Nutrient Limitation in Three Major Tributaries to Chesapeake Bay

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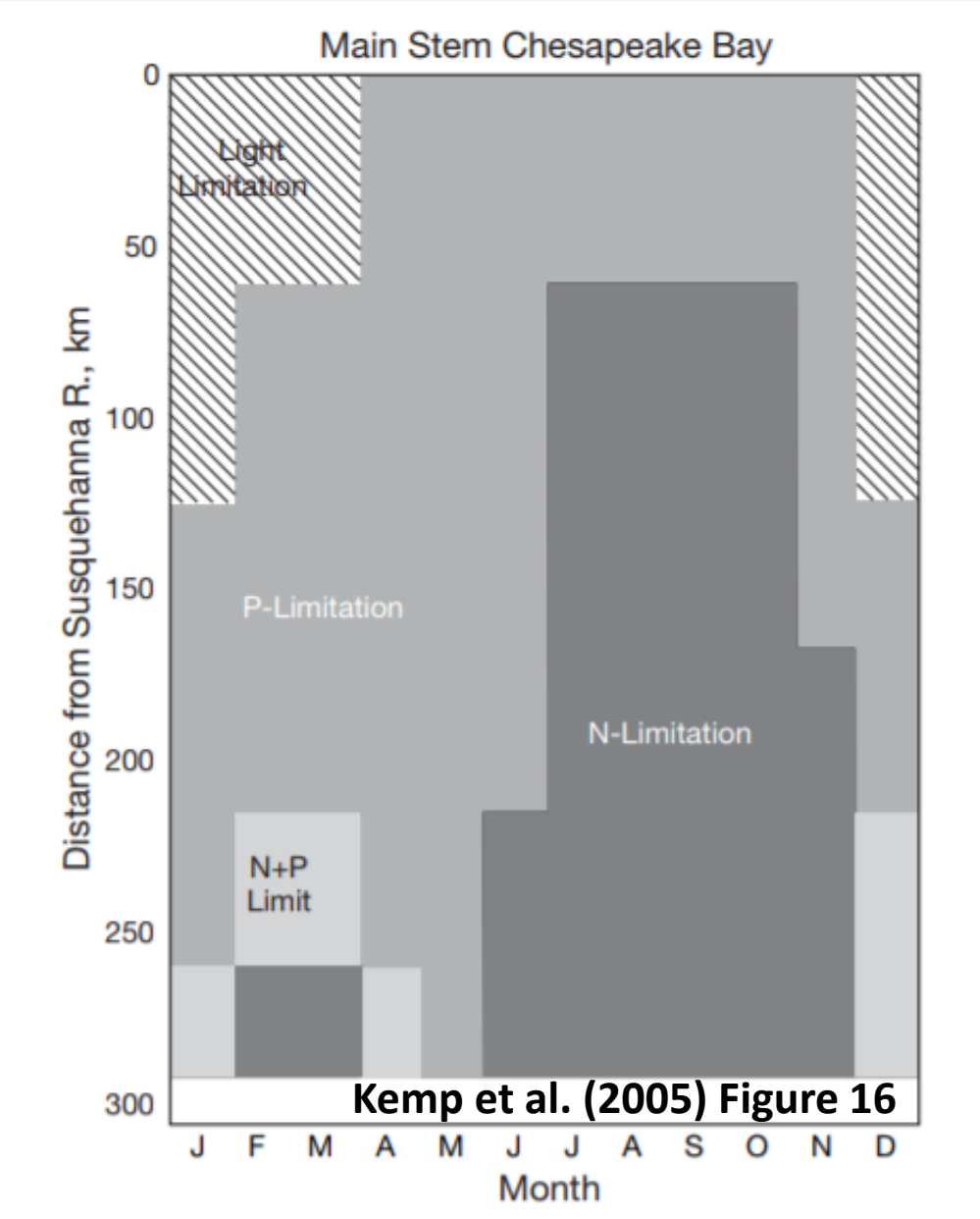
[h] UMCES Chesapeake Biological Laboratory

Background



Kemp et al. (2005) Figure 16

- Large-scale dual nutrient reduction goals have been in place across the Chesapeake Bay watershed for decades.
- Chesapeake Bay has well-documented seasonal and spatial variations in nutrient limitation (e.g., Fisher et al. 1999, Kemp et al., 2005).
- In comparison, nutrient limitation patterns in tidal tributaries are less documented.

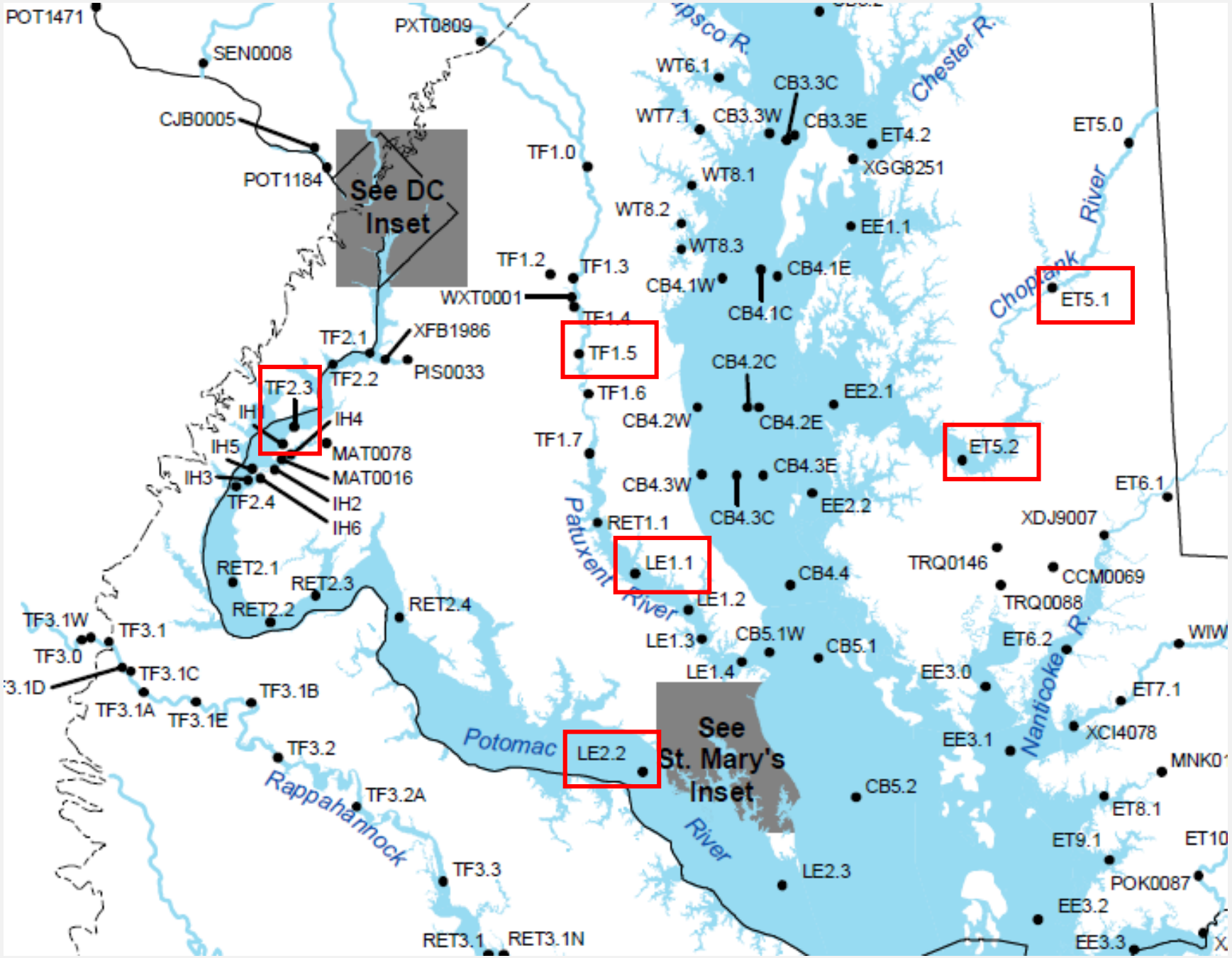
Hypothesis

Given the long-term efforts to reduce nutrients and different trends in N and P loads, nutrient limitation patterns in the tidal tributaries may have changed temporally.

Objectives

1. To develop empirical approaches to relate tidal monitoring data to bioassay-based nutrient limitation in the concurrent period of 1990-2003,
2. To apply the selected approach to monitoring data in recent periods to predict nutrient limitation and explore potential changes in limitation in response to altered nutrient loading.

Sites


POT1471
SEN0008
PXT0809
CJB0005
POT1184
See DC Inset
TF1.0
WT6.1
CB3.3C
WT7.1
CB3.3W
CB3.3E
ET4.2
XGG8251
ET5.0
WT8.1
WT8.2
EE1.1
WT8.3
TF1.2
TF1.3
CB4.1E
CB4.1W
CB4.1C
WXT0001
TF1.4
TF1.5
ET5.1
Choptank River
TF2.1
XFB1986
TF2.2
PIS0033
TF2.3
IH1
IH4
IH5
MAT0078
IH3
MAT0016
TF2.4
IH2
IH6
CB4.2C
EE2.1
TF1.6
CB4.2W
CB4.2E
TF1.7
ET5.2
CB4.3E
CB4.3W
CB4.3C
EE2.2
ET6.1
RET1.1
Patuxent River
XDJ9007
LE1.1
TRQ0146
CCM0069
CB4.4
TRQ0088
LE1.2
RET2.1
RET2.3
RET2.2
RET2.4
TF3.1W
TF3.1
LE1.3
CB5.1W
CB5.1
ET6.2
WIW
TF3.0
LE1.4
EE3.0
TF3.1C
3.1D
TF3.1A
TF3.1B
TF3.1E
ET7.1
Nanticoke R.
XCI4078
EE3.1
Potomac
LE2.2
See St. Mary's Inset
TF3.2
MNK0
CB5.2
Rappahannock
TF3.2A
ET8.1
ET9.1
ET10
River
LE2.3
TF3.3
POK0087
EE3.2
RET3.1
RET3.1N
EE3.3

Bioassay Data

Table 1. Station descriptions and sampling schedule for bioassays of resource limitation of phytoplankton growth. The number of samples at each station varied due to the sampling schedule (e.g., tidal fresh stations were sampled only 3 times per year), bad weather, boat mishaps, etc., and numbers of bioassays are cumulative since August, 1990. Turkey Point was sampled beginning in 2000, and several stations marked with "#" were sampled only in 2004. We discontinued sampling in Baltimore Harbor in 1993. Abbreviations: tidal fr. = tidal fresh.

sampling area		description	MDE sta.ID	sampling day	our ID#	# of Samples
Main Bay stations		Turkey Pt	CB 2.1	wed.	11	13
		Bay bridge	CB 3.3C	tues.	4	117
		R64 buoy	CB 4.3C	tues.	5	130
		Point-no-point	CB 5.2	mon.	1	131
Baltimore Harbor		Baltimore H.	WT 5.1	NA	8	26
Patuxent	(tidal fresh)	Nottingham	TF1.5	thurs.	9	66
	(tidal fresh)	Jug Bay	— #	thurs.	13	3
	(mesohaline)	Jack Bay	LE1.1	thurs.	10	154
Potomac	(tidal fresh)	Indian Head	TF2.3	mon.	2	64
	(mesohaline)	Ragged Pt	LE2.2	mon.	3	143
Choptank	(tidal fresh)	Ganey Wharf	ET5.1	tue.	6	64
	(mesohaline)	Cambridge	ET5.2	tue.	7	159
Chester	(tidal fresh)	Rt.290 Br.	ET4.1 #	varies	15	3
	(mesohaline)	Deep Landing	— #	varies	14	3
Bush	(tidal fresh)	Otter Point Cr.	— #	varies	16	2
	(oligohaline)	E of Gum Pt.	WT1.1	varies	17	2
Total number		Stations:	16		Bioassays:	1070

Fisher et al. (2005)

Bioassay Categories

Table 4. Weighting factors used to compute indices of N, P, and light limitation of algal growth in Chesapeake Bay using nutrient addition bioassays. Each classified bioassay (see Table 2 and Fig. 2) contributed the amounts shown below to the index, which was then divided by the total number of bioassays. Each index of N, P, or light limitation = $(\sum w)/n$, where w is the weighting factor assigned to each of the n bioassays. This results in an index ranging from 0 (no limitation) to 1 (completely limited). Abbreviations: EXN = exclusive N; PRN = primary N; BNP = balanced NP; PRP = primary P; EXP = exclusive P; NOR = no response to added nutrients.

	weighting factors					
Type of Index	EXN	PRN	BNP	PRP	EXP	NOR
N limitation	1.00	0.75	0.50	0.25	0.00	0.00
P limitation	0.00	0.25	0.50	0.75	1.00	0.00
Light limitation	0.00	0.00	0.00	0.00	0.00	1.00

Limitation Classes

N limitation:

- N index > 0.5

P limitation:

- P index > 0.5

N+P limitation:

- both indices ~0.5

NoR

- others

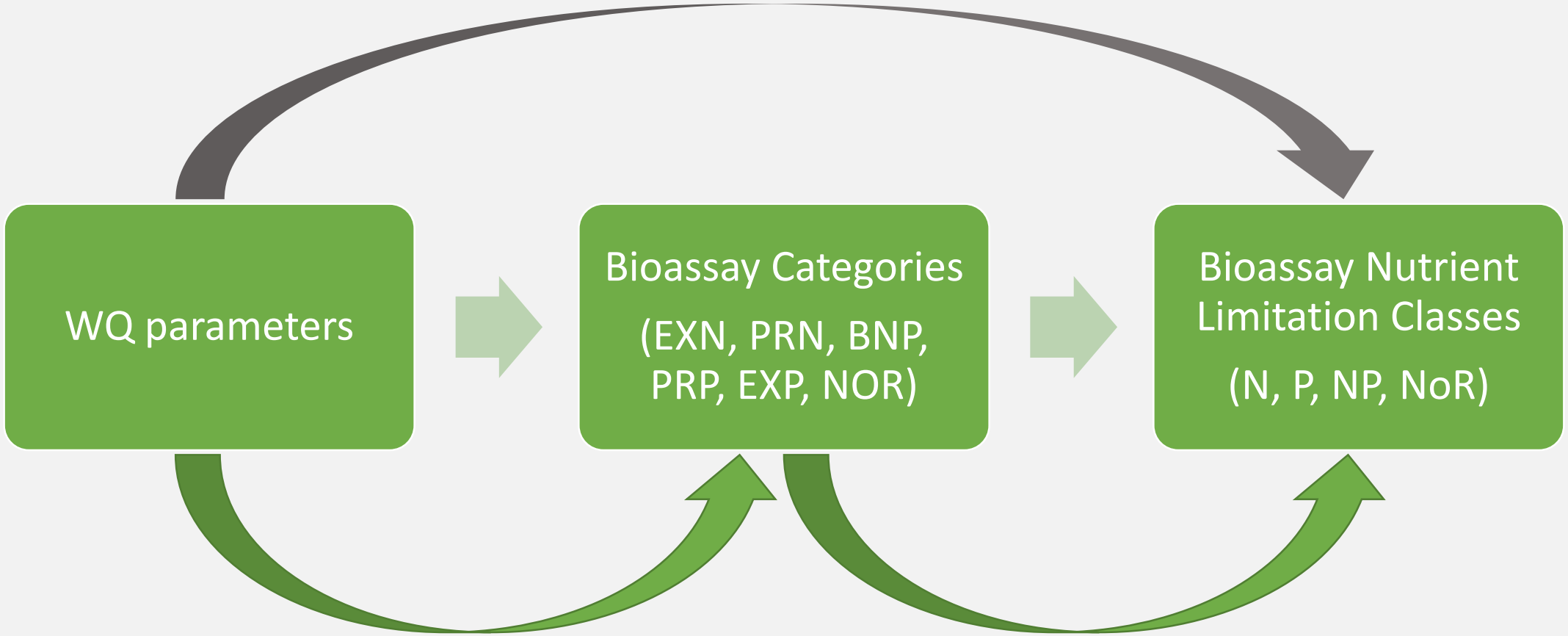
Data

- Bioassay data collected in 1990-2003 (Fisher et al.)
  - **Bioassay categories**: EXN, PRN, BNP, PRP, EXP, NOR
  - **Bioassay-based nutrient limitation classes**: N, P, NP, NoR

- Tidal WQ Monitoring Data in 1990-2018
  - Chesapeake Bay Program's fixed-station, long-term water-quality monitoring network (provided by MDDNR, VADEQ, etc.)
  - Downloaded from the Data Hub: https://datahub.chesapeakebay.net/
  - Data Manipulations:
    - ✓ missing values;
    - ✓ below-detection-limit values;
    - ✓ aggregation of different depths;
    - ✓ calculation of N:P ratios and indices, etc.

Summary of Tributary Bioassay & Tidal WQ Data

		Model Development (1990-2003)			Model Prediction (2 periods)	
Station	Tributary	Bioassay Categories (Y)	Tidal WQ Samples (Xs)	Matched Pairs	Tidal WQ Samples (1990-2003)	Tidal WQ Samples (2004-2017)
ET5.1	Choptank	55	249	48	249	191
ET5.2	Choptank	128	252	114	252	189
TF1.5	Patuxent	61	252	57	252	168
LE1.1	Patuxent	136	269	128	269	203
TF2.3	Potomac	60	241	48	241	211
LE2.2	Potomac	133	237	120	237	209



CART
(feature selection)
(cross validation)

Aggregation Rule
(N index)
(P index)

Hypothesis

Given the long-term efforts to reduce nutrients and different trends in N and P loads, nutrient limitation patterns in the tidal tributaries may have changed temporally.

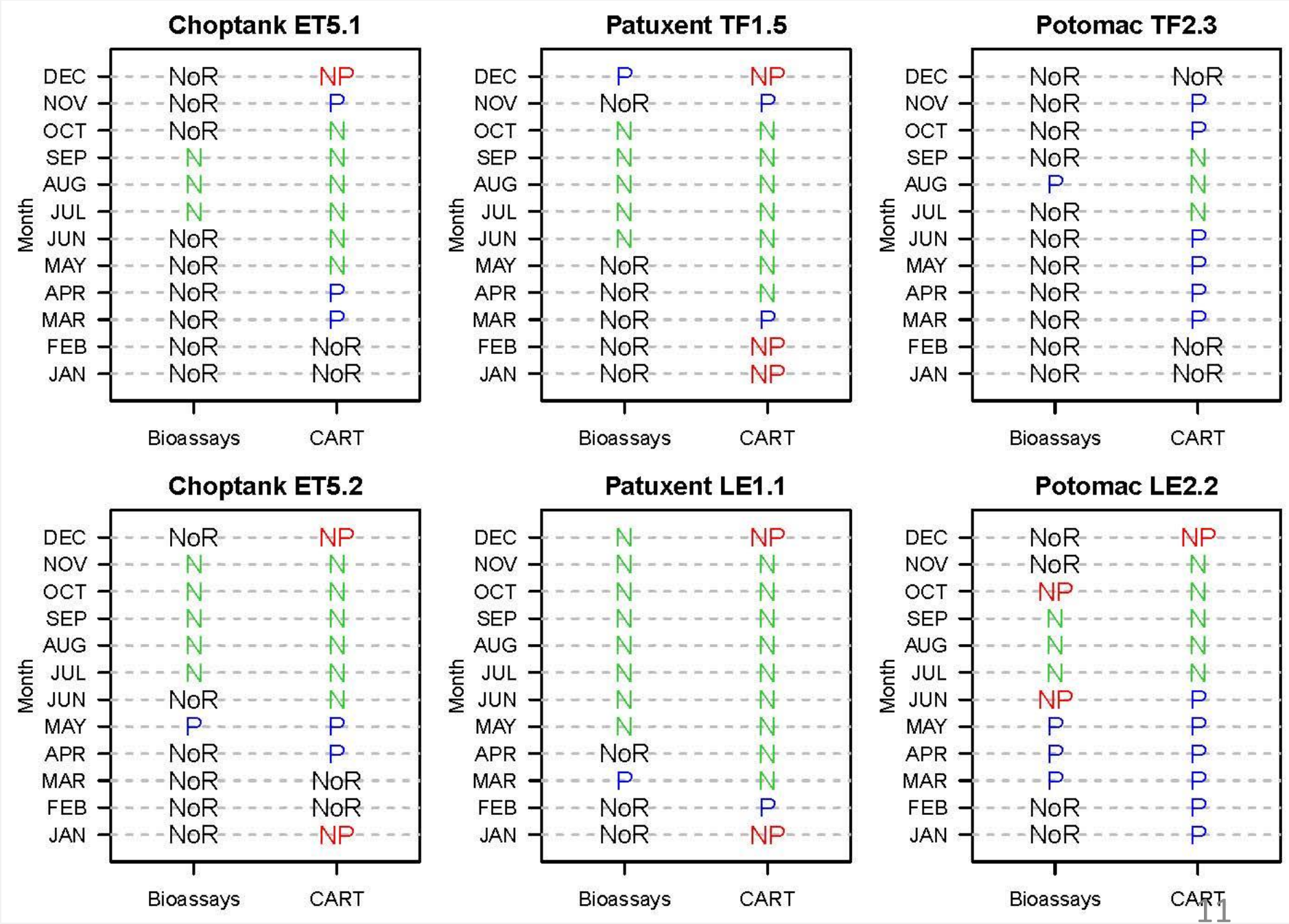
Objectives

1. To develop empirical approaches to relate tidal monitoring data to bioassay-based nutrient limitation in the concurrent period of 1990-2003,
2. To apply the selected approach to monitoring data in recent periods to predict nutrient limitation and explore potential changes in limitation in response to altered nutrient loading.

S1: We previously developed a CART model for the mainstem stations. How well can this model reproduce the bioassay-based nutrient limitation classes in the three tributaries?

<u>Mainstem Model</u>

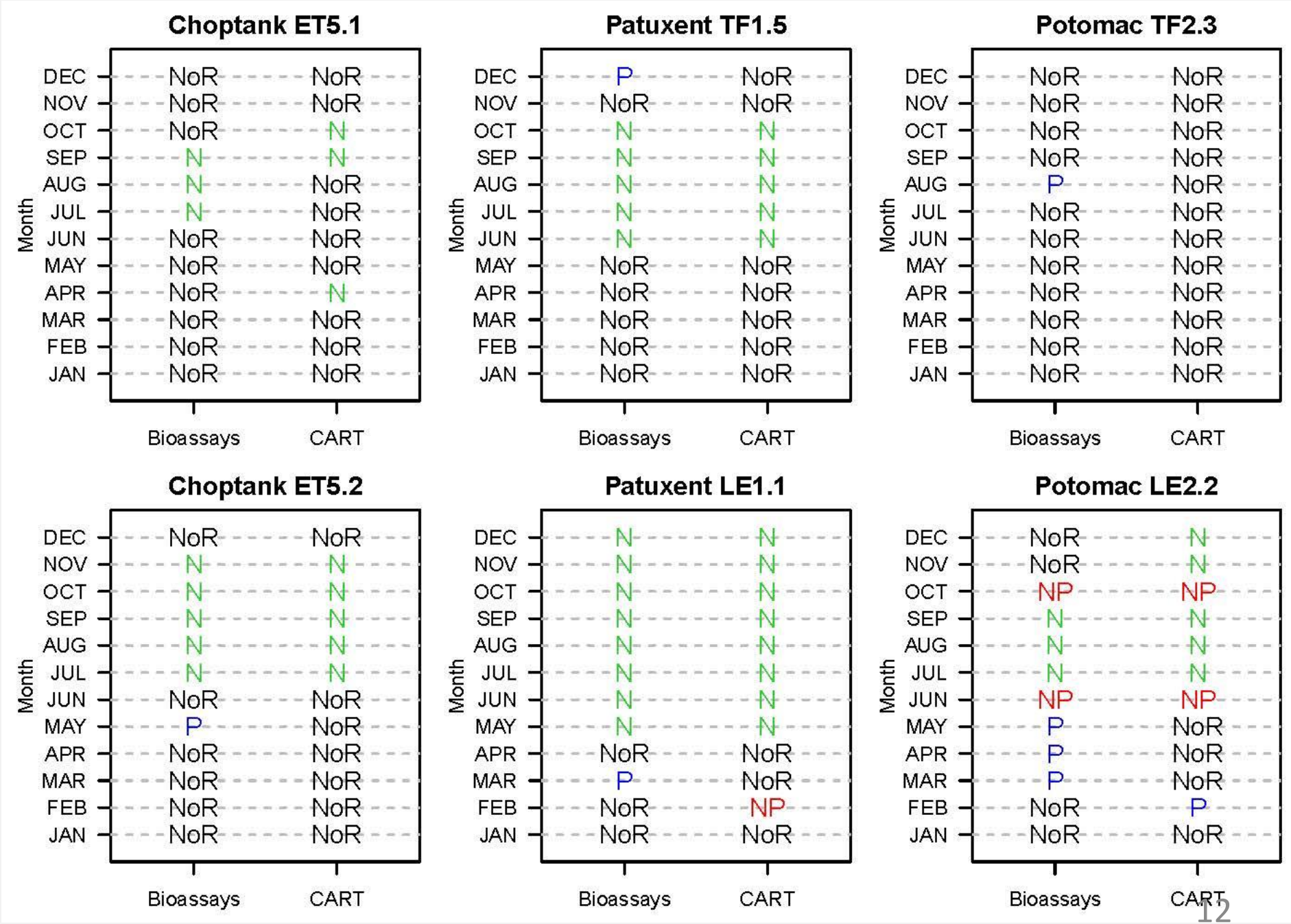
ET5.1: 5/12
ET5.2: 8/12
TF1.5: 5/12
LE1.1: 7/12
TF2.3: 3/12
LE2.2: 6/12
Total: 34/72 (47%)



S2: Since the mainstem model works poorly, let's develop a model for the six stations (response = bioassay categories, i.e., EXN, PRN, BNP, PRP, EXP, NOR).

<u>Single Tributary Model</u>

ET5.1: 8/12
ET5.2: 11/12
TF1.5: 11/12
LE1.1: 10/12
TF2.3: 11/12
LE2.2: 6/12
Total: 57/72 (79%)



S3: Let's develop two separate models, one for TF stations and the other for MH stations.

TF Model + MH Model

ET5.1: 10/12

ET5.2: 10/12

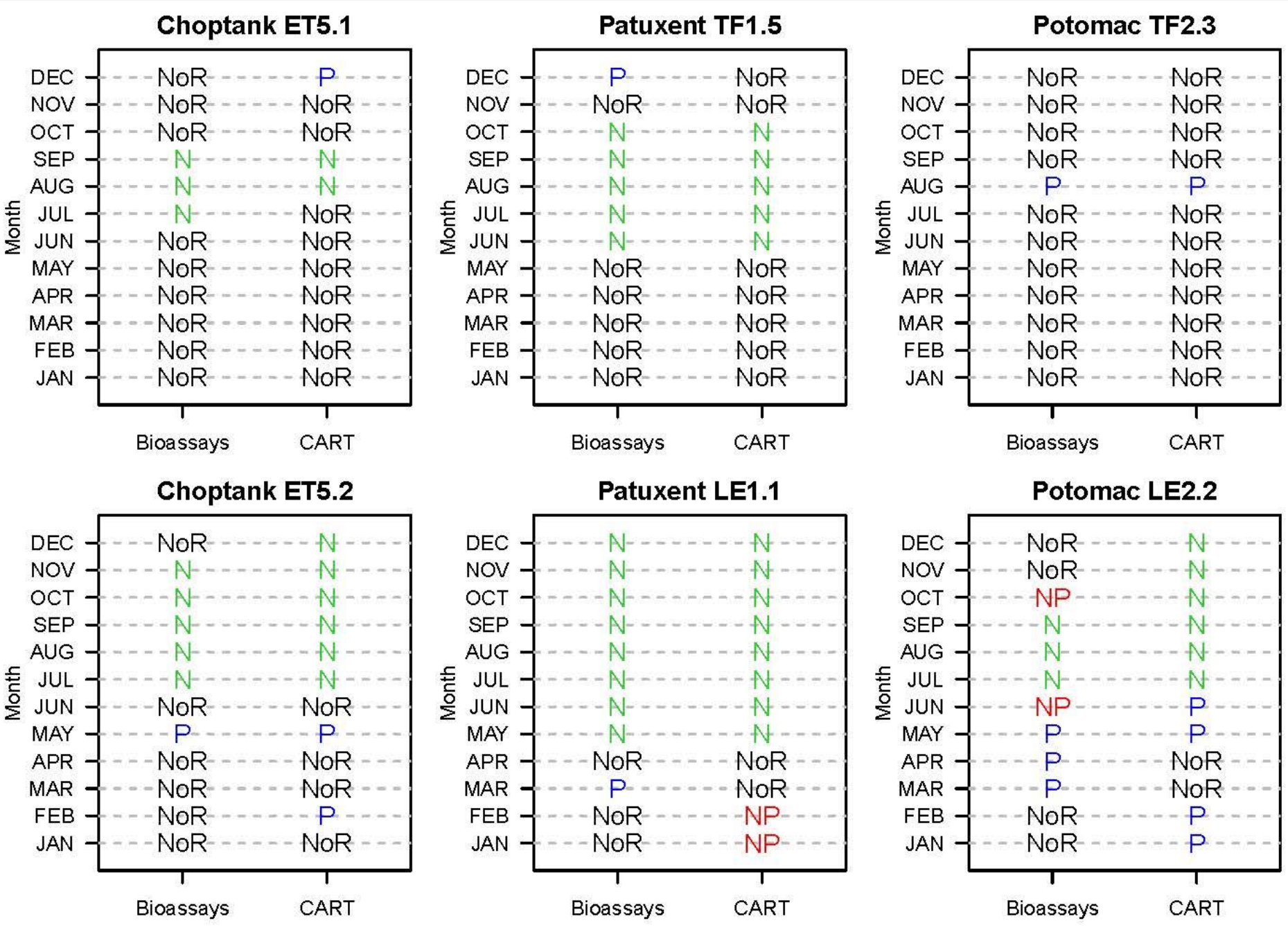
TF1.5: 11/12

LE1.1: 9/12

TF2.3: 12/12

LE2.2: 4/12

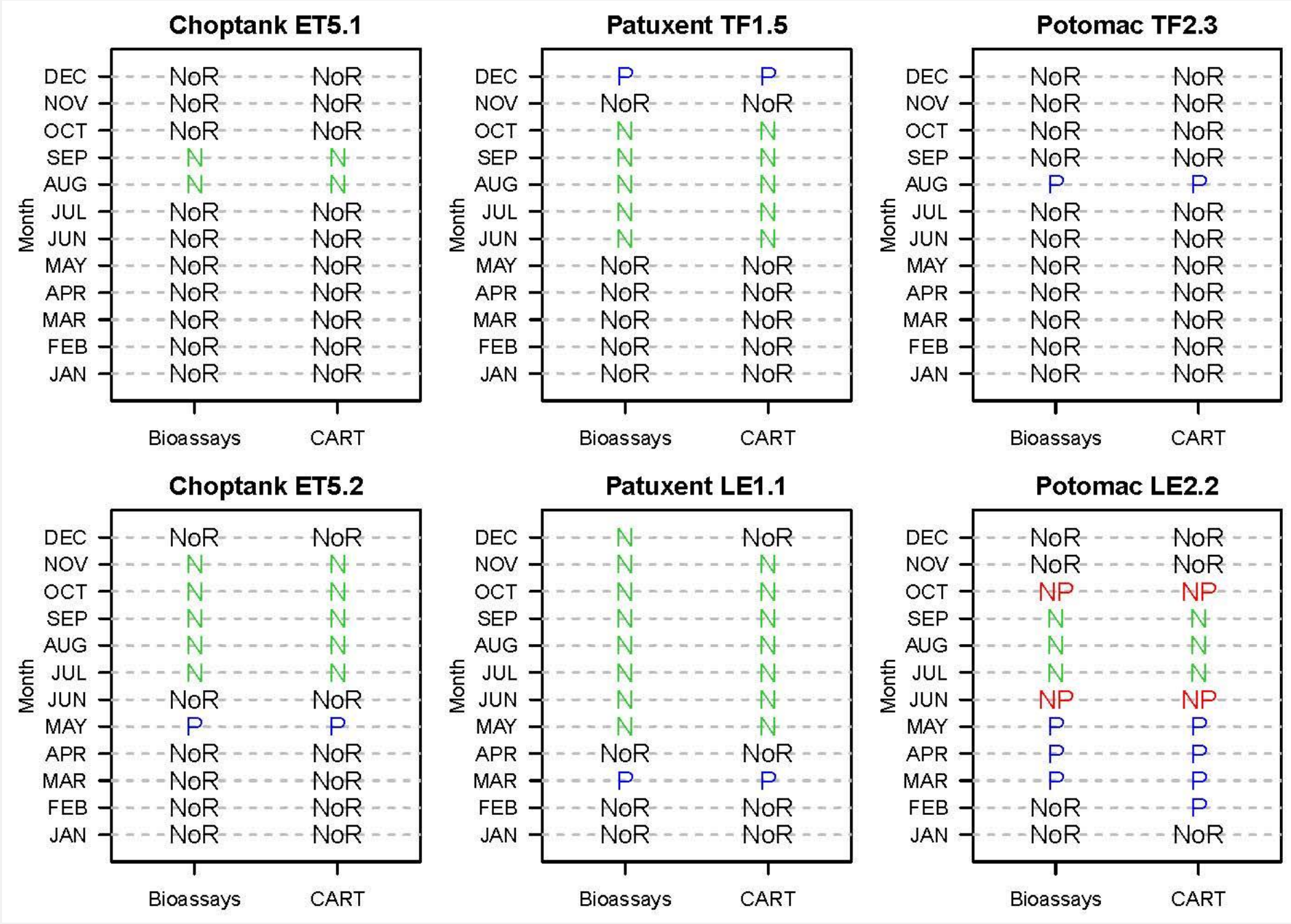
Total: 56/72 (78%)



S4: Let's develop a separate model for each tidal station.

Station-level Model

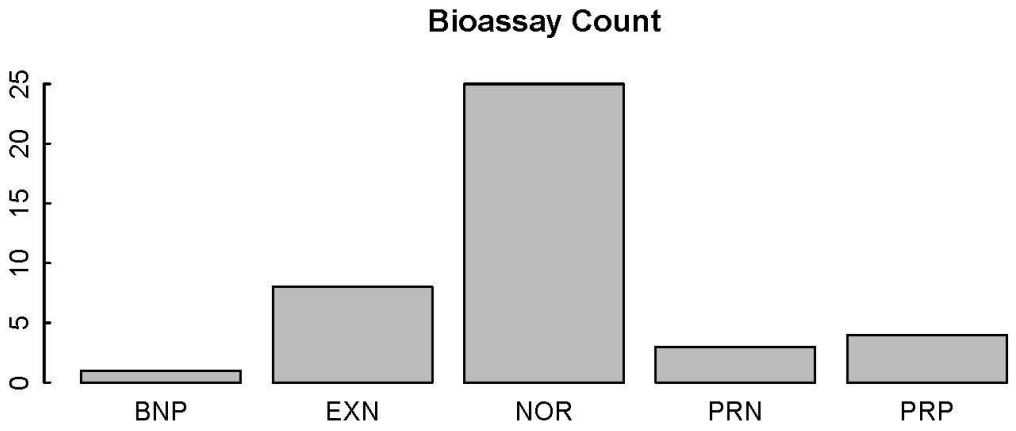
ET5.1: 12/12
ET5.2: 12/12
TF1.5: 12/12
LE1.1: 11/12
TF2.3: 12/12
LE2.2: 11/12
Total: 70/72 (97%)

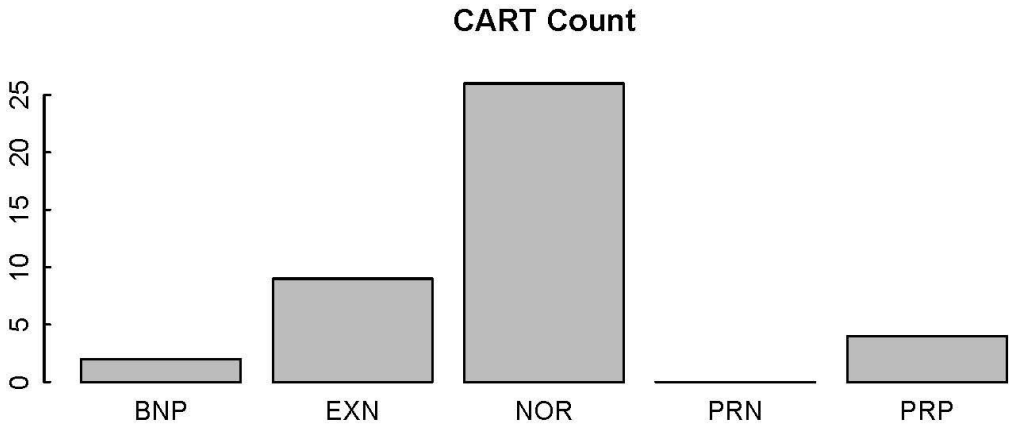


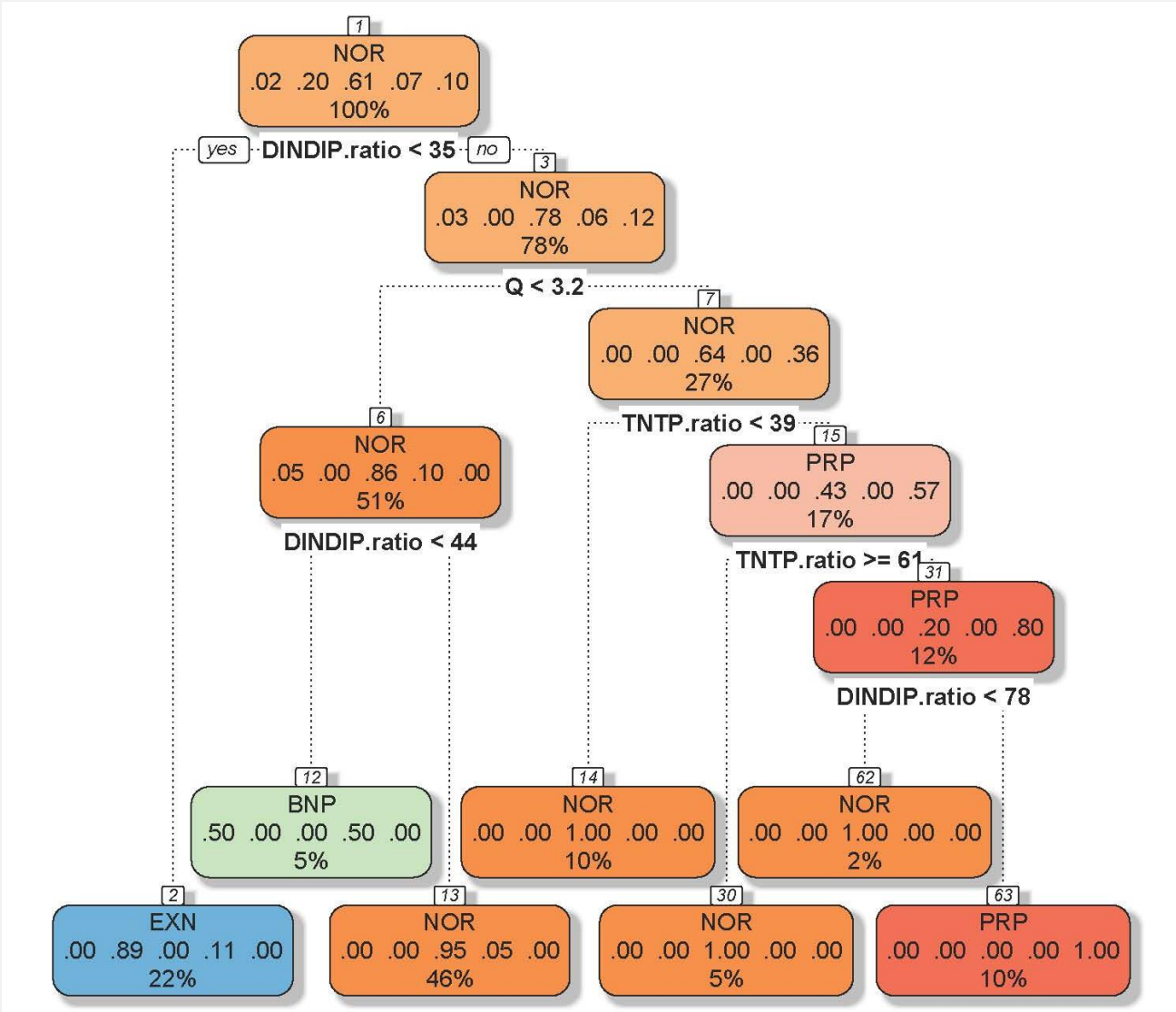
Summary of Model Performance

Models	ET5.1	ET5.2	TF1.5	LE1.1	TF2.3	TF2.3	Classification Rate
A. 1 model using mainstem data	5/12	8/12	5/12	7/12	3/12	6/12	34/72 = 47%
B. 1 model using tributary data	8/12	11/12	11/12	10/12	11/12	6/12	57/72 = 79%
C. 1 model for TF + 1 model for MH	10/12	10/12	11/12	9/12	12/12	4/12	56/72 = 78%
D. 6 models, one for each station	12/12	12/12	12/12	11/12	12/12	11/12	70/72 = 97%

Choptank ET5.1







Hypothesis

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Objectives

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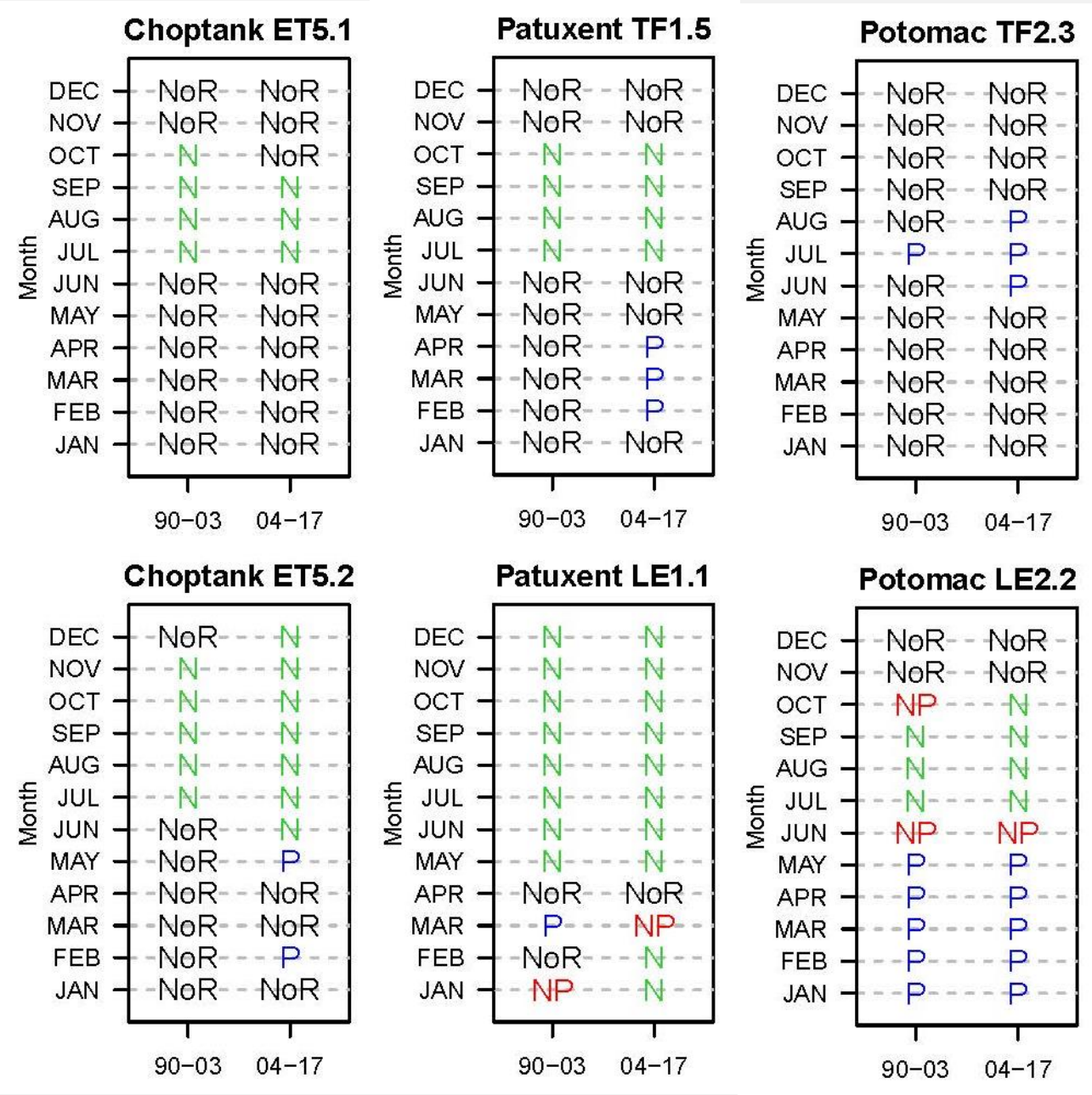
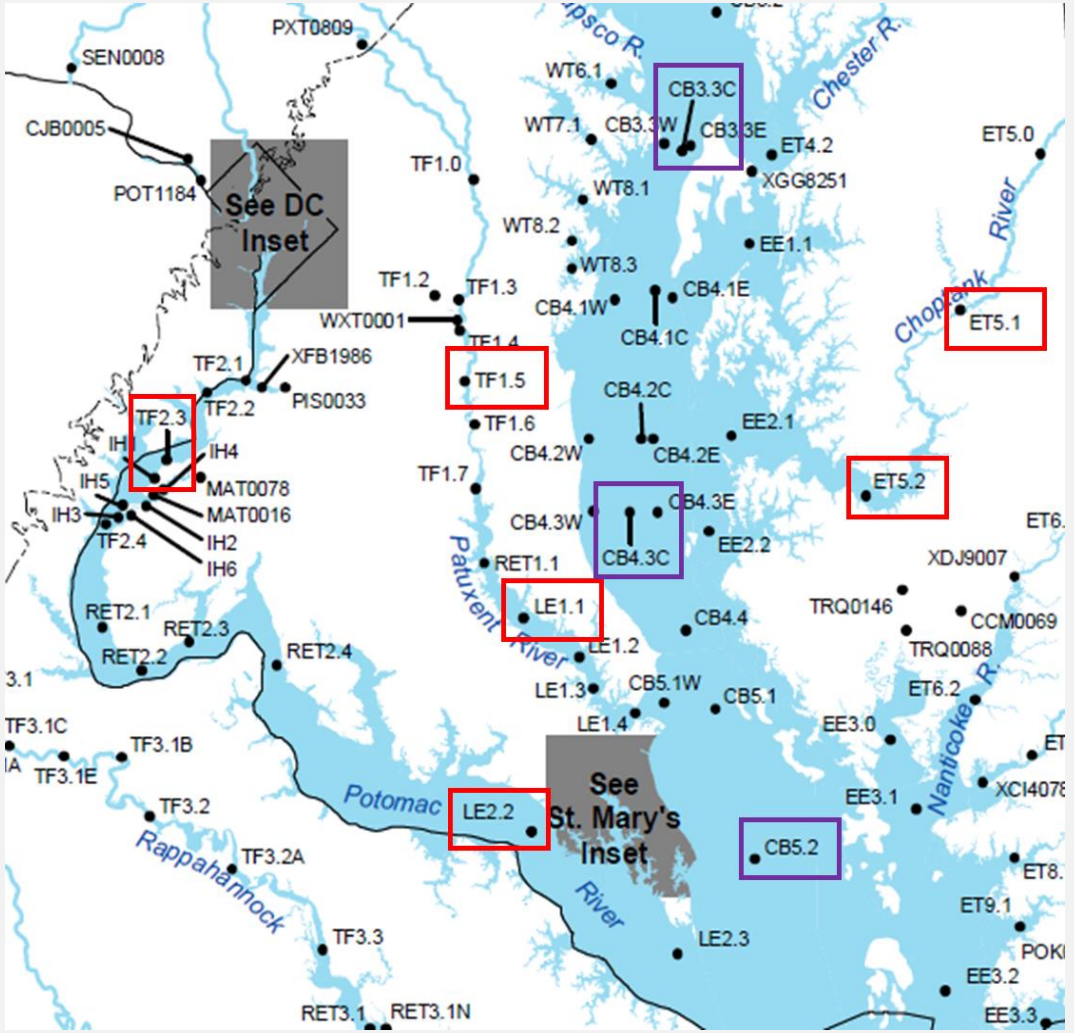
Predicted Limitation by 14-yr Periods





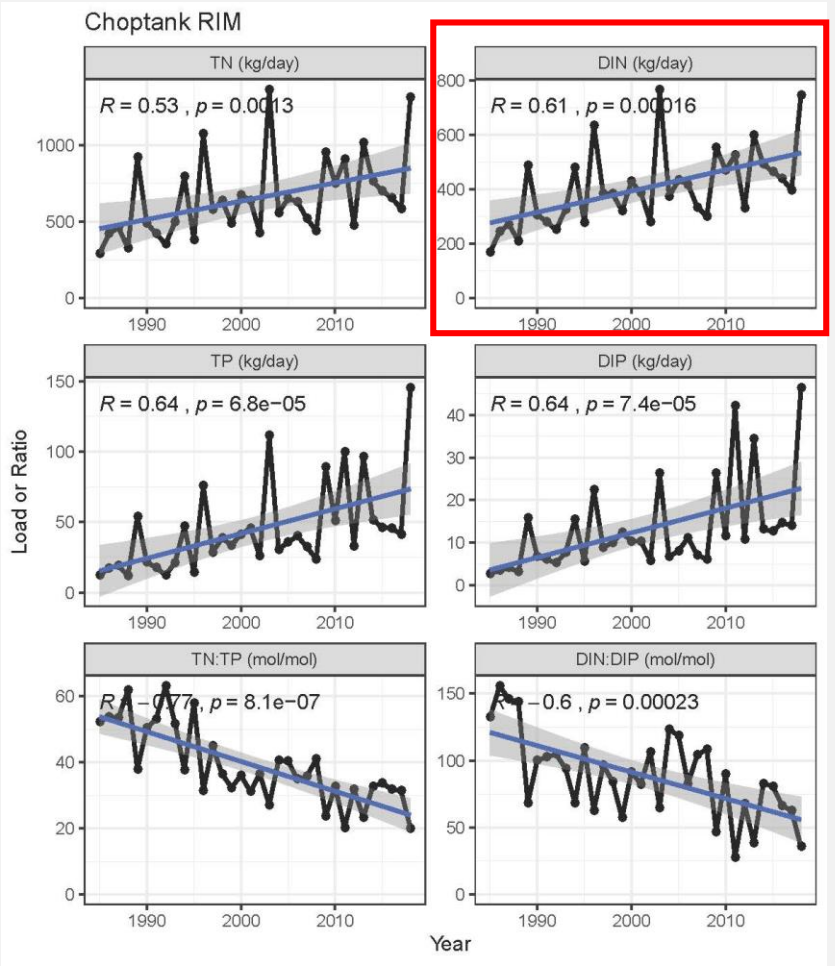
<u>Upstream station:</u>

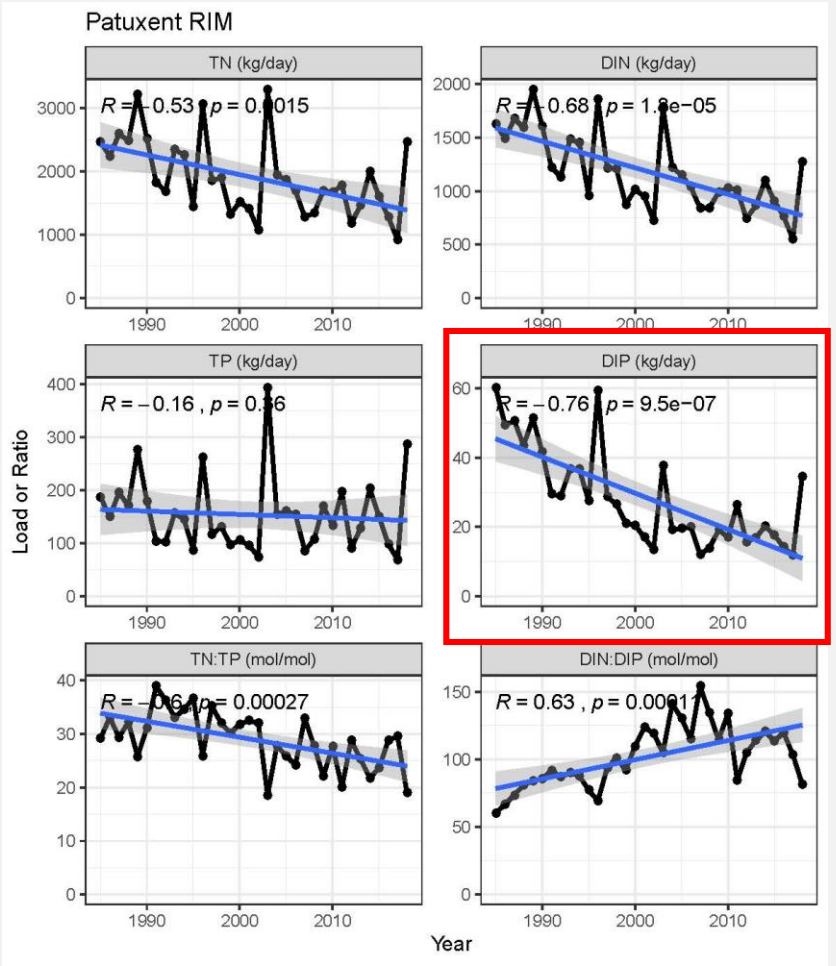
Mostly NoR and N, seldomly P, never NP.

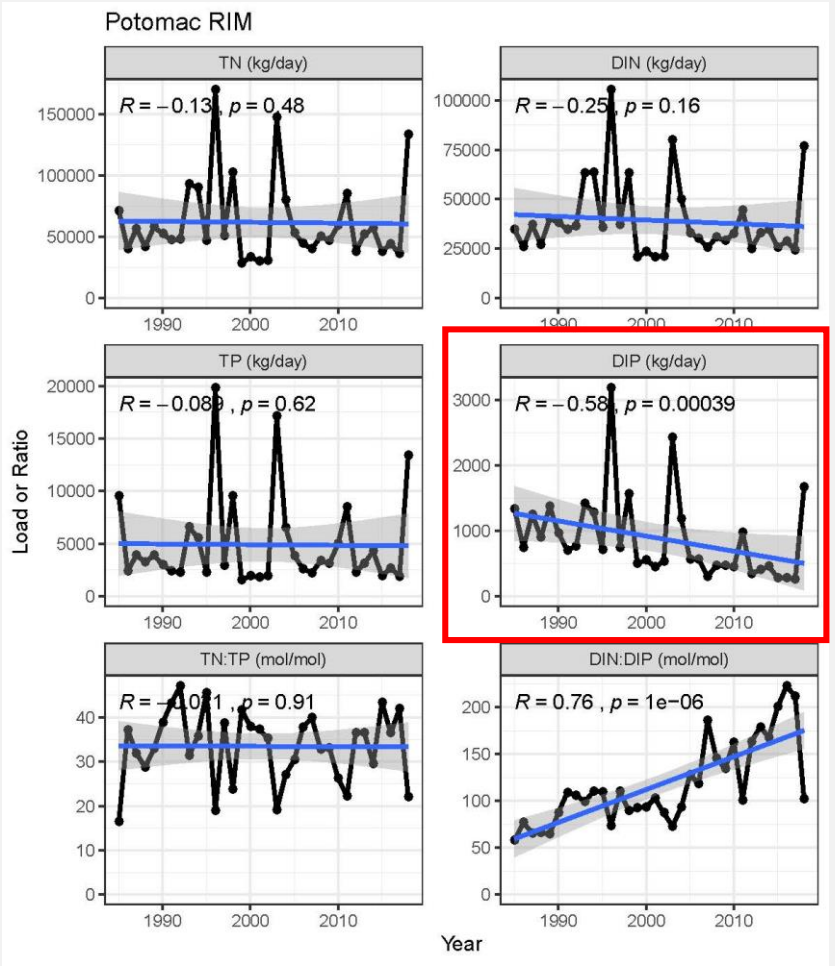
<u>Downstream station:</u>

Mostly N, fewer NoR, more P and NP.

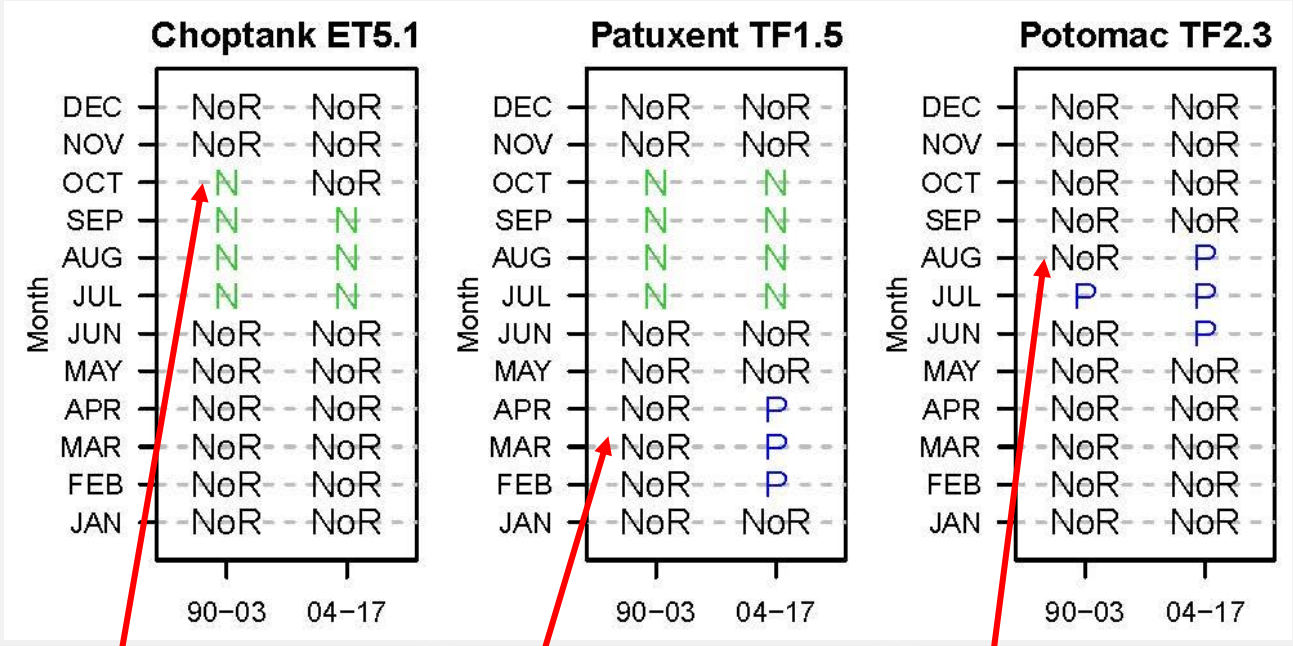
RIM Loads

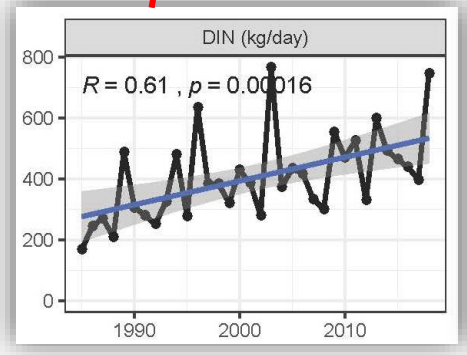

Choptank RIM
TN (kg/day)
R = 0.53 , p = 0.0013
DIN (kg/day)
R = 0.61 , p = 0.00016
TP (kg/day)
R = 0.64 , p = 6.8e−05
DIP (kg/day)
R = 0.64 , p = 7.4e−05
TN:TP (mol/mol)
R = −0.77 , p = 8.1e−07
DIN:DIP (mol/mol)
R = −0.6 , p = 0.00023
Load or Ratio
Year

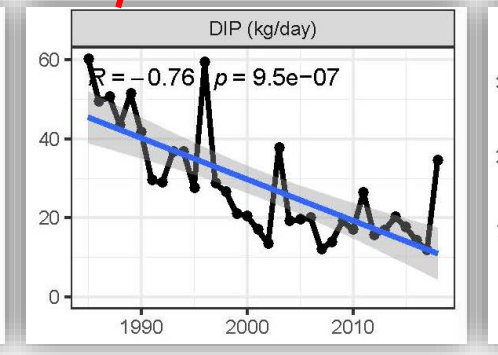

Patuxent RIM
TN (kg/day)
R = −0.53 , p = 0.0015
DIN (kg/day)
R = −0.68 , p = 1.8e−05
TP (kg/day)
R = −0.16 , p = 0.36
DIP (kg/day)
R = −0.76 , p = 9.5e−07
TN:TP (mol/mol)
R = −0.64 , p = 0.00027
DIN:DIP (mol/mol)
R = 0.63 , p = 0.00011
Load or Ratio
Year

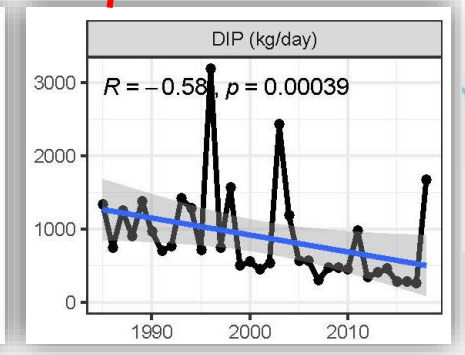

Potomac RIM
TN (kg/day)
R = −0.13 , p = 0.48
DIN (kg/day)
R = −0.25 , p = 0.16
TP (kg/day)
R = −0.089 , p = 0.62
DIP (kg/day)
R = −0.58 , p = 0.00039
TN:TP (mol/mol)
R = −0.011 , p = 0.91
DIN:DIP (mol/mol)
R = 0.76 , p = 1e−06
Load or Ratio
Year

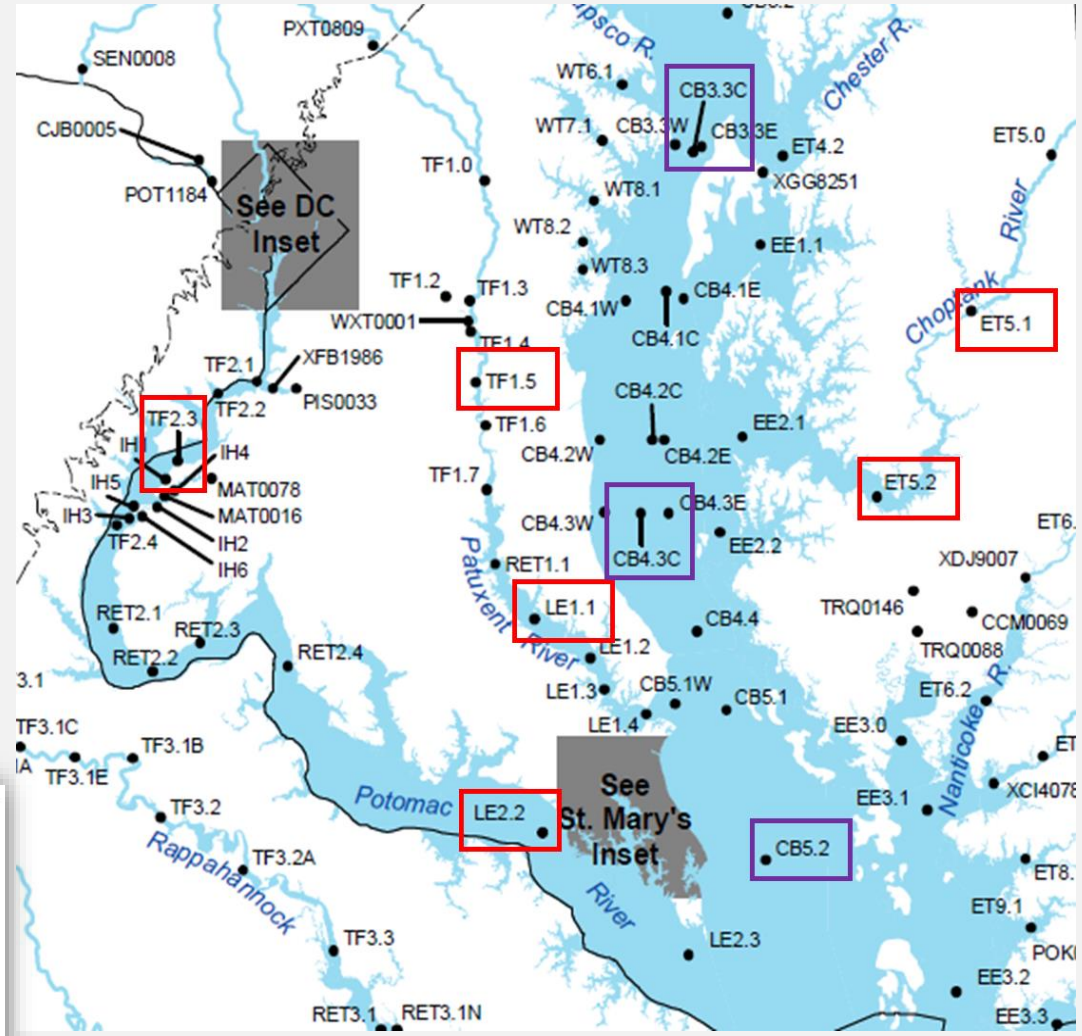
Predicted Limitation by 14-yr Periods



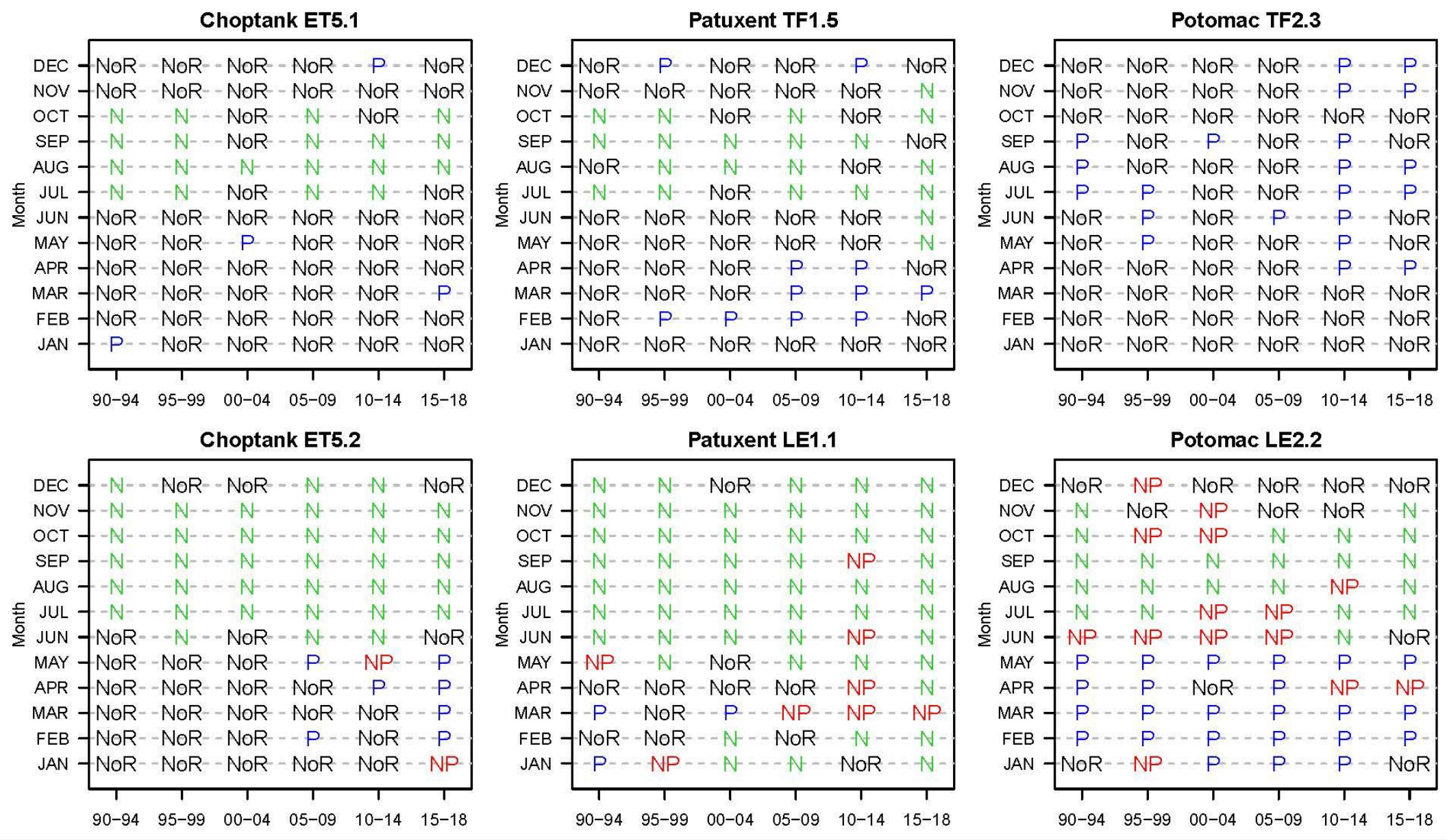




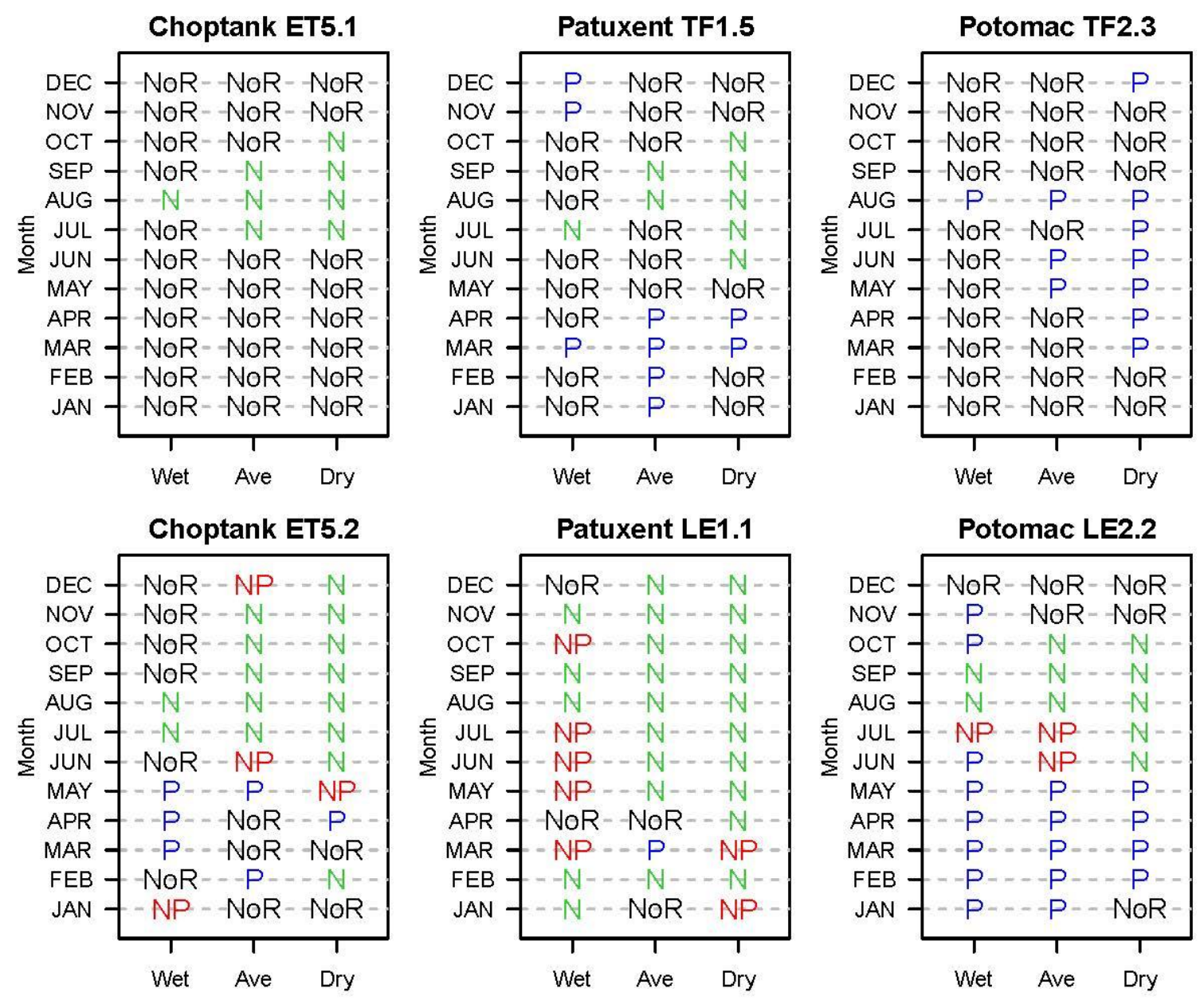




Predicted Limitation by 5-yr Periods



Predicted Limitation by Hydrology



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Objectives

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Next Steps

1. To develop empirical approaches to relate tidal monitoring data to bioassay-based nutrient limitation in the concurrent period of 1990-2003.
   - Refine residence time and RIM/below-RIM loads calculation
   - Consider ensemble models
   - WWTP signals in the three tribs

2. To apply the selected approach to monitoring data in recent periods to predict nutrient limitation and explore potential changes in limitation in response to altered nutrient loading.
   - Link to RIM and below-RIM load trends for specific months
   - Add uncertainties to CART predictions
   - Validate CART using additional bioassays from other tributaries