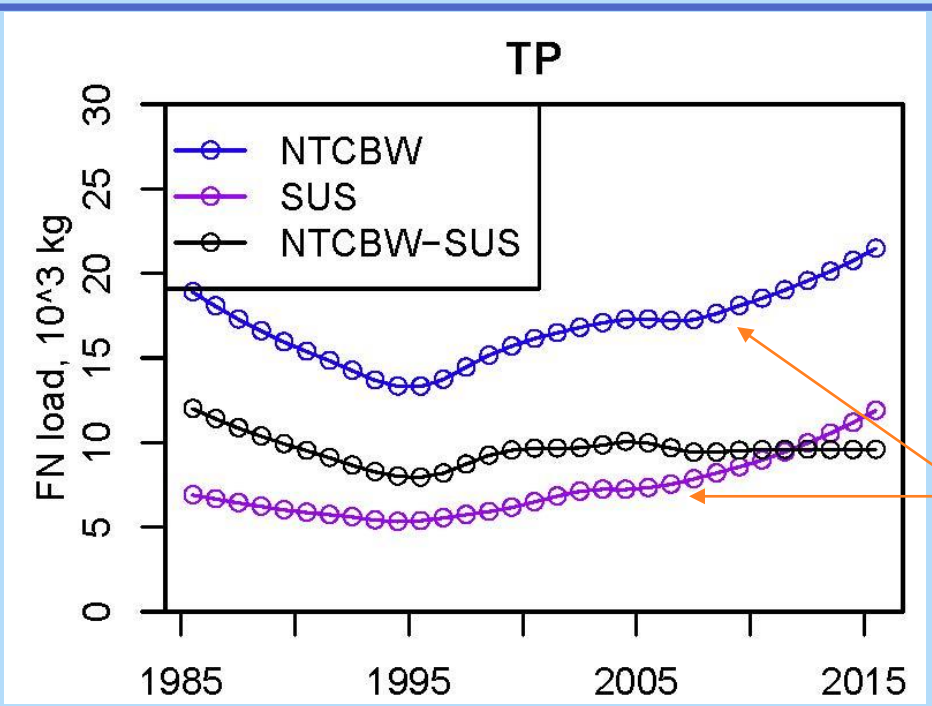
* Focused on the RIM watersheds (nontidal) in 1985-2016

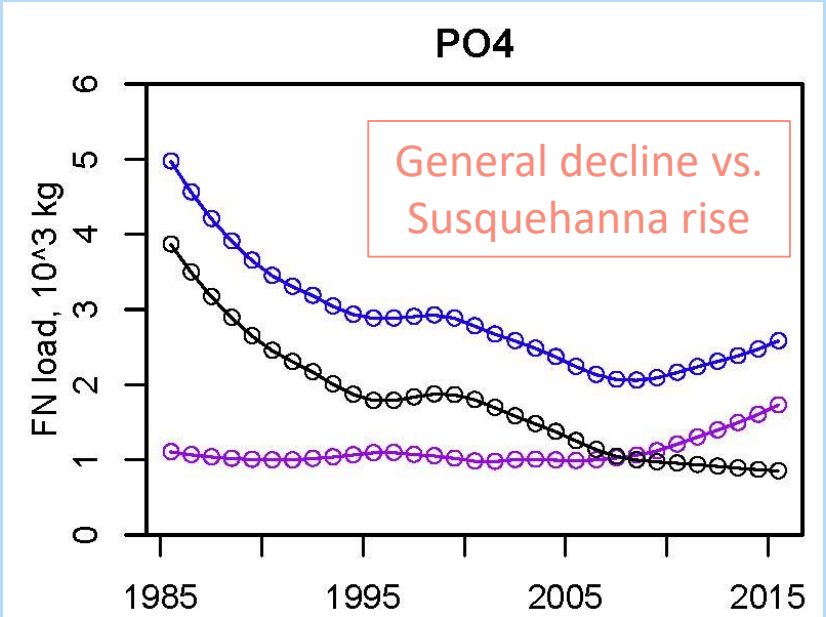
* Used USGS R workspaces by Moyer et al. (2017)

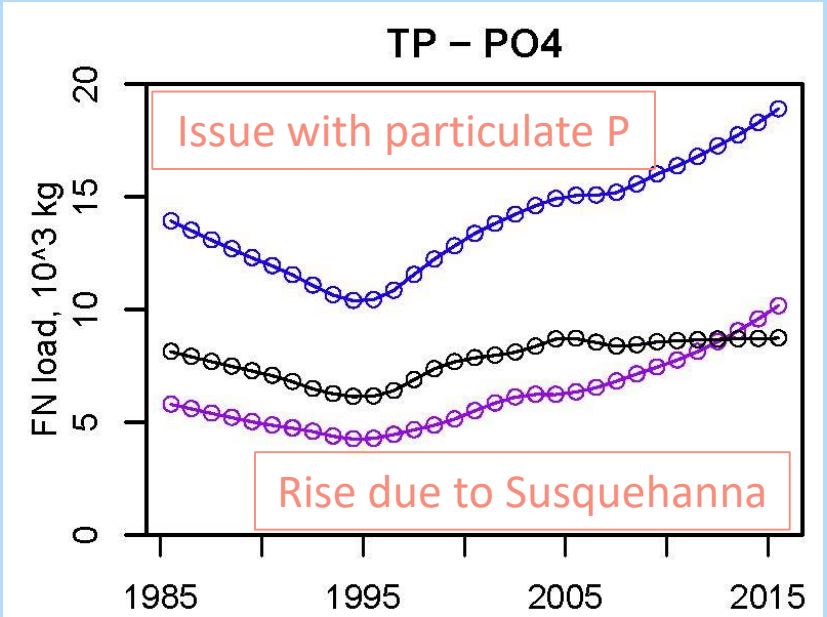
NTCBW Load = Sum of Loads at 9 RIM Stations



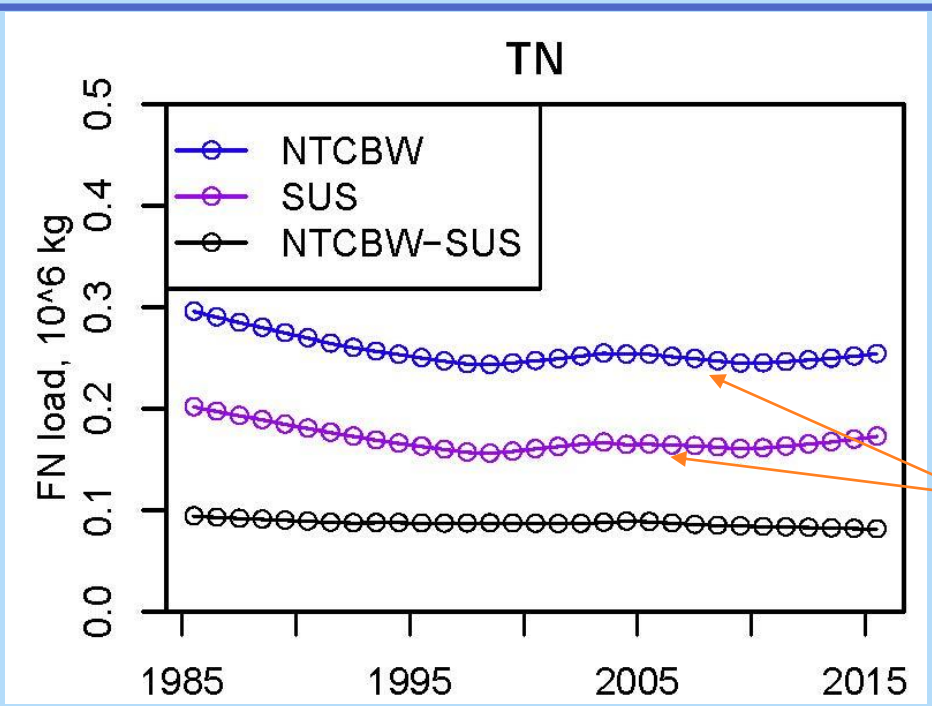
Trend - TP, PO4, TP-PO4

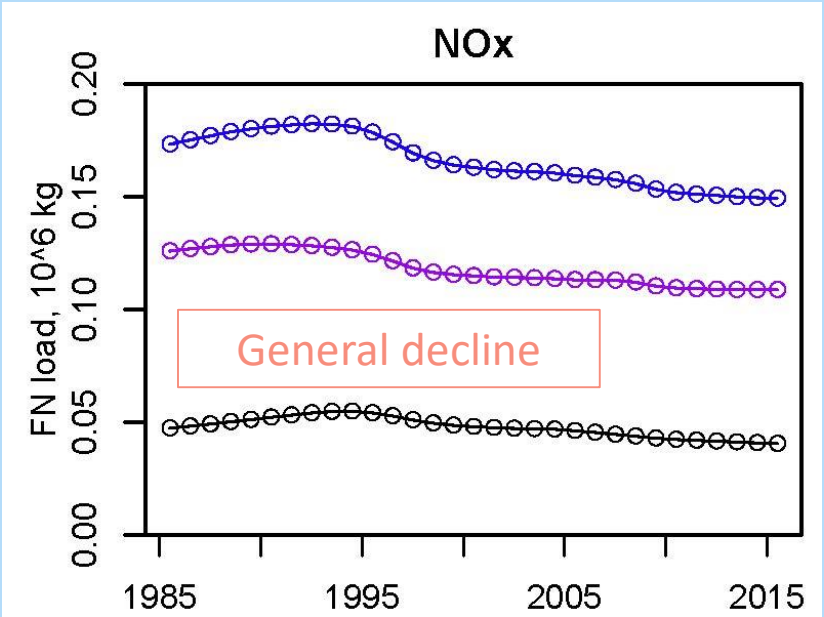


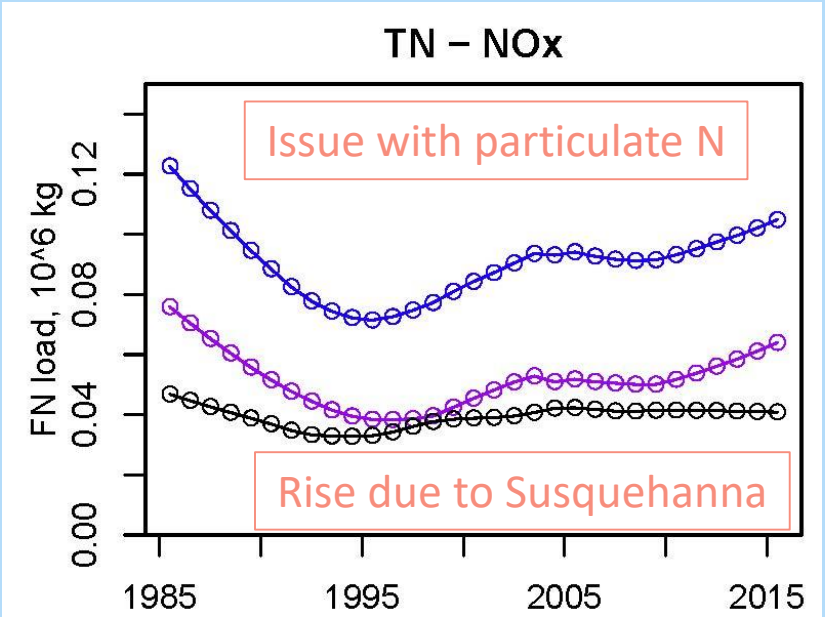




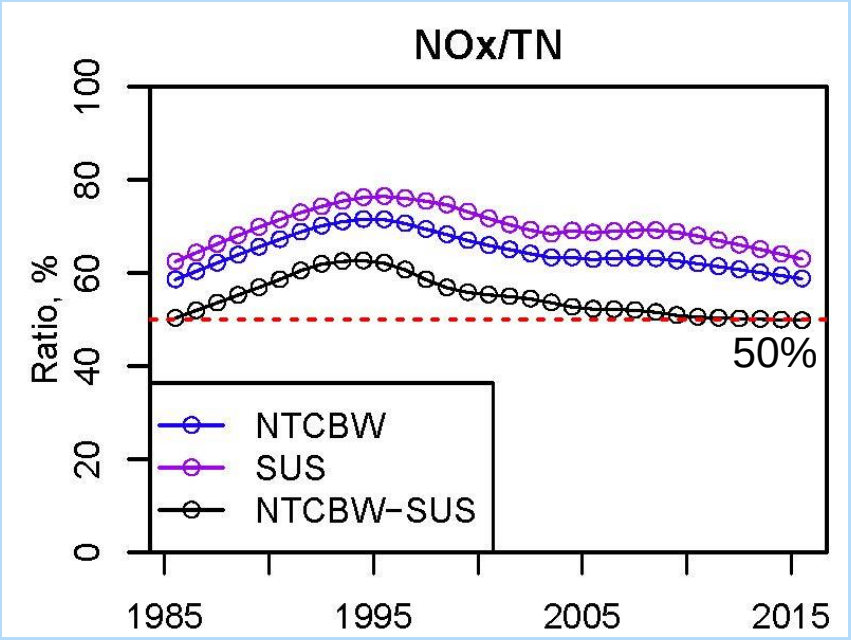
Trend - TN, NOx, TN-NOx

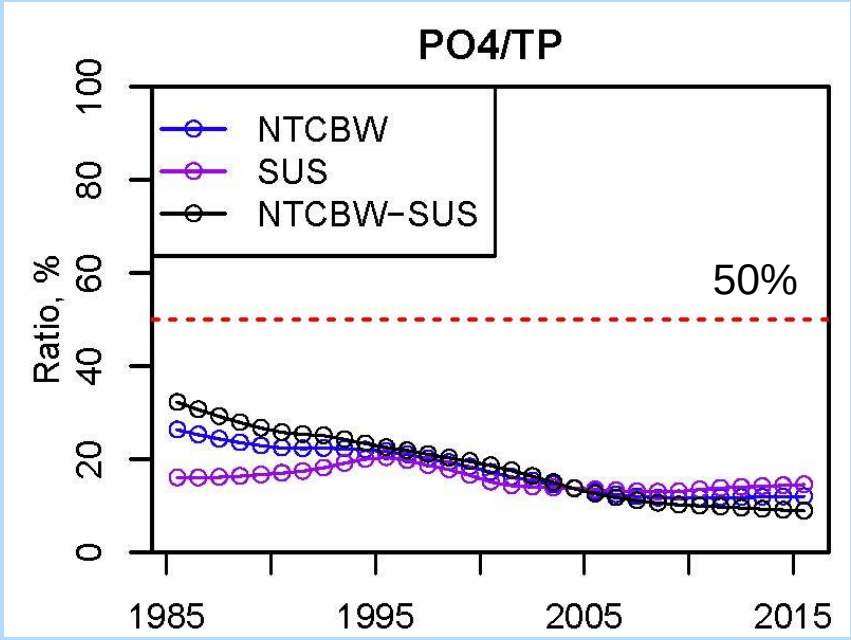


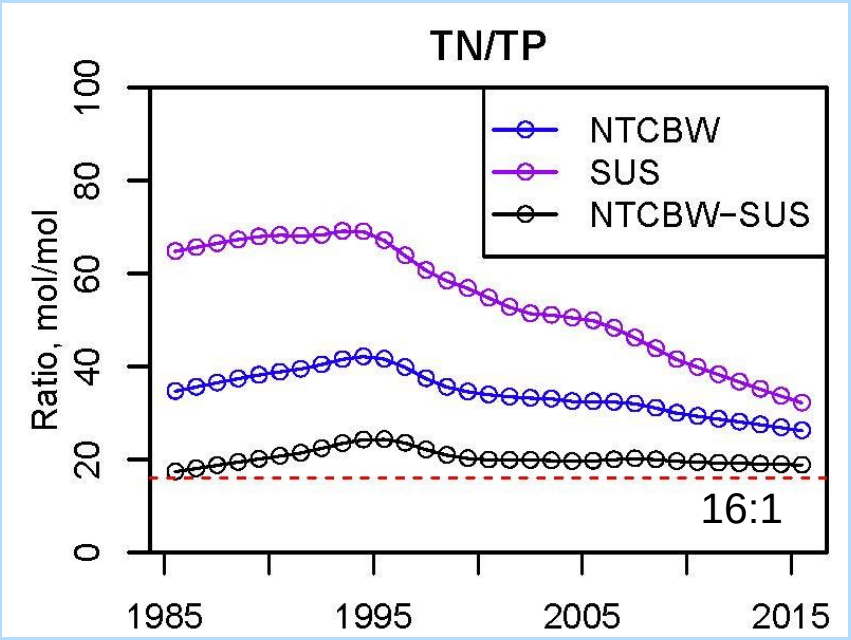


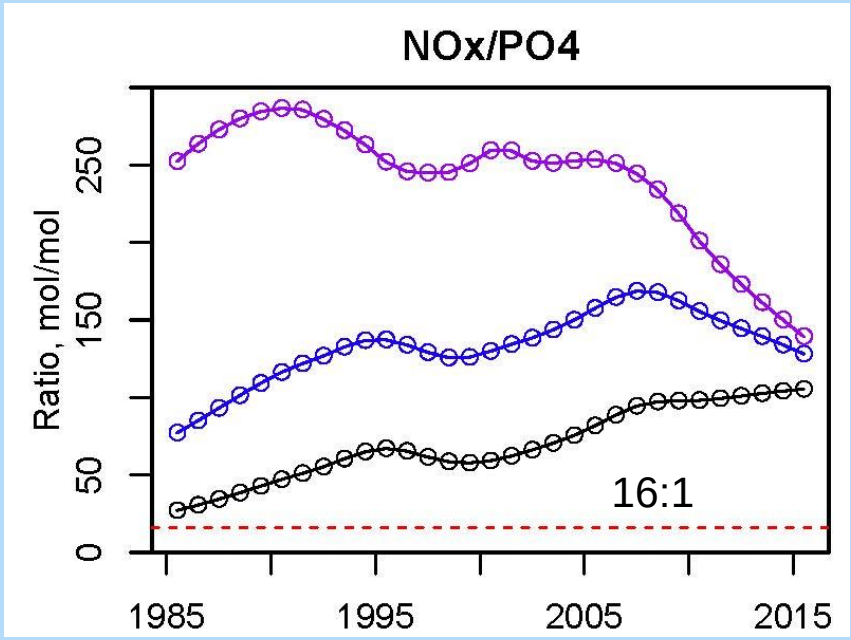


Trend - Ratio


NOx/TN
Ratio, %
0
20
40
60
80
100
1985
1995
2005
2015
50%
NTCBW
SUS
NTCBW-SUS


PO4/TP
Ratio, %
0
20
40
60
80
100
1985
1995
2005
2015
NTCBW
SUS
NTCBW-SUS
50%


TN/TP
Ratio, mol/mol
0
20
40
60
80
100
1985
1995
2005
2015
NTCBW
SUS
NTCBW-SUS
16:1

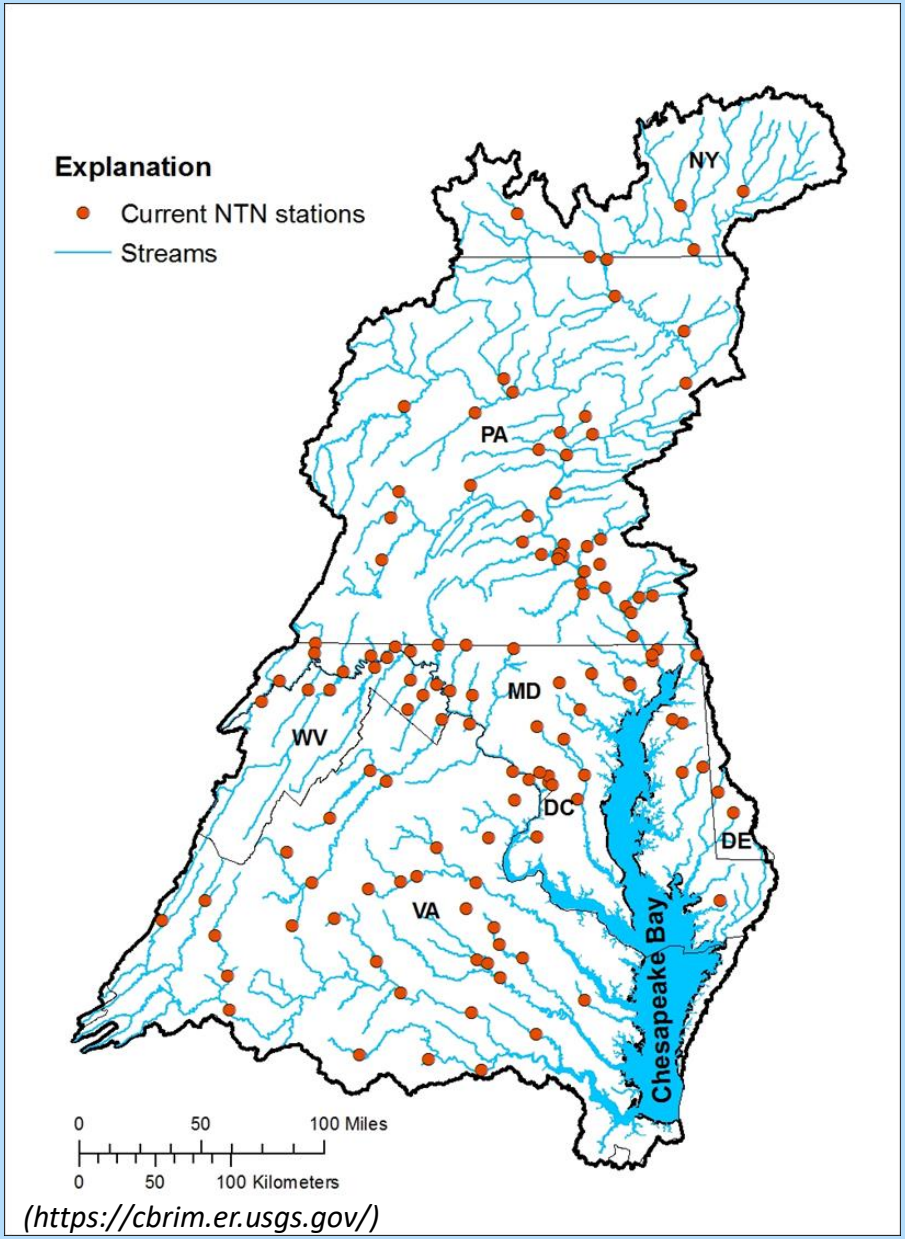

NOx/PO4
Ratio, mol/mol
0
50
150
250
1985
1995
2005
2015
16:1

Summary (Long-term Trends)

- Sediment and particulate nutrients loads from the NTCBW have risen since ~1995 – largely driven by Susquehanna trends.
- Dissolved nutrients loads from the NTCBW have declined in general – suggesting effectiveness of management (e.g., WWTP upgrades, Clean Air Act).
- NOx is a major fraction of TN in all years, whereas PO4 is always a minor fraction of TP.
- TN:TP and NOx:PO4 molar ratios are > 16:1 in all years, but TN:TP ratios have declined in recent years due to opposite trends in TN and TP – potentials for changes in nutrient limitation in the downstream estuaries.


THANK YOU!

Background



(https://cbrim.er.usgs.gov/)

- The **largest** estuary in North America;
- 64,000 mi^2 watershed -- Washington, D.C. and parts of **six states** (MD, VA, WV, DE, PA, NY);
- **14:1** land-to-water ratio, **the largest** of any coastal water body in the world;
- N, P, SS reduction enforced by the **2010 Chesapeake Bay TMDL**;
- Many major and minor tributaries, with **>90%** of load from the **9 major rivers** and **~60%** of that from **Susquehanna River**;
- River loads estimated and reported using a statistical tool called **WRTDS**.

WRTDS: Load Estimation

Daily flow & discretely-sampled concentration data at a sampling site

↓

WRTDS
(Hirsch et al. 2010)

↓

Daily conc. and load estimates

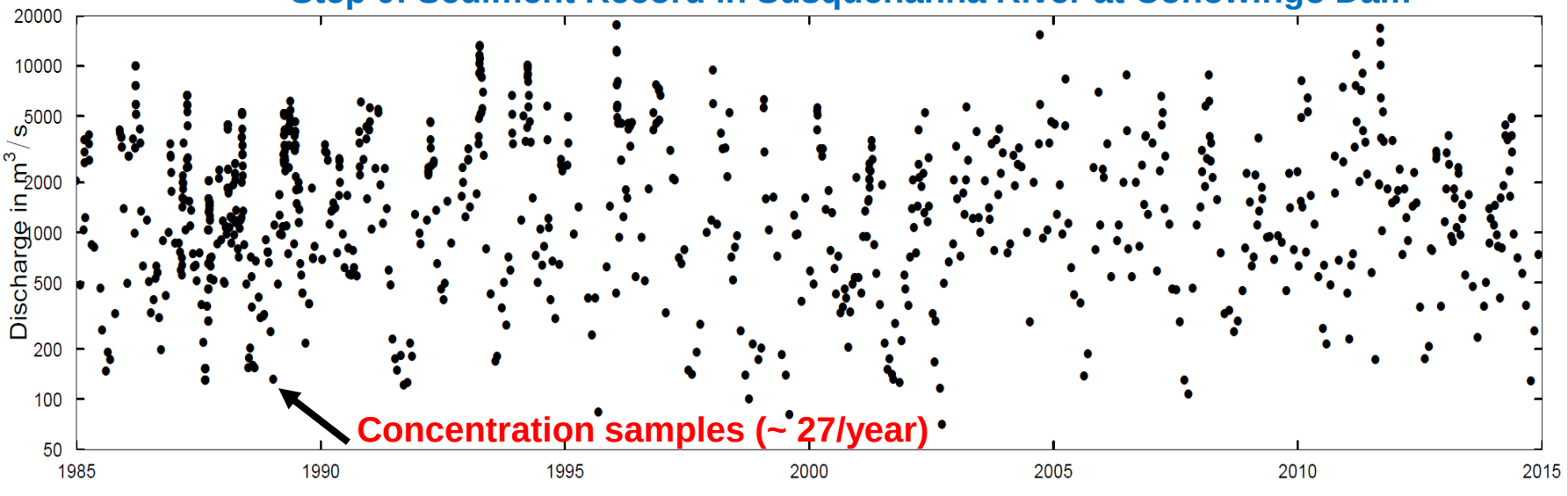
WRTDS (Hirsch *et al.*, 2010)
[Weighted Regressions on Time, Discharge, and Season]

$$ln(C) = \beta_0 + \beta_1 t + \beta_2 ln(Q) + \beta_3 sin(2\pi t) + \beta_4 cos(2\pi t) + \varepsilon$$

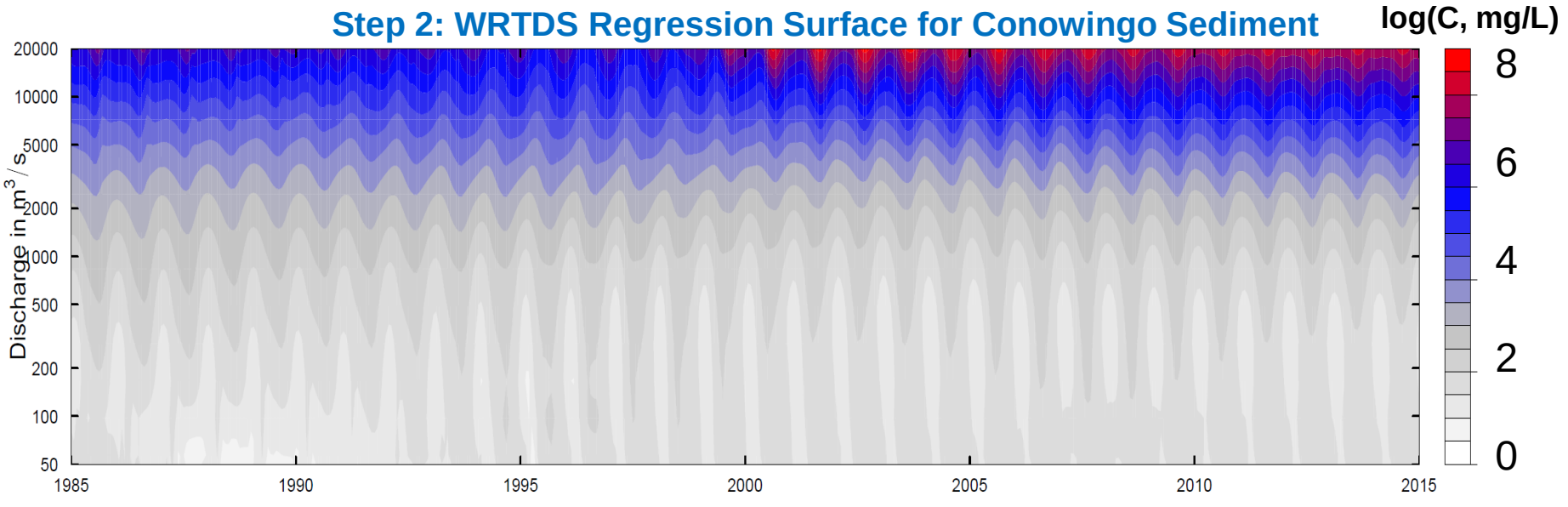
- One single model (coefficient set) for each day of estimation;
- No assumption on fixed C-Q relations over time or season;
- Better model performance;
- Adopted in a range of studies, including Chesapeake, Great Lakes, Mississippi, Baltic Sea.

For the latest load estimates, see Moyer et al. (2017); https://doi.org/10.5066/F7RR1X68.

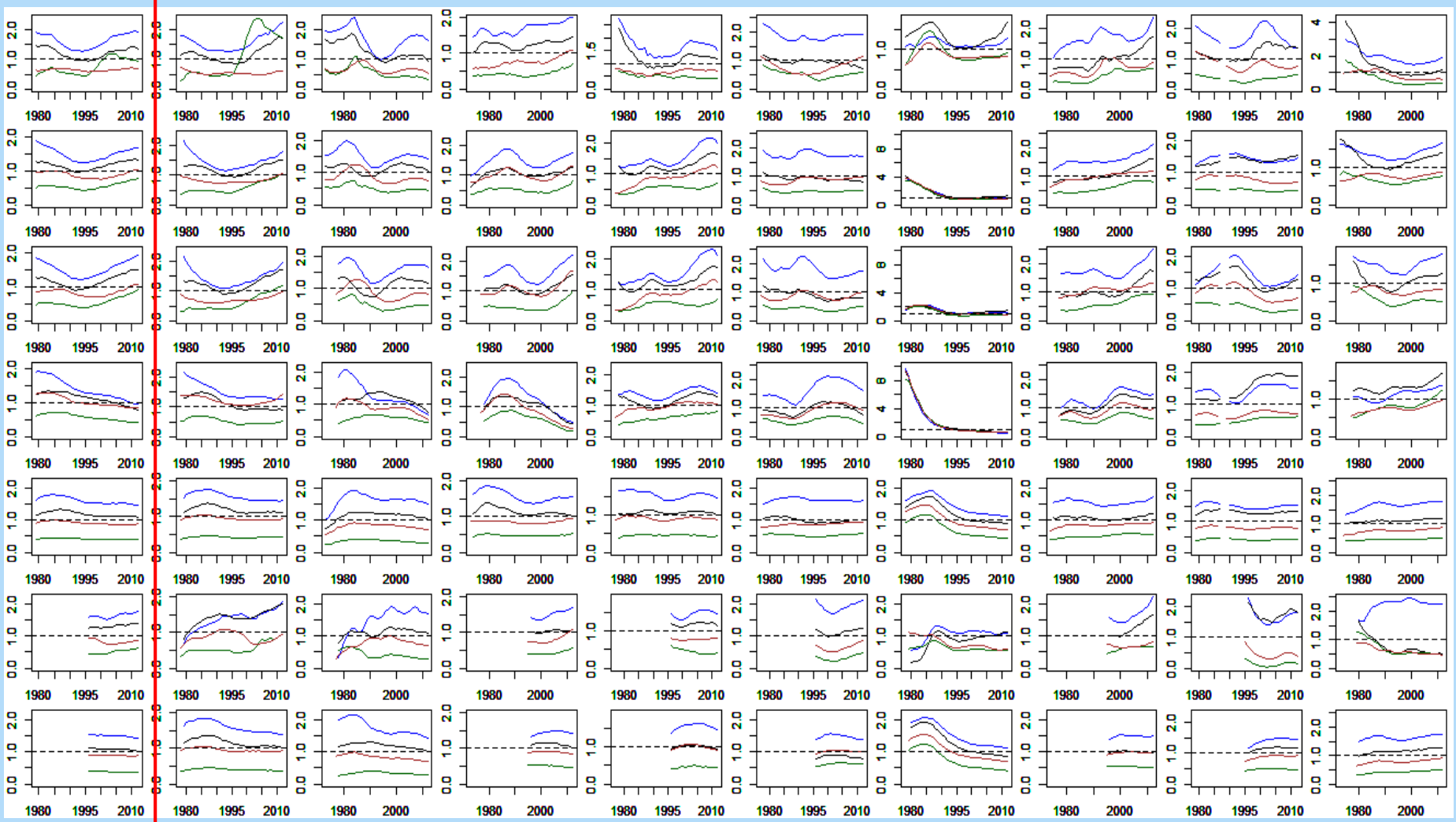
Method: WRTDS



Method: WRTDS

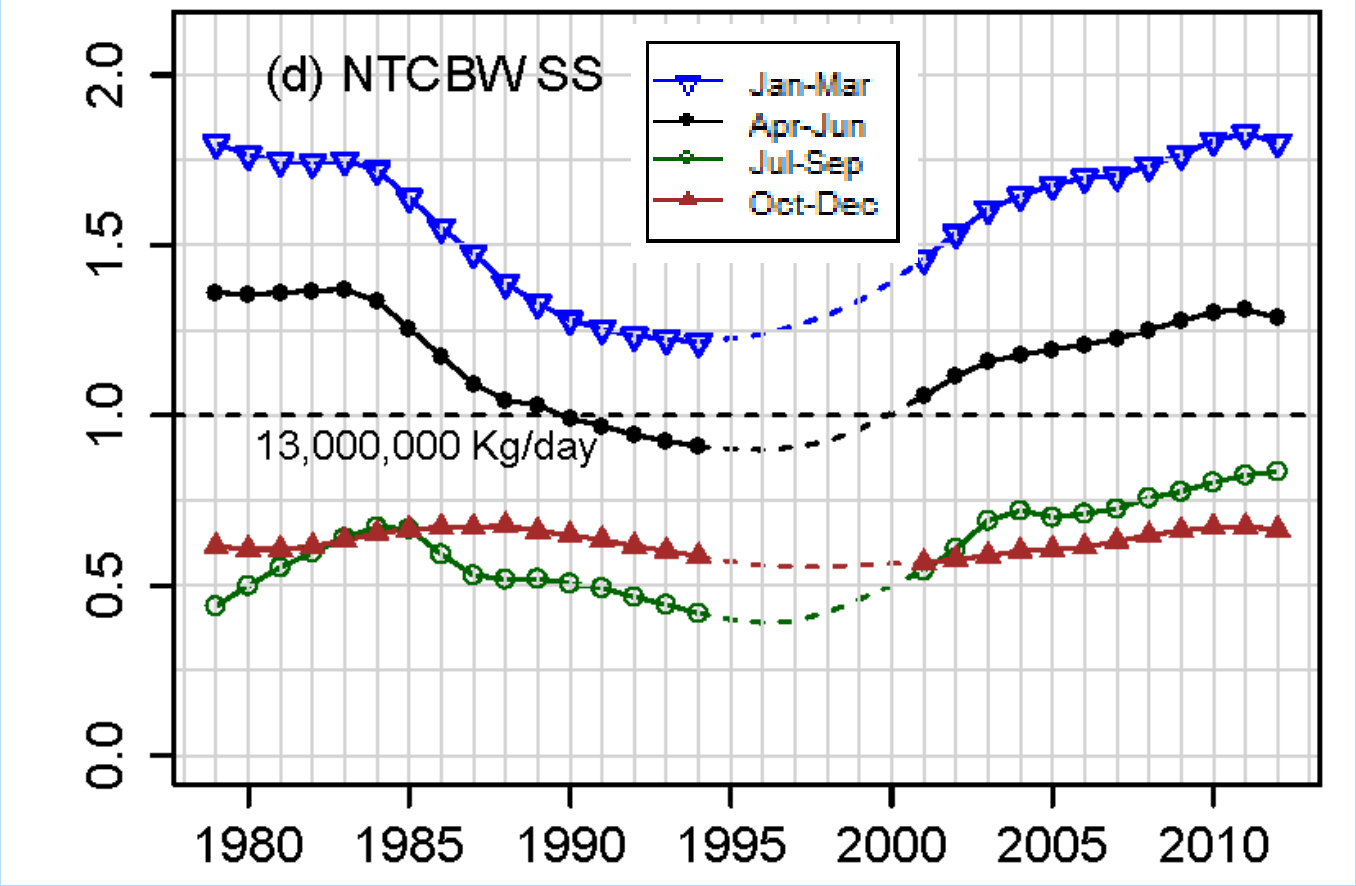


WRTDS Model Results



Zhang, Brady, Boynton, and Ball, JAWRA, 2015

NTCBW SS Load = Sum of Loads at 9 RIM Stations

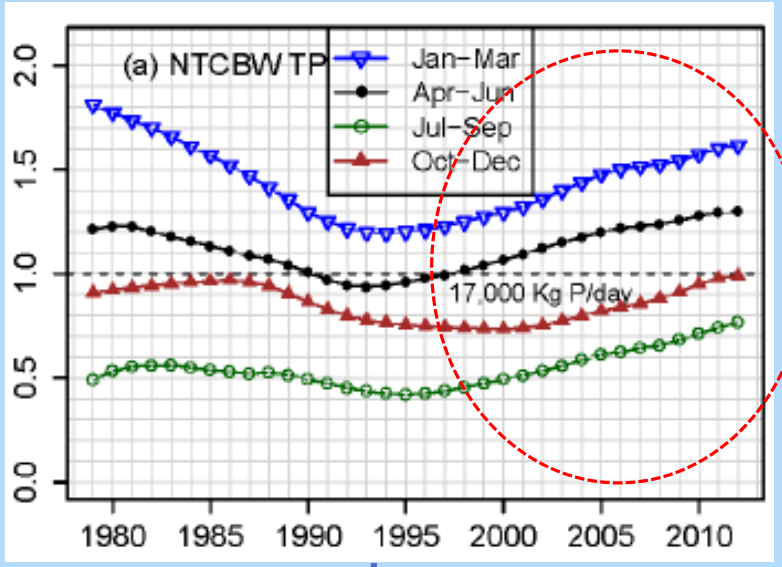


(1.0 = long-term *annual median* load; color = season)

Zhang, Brady, Boynton, and Ball, JAWRA, 2015

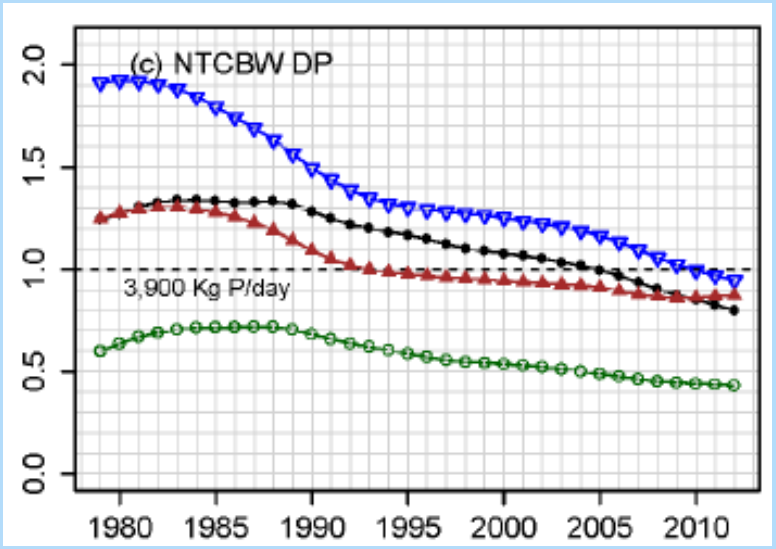
NTCBW TP, PP, DP

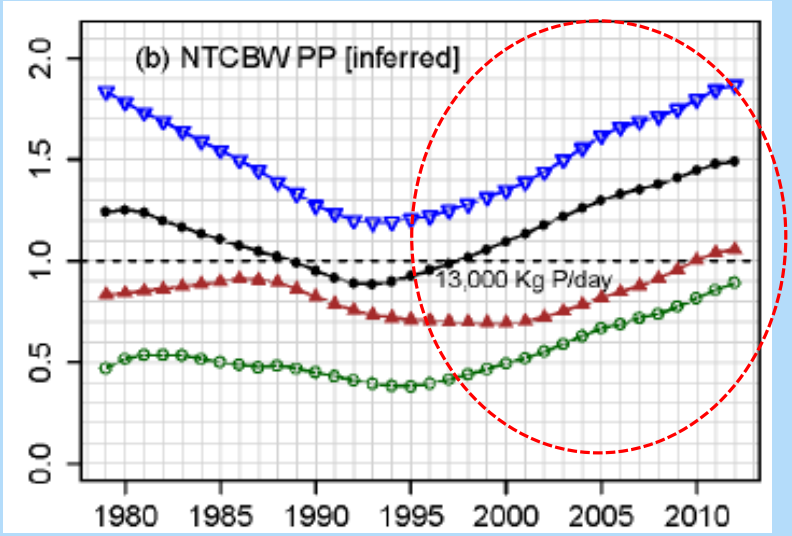
TP: Total Phosphorus
DP: Dissolved Phosphorus
PP: Particulate Phosphorus



Steady decline
in DP loading since 1985

Rising TP and PP
in last decade



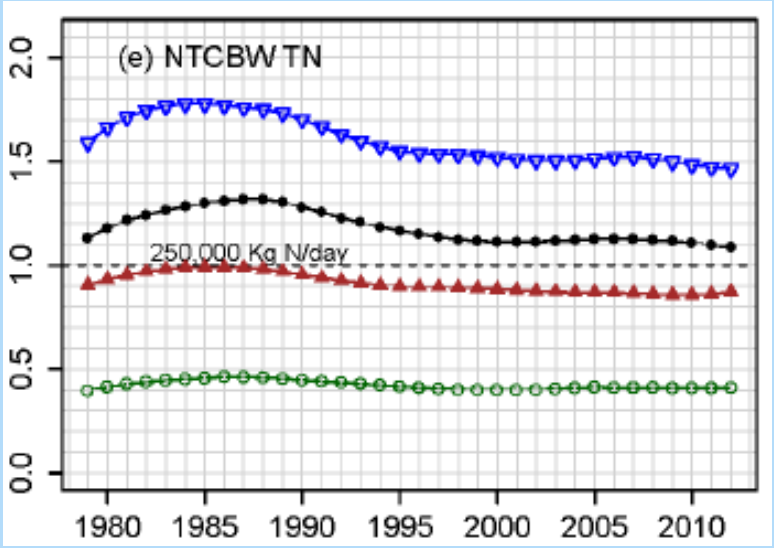


Zhang, Brady, Boynton, and Ball, JAWRA, 2015

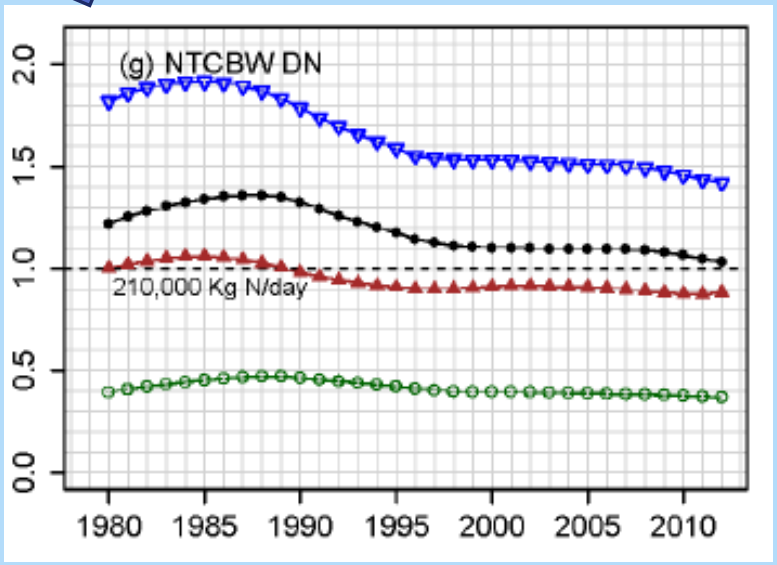
NTCBW TN, PN, DN

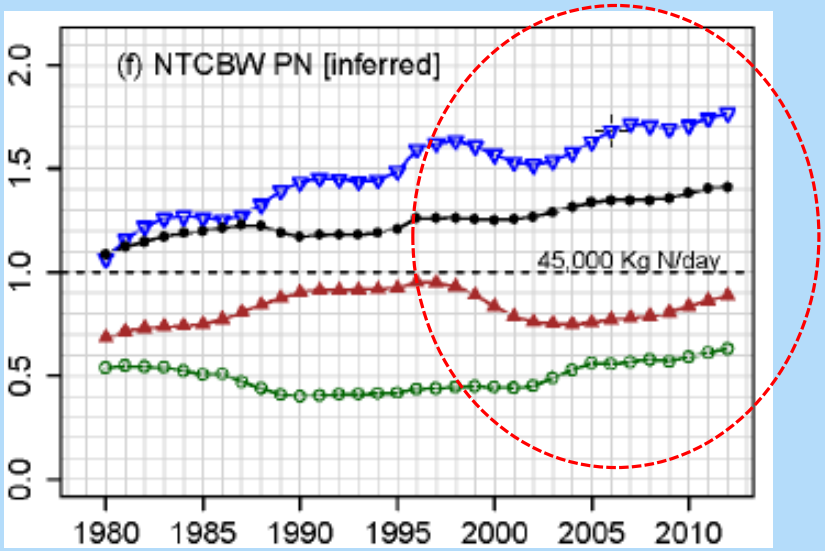
TN: Total Nitrogen
DN: Dissolved Nitrogen
PN: Particulate Nitrogen

Steady but lessening decline in TN and DN loading since 1985



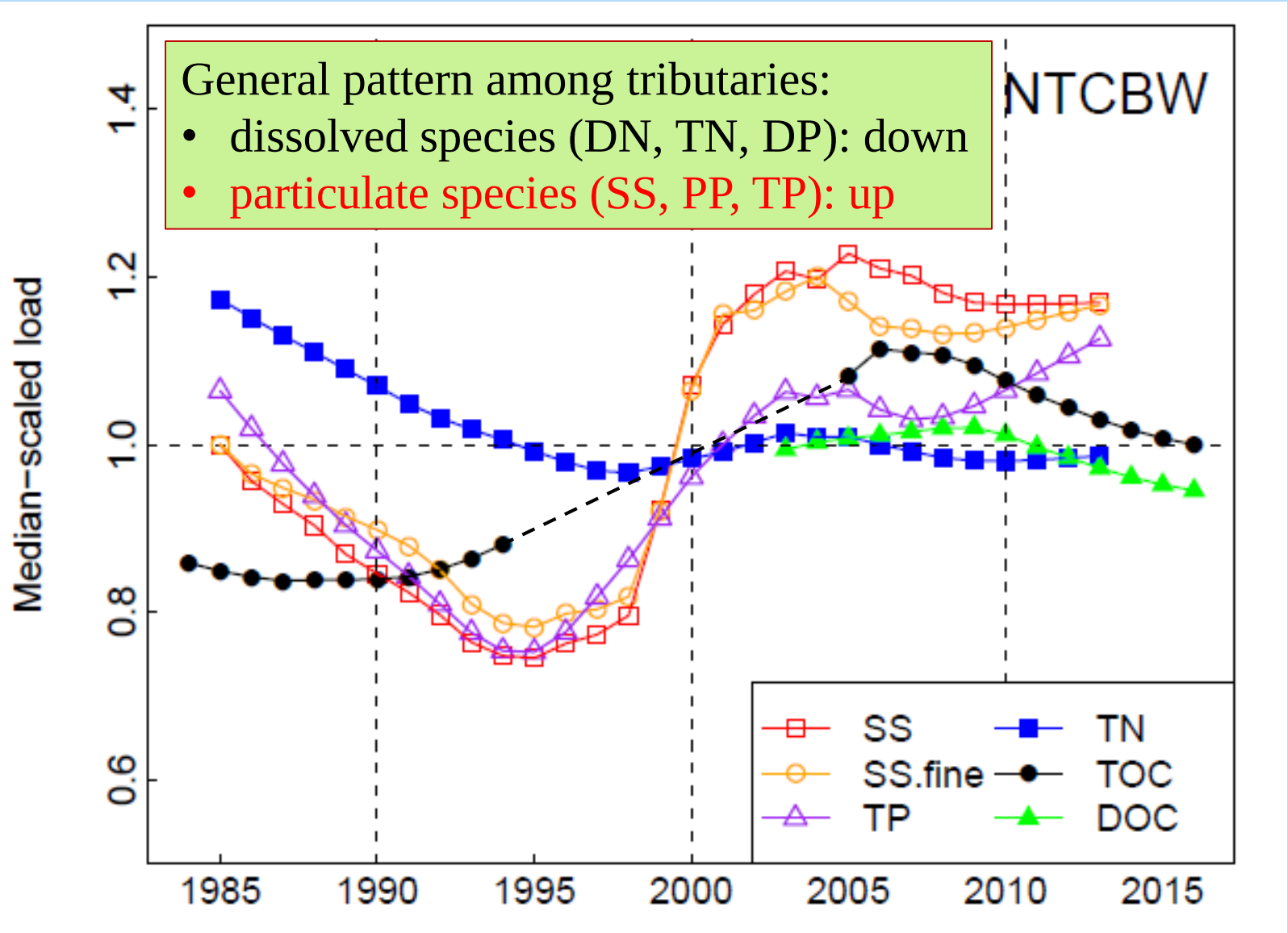
Rising PN in recent decades?? (small diff of large numbers





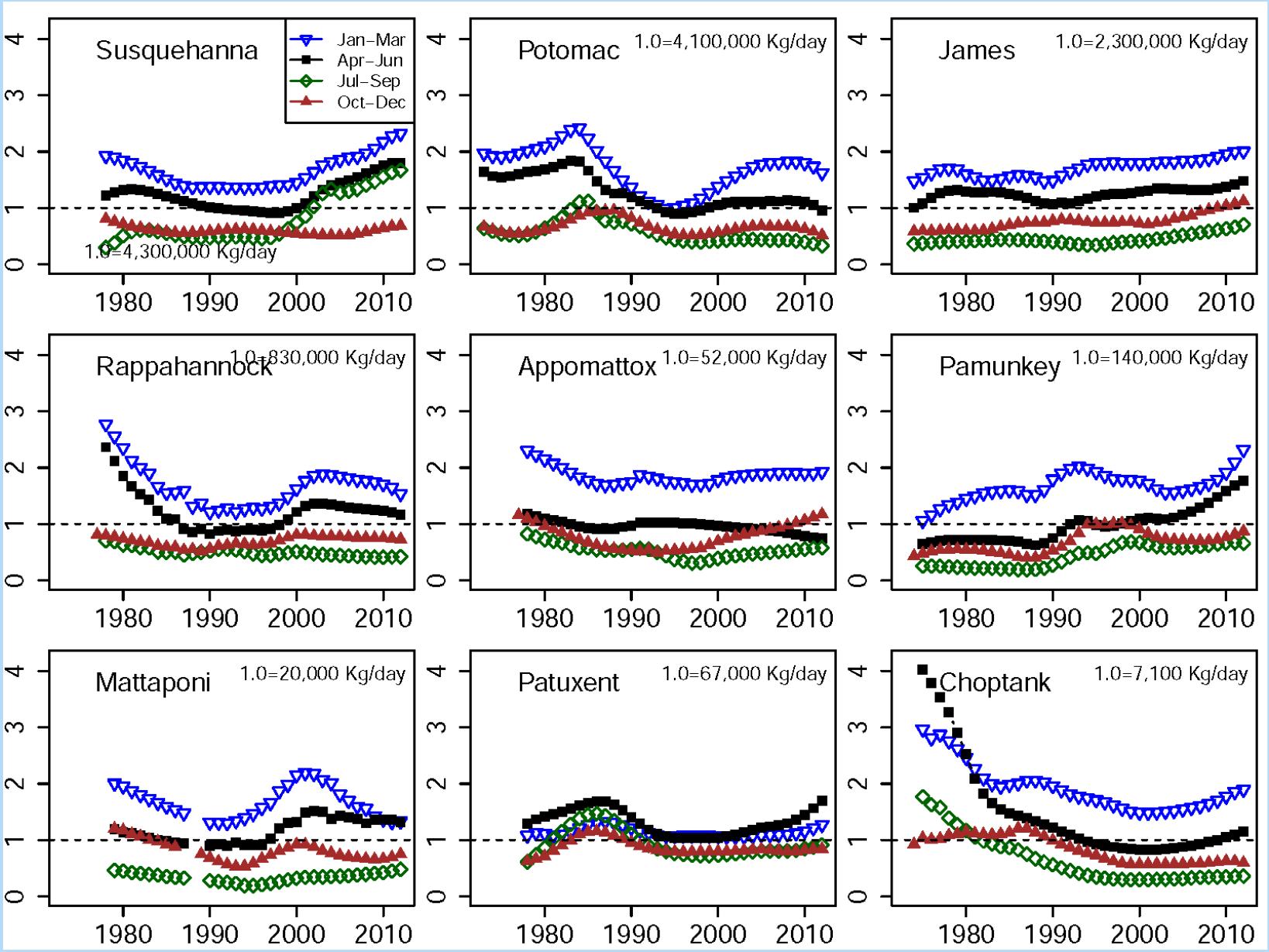
Zhang, Brady, Boynton, and Ball, JAWRA, 2015

NTCBW Annual Trends



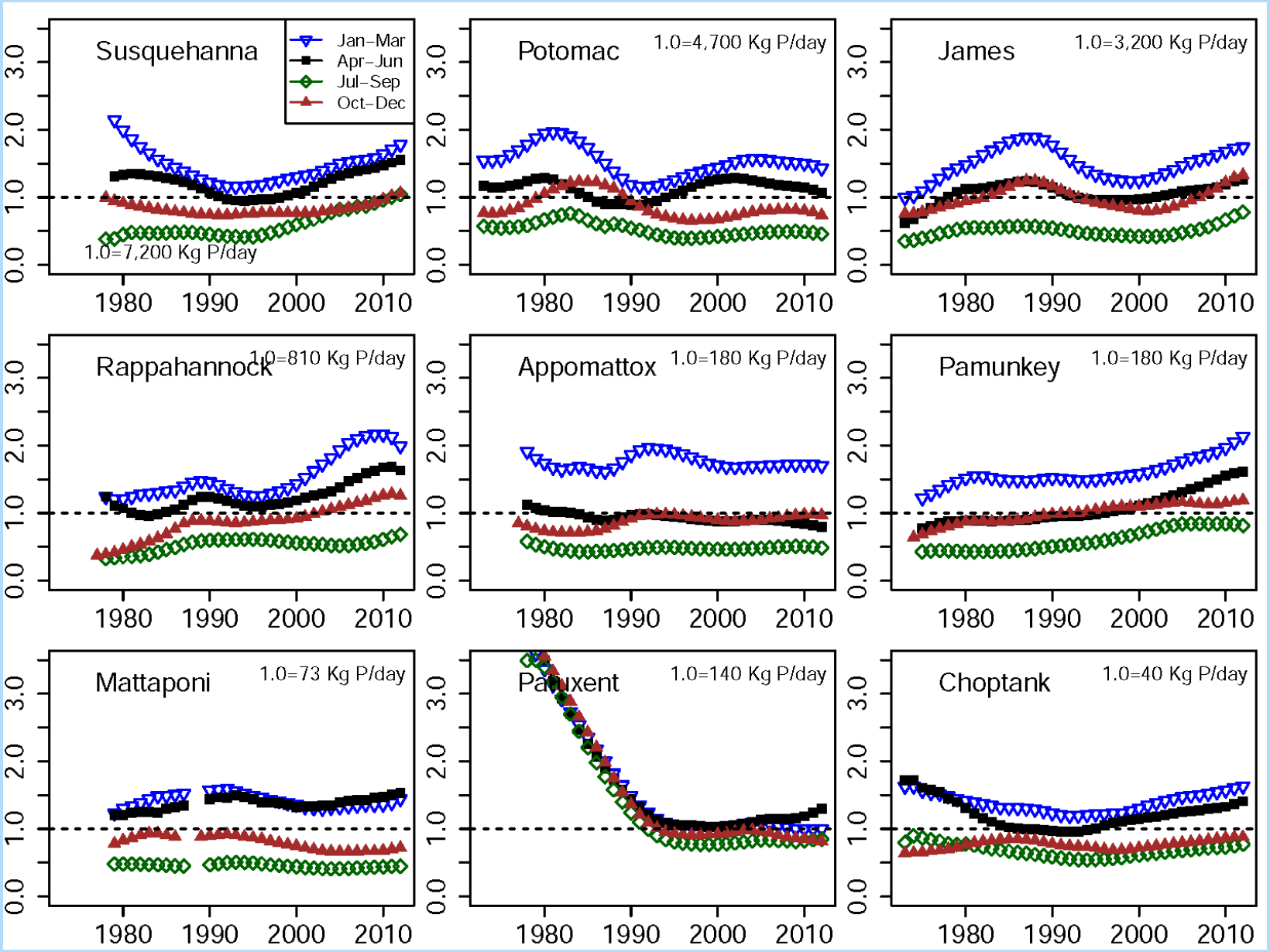
Zhang, Brady, Boynton, and Ball, JAWRA, 2015
Zhang and Blomquist, STOTEN, 2018

Tributary SS



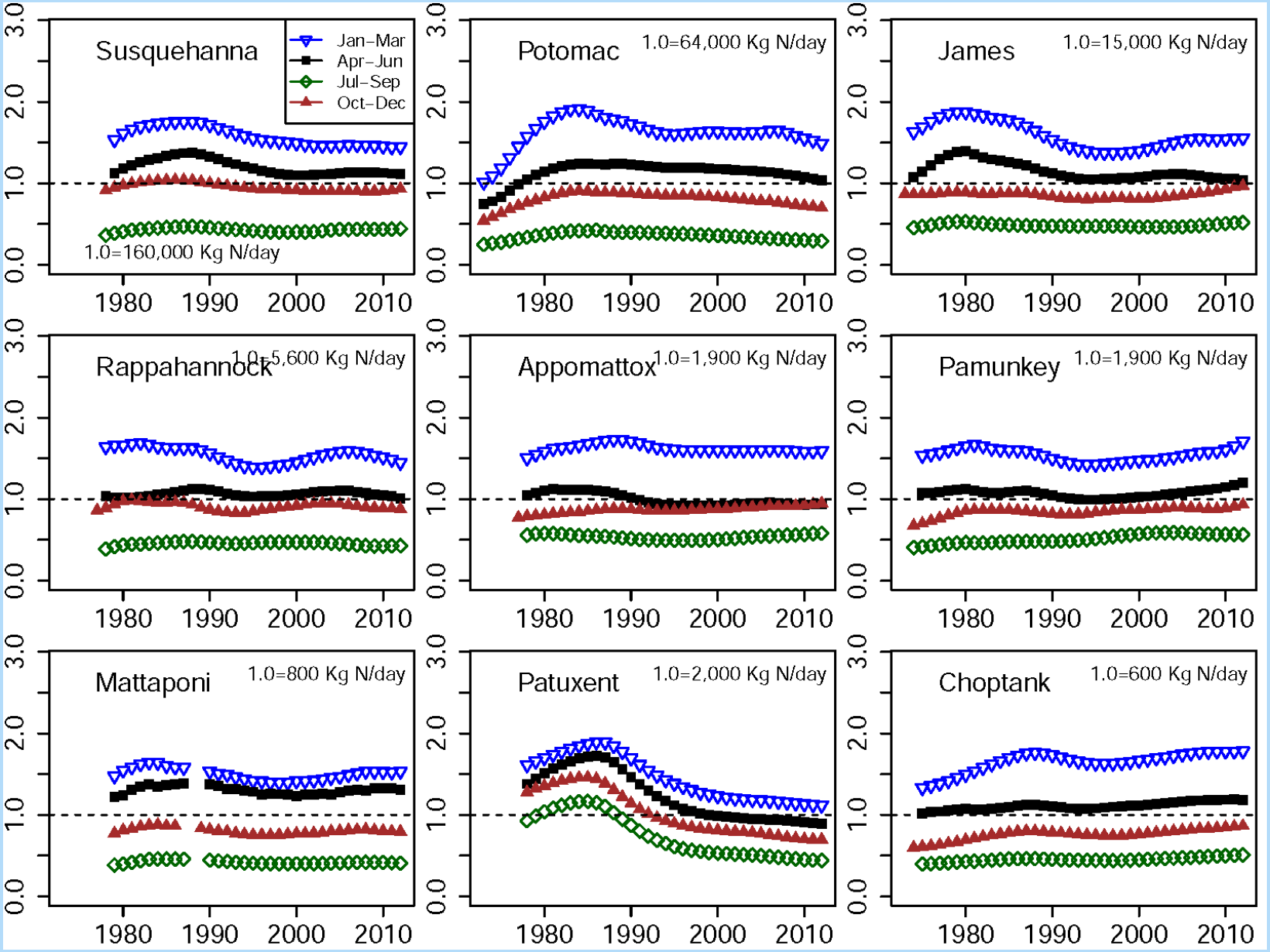
Zhang, Brady, Boynton, and Ball, JAWRA, 2015

Tributary TP



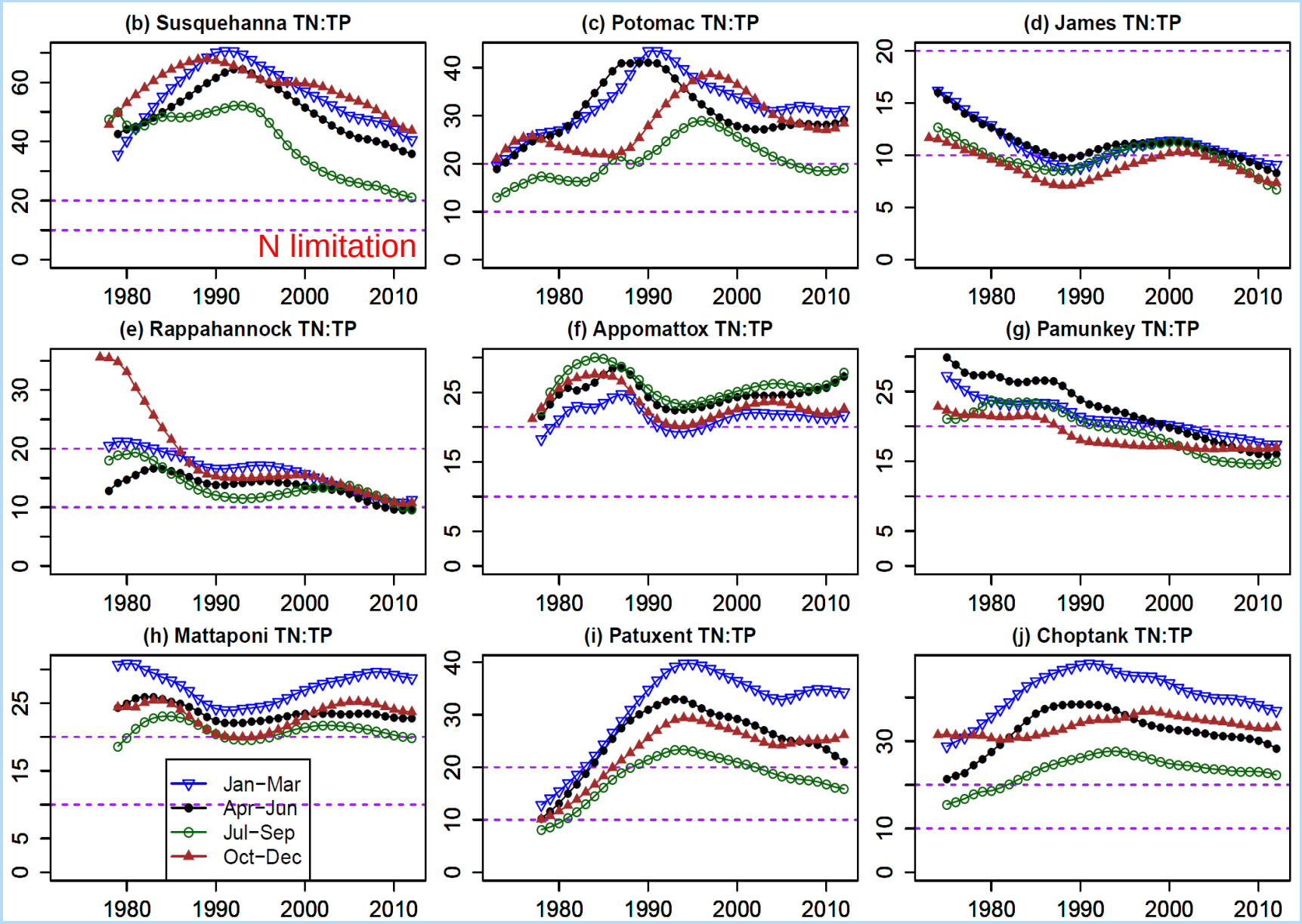
Zhang, Brady, Boynton, and Ball, JAWRA, 2015

Tributary TN



Zhang, Brady, Boynton, and Ball, JAWRA, 2015

Tributary TN:TP Molar Ratio



Zhang, Brady, Boynton, and Ball, JAWRA, 2015