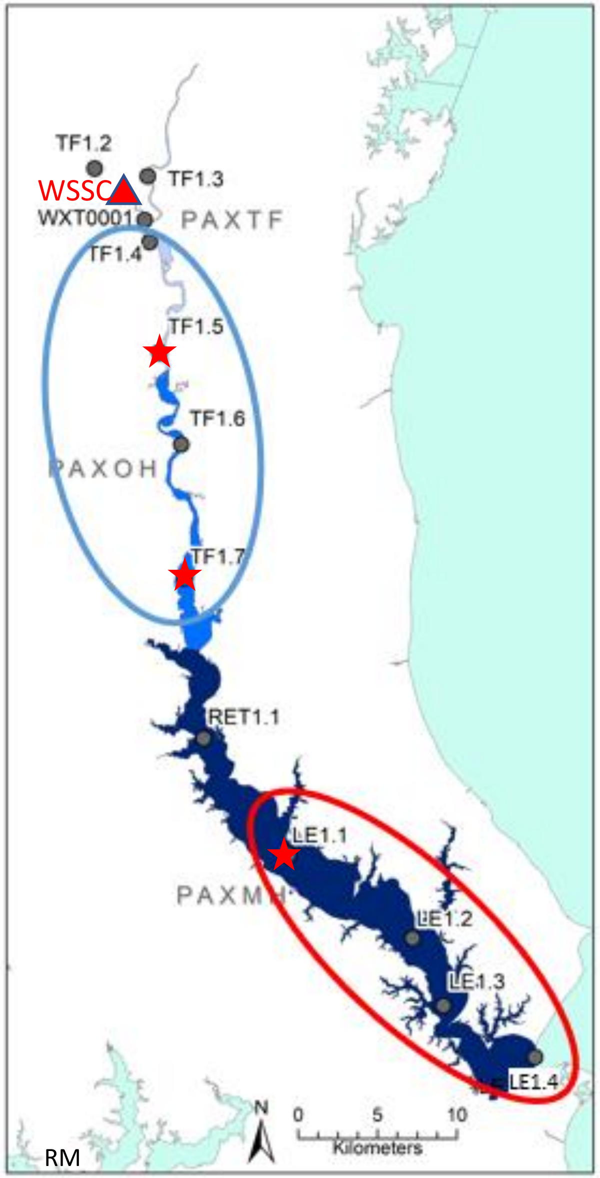
Patuxent River—Phytoplankton Stressor-Response Model (10/07/2020)



Purpose

- Investigate potential stressor-response models associated with higher phytoplankton biomass in recent years despite decreased nutrient loadings from the watershed.

Presenters

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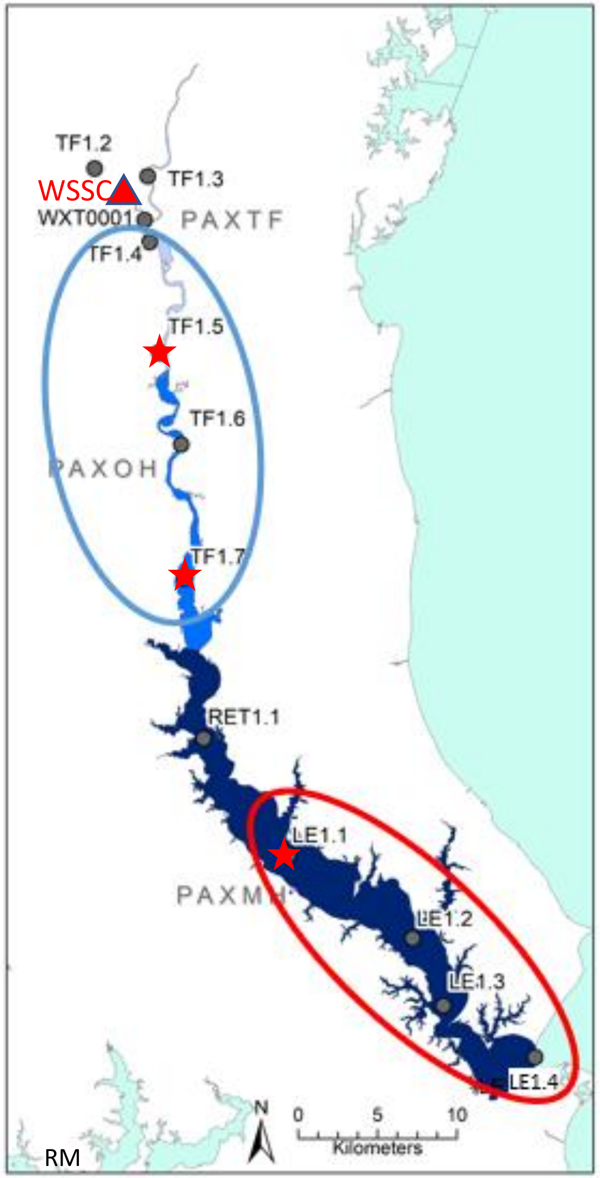
Patuxent River—Phytoplankton Stressor-Response Model



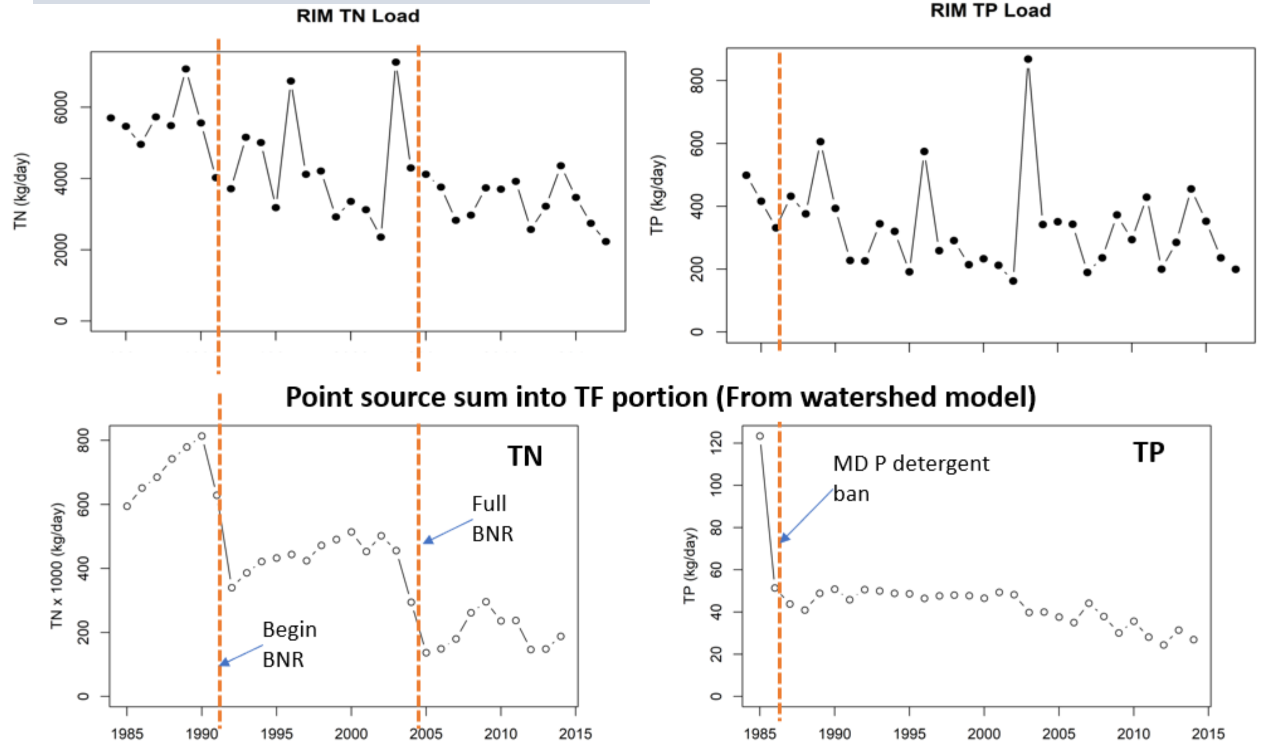
Content

- Background
  - Nutrient milieu
  - GAM models
- Conceptual nutrient v. chlorophyll *a* model
- Structural equation models

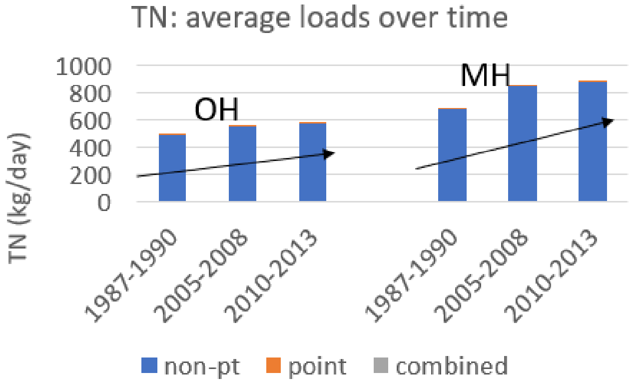
Nutrient Loads

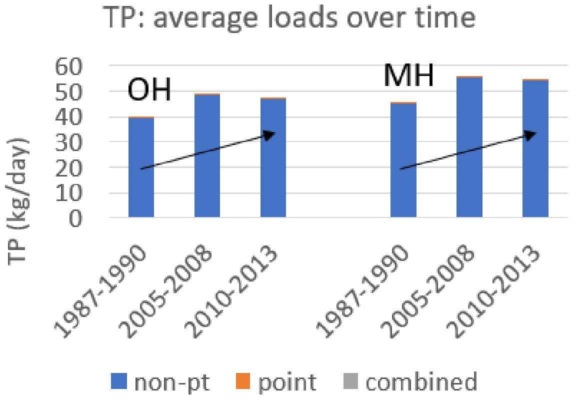
- Reductions from upstream
- Increases in lower estuary

Long-term Tidal Fresh: Loads



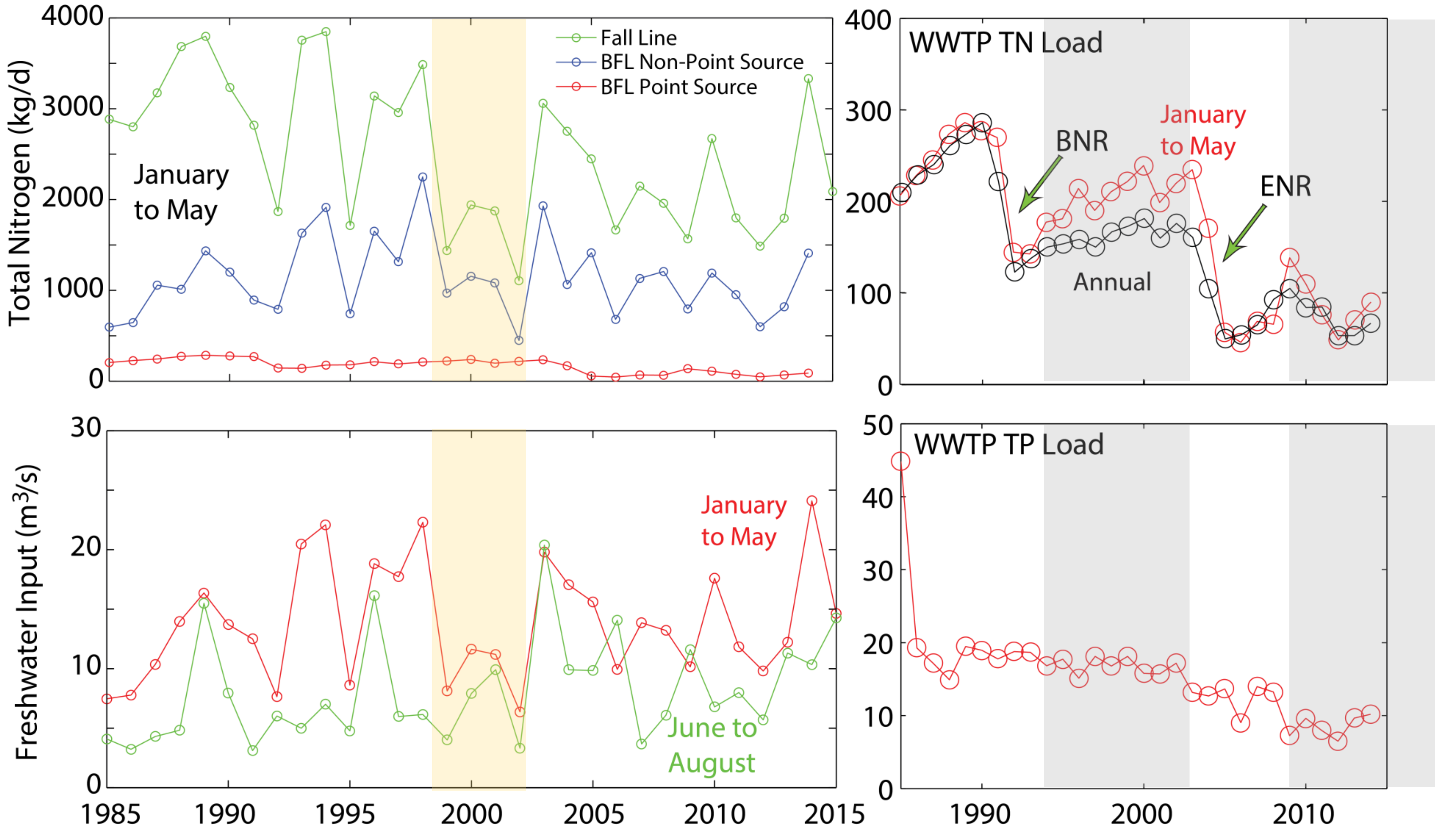
Lower Estuary: Direct Loads





Source: R. Murphy slides (5-16-19)

Study period



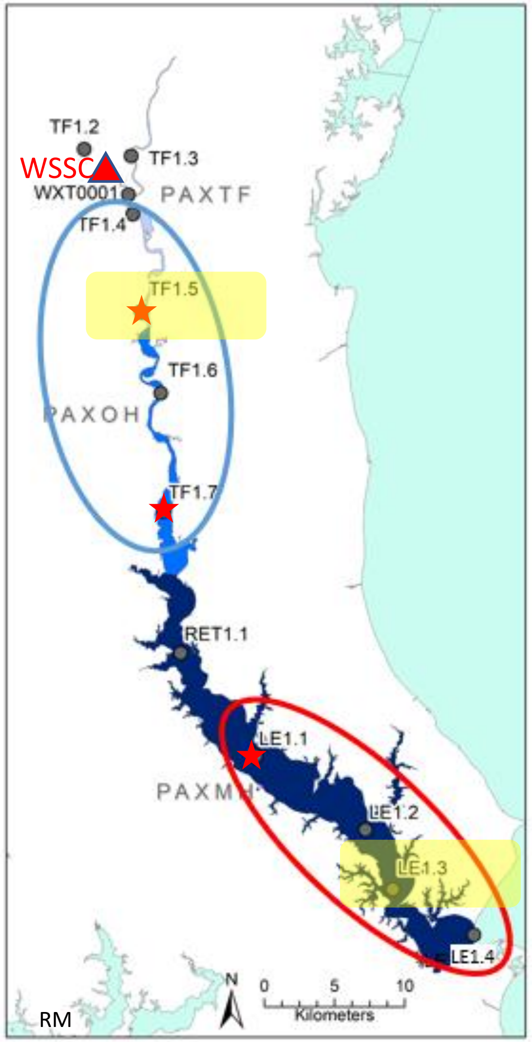
1999-2002 drought

1994-2003

2009-2018

Source: J. Testa (p.c. 7-10-2020)

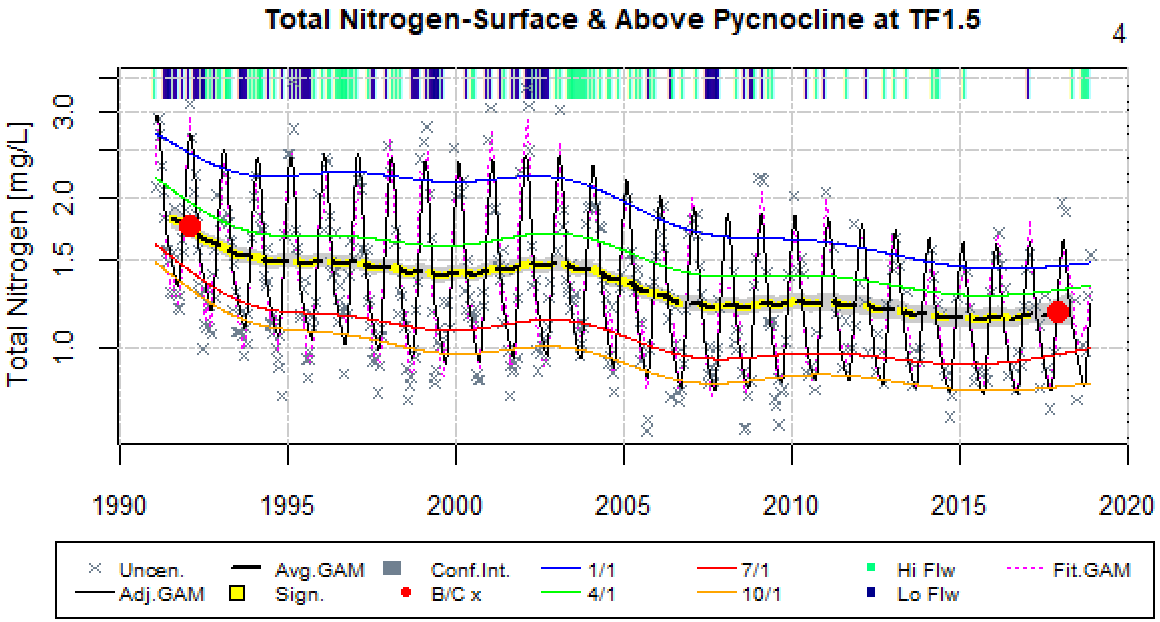
Total Nitrogen [mg/L]

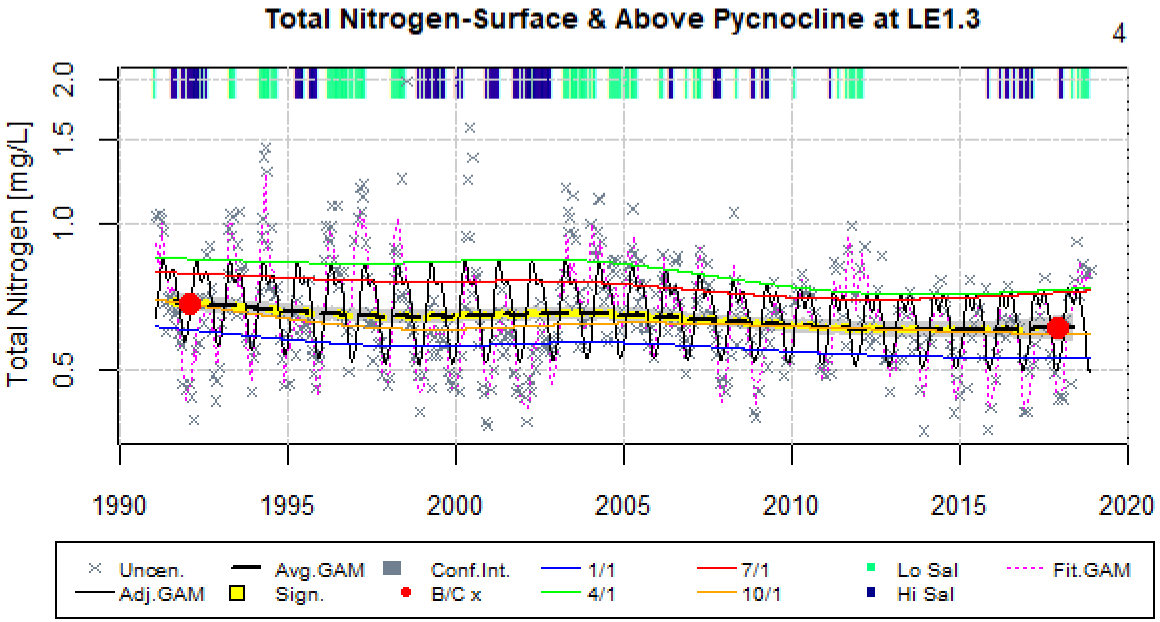


Flow adjusted trends

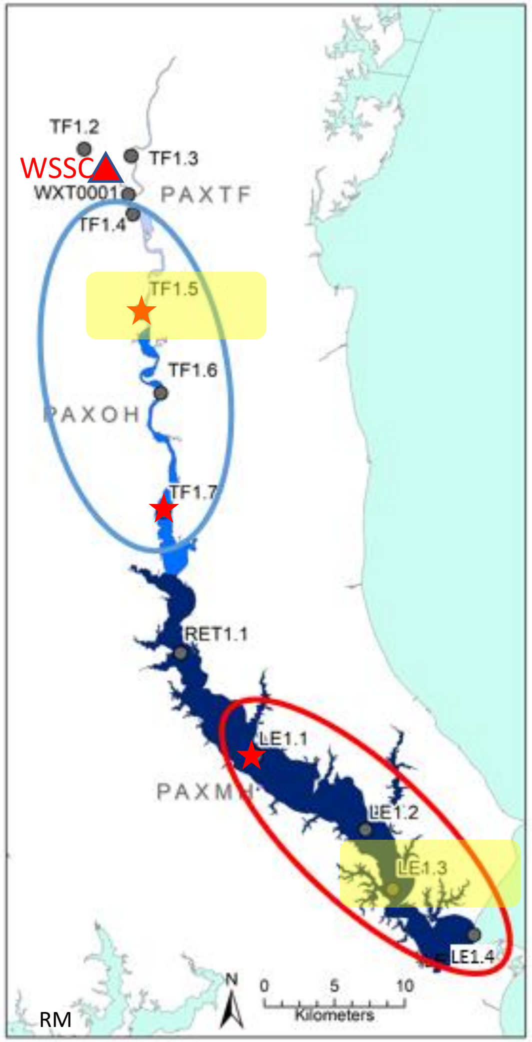
TF1.5: 33% ↓

LE1.3: 11% ↓





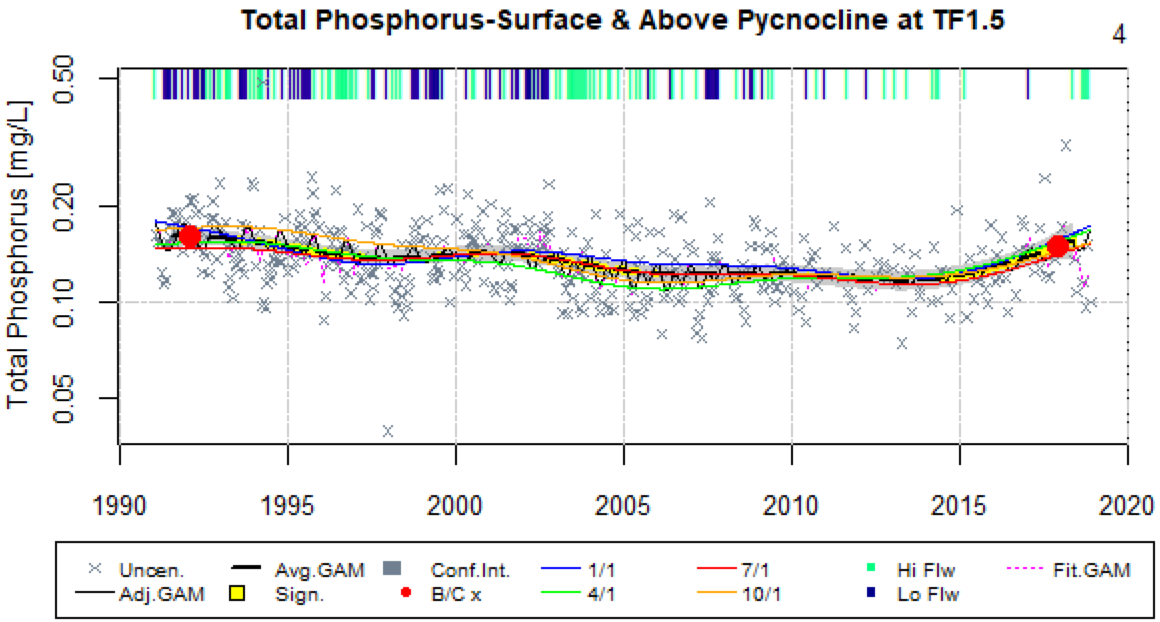
Total Phosphorus [mg/L]

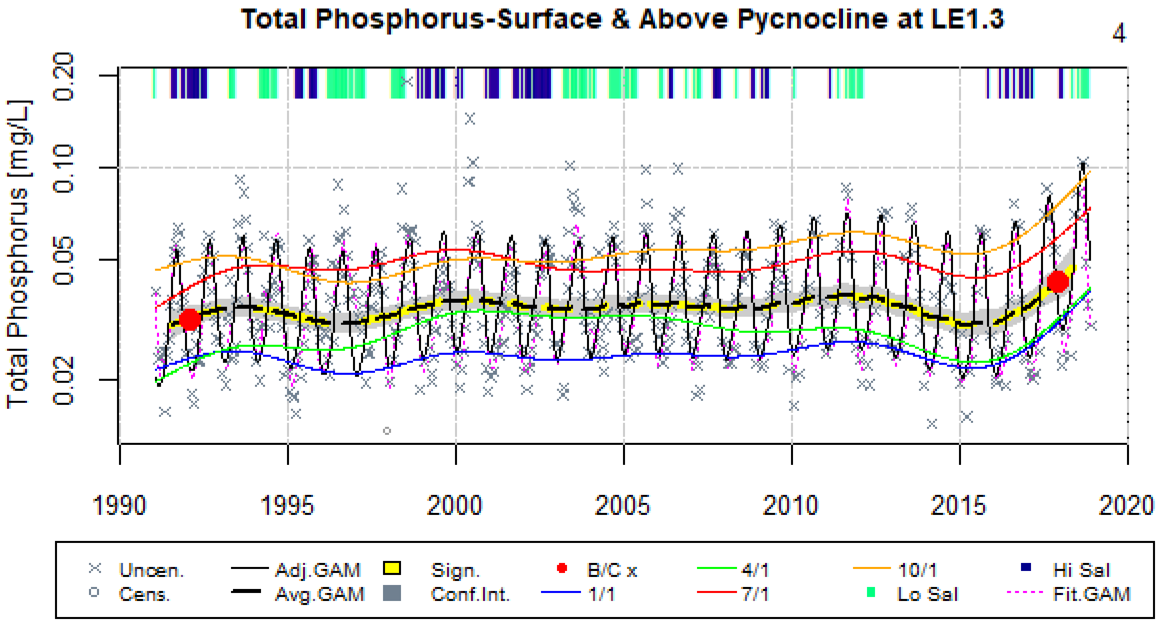


Flow adjusted trends

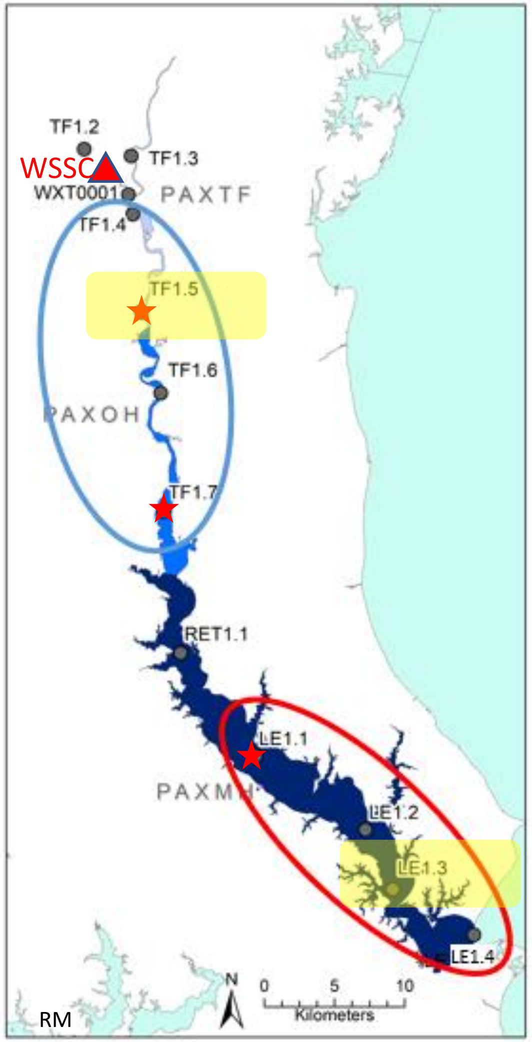
TF1.5: 6% ↓(n.s.)

LE1.3: 35% ↑





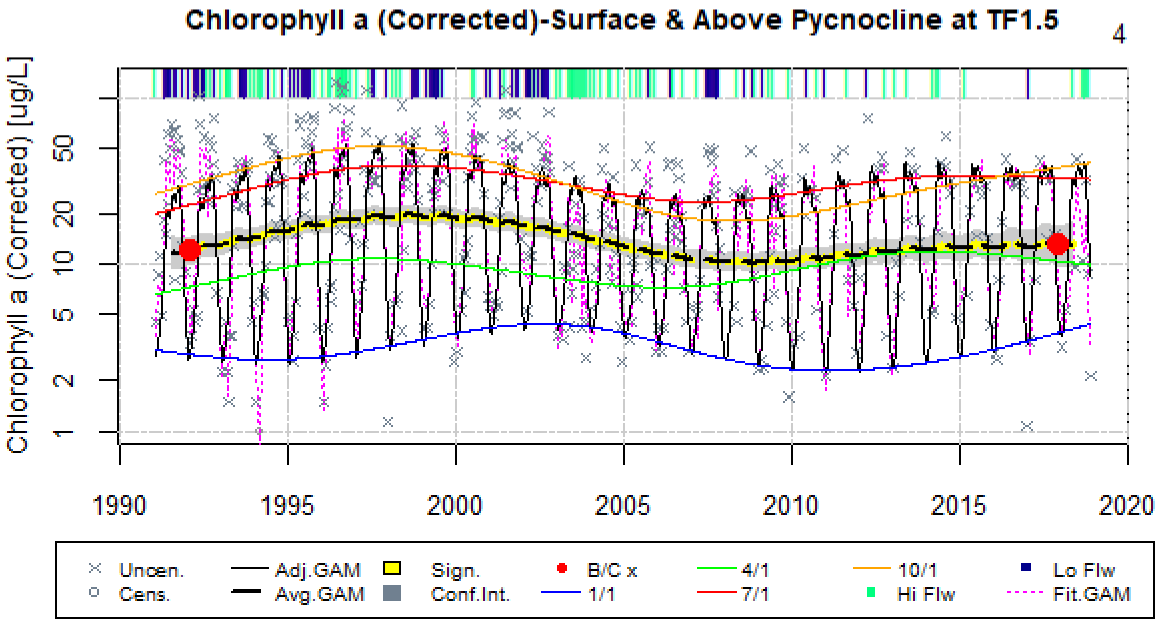
Chlorophyll a [μg/L]

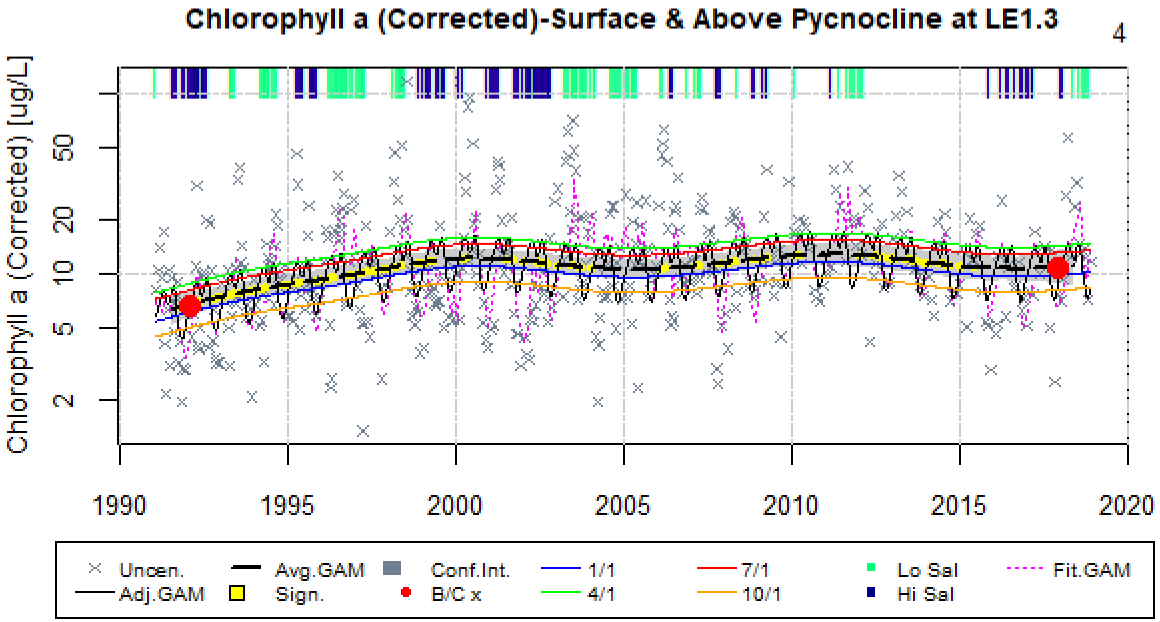


Flow adjusted trends

TF1.5: 9% ↑ (n.s.)

LE1.3: 63% ↑

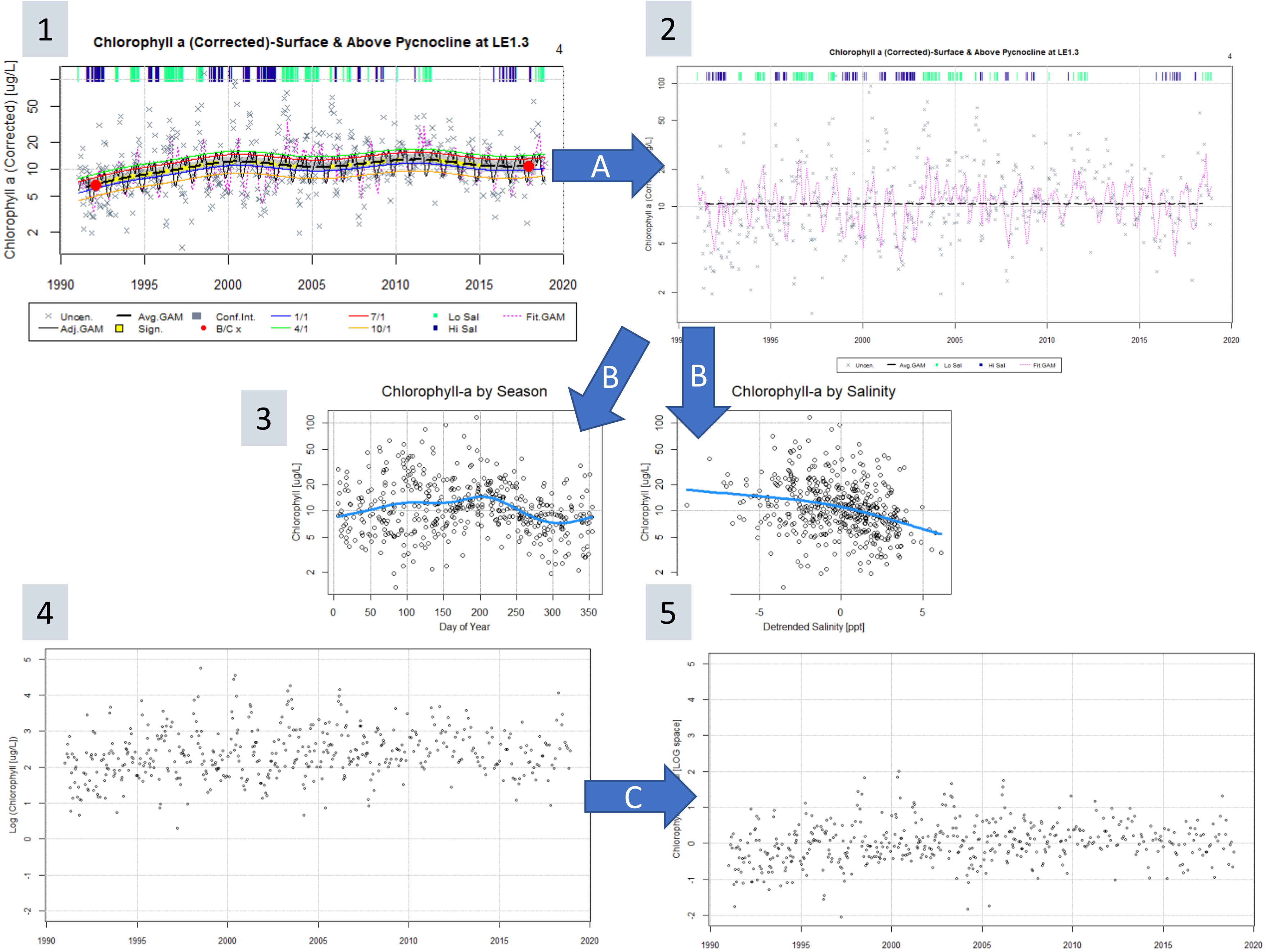




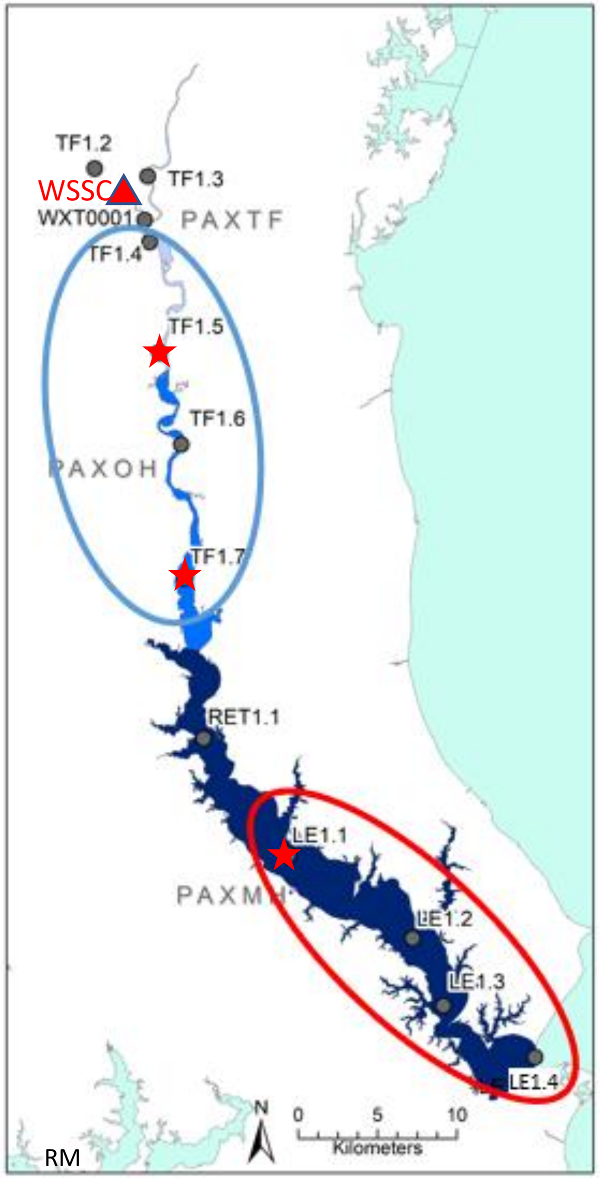
Chlorophyll-a Residuals: LE1.3

1. GAM4—Includes year, season, and hydrology term.
2. GAM—season and hydrology.
3. a) GAM—chla ~ season
   b) GAM—chla ~ salinity
4. Log-transformed chla observations
5. Chlorophyll residuals (Log-transformed observations - GAM—season and hydrology)

C. Variance decreased by 28%



Patuxent River—Preliminary Analyses



Higher phytoplankton biomass levels (as judged by chla) exist between station, season, and flow conditions

- Tidal Fresh (TF): Summer
- Lower Estuary (LE): Spring (bottom layer more pronounced than surface)

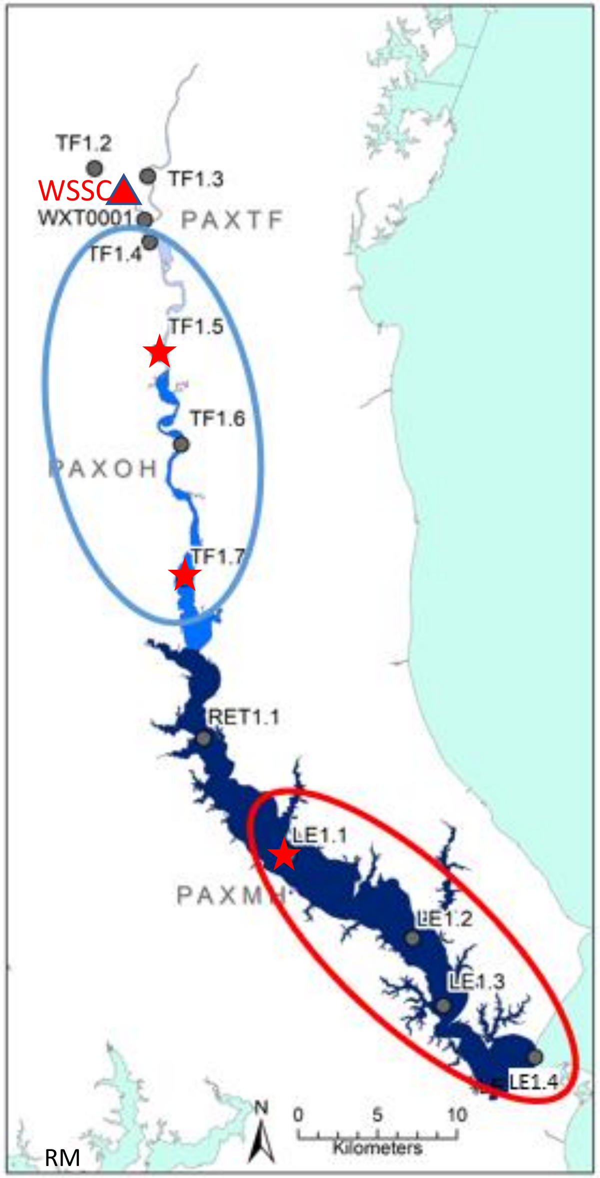
Flow/salinity & season effect

- baytrends: identify "robust" hydrologic term
- Tidal Fresh: 5-day average flow
- Mesohaline: Surface: Salinity | Bottom: 120-day average flow
- Compute residuals—s(doy) + s(flw_sal) + ti(flw_sal,doy)

Inspected residuals

- Cross-correlations—Visually seasonal/station differences exist
- Residuals of key variables appear to be "mostly" linear

Patuxent River—Refinements



Stations (also informed by E. Perry's cluster analyses)

- ✓ Tidal Fresh: TF1.4, TF1.5, TF1.6, TF1.7
- ✓ Lower Estuary: LE1.1, LE1.2, LE1.3, LE1.4
- o TF1.3, WXT0001, RET1.1, CB5.1W, CB5.1

Layers

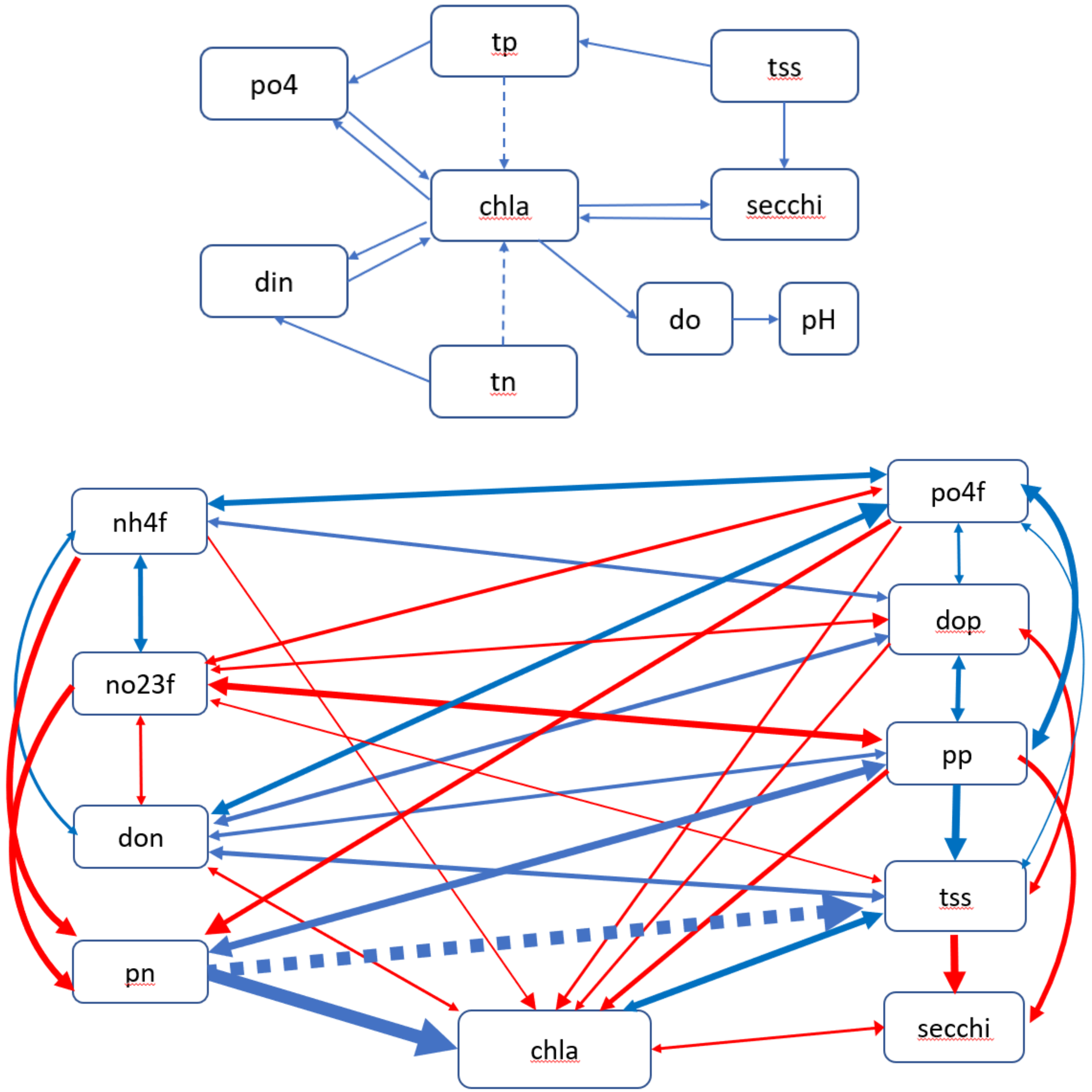
- ✓ Surface & Above pycnocline (SAP)
- o Surface (S)
- o Bottom & Below pycnocline (BBP)
- o Bottom (B)

Season

- ✓ Tidal Fresh (Summer1): Jun-Sep
- ✓ Lower Estuary (Spring1): Mar-May
- ✓ Tidal Fresh (Spring1): Mar-May
- ✓ Lower Estuary (Summer1): Jun-Sep

Date

- o 1/1/1991 – 12/31/2018
- ✓ 1994-2003
- ✓ 2009-2018



Conceptual model evolution:

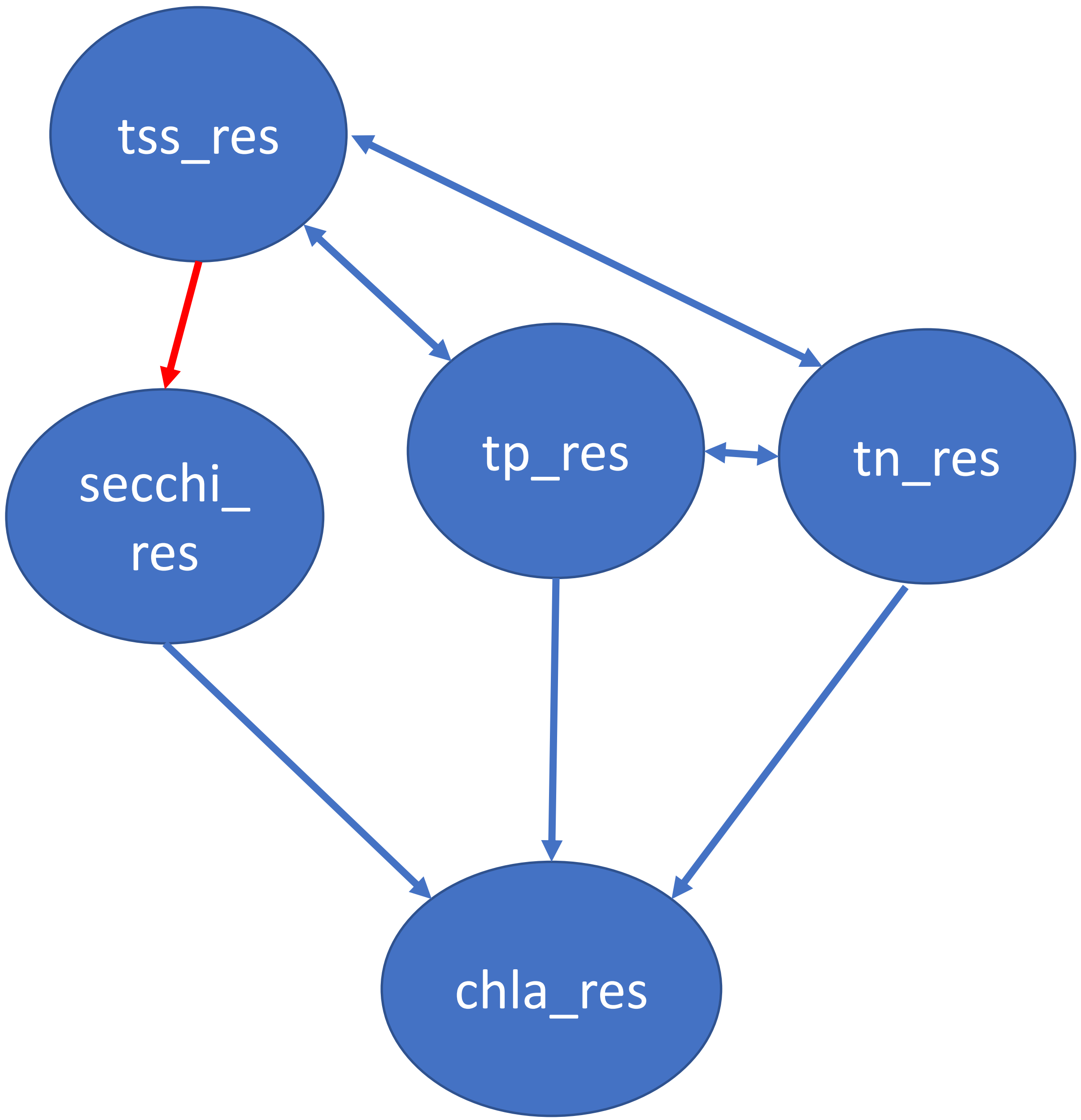
DO, pH

Inorganic nutrients

Time lagged chlorophyll *a*

Light attenuation

Phytoplankton



Conceptual model for SEM

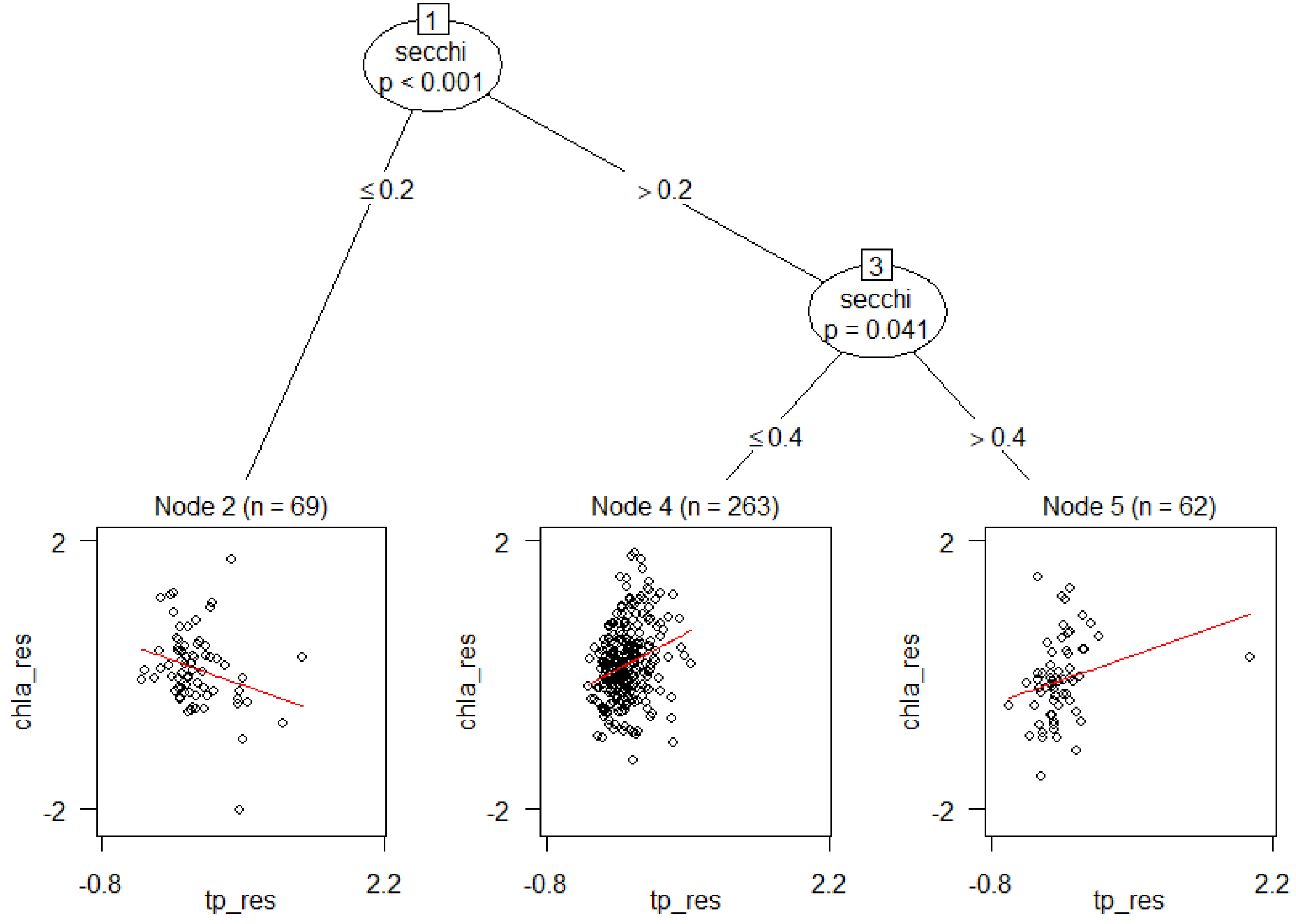
1. Nutrient concentrations influence chla (+)
2. Light availability (Secchi) influences chla (+)
3. TSS influences light availability (Secchi)(-)
4. TP and TSS share an unmodelled common driver, and/or are part of each other
5. TP and TN share an unmodelled common driver

Nutrient v. chlorophyll relationships and Secchi depth

TF group 1994 – 2003 data

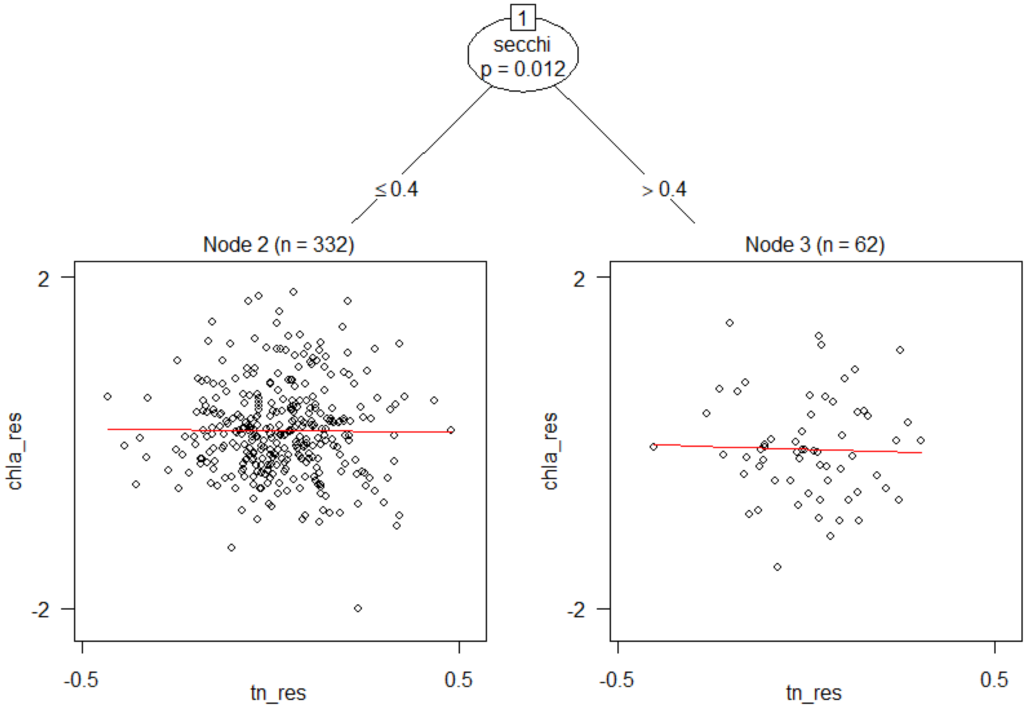
TP:

For secchi > 0.2 m ,
Chla has a + relationship to TP

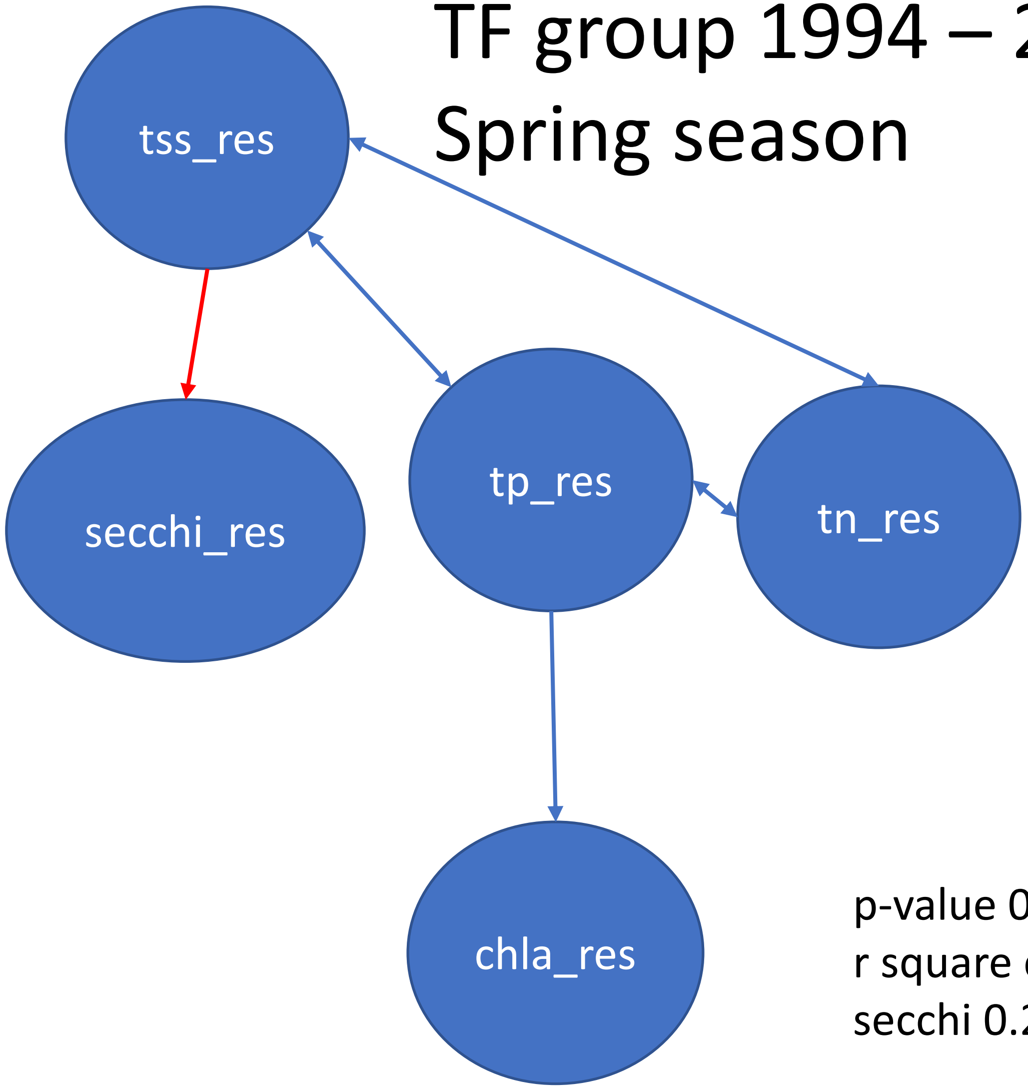


TN:

Chla has limited relationship to TN.
Intercept slightly higher at lower secchi depths

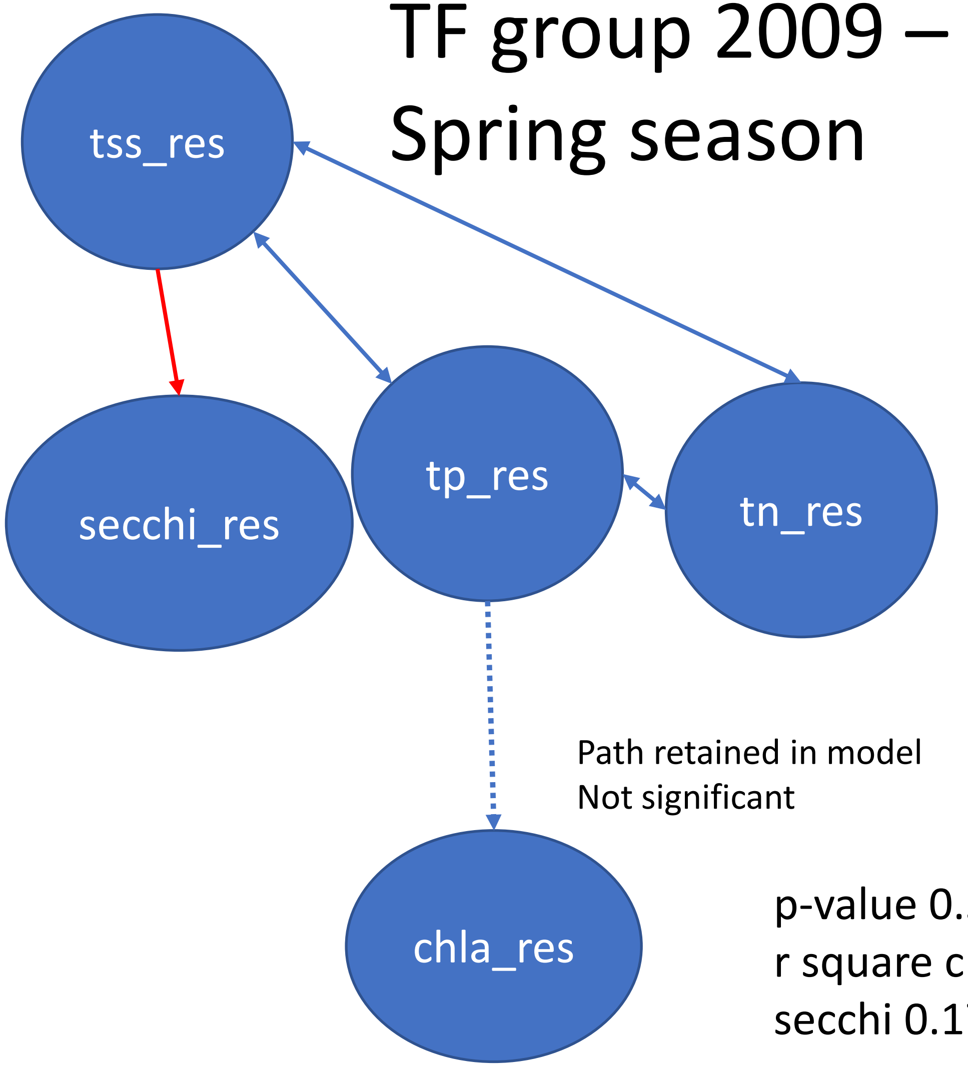


TF group 1994 – 2003
Spring season



p-value 0.224
r square chla 0.08
secchi 0.235

TF group 2009 – 2018
Spring season



p-value 0.56
r square chla 0.004
secchi 0.17

SEM confirms basic premises, however:
Chla is responsive to TP concentration, only in the earlier decade
Caveat: Models extremely weak in terms of chla variation explanatory power (basically absent)

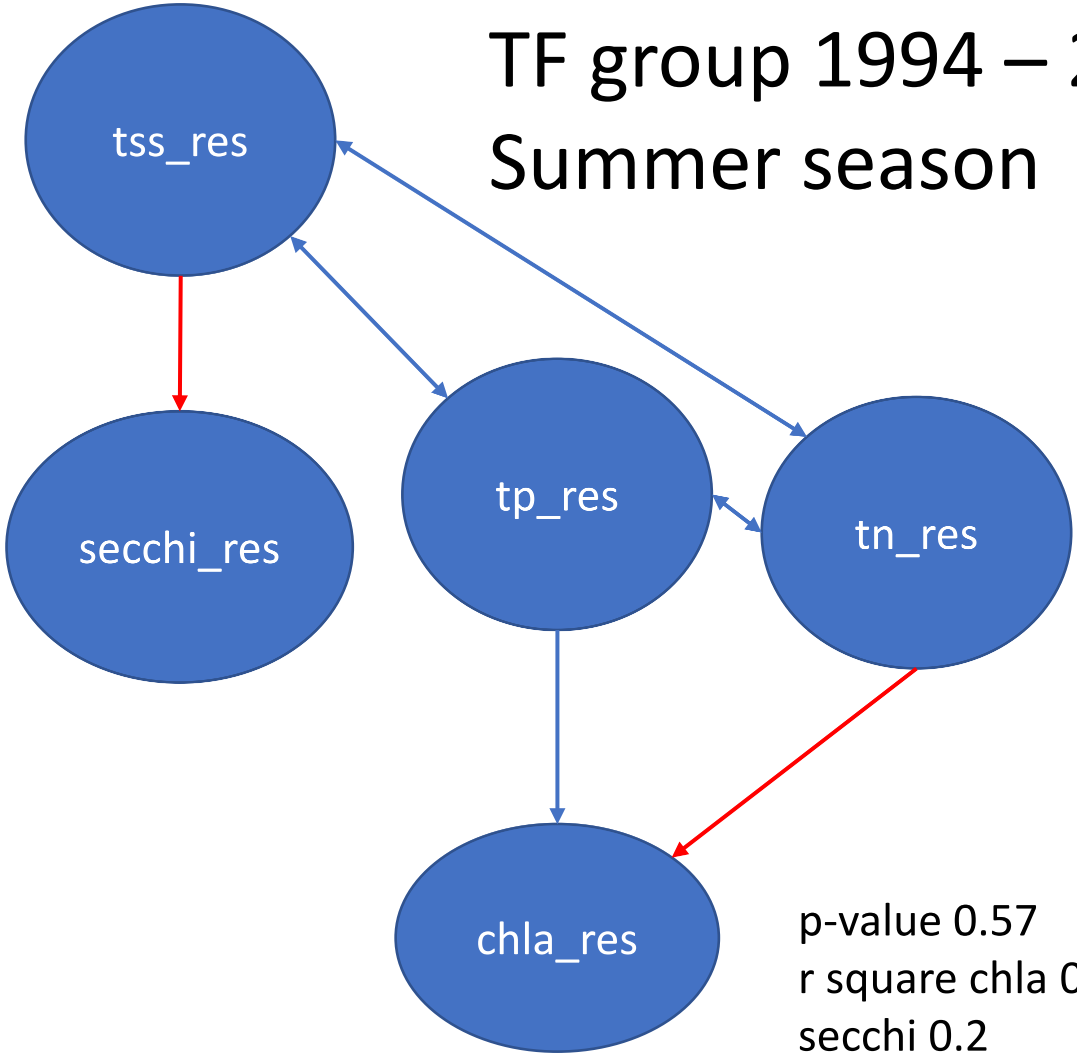
	Spring, 1994 - 2003		Spring, 2009 - 2018	
path	p.value	standard estimate	p.value	standard estimate
chla_res ~ tn_res				
chla_res ~ tp_res	0.001	0.279	0.685	0.060
secchi_res ~ tss_res	0.000	-0.484	0.000	-0.708
chla_res ~~ chla_res	0.000	0.922	0.000	0.996
chla_res ~~ secchi_res	0.581	0.049	0.944	-0.010
secchi_res ~~ secchi_res	0.000	0.765	0.000	0.499
tn_res ~~ tn_res	0.000	1.000	0.000	1.000
tn_res ~~ tss_res				
tp_res ~~ tn_res	0.005	0.255	0.014	0.387
tp_res ~~ tp_res	0.000	1.000	0.000	1.000
tp_res ~~ tss_res	0.000	0.895	0.000	0.883
tss_res ~~ tn_res	0.236	0.106	0.028	0.344
tss_res ~~ tss_res	0.000	1.000	0.000	1.000

Data limited to samples with raw secchi > 0.2 m, so some affects of very low light may not be apparent

Interpretation:

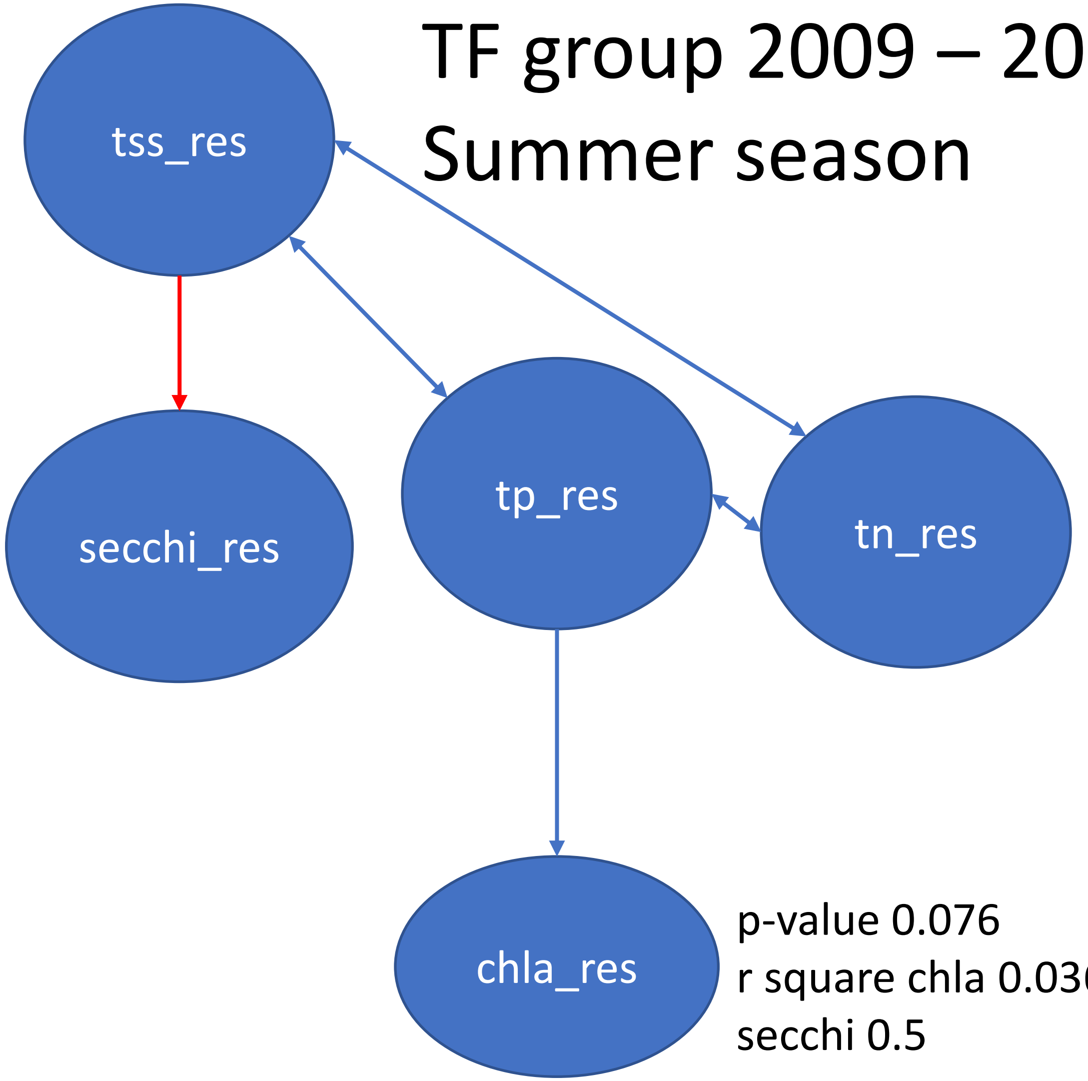
1. Much of the variation already removed in the process of the GAM model used to develop residuals
2. Nutrients not limiting to chlorophyll *a* in later time period (in terms of explaining residual variation)
3. TN inputs decreased more than TP (but TN not limiting in this tidal fresh system). TP coming from alternative source? (bottom, nutrient recycling by phytoplankton?)

TF group 1994 – 2003
Summer season



p-value 0.57
r square chla 0.11
secchi 0.2

TF group 2009 – 2018
Summer season



p-value 0.076
r square chla 0.036
secchi 0.5

SEM confirms basic premises, however:
Chla is responsive to TP concentration only. Similar to spring season, this effect is weaker in the later decade
Caveat: Models extremely weak in terms of chla variation explanatory power (basically absent)

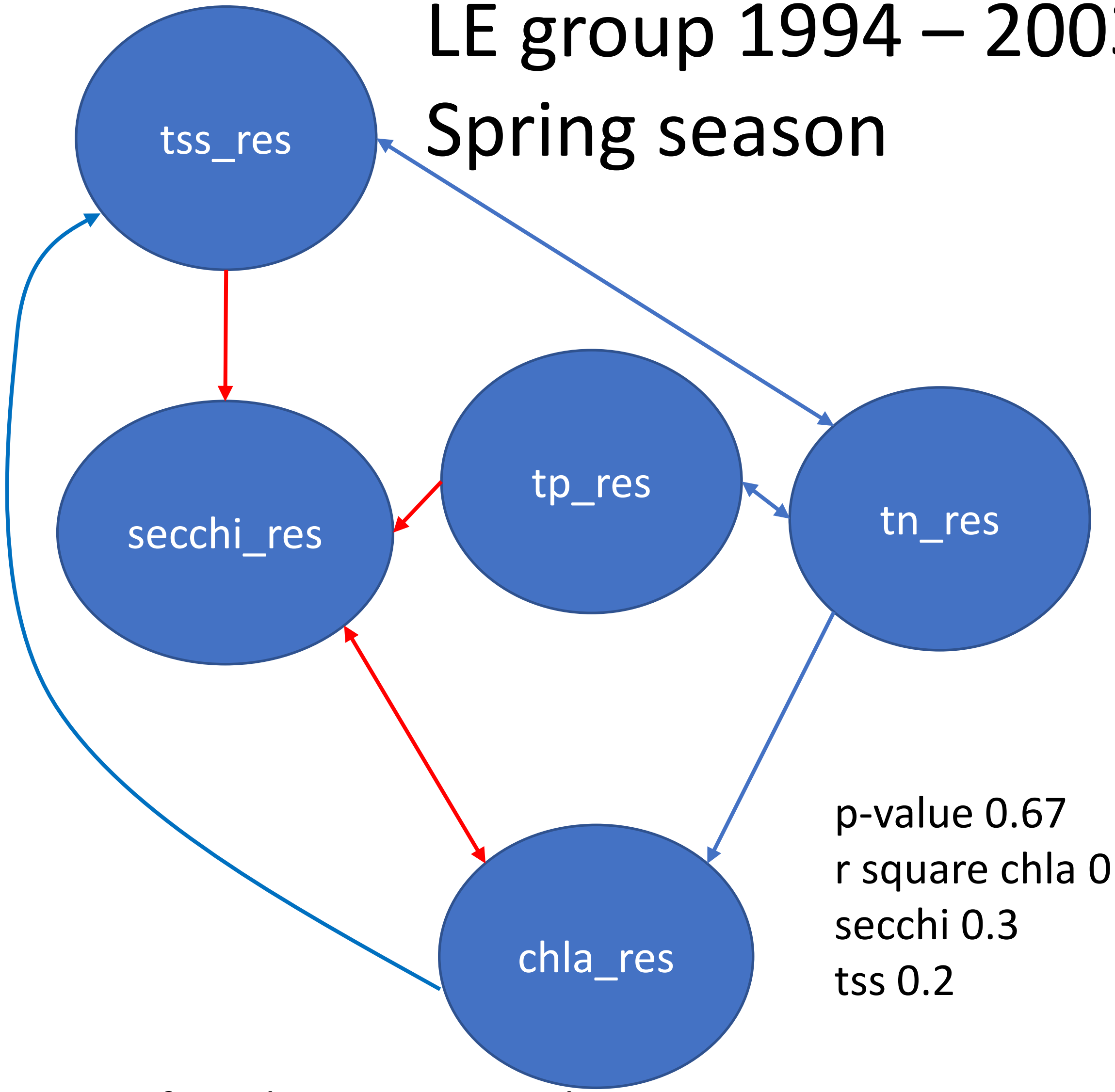
path	Summer, 1994 - 2003 p.value	standard estimate	Summer, 2009 - 2018 p.value	standard estimate
chla_res ~ tn_res	0.002	-0.238		
chla_res ~ tp_res	0.000	0.381	0.061	0.190
secchi_res ~ tss_res	0.000	-0.455	0.000	-0.415
chla_res ~~ chla_res	0.000	0.892	0.000	0.964
chla_res ~~ secchi_res	0.529	0.045	0.288	-0.111
secchi_res ~~ secchi_res	0.000	0.793	0.000	0.828
tn_res ~~ tn_res	0.000	1.000	0.000	1.000
tn_res ~~ tss_res	0.000	0.345		
tp_res ~~ tn_res	0.000	0.514	0.000	0.553
tp_res ~~ tp_res	0.000	1.000	0.000	1.000
tp_res ~~ tss_res	0.000	0.774	0.000	0.650
tss_res ~~ tn_res			0.002	0.341
tss_res ~~ tss_res	0.000	1.000	0.000	1.000

Data limited to samples with raw secchi > 0.2 m, so some affects of very low light may not be apparent

Interpretation:

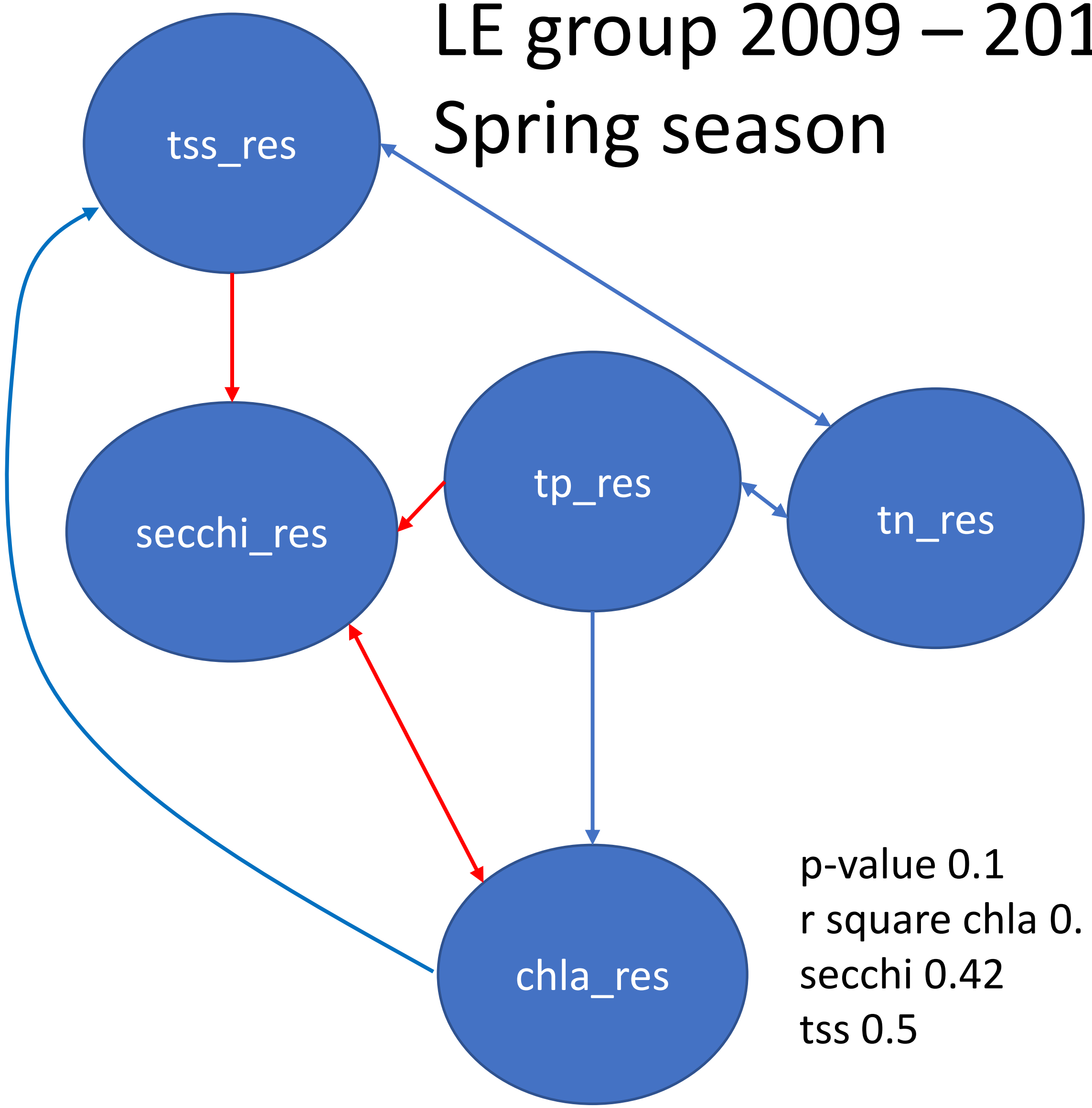
1. Much of the variation already removed in the process of the GAM model used to develop residuals
2. TP appears to be driving chlorophyll *a* somewhat, esp. in the earlier decade (in terms of explaining residual variation)
3. TP coming from alternative source in later decade (bottom? nutrient recycling by phytoplankton?)

LE group 1994 – 2003
Spring season



p-value 0.67
r square chla 0.1
secchi 0.3
tss 0.2

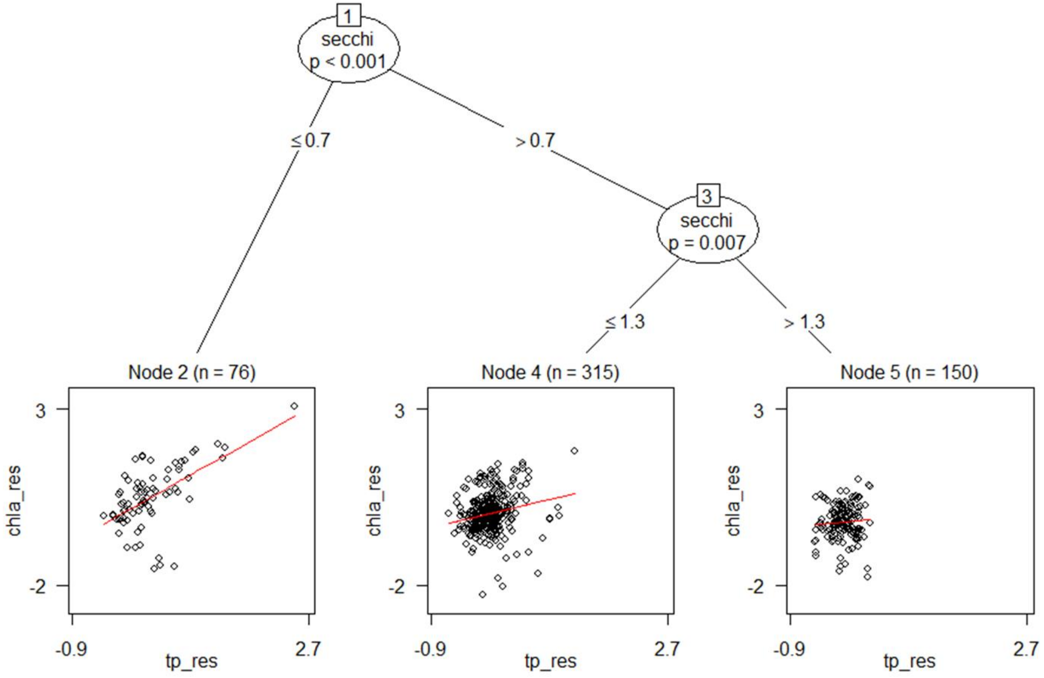
LE group 2009 – 2018
Spring season

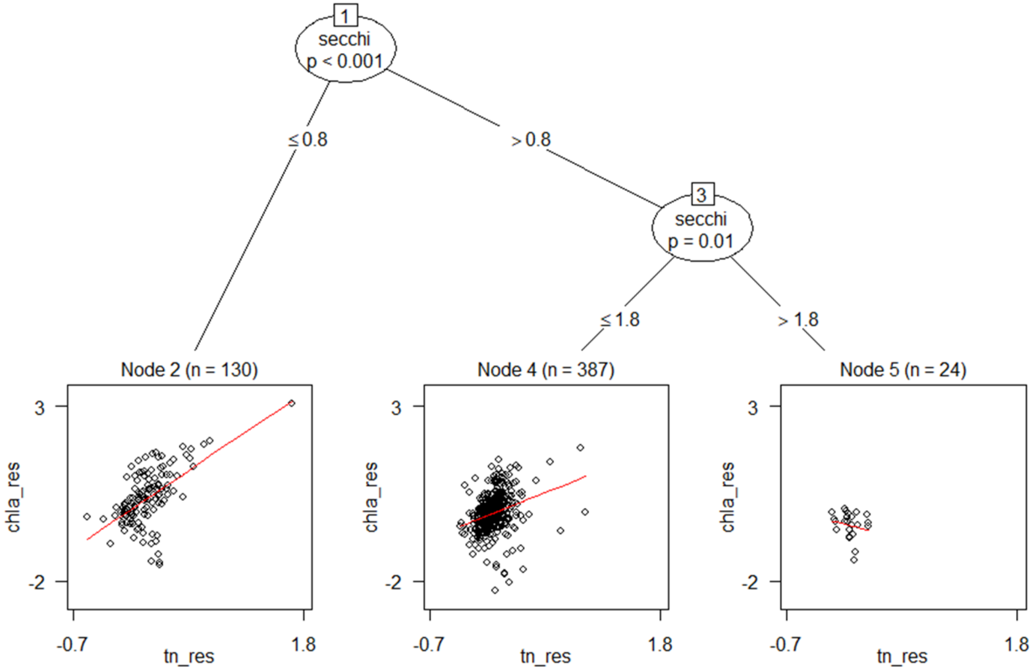


p-value 0.1
r square chla 0. 15
secchi 0.42
tss 0.5

SEM confirms basic premises, however:
Chla responsive to TN concentration in early decade, TP in later decade.
Relationship between chla and secchi is negative, implying that that path is dominated by phytoplankton affect on light
Chla and TSS have a positive relationship indicating phytoplankton effect on tss

	Spring, 1994 - 2003		Spring, 2009 - 2018	
path	p.value	standard estimate	p.value	standard estimate
chla_res ~ tn_res	0.000	0.319		
chla_res ~ tp_res			0.000	0.388
chla_res ~~ chla_res	0.000	0.898	0.000	0.849
chla_res ~~ secchi_res	0.010	-0.194	0.000	-0.500
secchi_res ~ tp_res	0.033	-0.137	0.000	-0.518
secchi_res ~ tss_res	0.000	-0.438	0.131	-0.136
secchi_res ~~ secchi_res	0.000	0.671	0.000	0.583
tn_res ~~ tn_res	0.000	1.000	0.000	1.000
tn_res ~~ tp_res	0.000	0.686		
tn_res ~~ tss_res				
tp_res ~~ tn_res			0.000	0.417
tp_res ~~ tp_res	0.000	1.000	0.000	1.000
tp_res ~~ tss_res				
tss_res ~ chla_res	0.000	0.430	0.000	0.598
tss_res ~~ tn_res	0.000	0.308	0.018	0.216
tss_res ~~ tp_res	0.000	0.489	0.000	0.406
tss_res ~~ tss_res	0.000	0.742	0.000	0.507



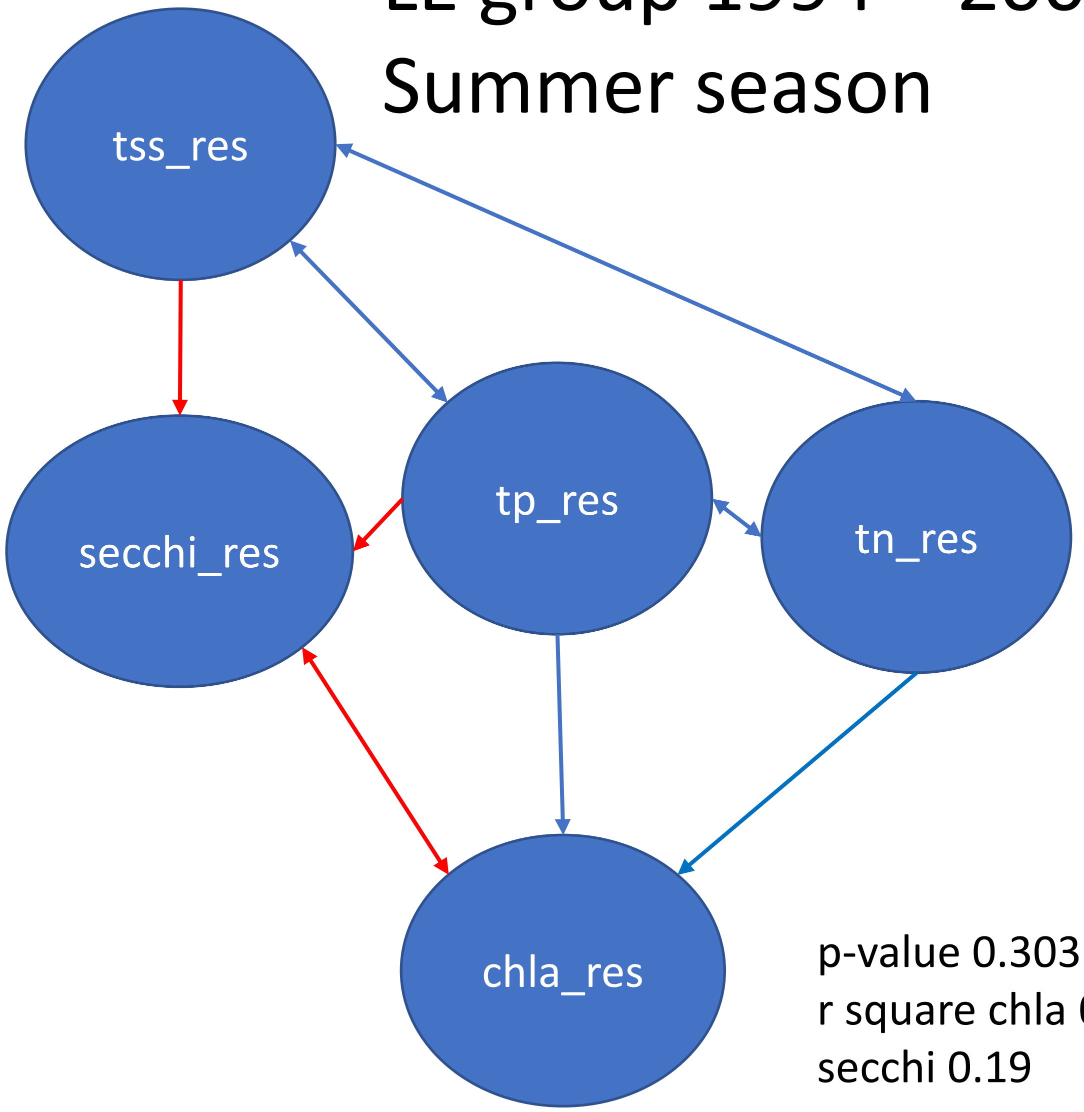


No secchi filter applied.

Models explain more chlorophyll a concentration variation (in terms of r^2) than TF stations.
I.e. LE stations more nutrient limited than TF.

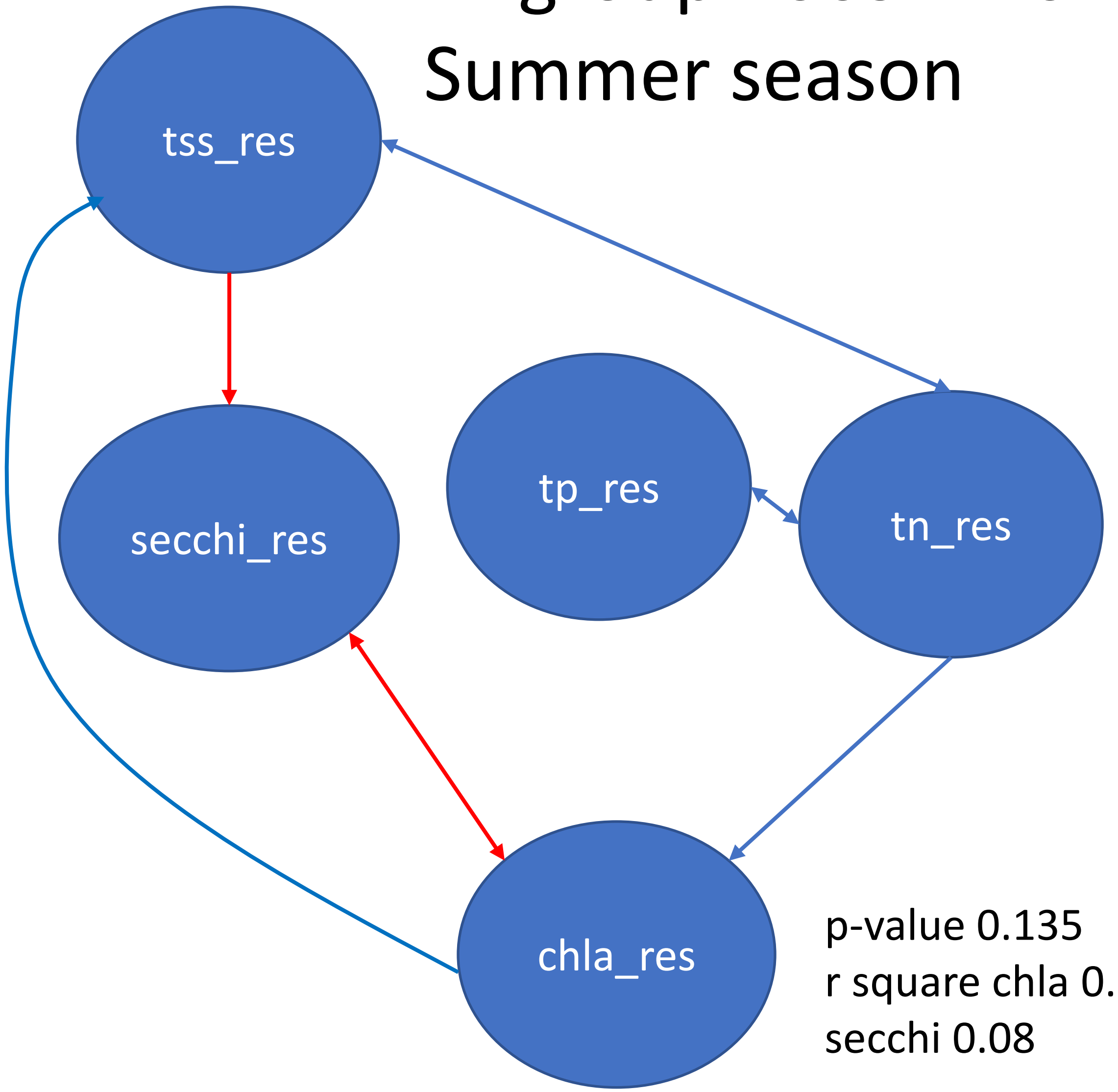
No obvious seasonal or decade pattern.

LE group 1994 – 2003
Summer season



p-value 0.303
r square chla 0.52
secchi 0.19

LE group 2009 – 2018
Summer season



p-value 0.135
r square chla 0.23
secchi 0.08

Story: Chla responsive to TP and TN concentration in early decade but just to TN in later decade.
Explanation: TN decreased relative to TP and became limiting.

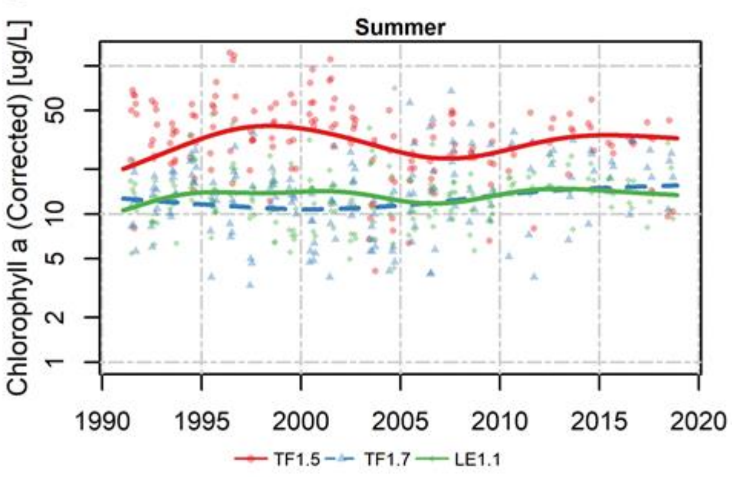
	Summer, 1994 - 2003		Summer, 2009 - 2018	
path	p.value	standard estimate	p.value	standard estimate
chla_res ~ tn_res	0.000	0.431	0.000	0.482
chla_res ~ tp_res	0.000	0.348		
chla_res ~~ chla_res	0.000	0.483	0.000	0.768
chla_res ~~ secchi_res	0.003	-0.172	0.000	-0.385
secchi_res ~ tp_res	0.000	-0.364		
secchi_res ~ tss_res	0.017	-0.132	0.002	-0.214
secchi_res ~~ secchi_res	0.000	0.812	0.000	0.918
tn_res ~~ tn_res	0.000	1.000	0.000	1.000
tn_res ~~ tp_res			0.005	0.222
tn_res ~~ tss_res	0.000	0.462		
tp_res ~~ tn_res	0.000	0.703		
tp_res ~~ tp_res	0.000	1.000	0.000	1.000
tp_res ~~ tss_res	0.000	0.397		
tss_res ~ chla_res			0.002	0.259
tss_res ~~ tn_res			0.242	0.100
tss_res ~~ tp_res				
tss_res ~~ tss_res	0.000	1.000	0.000	0.909

No secchi filter applied.

Models explain more chlorophyll a concentration variation (in terms of r^2) than TF stations.
In general, chla is linked to higher nutrient concentrations without an obvious seasonal or decade pattern.

System moved from colimitation to TN limited. Consistent with knowledge that LE summer season is when/where TN has decreased the most in Patuxent

Summary
Tidal Fresh



GAM models explain much of the variation in chl *a*

Potential sources of remaining variation: noise, results of unmeasured variables (e.g. actual phytoplankton biomass)

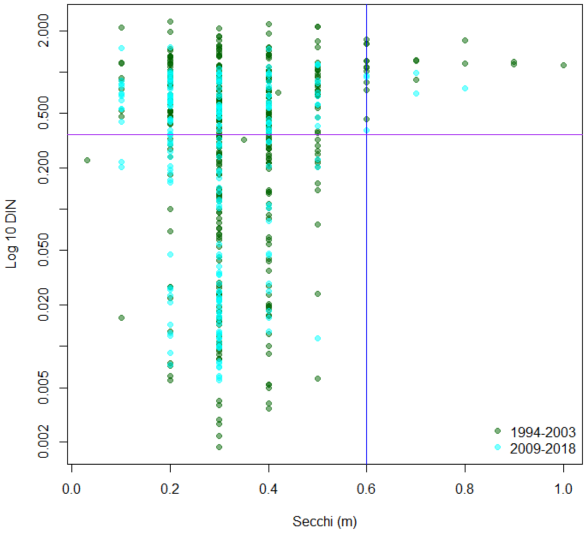
TP residuals drive chlorophyll a residuals to a limited degree especially in summer and in the earlier decade.

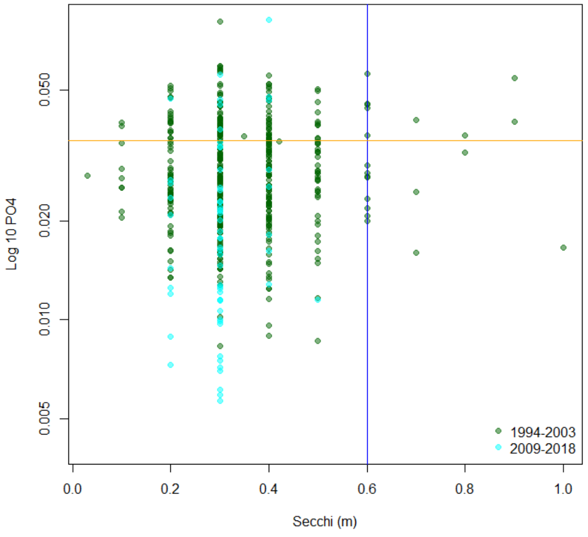
No conclusive answers to driving question

about later decade wherein

chlorophyll *a* not limited by nutrients

- Phosphorus inputs from sediment?
- Changes in phytoplankton assemblage?

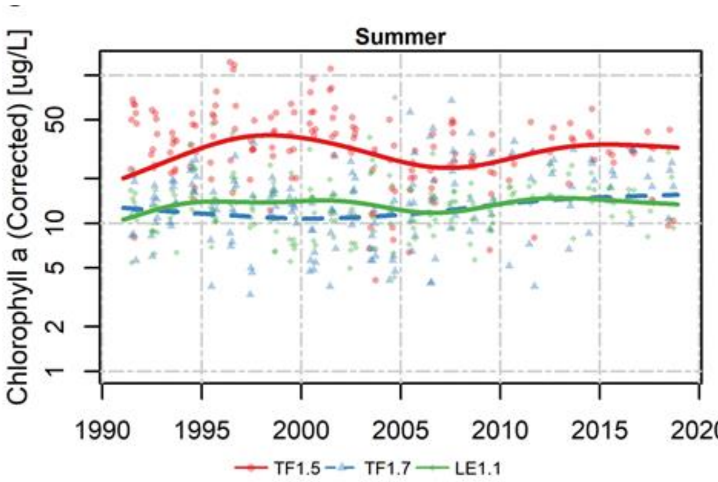


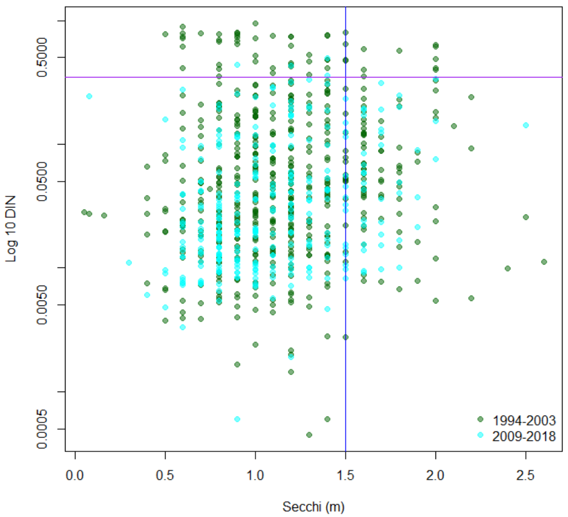


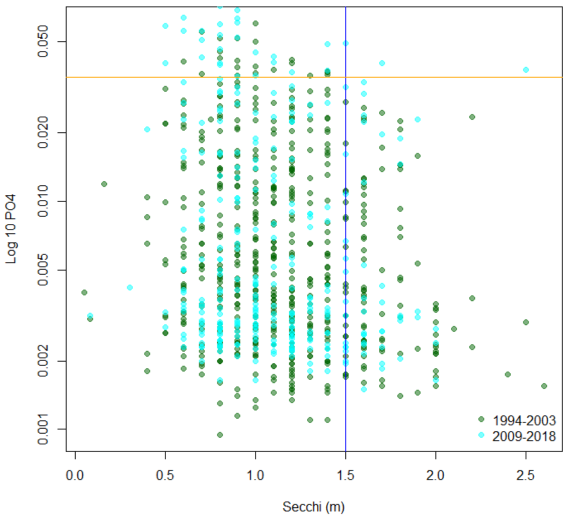
Summary
Lower estuary

SEM models explain more variation in chlorophyll *a* than in TF

In summer, movement from colimitation to TN limitation is consistent with relative decrease in N concentrations as opposed to P. Supports idea than chla will respond to changing nutrients (if they are near enough to limiting values)







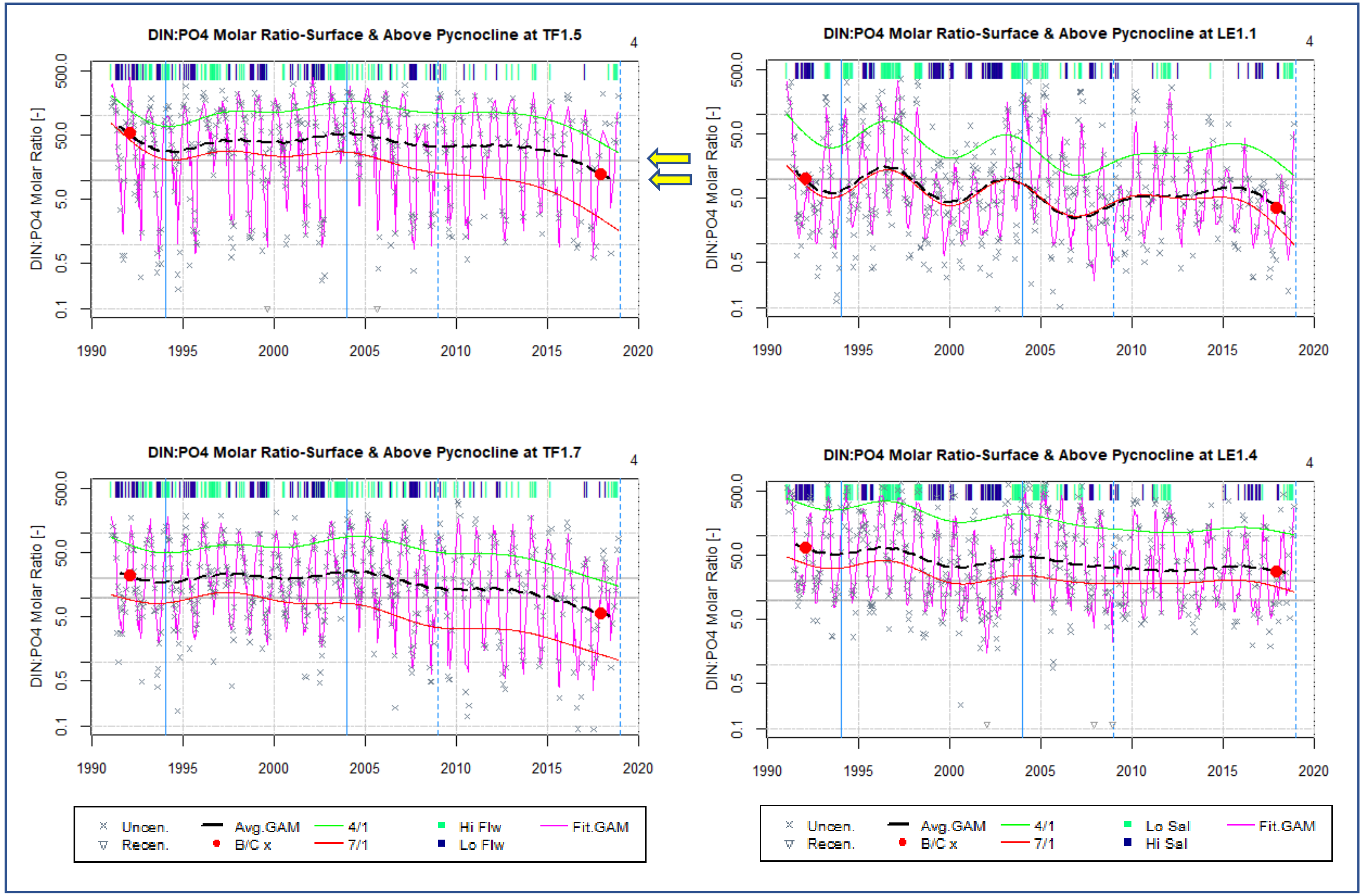
Patuxent River: Changes in Inorganic Nutrient Concentrations and DIN:PO4 Molar Ratio

Station	Season	Dissolved Inorganic Nitrogen [mg/L]		Orthophosphorus (Filtered) [mg/L]		DIN:PO4 Molar Ratio [-]	
TF1.4	Annual	-1.31	p≤0.05	-0.029	p≤0.05	-25	p≤0.05
TF1.4	Mar-May	-1.55	p≤0.05	-0.031	p≤0.05	-7	0.25<p
TF1.4	Jun-Sep	-0.94	p≤0.05	-0.029	p≤0.05	-31	p≤0.05
TF1.5	Annual	-0.51	p≤0.05	-0.009	p≤0.05	-43	p≤0.05
TF1.5	Mar-May	-0.94	p≤0.05	-0.010	p≤0.05	-81	p≤0.05
TF1.5	Jun-Sep	-0.16	p≤0.05	-0.006	p≤0.05	-13	p≤0.05
TF1.6	Annual	-0.24	p≤0.05	-0.007	p≤0.05	-12	p≤0.05
TF1.6	Mar-May	-0.60	p≤0.05	-0.007	p≤0.05	-33	p≤0.05
TF1.6	Jun-Sep	-0.08	p≤0.05	-0.004	0.05<p≤0.25	-3	p≤0.05
TF1.7	Annual	-0.31	p≤0.05	-0.006	0.05<p≤0.25	-17	p≤0.05
TF1.7	Mar-May	-0.48	p≤0.05	-0.011	p≤0.05	-31	p≤0.05
TF1.7	Jun-Sep	-0.12	p≤0.05	0.013	0.05<p≤0.25	-5	p≤0.05
LE1.1	Annual	-0.02	p≤0.05	0.002	0.05<p≤0.25	-7	p≤0.05
LE1.1	Mar-May	-0.05	p≤0.05	0.000	0.25<p	-31	p≤0.05
LE1.1	Jun-Sep	-0.01	0.05<p≤0.25	0.017	p≤0.05	-3	p≤0.05
LE1.2	Annual	-0.03	p≤0.05	0.002	0.05<p≤0.25	-14	p≤0.05
LE1.2	Mar-May	-0.11	p≤0.05	0.000	0.25<p	-79	p≤0.05
LE1.2	Jun-Sep	-0.02	p≤0.05	0.010	p≤0.05	-6	p≤0.05
LE1.3	Annual	-0.04	p≤0.05	0.001	0.05<p≤0.25	-21	p≤0.05
LE1.3	Mar-May	-0.12	p≤0.05	0.000	0.25<p	-90	p≤0.05
LE1.3	Jun-Sep	-0.03	p≤0.05	0.004	p≤0.05	-11	p≤0.05
LE1.4	Annual	-0.06	p≤0.05	0.000	0.25<p	-39	p≤0.05
LE1.4	Mar-May	-0.23	p≤0.05	0.000	0.25<p	-192	p≤0.05
LE1.4	Jun-Sep	-0.02	0.05<p≤0.25	0.001	0.05<p≤0.25	-12	p≤0.05

p values: p≤0.05 | 0.05<p≤0.25 | 0.25<p

Tidal Fresh

Mesohaline

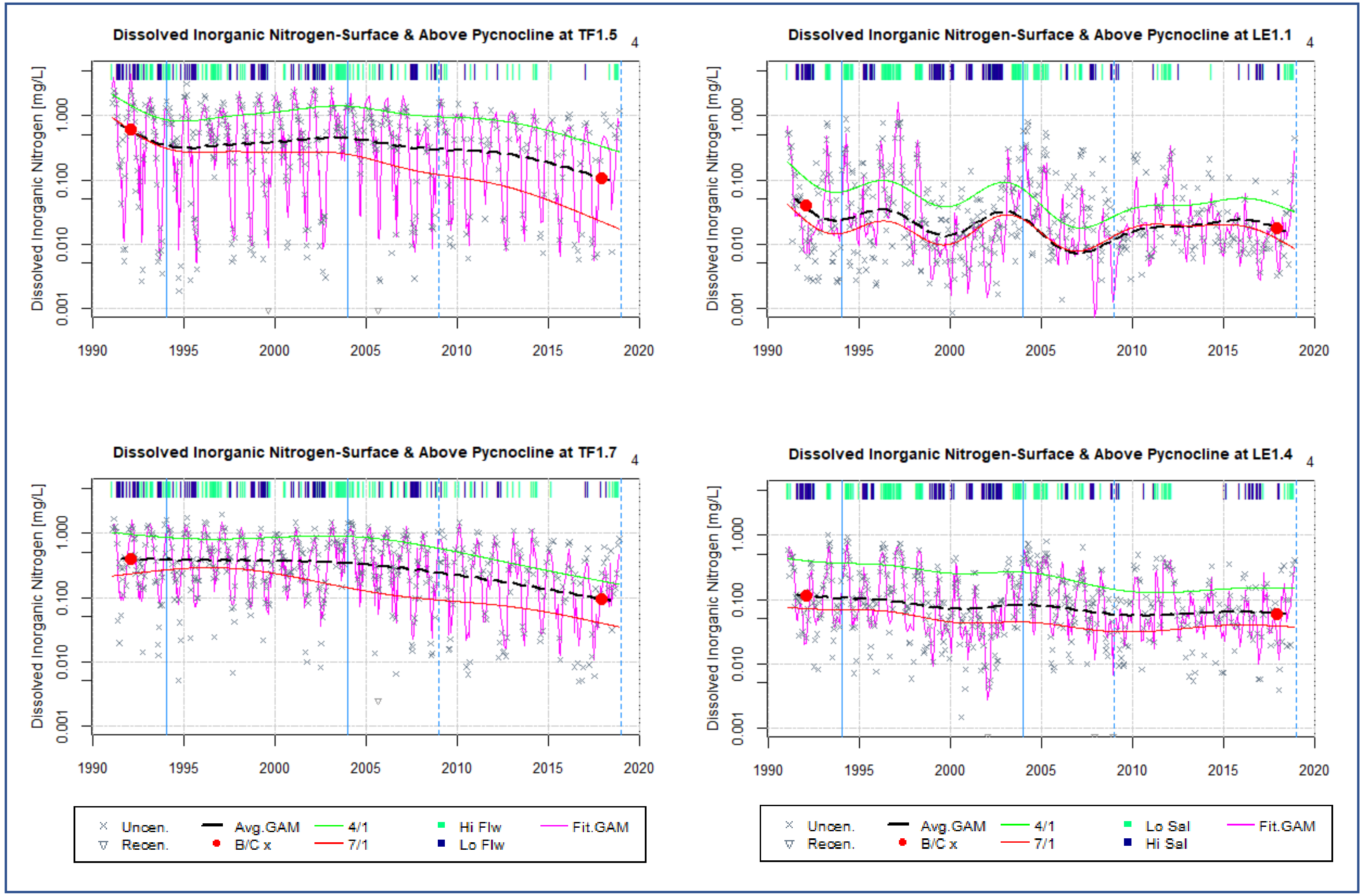


Patuxent River: Changes in Dissolved Inorganic Nitrogen

- Spring concentrations greater than summer
- Wet/dry year signal
- Tidal Fresh
  - Decreased annual and seasonal concentrations
  - Largest decreases at TF1.4
- Mesohaline
  - Decreases more modest than tidal fresh
  - Summer not always significant

Tidal Fresh

Mesohaline

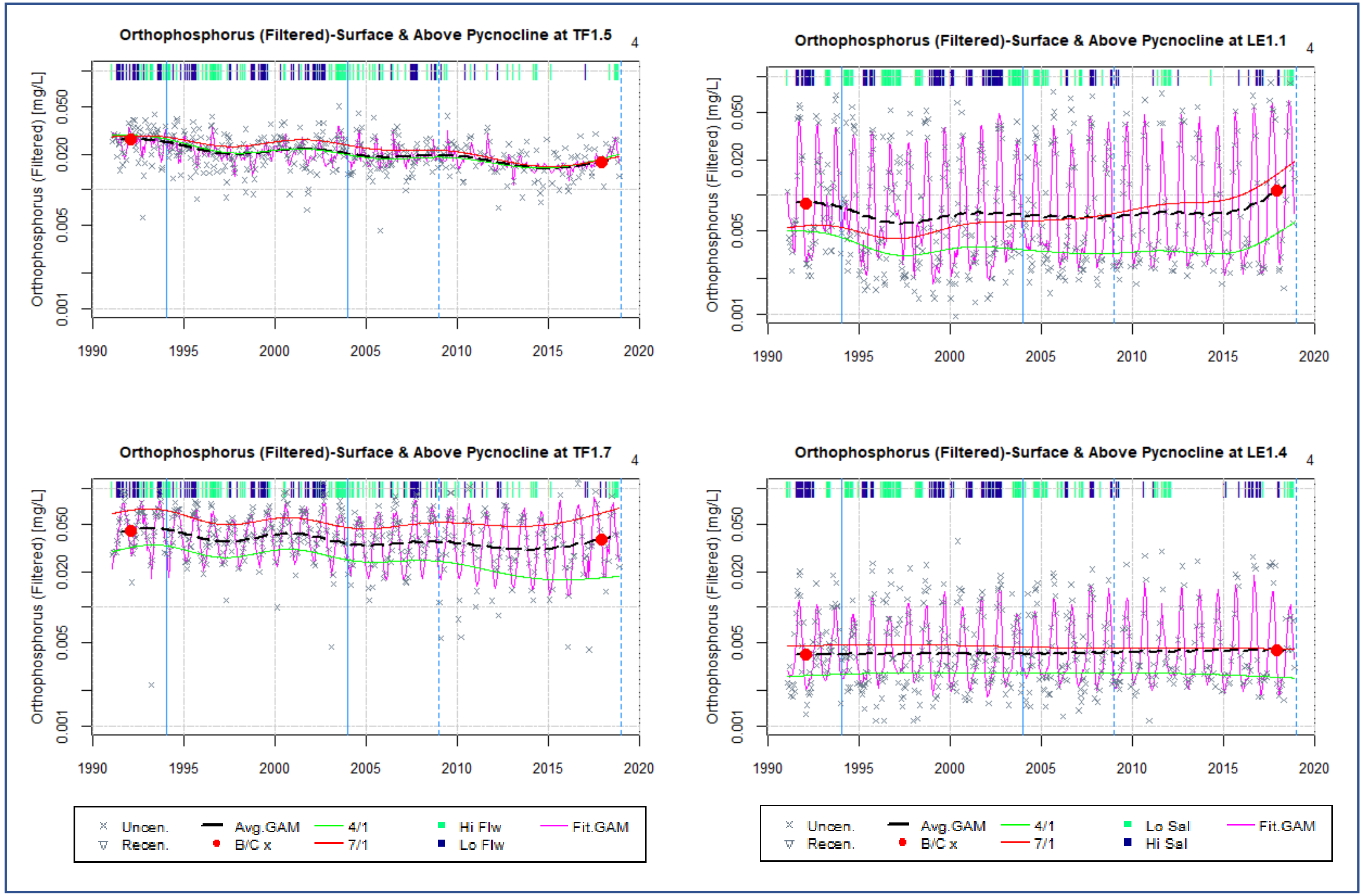


Patuxent River: Changes in Dissolved Inorganic Phosphorus

- Summer concentrations greater than spring
- Weaker wet/dry year signal
- Tidal Fresh
  - Decreased annual and seasonal concentrations (except summer TF1.7)
  - Largest decreases at TF1.4
- Mesohaline
  - Increased summer concentrations (except LE1.4)
  - Generally no change for annual and spring season

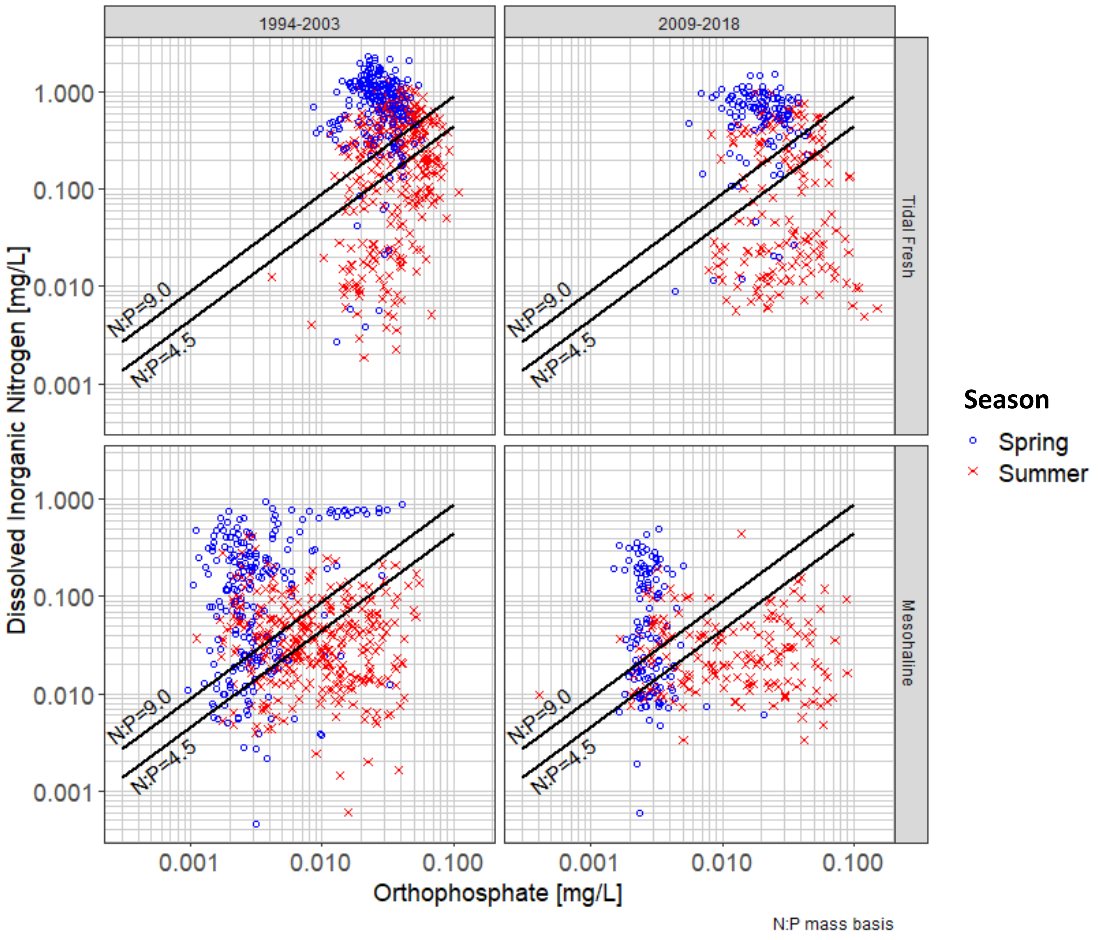
Tidal Fresh

Mesohaline

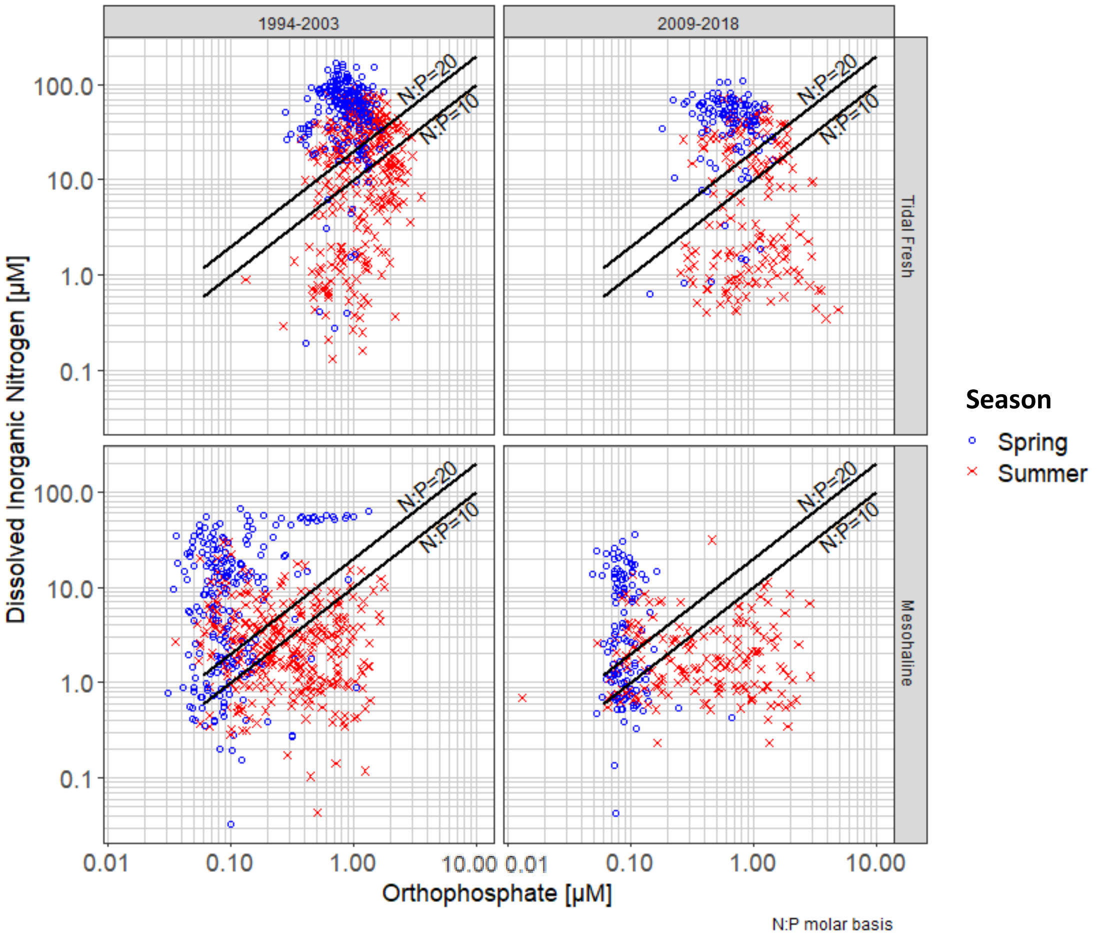


Patuxent River: Inorganic Nutrient Concentrations

Mass basis

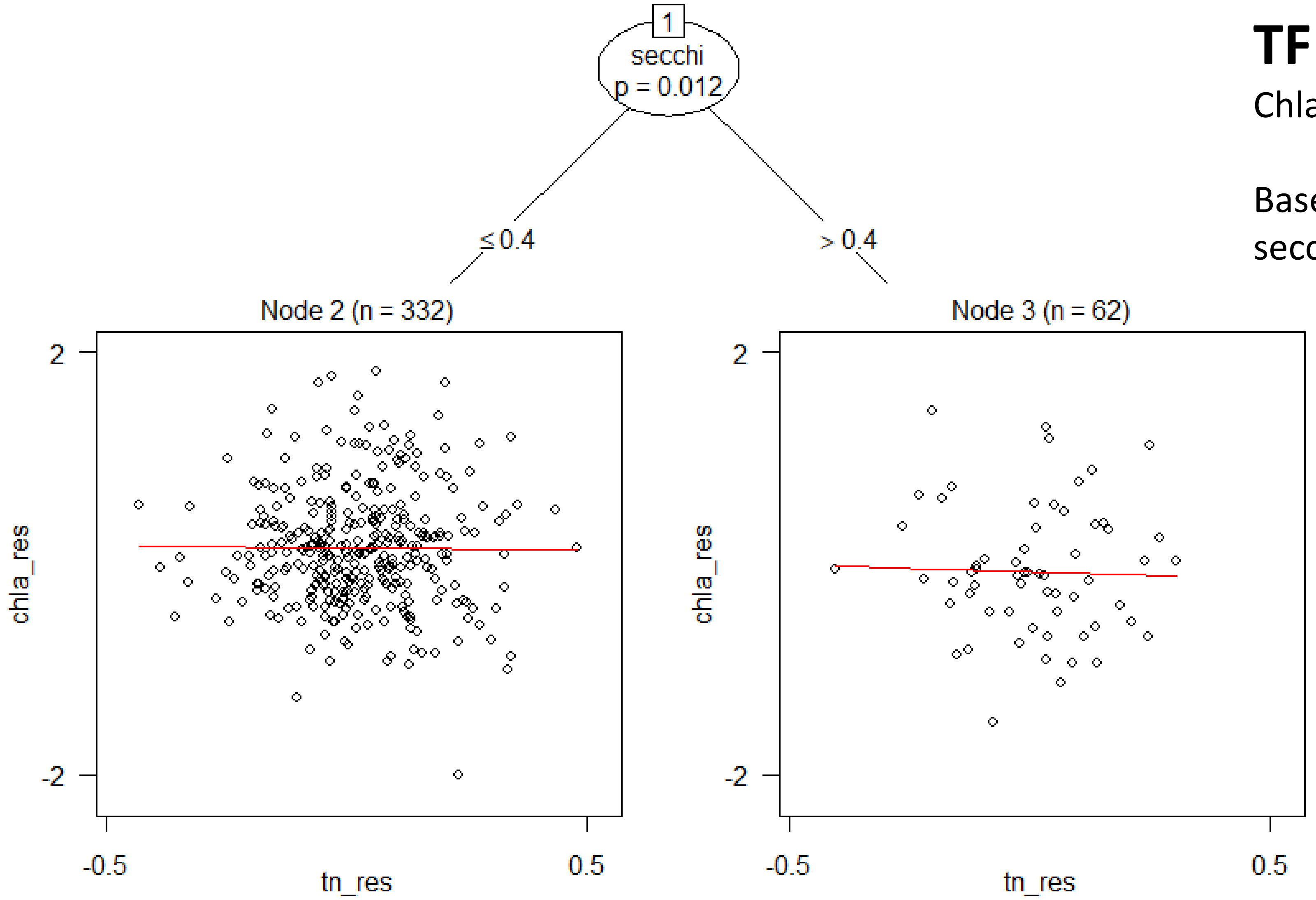


Molar basis



Tidal Fresh: TF1.4, TF1.5, TF1.6, TF1.7
Mesohaline: LE1.1, LE1.2, LE1.3, LE1.4

Are nutrient v. chlorophyll relationships in the Patuxent light limited?

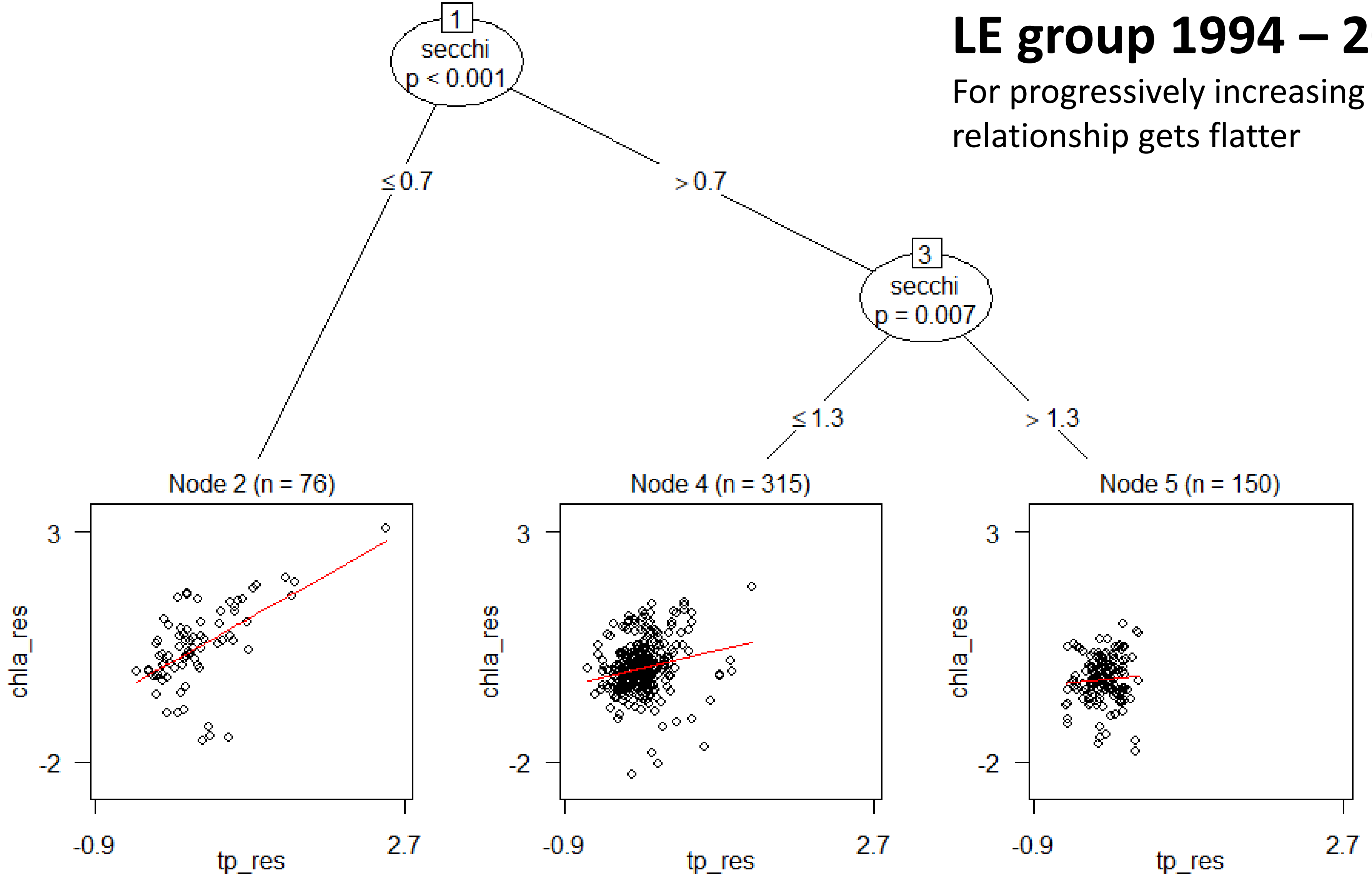


TF group 1994 – 2003 data

Chla has limited relationship with TN

Based on TP figure on previous slide, choose secchi threshold 0.2

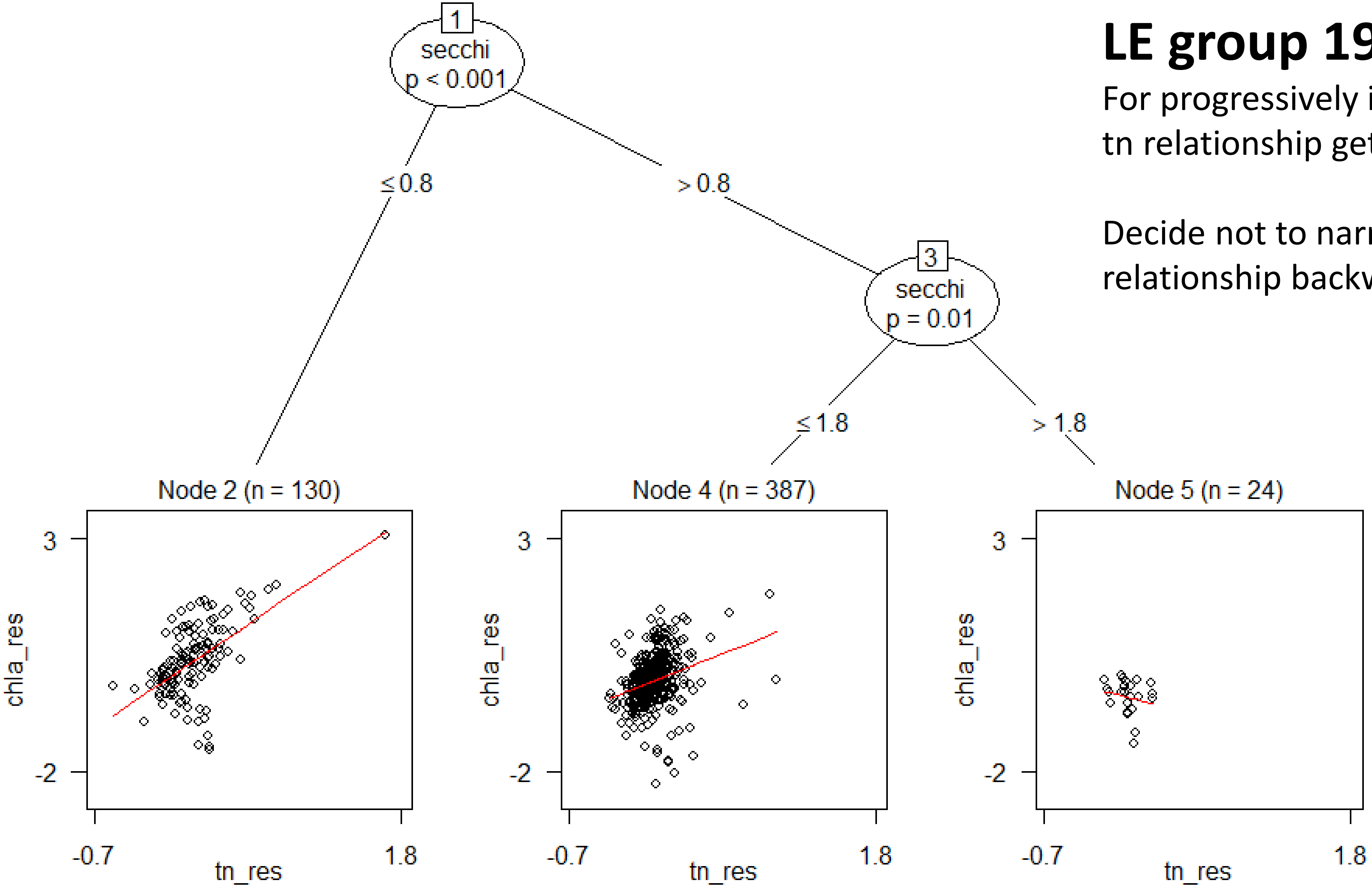
Are nutrient v. chlorophyll relationships in the Patuxent light limited?



LE group 1994 – 2003 data

For progressively increasing secchi depths, chla vs. tp relationship gets flatter

Are nutrient v. chlorophyll relationships in the Patuxent light limited?

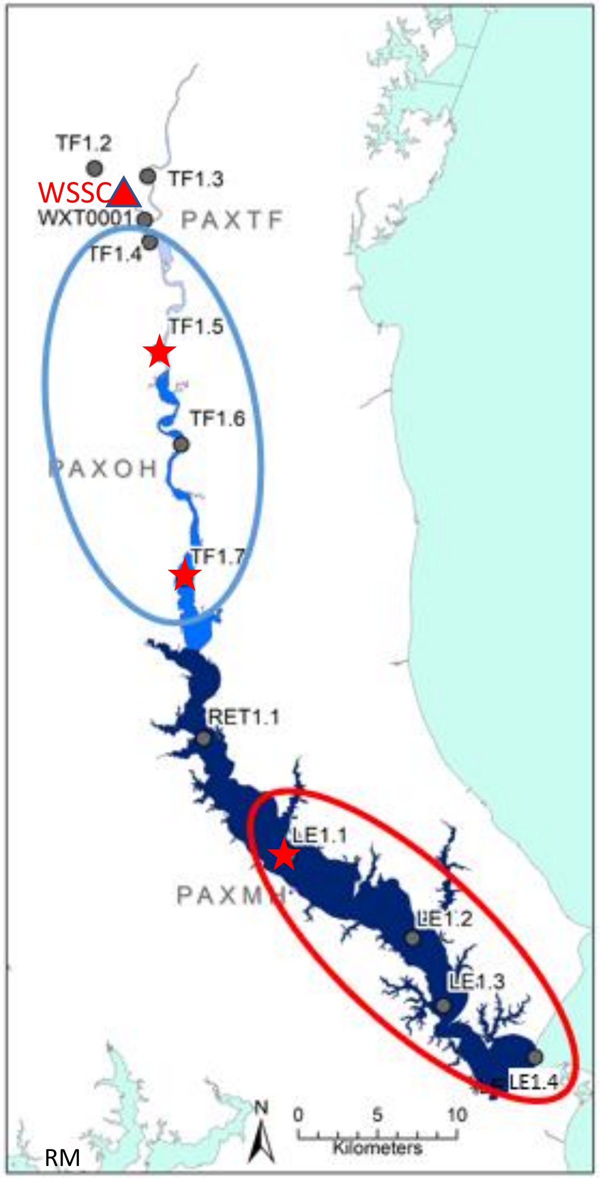


LE group 1994 – 2003 data

For progressively increasing secchi depths, chla vs. tn relationship gets flatter

Decide not to narrow this dataset by secchi as relationship backwards from expected.

CBP Phytoplankton data set (1984-2010)



- Three (3) stations with data in the Patuxent River (TF1.5, TF1.7, LE1.1).
- ~8-10 samples per station-year from 1985-2009.
  - Four and six observations in 1984 and 2010.
- Focused on 1991-2010 data with
  - Layer: AP
  - Season: “Spring” & “Summer”
- Typically 5-6 observation per Station-Season-Year

Phytoplankton biomass [µg-C/L]

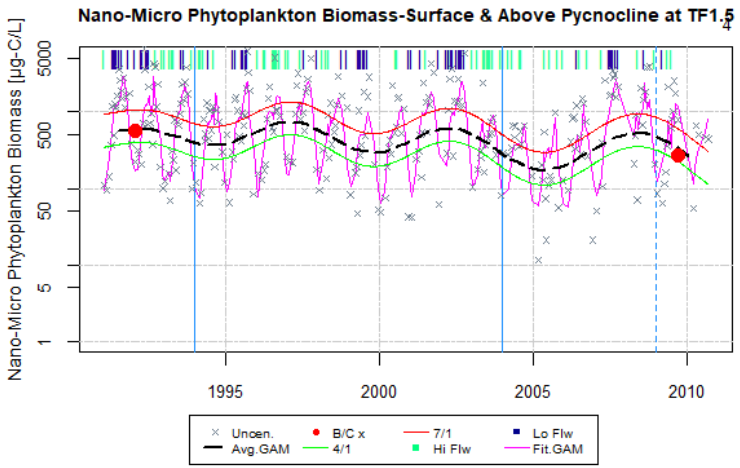
Change, 1991-2010

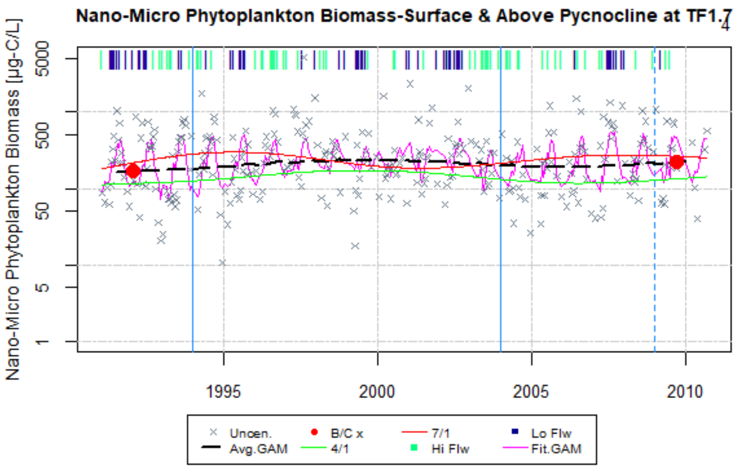
- TF1.5
  - Decreased total and diatom biomass
- LE1.1
  - Increased total, diatom, and dinoflagellate biomass

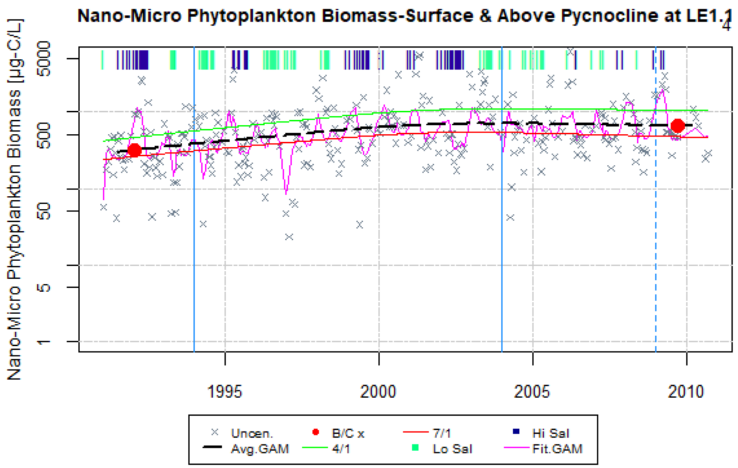
Phytoplankton Biomass Change [µg-C/L] by Taxa Group

Station	Season	Total	Diatom	Dinoflagellate	Cryptophyte	Cyanophyte	Other
TF1.5	Annual	-296 (p≤0.05)	-255 (p≤0.05)	0 (0.25<p)	3 (0.05<p≤0.25)	-10 (0.05<p≤0.25)	-8 (0.25<p)
TF1.5	Mar-May	-230 (p≤0.05)	-245 (p≤0.05)	0 (0.25<p)	5 (p≤0.05)	-3 (0.25<p)	9 (0.25<p)
TF1.5	Jun-Sep	-728 (p≤0.05)	-206 (0.25<p)	0 (0.25<p)	3 (0.05<p≤0.25)	-53 (0.05<p≤0.25)	-36 (0.25<p)
TF1.7	Annual	56 (0.05<p≤0.25)	-11 (0.25<p)	15 (0.05<p≤0.25)	15 (p≤0.05)	-1 (p≤0.05)	3 (0.25<p)
TF1.7	Mar-May	30 (0.25<p)	-22 (0.25<p)	4 (0.05<p≤0.25)	10 (p≤0.05)	0 (0.25<p)	-1 (0.25<p)
TF1.7	Jun-Sep	73 (0.25<p)	-29 (0.25<p)	42 (p≤0.05)	16 (p≤0.05)	-10 (p≤0.05)	6 (0.25<p)
LE1.1	Annual	338 (p≤0.05)	113 (p≤0.05)	90 (p≤0.05)	15 (p≤0.05)	1 (p≤0.05)	23 (p≤0.05)
LE1.1	Mar-May	458 (p≤0.05)	157 (p≤0.05)	86 (p≤0.05)	15 (0.05<p≤0.25)	1 (p≤0.05)	20 (p≤0.05)
LE1.1	Jun-Sep	197 (p≤0.05)	44 (p≤0.05)	143 (p≤0.05)	12 (0.05<p≤0.25)	3 (p≤0.05)	25 (p≤0.05)

p values:	p≤0.05	0.05<p≤0.25	0.25<p







Patuxent River Chl-a:C