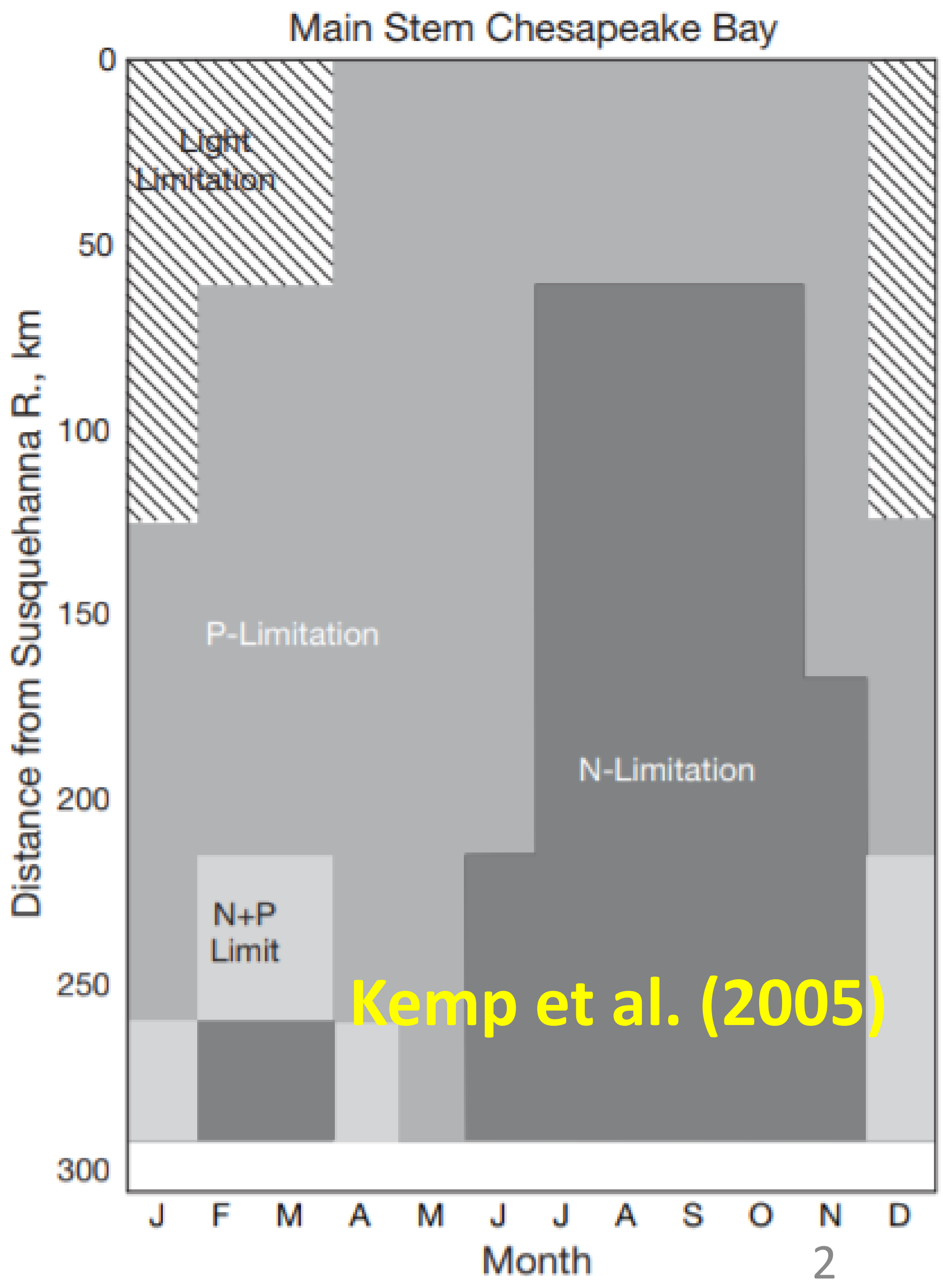
Refined Analysis of Tidal Bay Nutrient Limitation and Potential Applications to the 2017 Bay Model

Qian Zhang, Tom Fisher, Emily Trentacoste, Claire Buchanan,
Anne Gustafson, Renee Karrh, Rebecca Murphy, Jennifer Keisman,
Cuiyin Wu, Richard Tian, Jeremy Testa, Peter Tango
with Richard Tian and Lew Linker

Modeling Workgroup Quarterly Review
July 2020

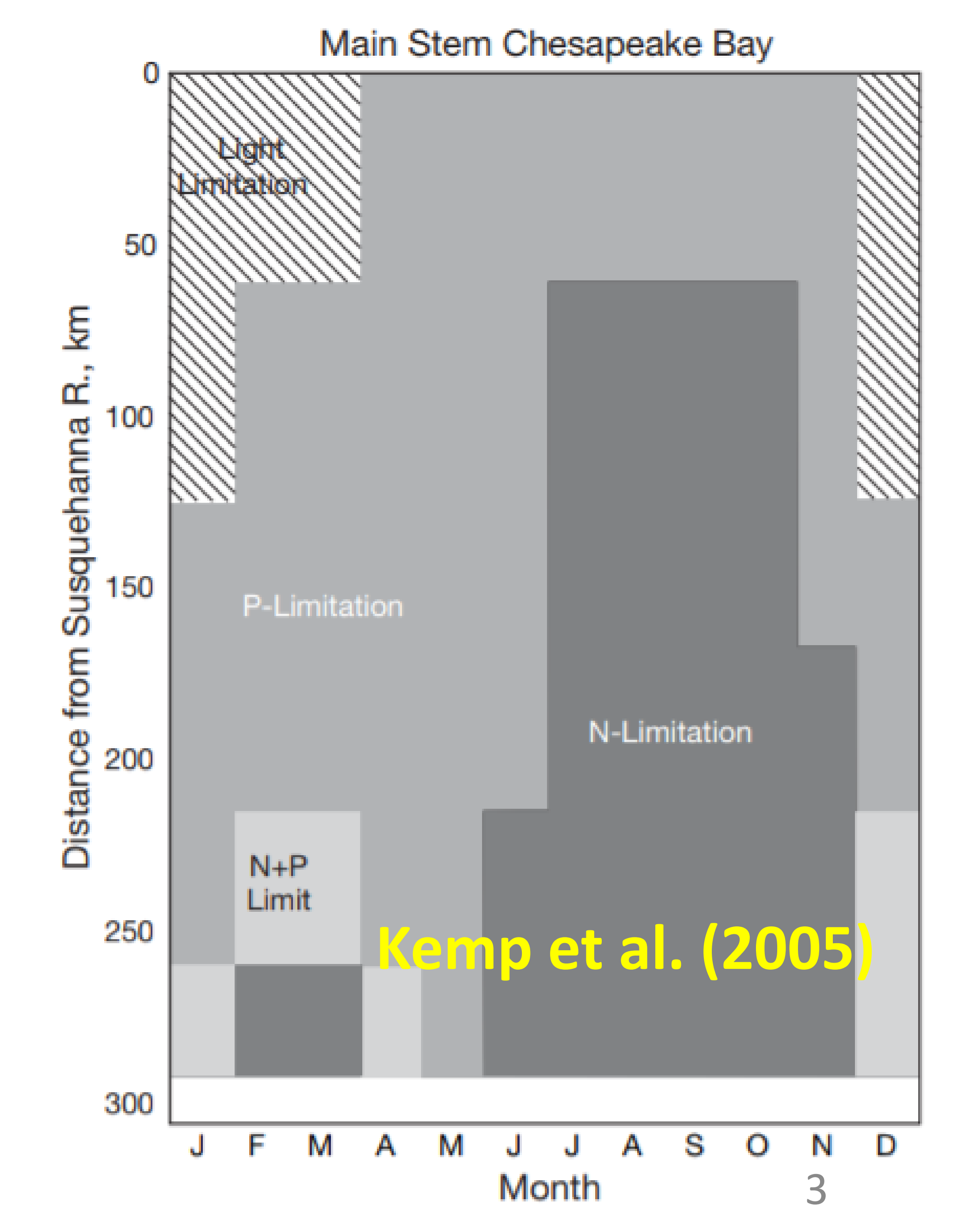
Background

- Large-scale dual nutrient reduction goals have been in place across the watershed for decades.
- Chesapeake Bay has well-documented seasonal and spatial variations in nutrient limitation to algal growth (Kemp et al., 2005).
- These patterns were determined using bioassays from the 1992-2002 (Fisher et al., 2002, 2005).



Application to the 2017 WQSTM

- The nutrient limitation patterns published in Kemp et al. (2005) were used in the calibration of the 2017 Chesapeake Bay estuarine model.



Recent Research

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

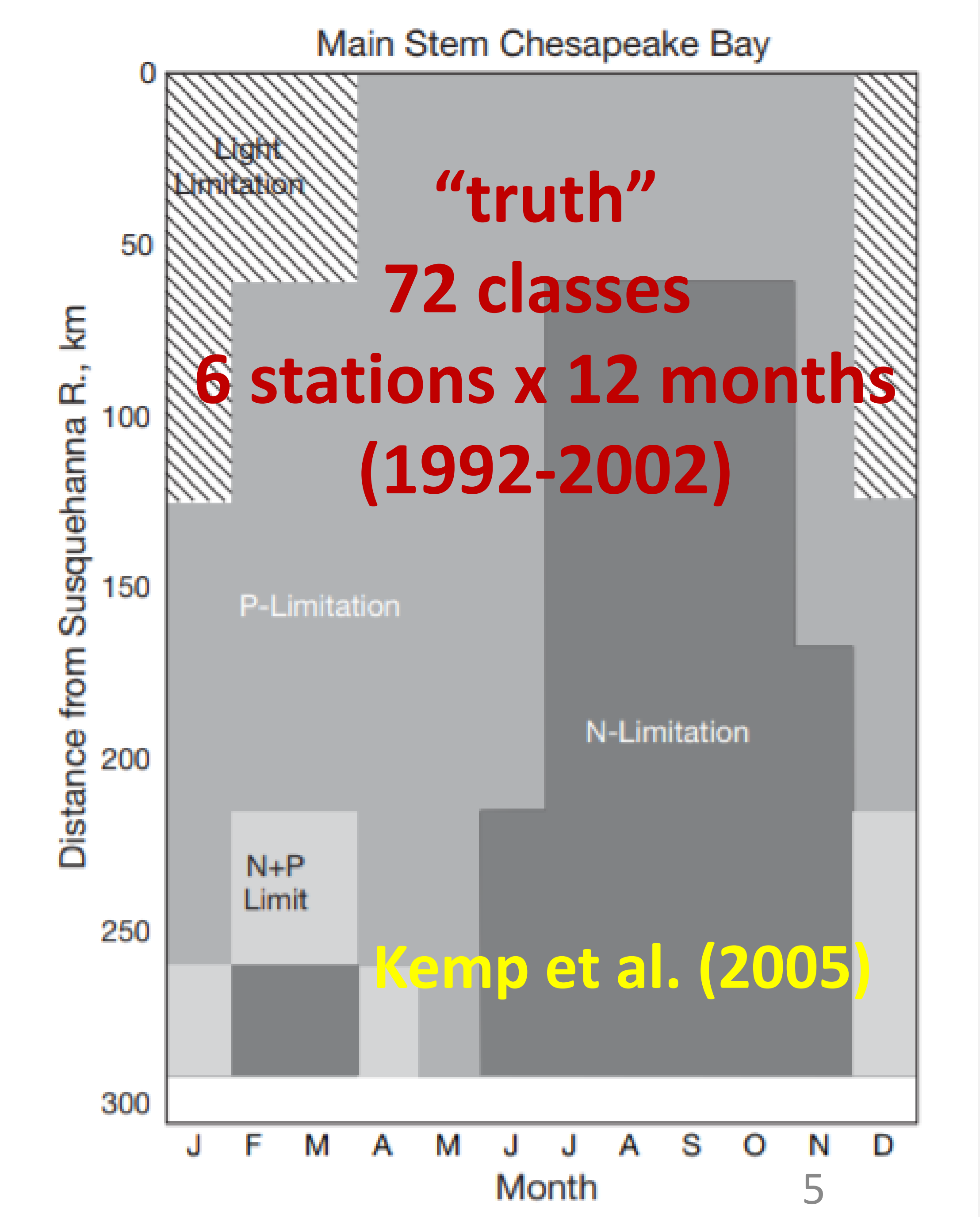
Objectives

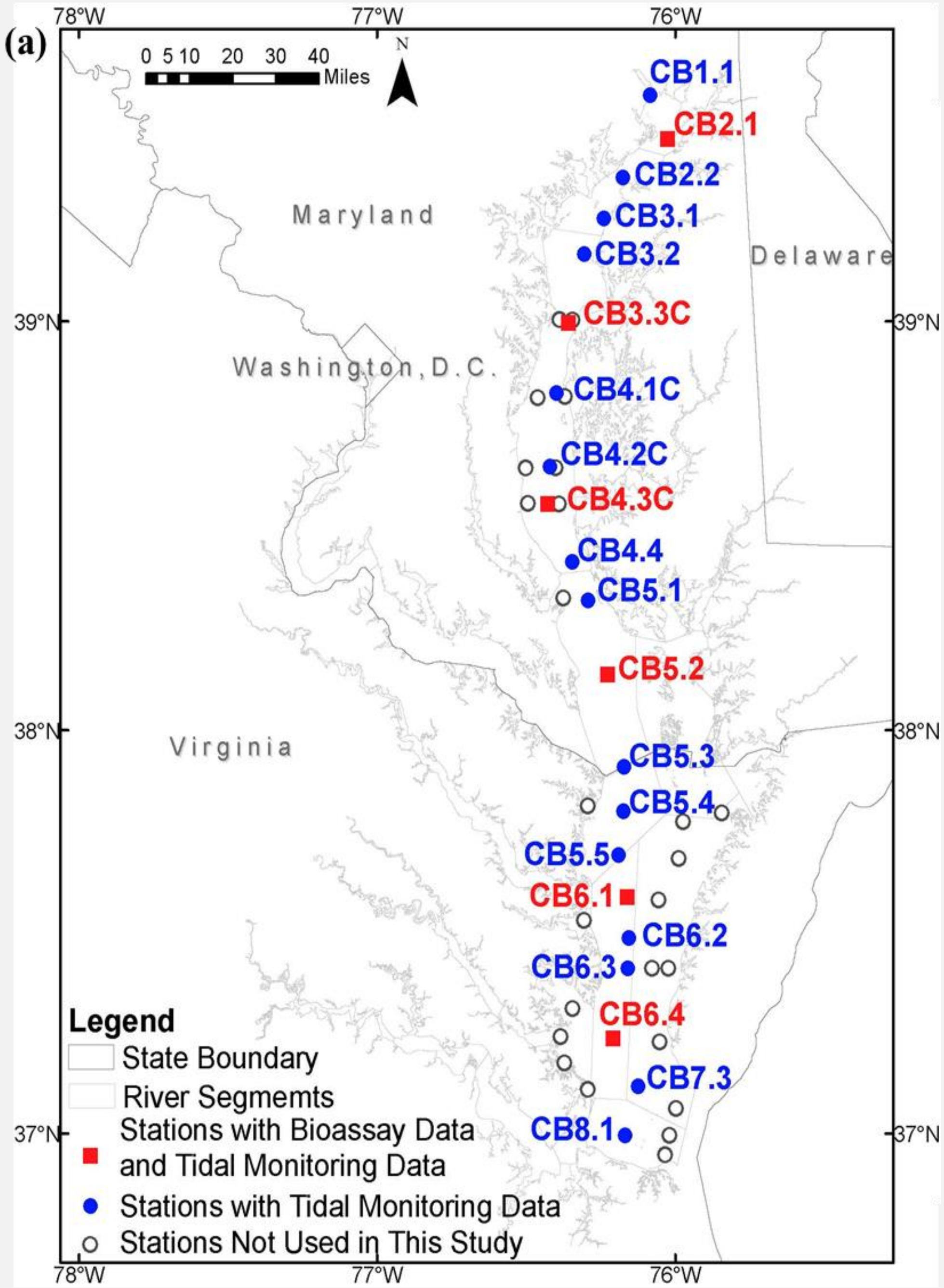
1. To develop empirical approaches to relate tidal monitoring data to bioassay-based nutrient limitation ("truth") in the concurrent period of 1992-2002 ("Goal 1"),
2. To apply the selected approach to tidal monitoring data in more recent periods to predict nutrient limitation and explore potential changes in limitation in response to altered nutrient loading ("Goal 2").

Study Sites & Data

- Bioassay-based Limitation Classes for 1992-2002
  - ❑ 6 stations x 12 months

- Tidal WQ Monitoring Data in 1990-2018 (21 Stations)
  - ❑ Chesapeake Bay Program Data Hub (> 3,000,000 values)
  - ❑ Aggregated 1992-2002 data to the same size as bioassay classes (6 stations x 12 months)





I. Mainstem Limitation (1992-2002)

Goal 1: To develop empirical approaches to relate tidal monitoring data to bioassay-based nutrient limitation ("truth") in the concurrent period of 1992-2002.

Analysis of Mainstem Limitation (1992-2002)

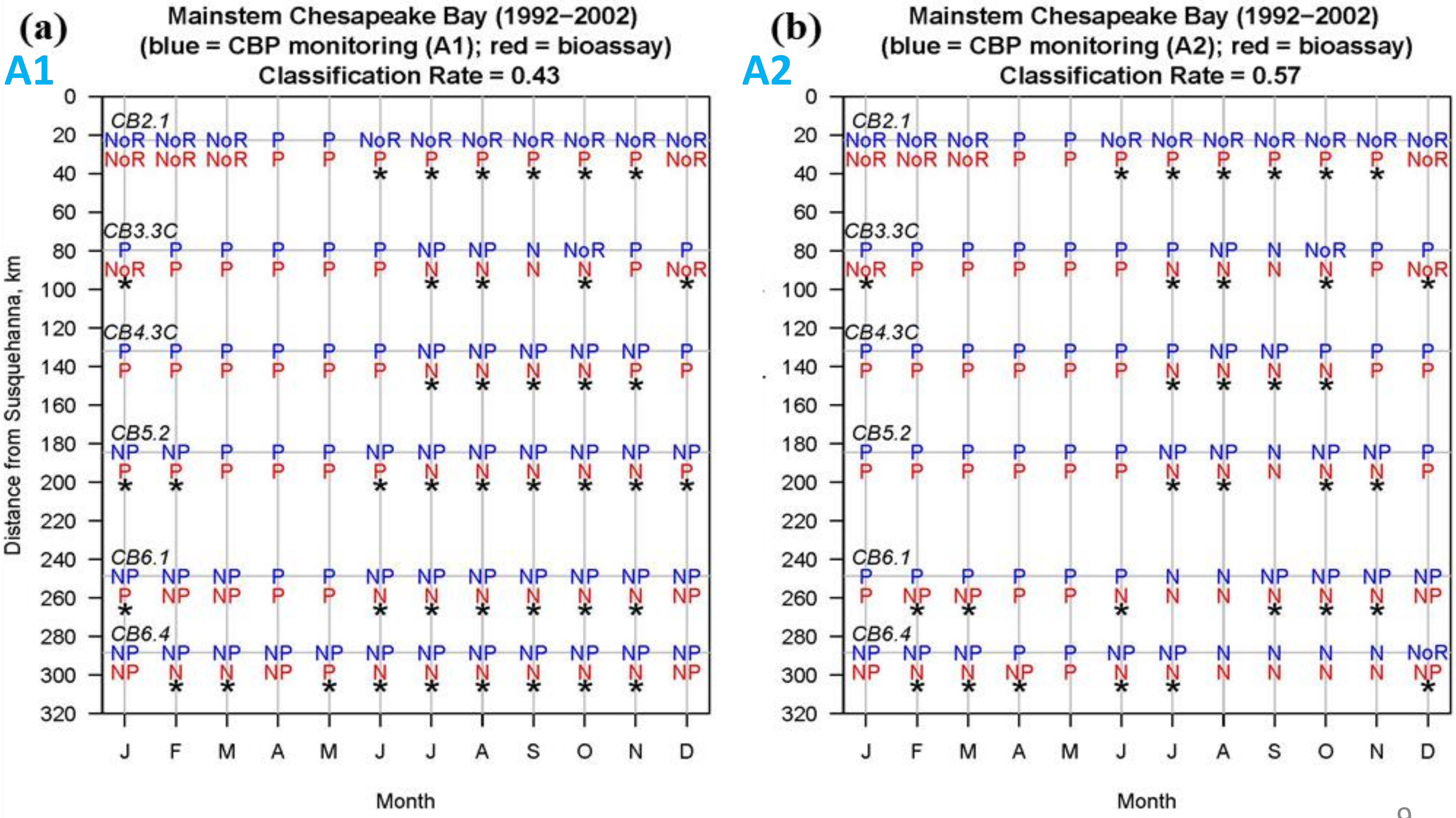
Target: 72 bioassay-based limitation classes

Approach	Variables	Decision Rules	Classification Rate
A1. Probability-based approach	DIN and DIP concentrations	N (low DIN ≥ 50%) P (low DIP ≥ 50%) NP (both ≥ 40%) NoR (else)	43% (31 matches / 72)
A2. Nutrient index-based approach	DIN and DIP indices (based on concentrations)	N (N-index ≥ 0.5) P (P-index ≥ 0.5) NP (both ≥ 0.4) NoR (else)	57% (41 matches / 72)

Analysis of Mainstem Limitation (1992-2002)

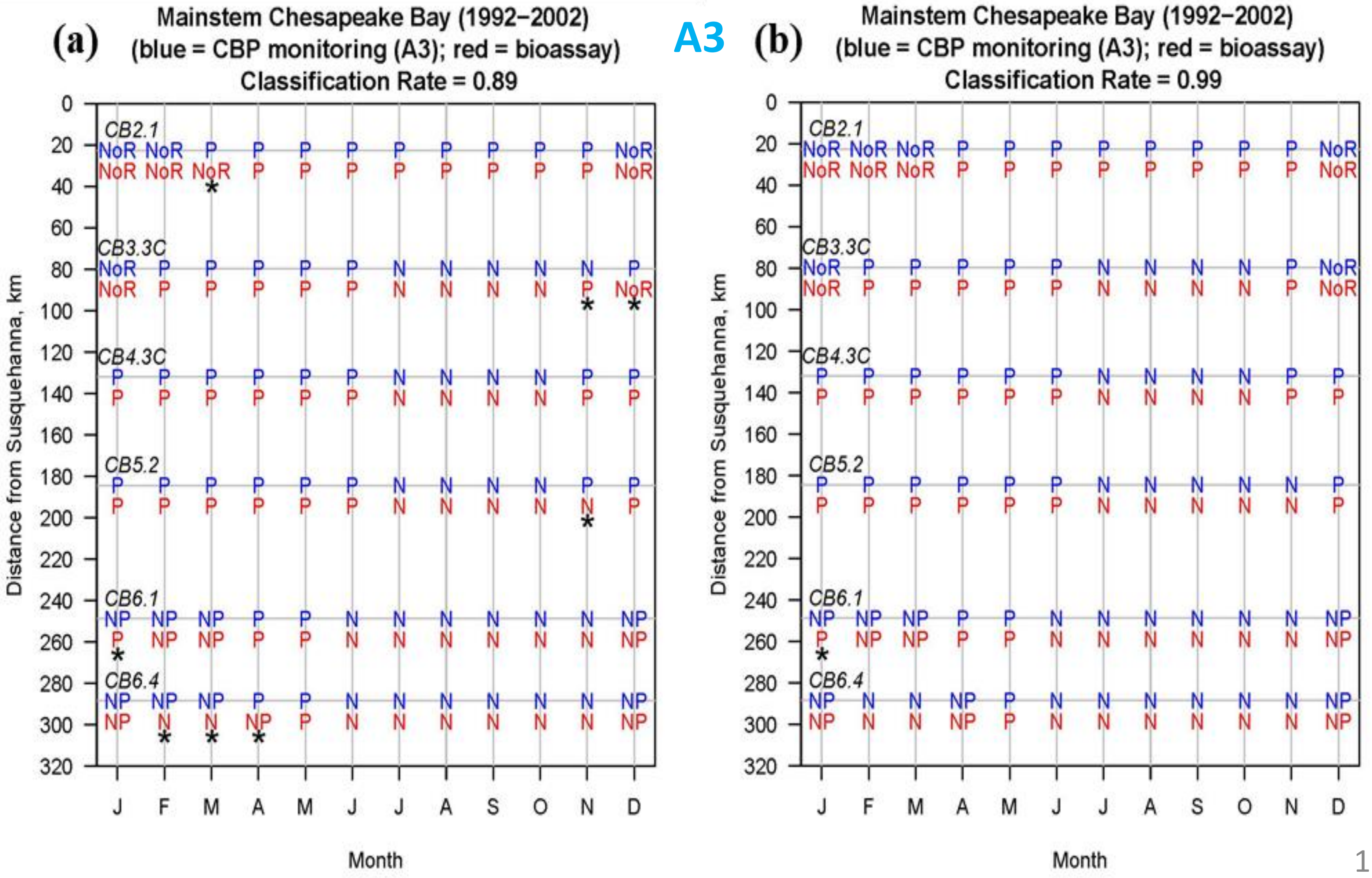
Target: 72 bioassay-based limitation classes

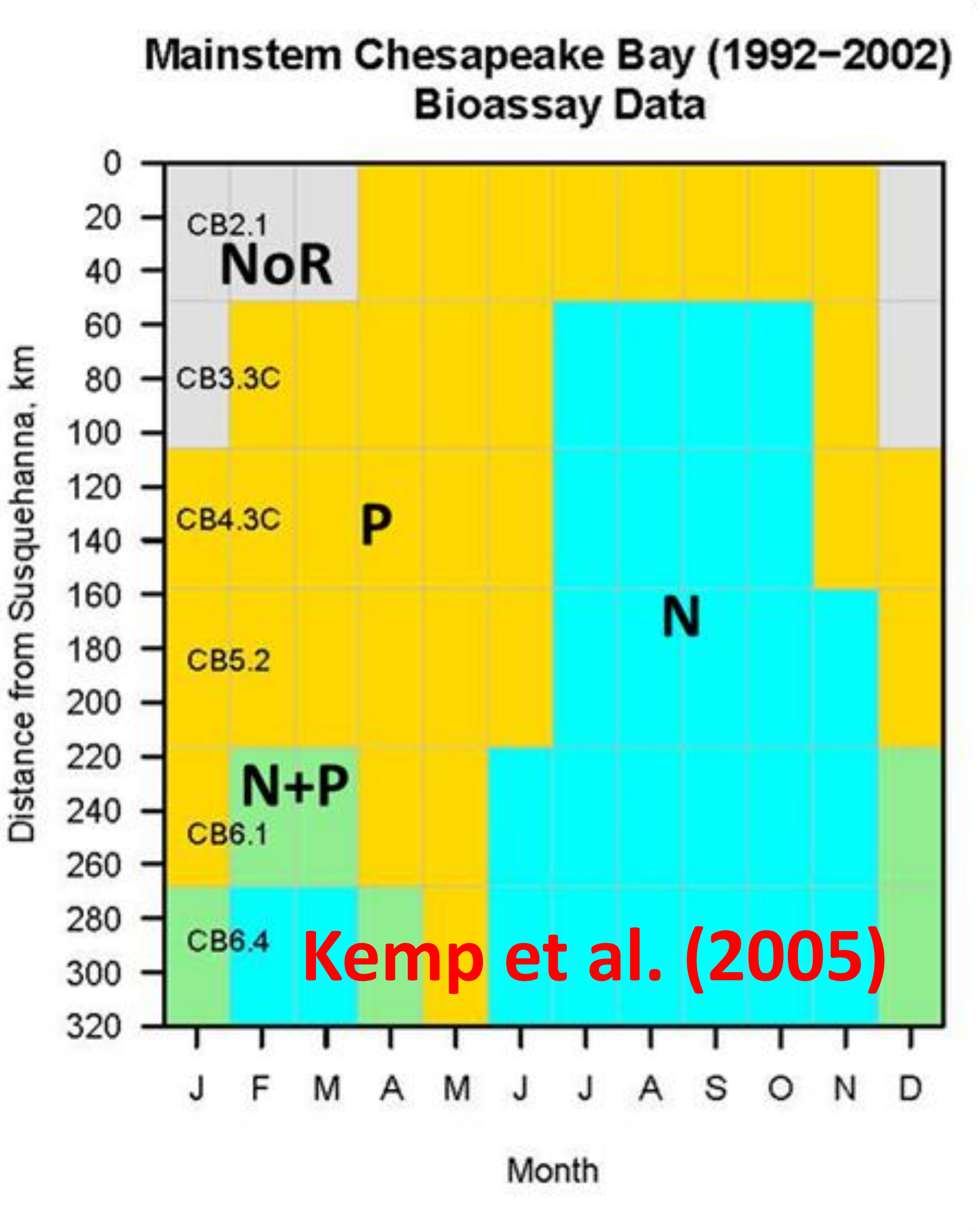
Approach	Variables	Decision Rules	Classification Rate
A1. Probability-based approach	DIN and DIP concentrations	N (low DIN ≥ 50%) P (low DIP ≥ 50%) NP (both ≥ 40%) NoR (else)	43% (31 matches / 72)
A2. Nutrient index-based approach	DIN and DIP indices (based on concentrations)	N (N-index ≥ 0.5) P (P-index ≥ 0.5) NP (both ≥ 0.4) NoR (else)	57% (41 matches / 72)
A3. Classification and Regression Trees (CART)	DIN, DIP, + more (e.g., WTEMP, N:P ratio, CHLA, Secchi, Salinity)	Data-driven (through CART)	89% (64/72; LOOCV); 99% (71/72; Full Data)

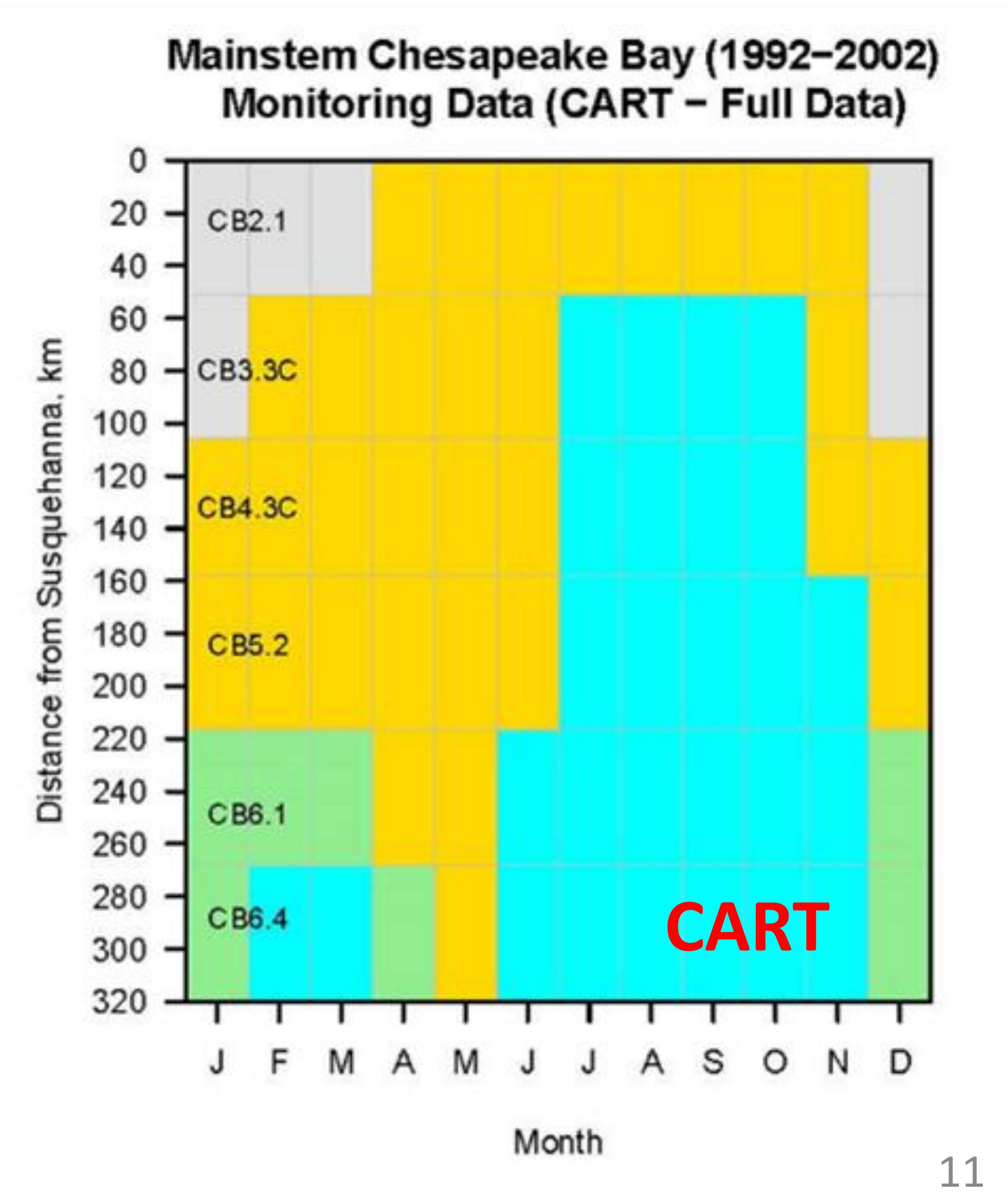


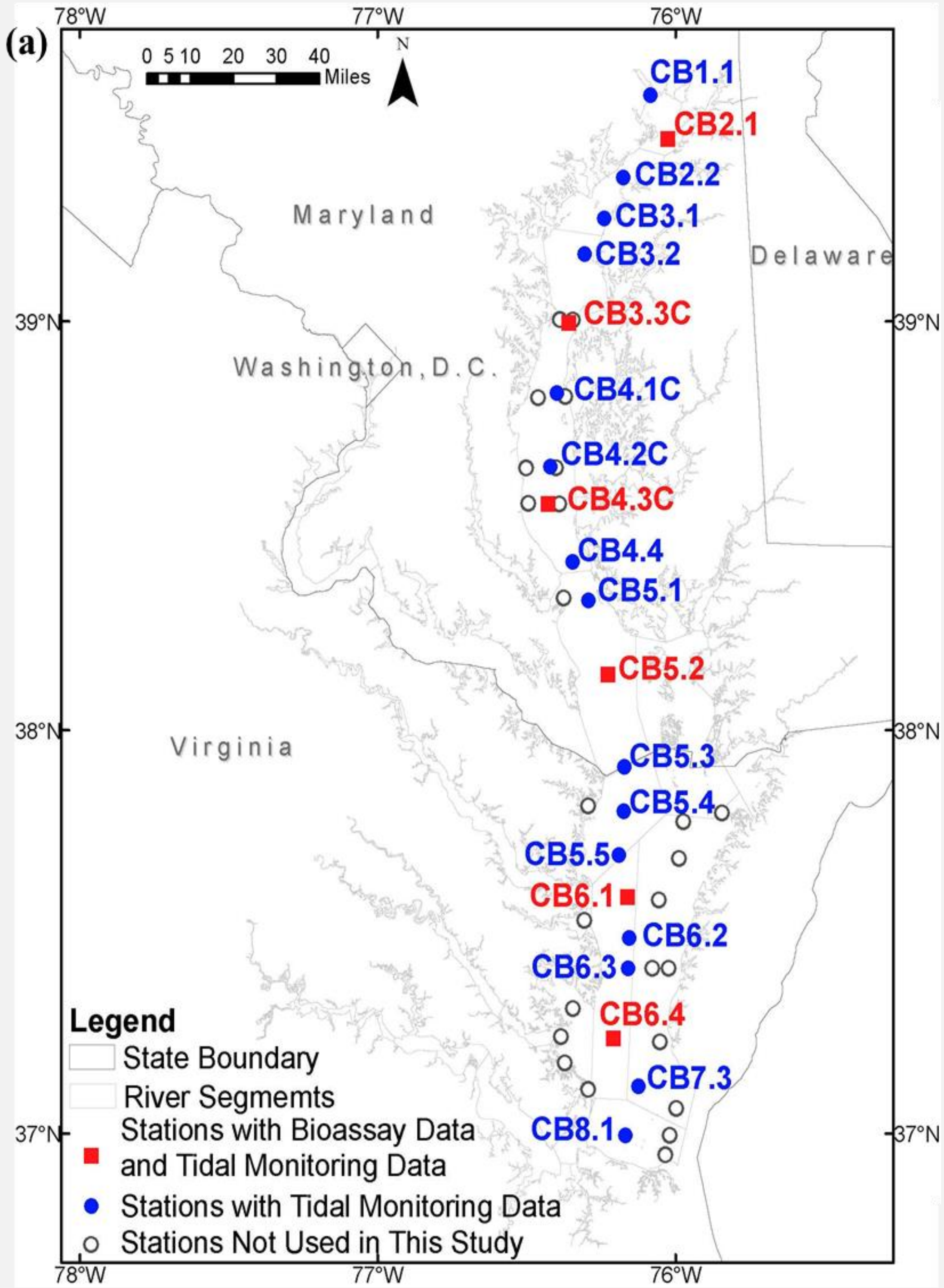
(a)
A1
Mainstem Chesapeake Bay (1992−2002)
(blue = CBP monitoring (A1); red = bioassay)
Classification Rate = 0.43
(b)
A2
Mainstem Chesapeake Bay (1992−2002)
(blue = CBP monitoring (A2); red = bioassay)
Classification Rate = 0.57
CB2.1
CB3.3C
CB4.3C
CB5.2
CB6.1
CB6.4
Distance from Susquehanna, km
J F M A M J J A S O N D
Month

A3


(a)
Mainstem Chesapeake Bay (1992−2002)
(blue = CBP monitoring (A3); red = bioassay)
Classification Rate = 0.89
(b)
Mainstem Chesapeake Bay (1992−2002)
(blue = CBP monitoring (A3); red = bioassay)
Classification Rate = 0.99
CB2.1
CB3.3C
CB4.3C
CB5.2
CB6.1
CB6.4
Distance from Susquehanna, km
Month
J F M A M J J A S O N D


Mainstem Chesapeake Bay (1992−2002)
Bioassay Data
Distance from Susquehanna, km
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
CB2.1
NoR
CB3.3C
CB4.3C
P
N
CB5.2
N+P
CB6.1
CB6.4
Kemp et al. (2005)
J F M A M J J A S O N D
Month

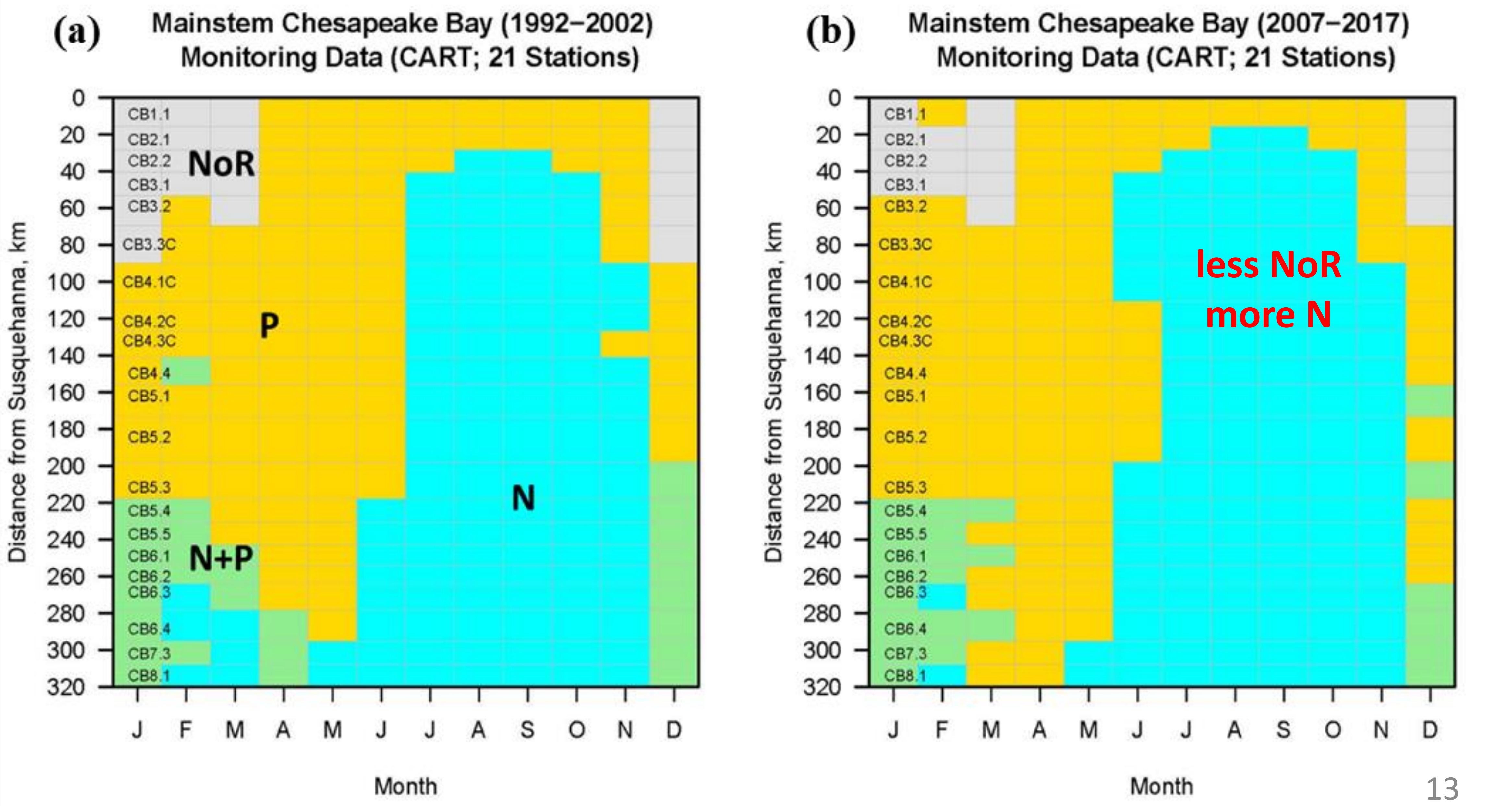

Mainstem Chesapeake Bay (1992−2002)
Monitoring Data (CART − Full Data)
Distance from Susquehanna, km
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
CB2.1
CB3.3C
CB4.3C
CB5.2
CB6.1
CB6.4
CART
J F M A M J J A S O N D
Month



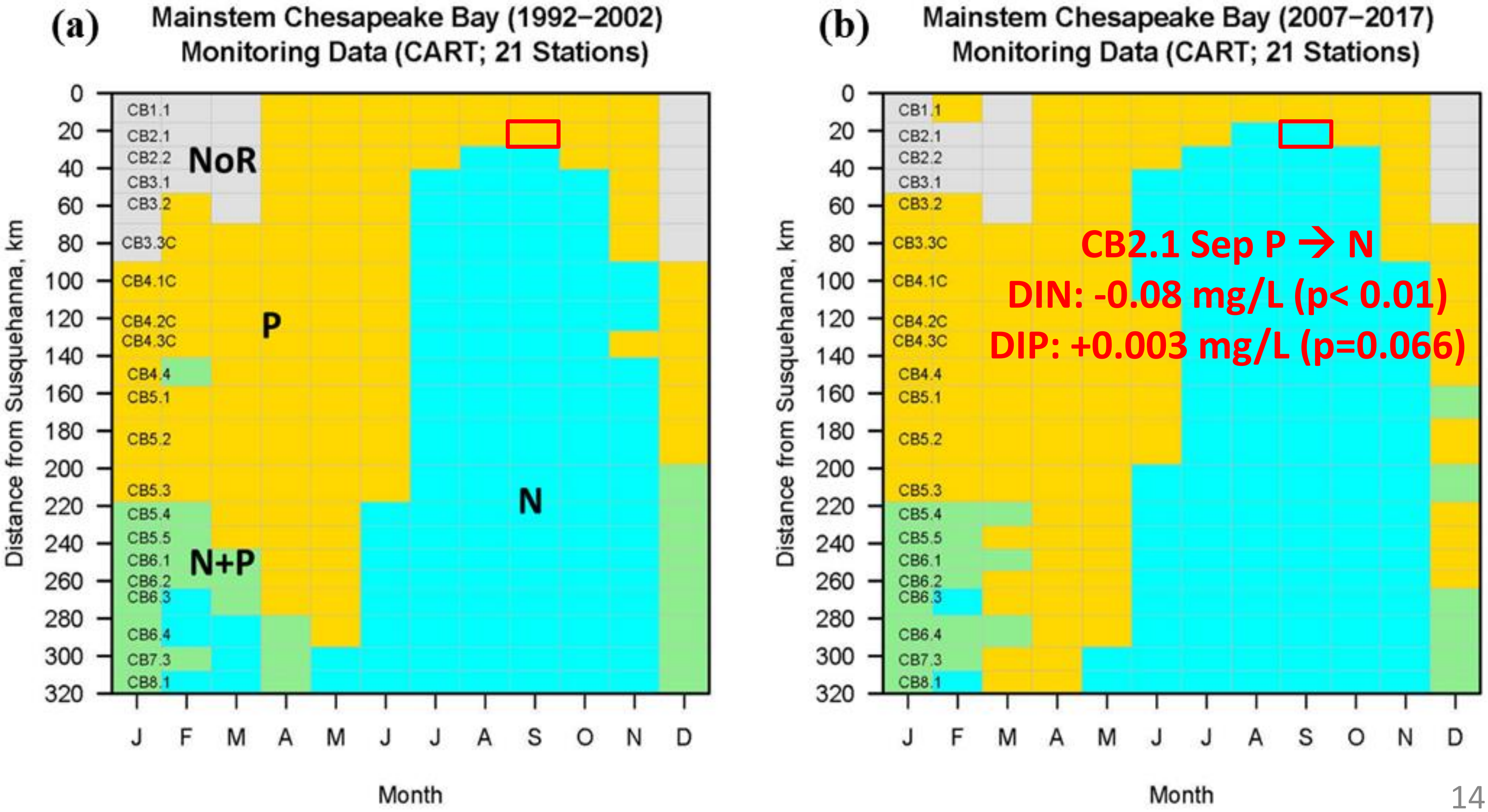
II. Mainstem Limitation (2007-2017)

Goal 2: To apply the selected approach to tidal monitoring data in more recent periods to predict nutrient limitation and explore potential changes in response to altered nutrient loading.

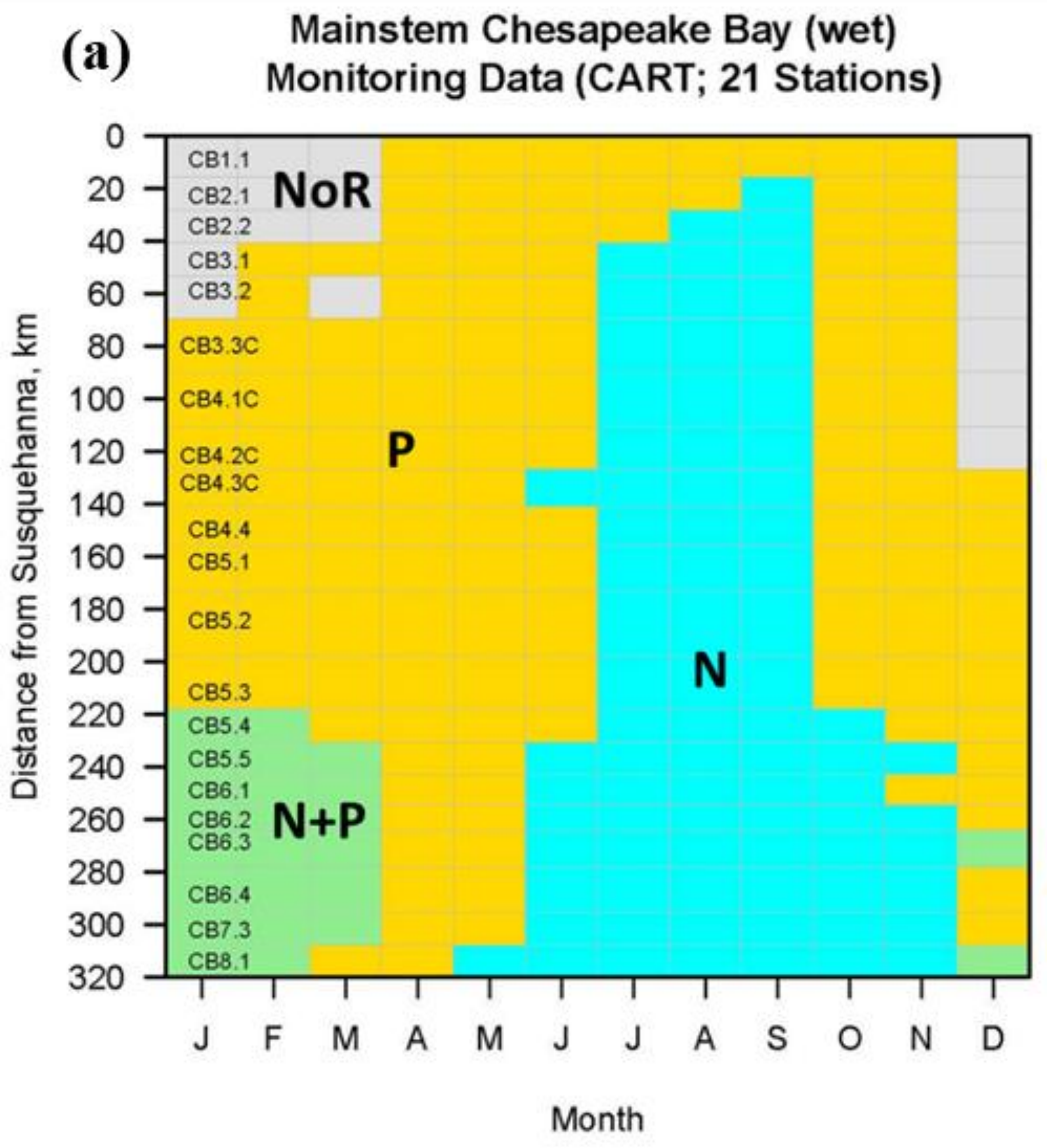
1992-2002 vs. 2007-2017 (Similar Hydrology)

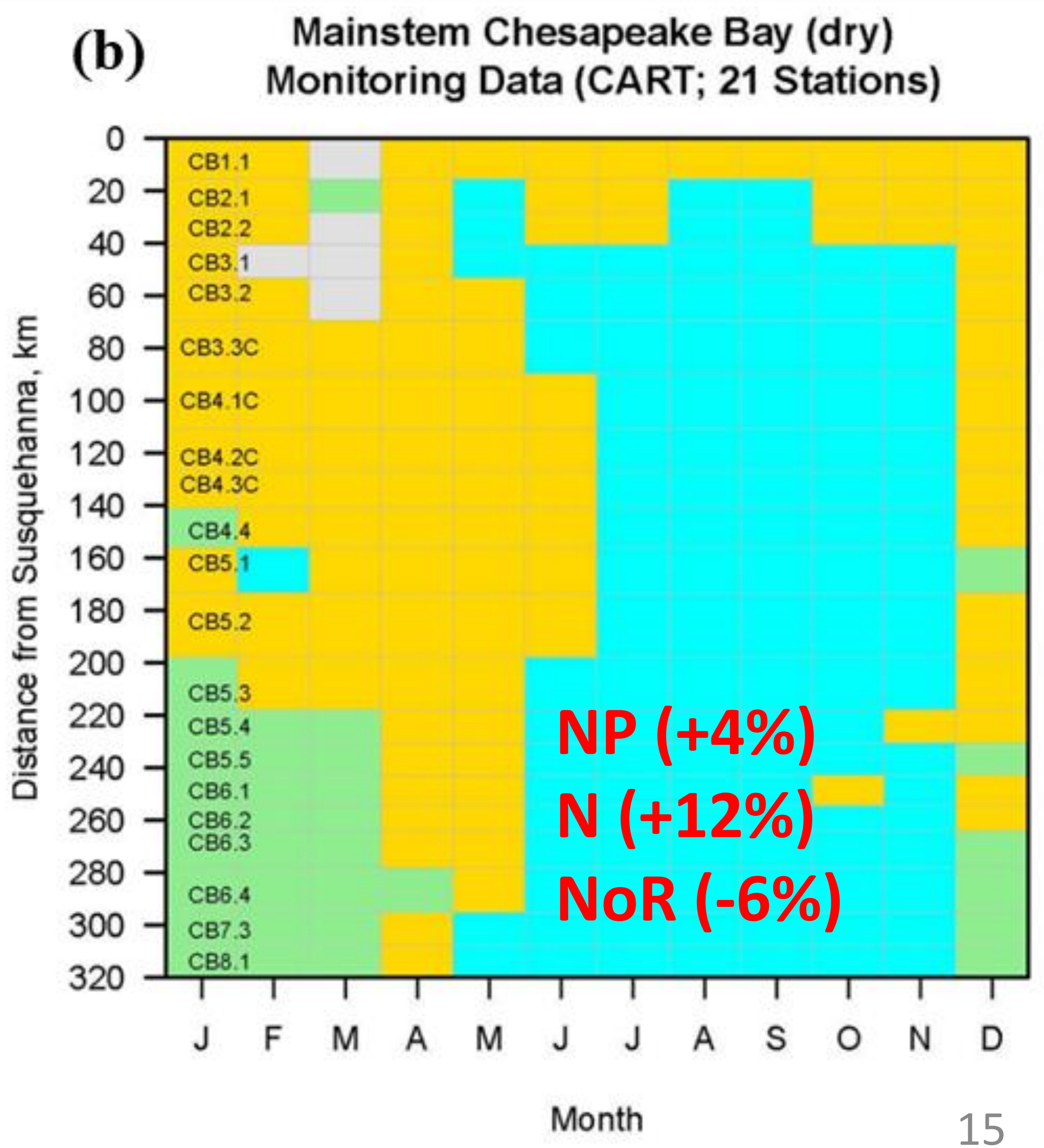


1992-2002 vs. 2007-2017 (Similar Hydrology)

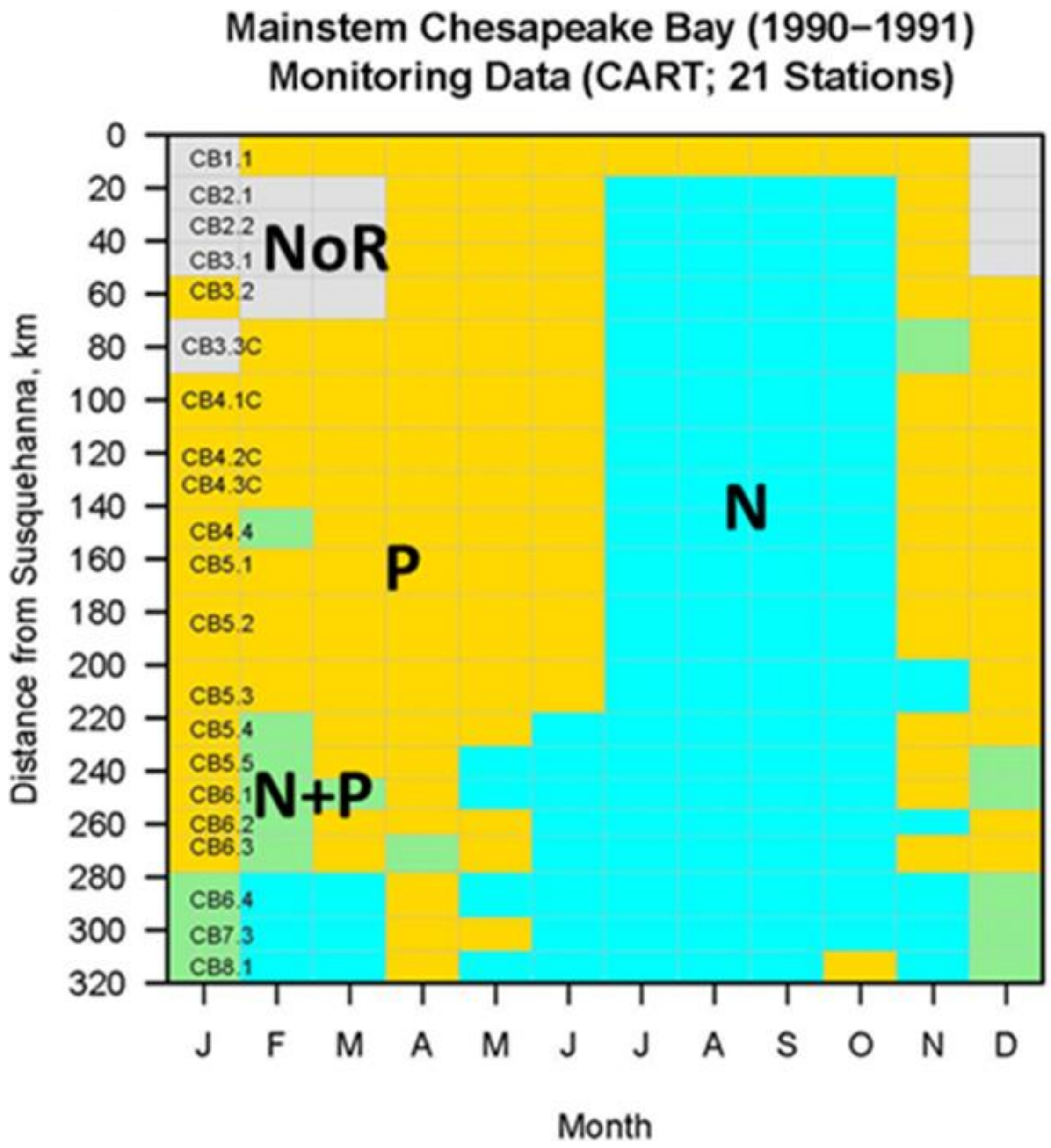


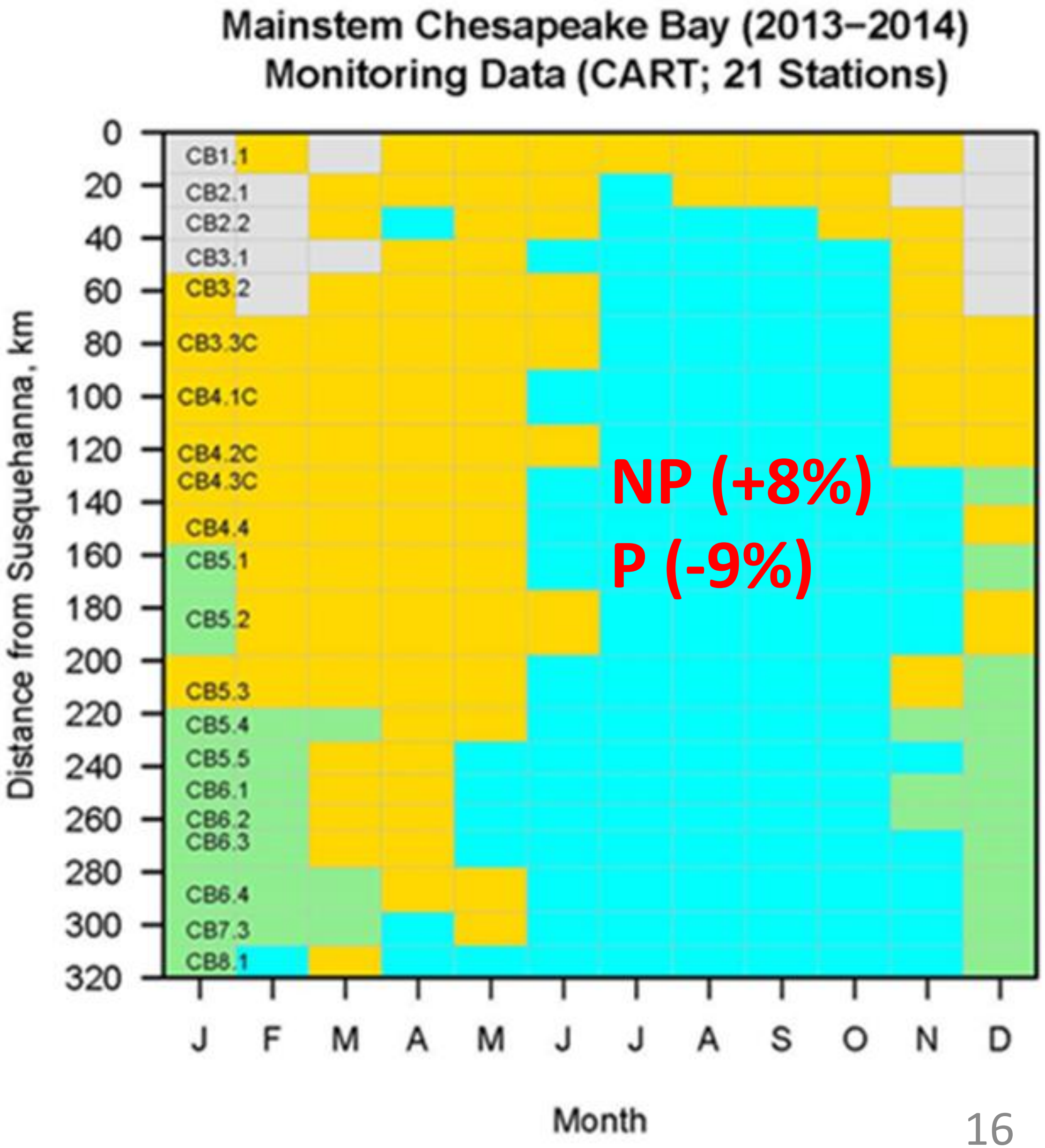
Different Hydrologic Conditions (Fixed Period = 2003-2017)





Different Sub-periods (Similar Hydrologic Condition)





Summary

Goal 1: To develop empirical approaches to relate tidal monitoring data to bioassay-based nutrient limitation ("truth") in the concurrent period of 1992-2002.

- CART reproduced the bioassay-based nutrient limitation patterns in 1992-2002 much better than two simpler, non-statistical approaches.

Goal 2: To apply the selected approach to tidal monitoring data in more recent periods to predict nutrient limitation and explore potential changes in limitation in response to altered nutrient loading.

- The mainstem showed modest changes, with less NoR and more N-limitation in 2007-2017 than 1992-2002. (Long-term reductions in N load appear to have led to expanded areas with nutrient-limitation.)
- The patterns remain largely unchanged. (Continued reductions are needed to achieve a less nutrient-saturated ecosystem.)

Remarks

- We emphasize that these CART-based nutrient limitation patterns should be viewed as the overall behavior for the specified periods.
- An underlying assumption of CART is the stationarity in the derived model relationships (including decision rules).
- As bioassays are time intensive and often costly, CART can be a useful tool for providing complementary information on nutrient limitation since it can make good use of the routine monitoring data, greatly expanding the spatial & temporal extent of assessments to guide management.

Remarks

- New bioassay experiments can be particularly useful for validating and updating the CART models.
- Further work will assess limitation patterns in major tributaries.
- The developed models and results may help:
  - explain changes (or lack of changes) in water quality (e.g., *Chl-a*) in different parts of the Bay.
  - provide information for future refinement of Chesapeake estuarine models.

Potential Applications to the 2017 WQSTM

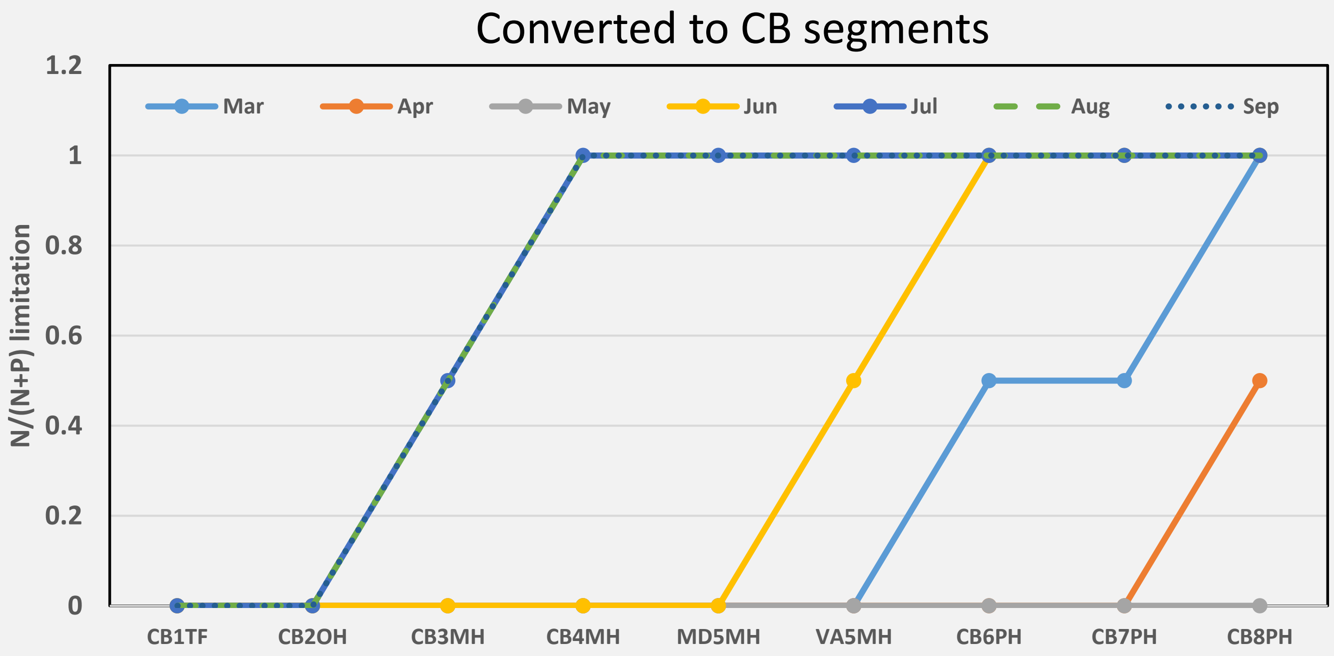
1. Run CART on monitoring data and modelled data to determine and compare nutrient limitation:
   - ❖monitoring data in 1991-2000 (2017 WQSTM calibration and base years).
   - ❖WQSTM model data for all days in 1991-2000.
   - ❖WQSTM model data for days matched with the monitoring data in 1991-2000.

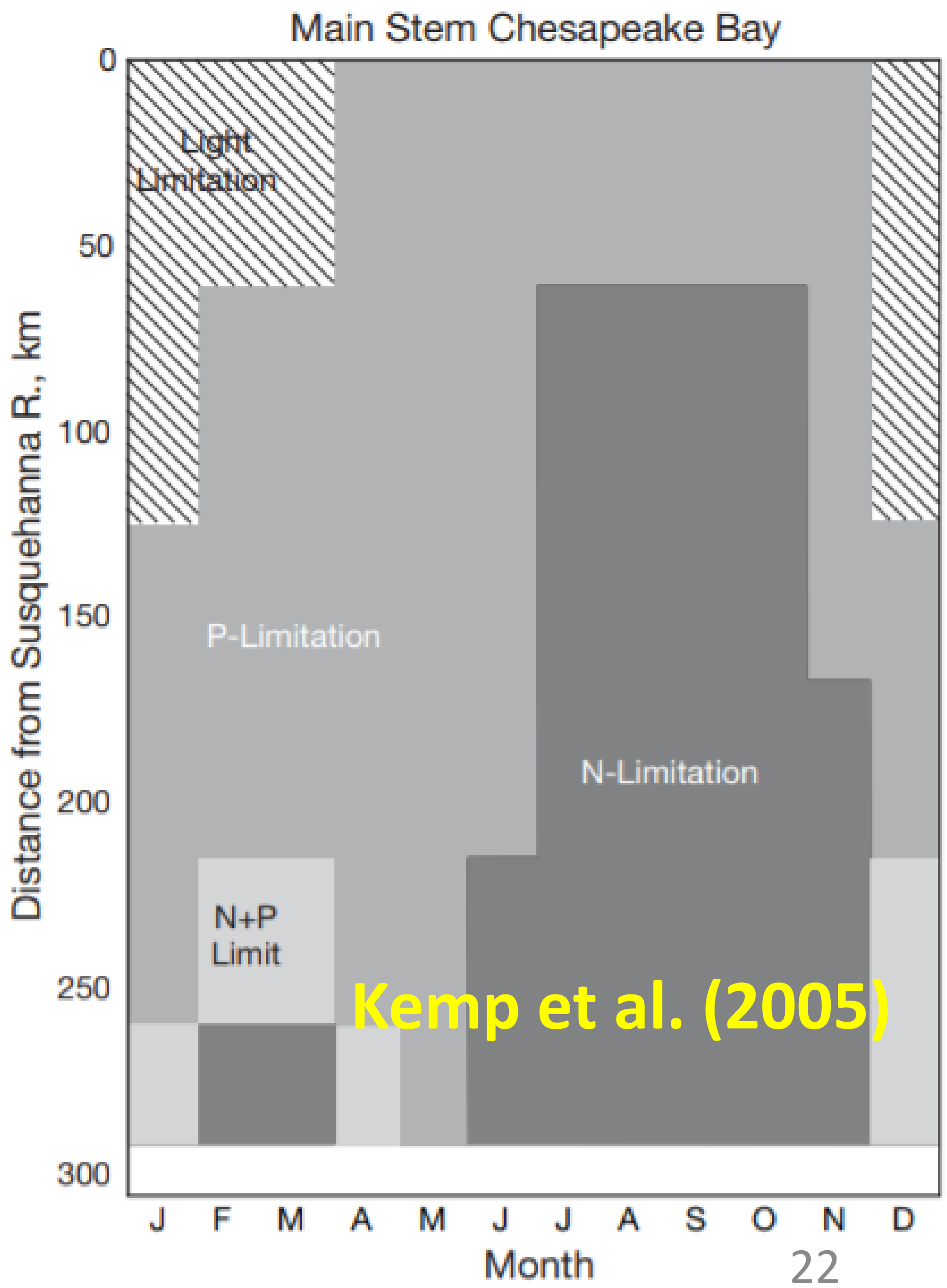
2. Run CART for key scenarios (high nutrient loads to low) for 1991-2000:
   - ❖No Action
   - ❖1985 Progress
   - ❖2019 Progress
   - ❖WIP3
   - ❖E3
   - ❖All forest


#BayStrong

Application to the 2017 WQSTM

- The nutrient limitation patterns published in Kemp et al. (2005) were used in the calibration of the 2017 Chesapeake Bay estuarine model.





Model selection