Further Analysis and Synthesis of Narragansett Bay Oxygen, Chlorophyll, and Temperature

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Update to NBEP Science Advisory Committee

Six mini-stories to tell today about the bay

- Loads of Total Nitrogen
- River flow
- Hypoxia Index (from time series) and its drivers
- A refined Chlorophyll Index (from time series)
- Vessel-based surveys & time series (D.O. & chlorophyll)
- Long-term trends: temperature, salinity, stratification

Overall context

- NBEP-funded follow-up to State of Narragansett Bay and Its Watershed
- Synthesize multiple variables, multiple datasets; emphasis on bay-wide conditions; includes years extending through 2017
- Results downloadable as spreadsheets, including figure/table values
- Details in two recently completed reports available online:
  - **"Main report":** Codiga, D.L. Further Analysis and Synthesis of Narragansett Bay Oxygen, Chlorophyll, and Temperature. NBEP Technical Report. NBEP-20-231A. URL: https://figshare.com/s/7d51f2540df6638a4552. DOI: 10.6084/m9.figshare.12547676.
  - **"Nutrient loads report":** Codiga, D.L. Daily-Resolution 2001-2017 Time Series of Total Nitrogen Load to Narragansett Bay from Bay-Wide Treatment Facility and Watershed Sources. NBEP Technical Report. NBEP-20-231B. URL: https://figshare.com/s/95abe0296139515ffb88. DOI: 10.6084/m9.figshare.12573851.

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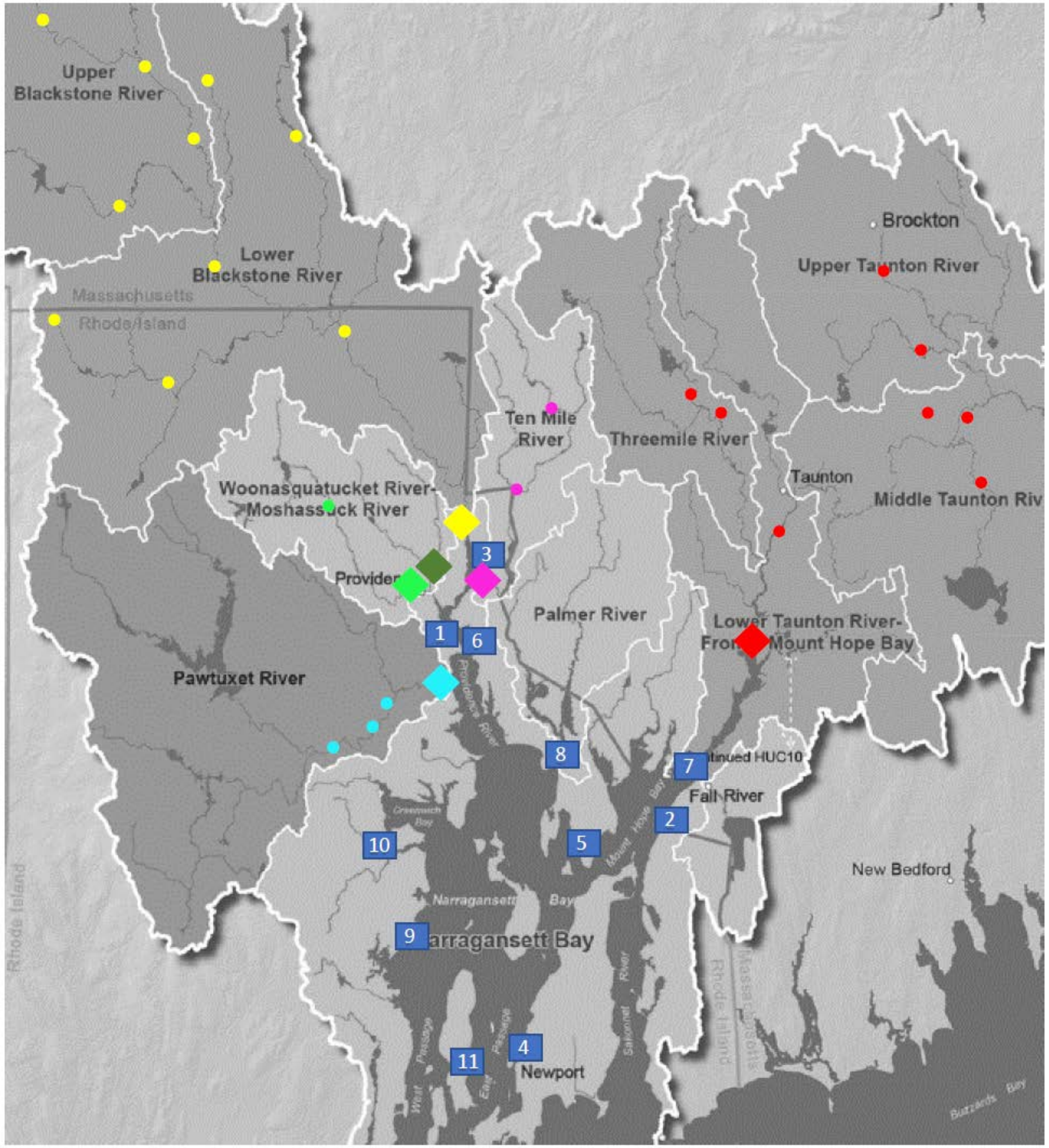
Loads of Total Nitrogen

- Daily-resolution, 2001-2017
- Load = flow x concentration
  - Flow measurements **daily** – variability in flow dominates variability in load
  - Concentration measurements **~weekly/monthly** -- interpolated linearly
- TN measured; computed as sum of constituent measurements; or estimated using correlation to other measured constituent
- Results generally within ~10-25% of prior annual-mean estimates
- Data sources: RIDEM, NBC, and Fall River Treatment Facility

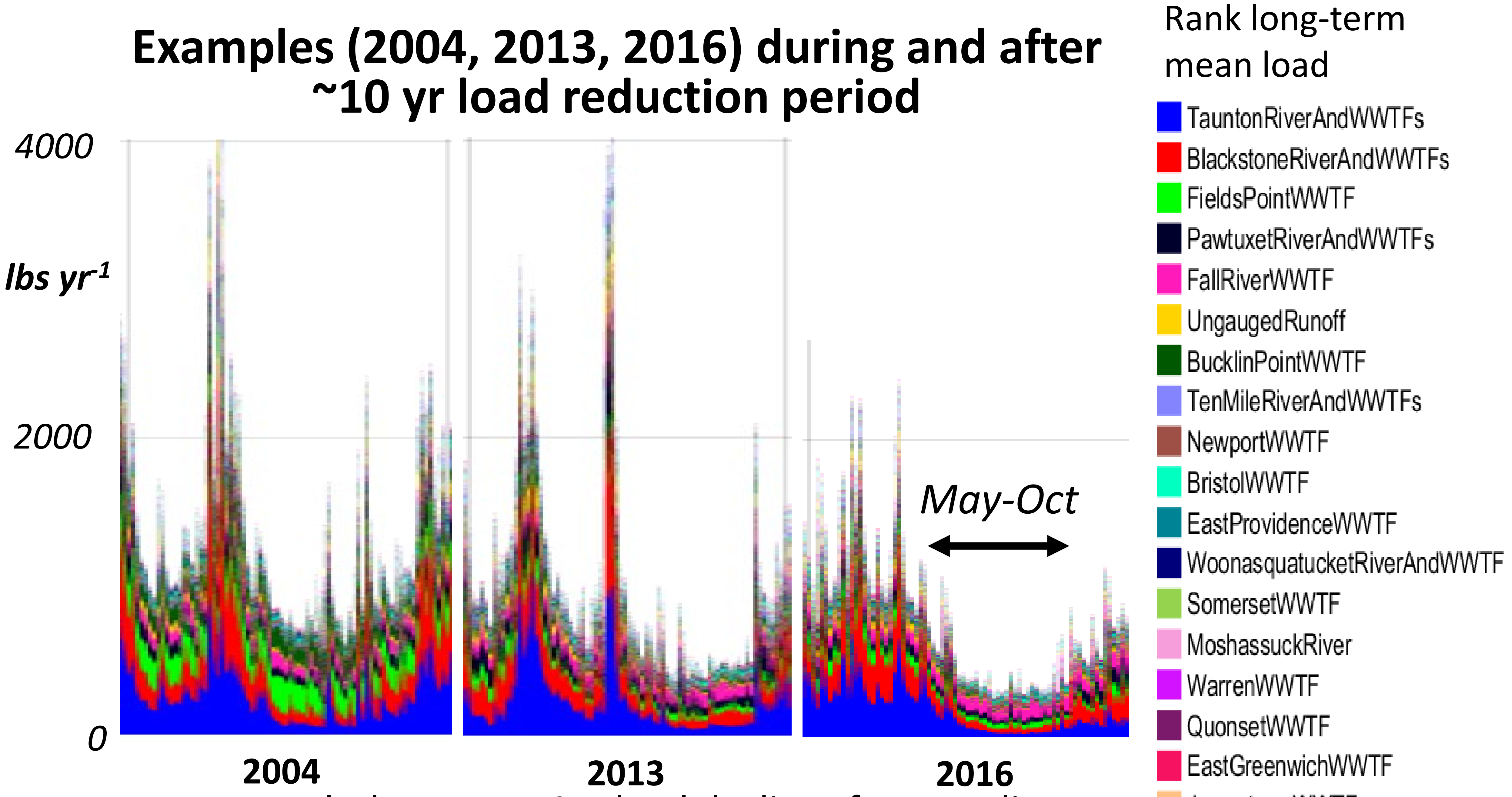


- 18 Sources
  - 11 treatment facilities discharge direct to bay
    - 9 in RI
    - 2 in MA
  - 6 rivers: these include load from upstream treatment facilities
  - Ungauged runoff direct to bay

Source
Taunton River and upstream WWTFs ★
Blackstone River and upstream WWTFs
Fields Point WWTF
Pawtuxet River and upstream WWTFs
Fall River WWTF
Ungauged direct runoff to bay ★
Bucklin Point WWTF
Ten Mile River and upstream WWTFs
Newport WWTF
Bristol WWTF
East Providence WWTF
Woonasquatucket River and upstream WWTF
Somerset WWTF
Moshassuck River
Warren WWTF
Quonset WWTF
East Greenwich WWTF
Jamestown WWTF

- Order of descending load, average over 2001-2017
- ★ Possibly not previously recognized so clearly:
  - **Taunton River** in top tier (w/ Blackstone River, Fields Point WWTF)
  - **Ungauged runoff** in second tier (w/Pawtuxet River, and Fall River WWTF, Bucklin Point WWTF)

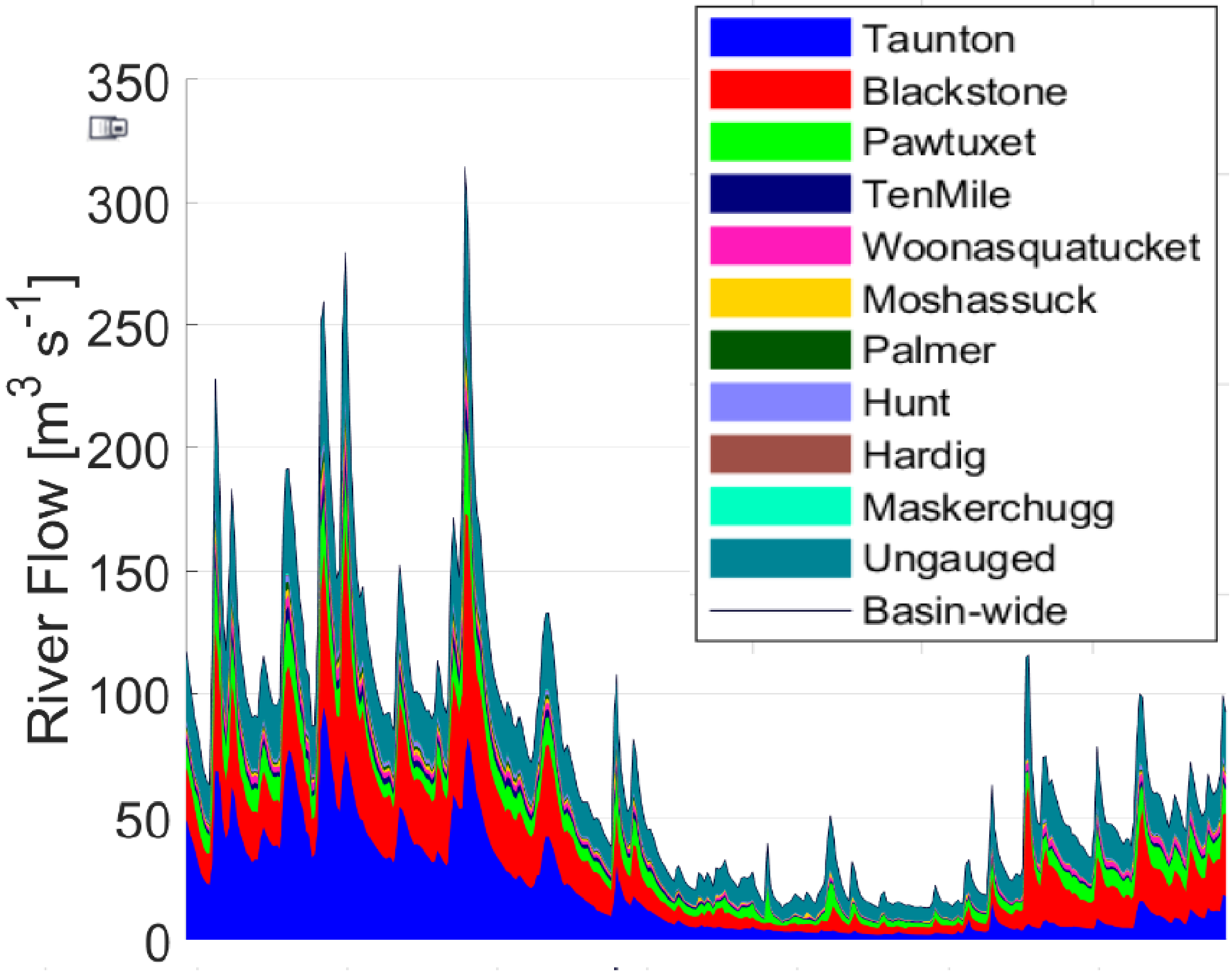
Examples (2004, 2013, 2016) during and after ~10 yr load reduction period



As expected, sharp May-Oct load declines for compliance

River flow

Bay-wide river flow: Two-stage method



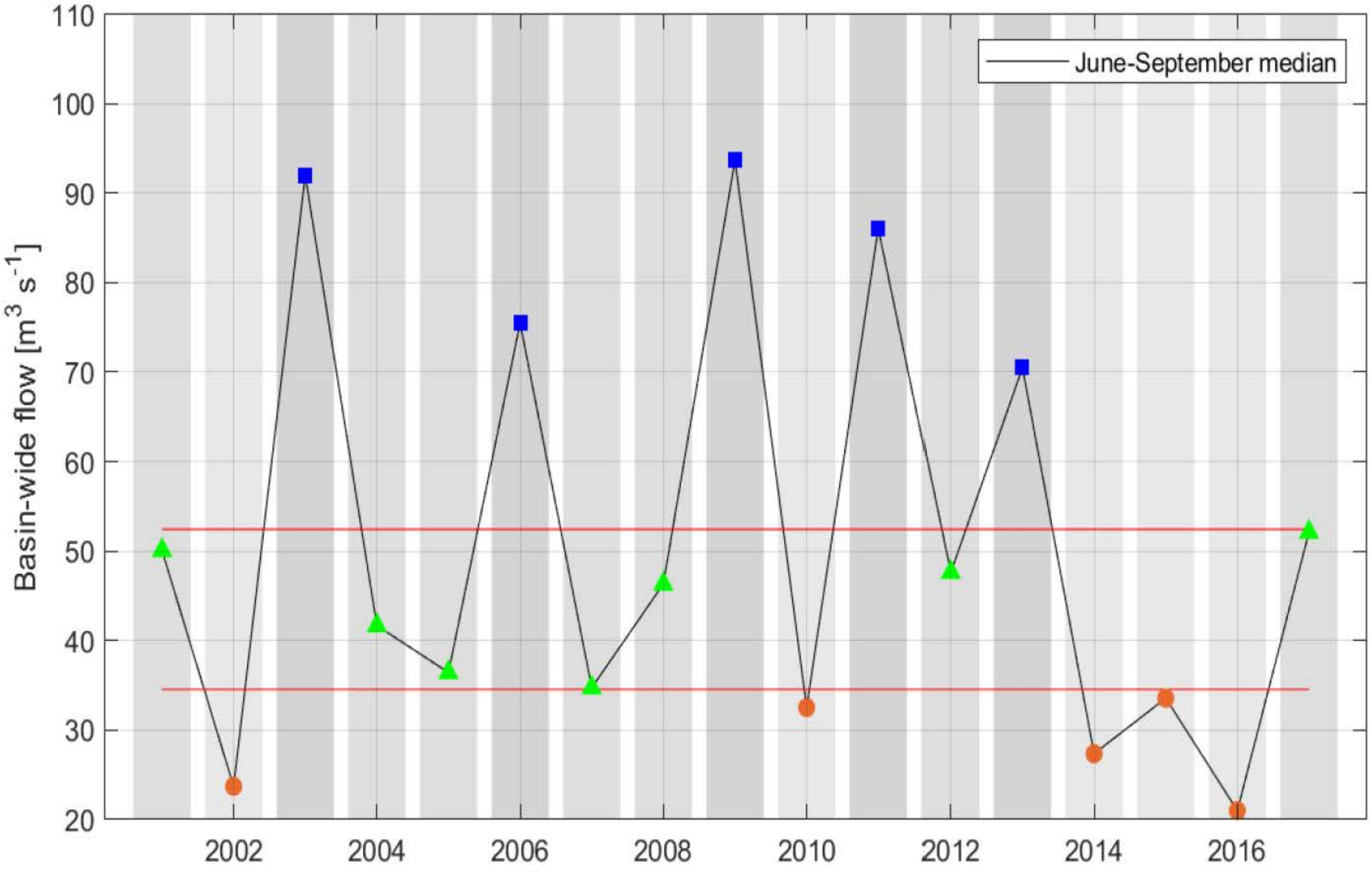
Jan 1 to Dec 31, 2016 (example year)

1. Individual rivers scaled up for ungauged flow upstream from gauge

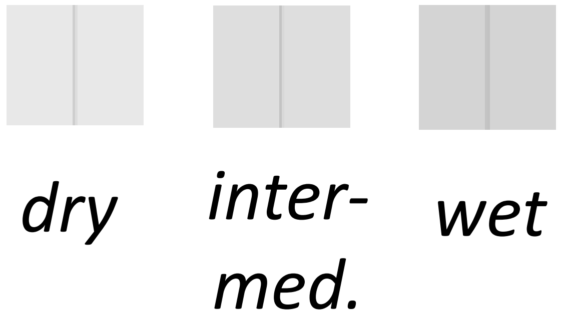
2. Summed results then scaled up for ungauged flow direct to bay

- Scale-up factors (monthly) are from Ries (1990)
- Ten rivers plus ungauged
- Hardig, Maskerchugg based on tight correlations to the Hunt

Bay-wide river flow: Wet, dry, intermediate



- Median of daily bay-wide flow
- June to September
- Compute 33rd and 66th percentiles 1990-2017
- Wet > 66th (53.4 $m^3 s^{-1}$)
- Dry < 33rd (34.5 $m^3 s^{-1}$)

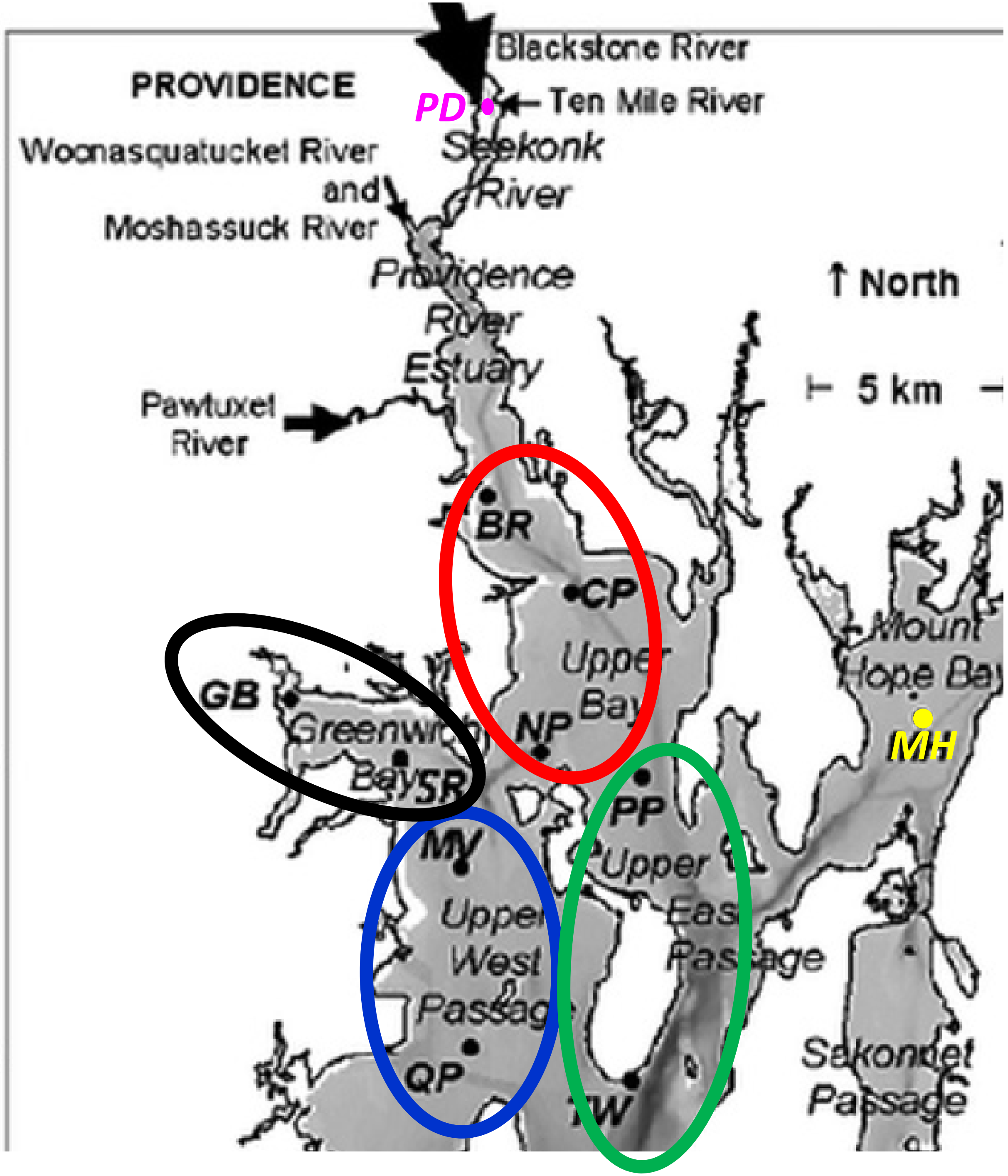


Hypoxia Index (from time series) and its drivers

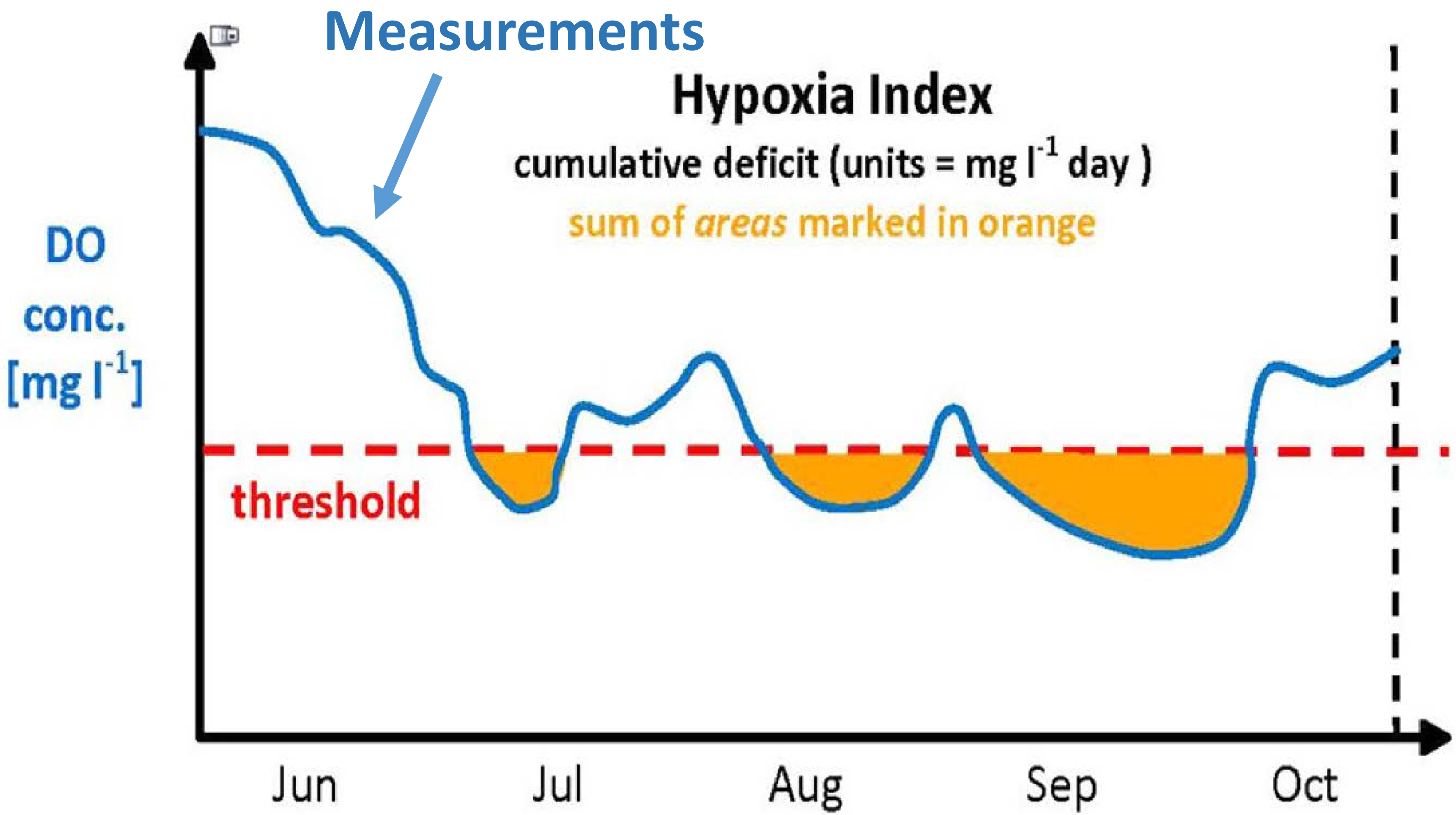
Fixed-site monitoring network – 11 sites

Stations grouped for certain analyses:

- Prov. River & Upper Bay **"PRUB"**
  - Bullocks Reach, Conimicut Point, North Prudence
- Greenwich Bay **"GRBY"**
  - Greenwich Bay, Sally Rock
- Upper West Passage **"UWP"**
  - Mount View, Quonset Point
- Upper East Passage **"UEP"**
  - Poppasquash Point, T-Wharf

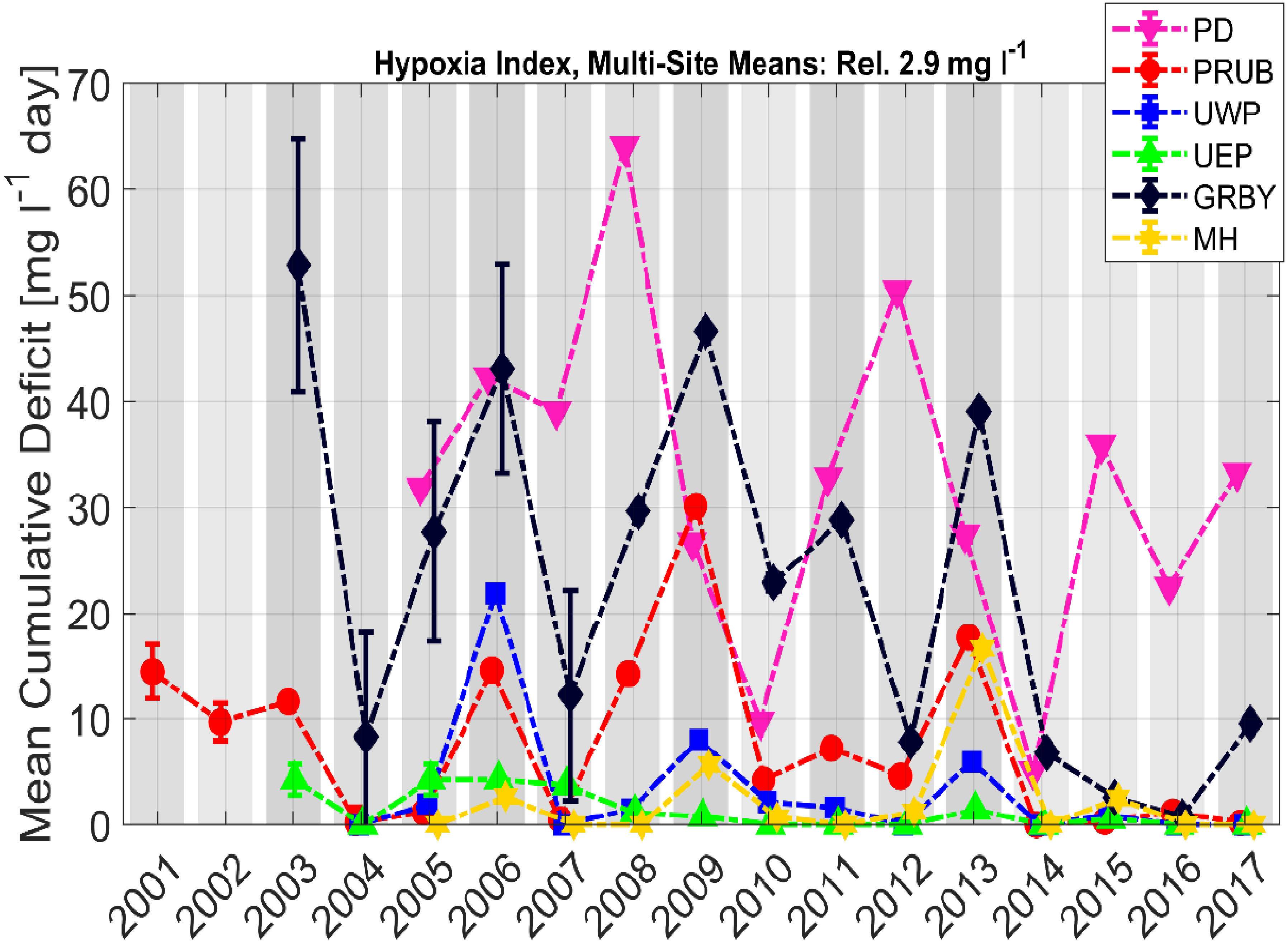


Hypoxia Index from time series



Index is a **seasonal measure** that increases with:

- number of events
- longer event durations
- lower concentrations during events

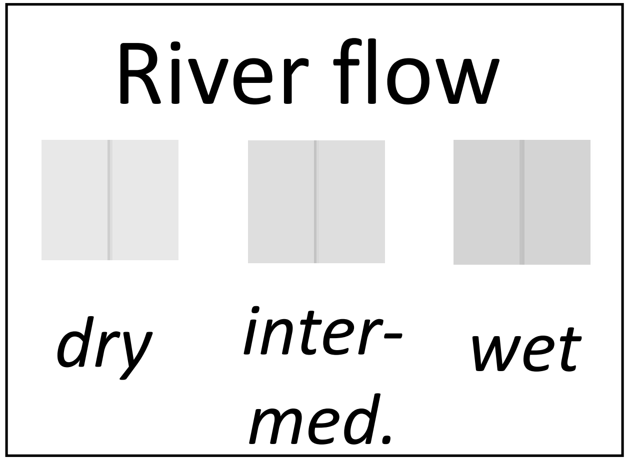


Phillipsdale & *Greenwich Bay:*

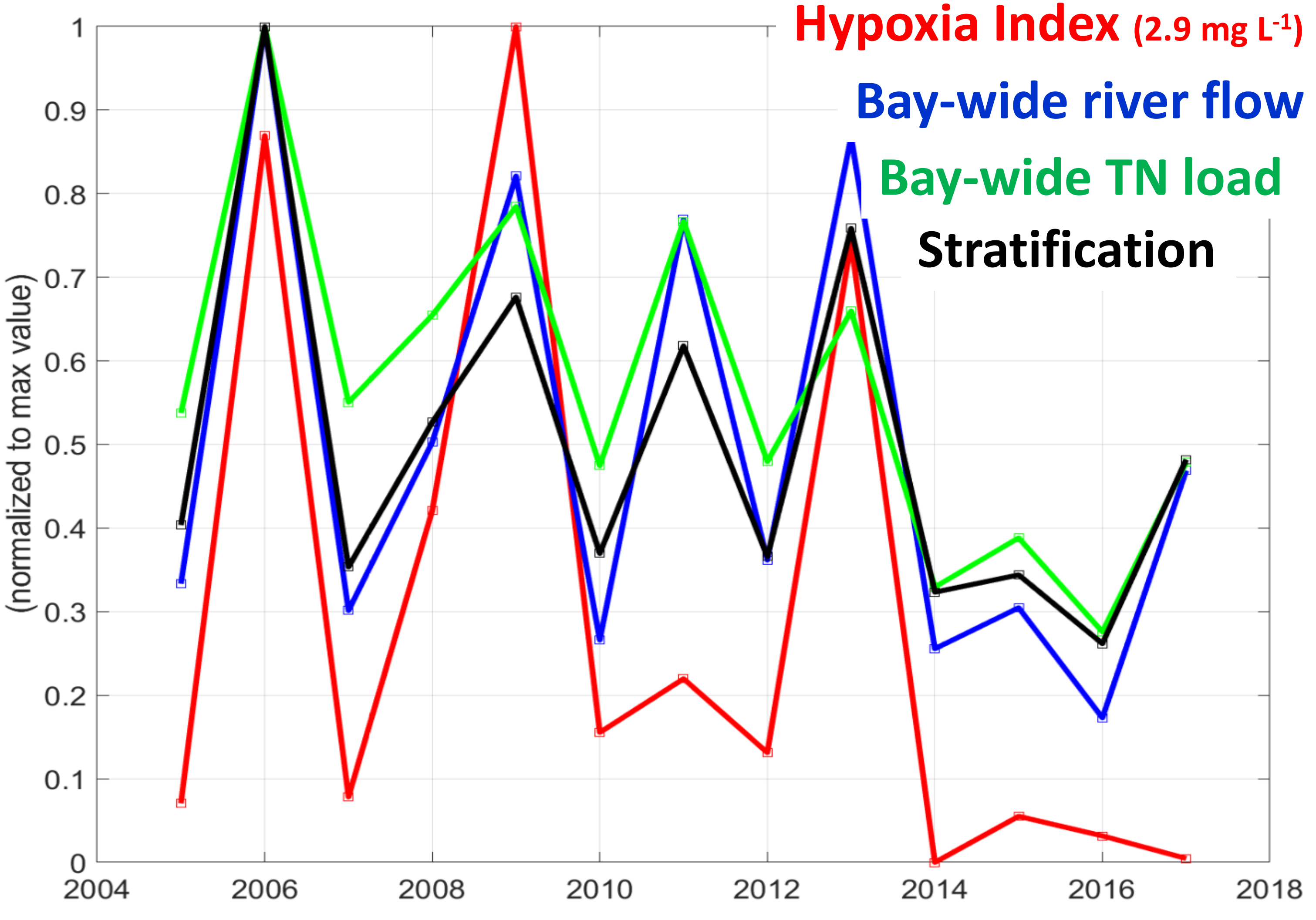
Most severe

Most variable

Least correlated to other stations



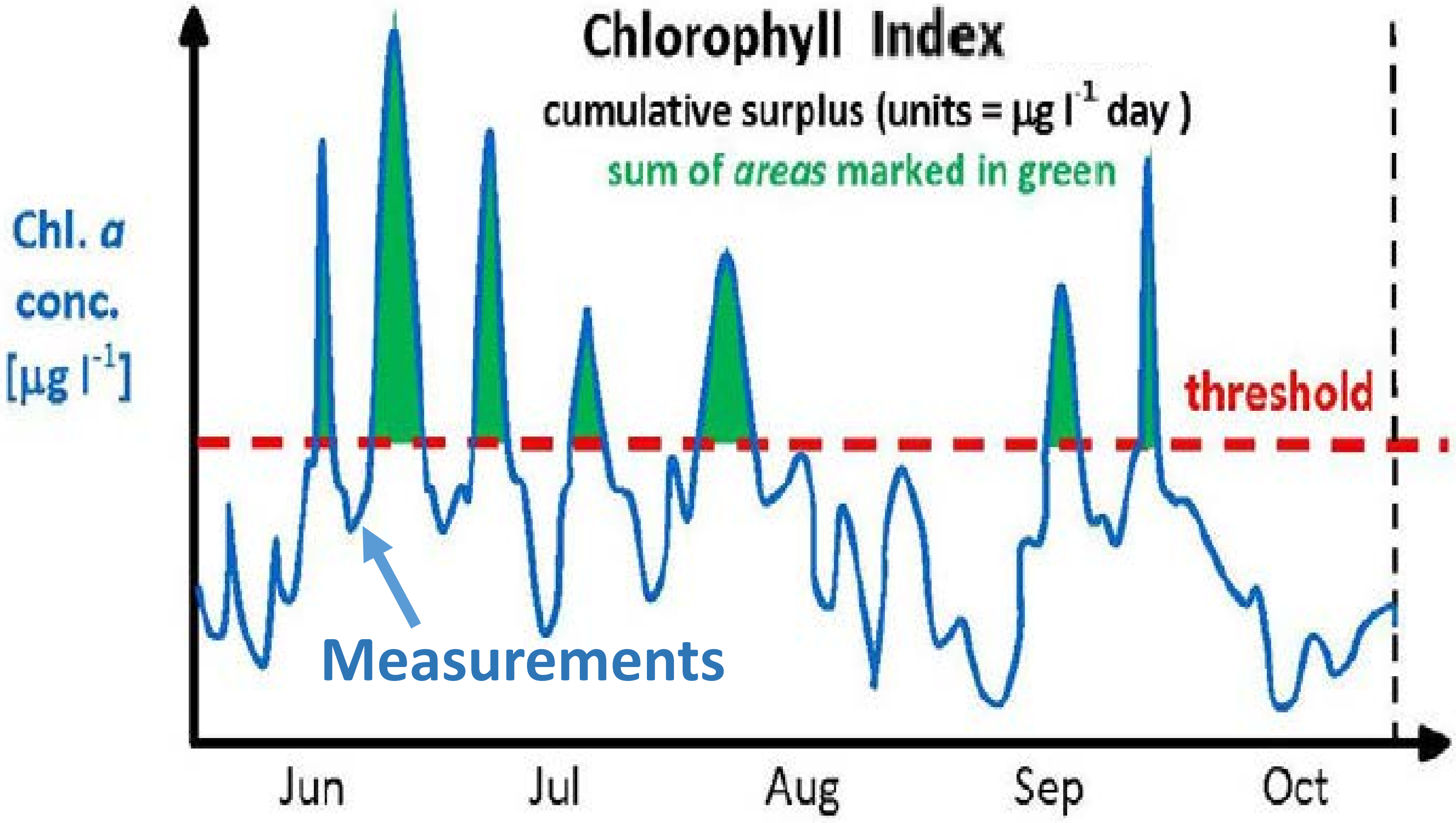
Hypoxia and drivers



Jun – Sep period; all stations averaged except PD, GB, SR

- Inter-annual variability:
  - **River flow**, **TN load**, **stratification** all strongly correlated
  - **Hypoxia** co-varies but is not as strongly correlated
    - e.g., higher 2009, lower 2011
- Long-term decline in **TN load**
  - Substantially lower by 2013 but hypoxia strong that year
- No year 2014-2017 as wet as earlier "wet" years
- **2017:** intermediate flow/load
  - **Hypoxia weaker than earlier comparable flow/load years**

A refined Chlorophyll Index (from time series)



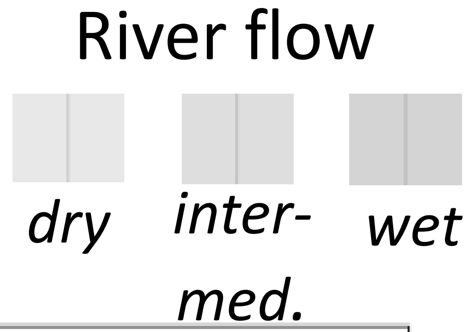
- **"Chlorophyll Index"** (parallel Hypoxia Index)
- Seasonal measure that increases with number, duration, intensity of events

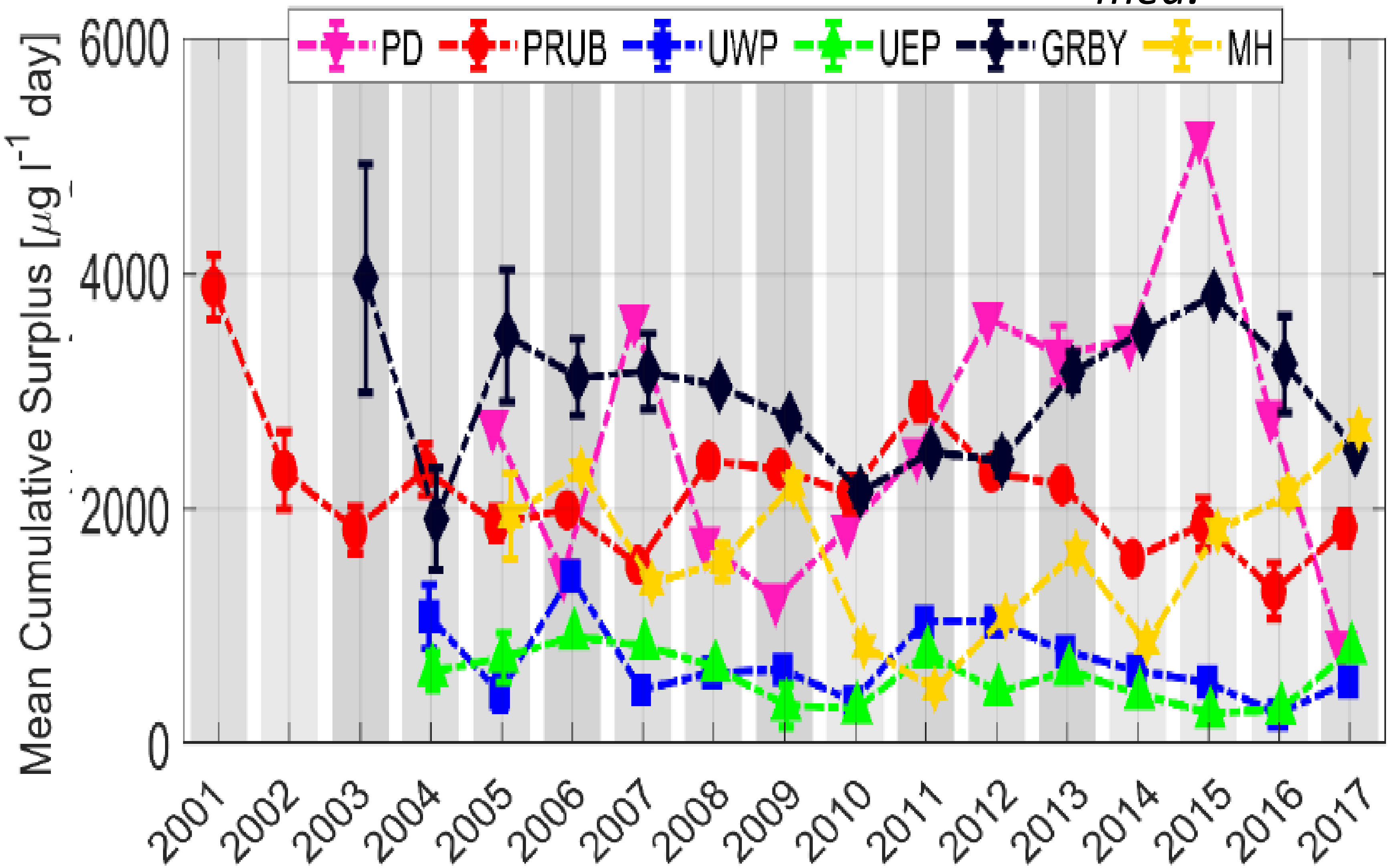
- In "State of Bay" report
  - thresholds based on *individual stations*
- **Refined approach:** thresholds instead are:
  - $20^{th}/50^{th}/80^{th}$ percentile of May-Oct measurements at ***all stations***:

    4.9, 9.4, 17.4 ug L^{-1}
  - **applied to all stations bay-wide**
- **More useful to gauge regional patterns/trends**

Chlorophyll Index results

50th p'tile (9.4 ug L^{-1}) threshold





Down-bay gradient:

- as expected

Inter-annual variability:

- not as strong as for oxygen
- weakly linked to river flow

Long-term response to load reductions:

- weakly apparent

Vessel-based spatial surveys & time series (D.O. & chlorophyll)

Complementary strengths/weaknesses of two datasets

Spatial Surveys

- Large geographic coverage including both deeper and shallower areas
- Finer spatial resolution– 77 stations
- Sampling throughout water column resolves vertical structure
- Infrequent: 5-7 times/season

Time Series

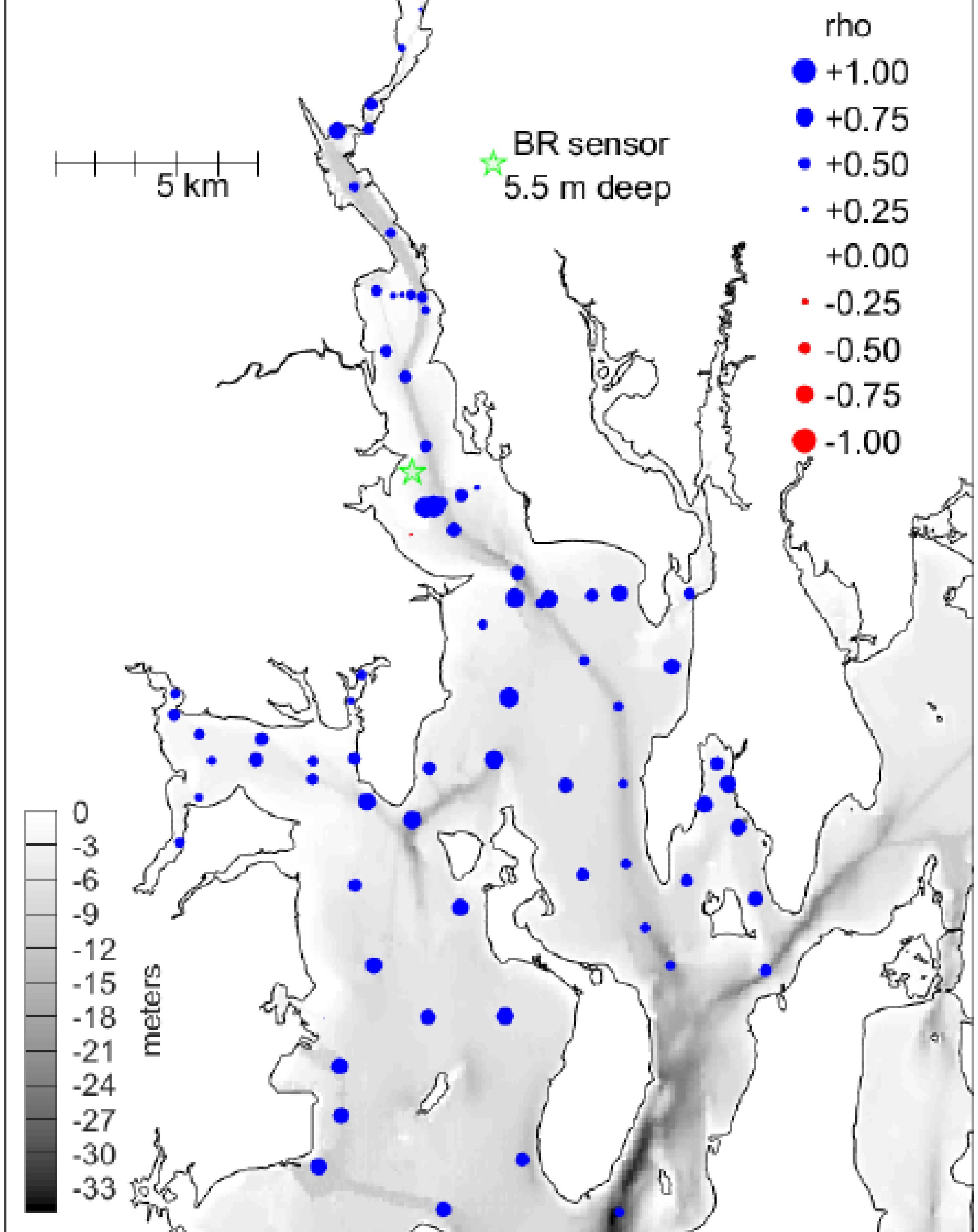
- Span mid-May to mid-Oct, high-frequency (15-min) temporal resolution
- Fewer stations (11)
- Stations located mostly in deeper channelized areas
- Sensors mostly near-surface or near-seabed; do not resolve vertical structure within water column

Example correlation calculation

- Near-bottom D.O. at Bullocks Reach time series site on day/time of spatial survey
- Correlation to near-bottom D.O. measured at all spatial survey station locations
- Using ~62-71 surveys over all years through 2017

Results

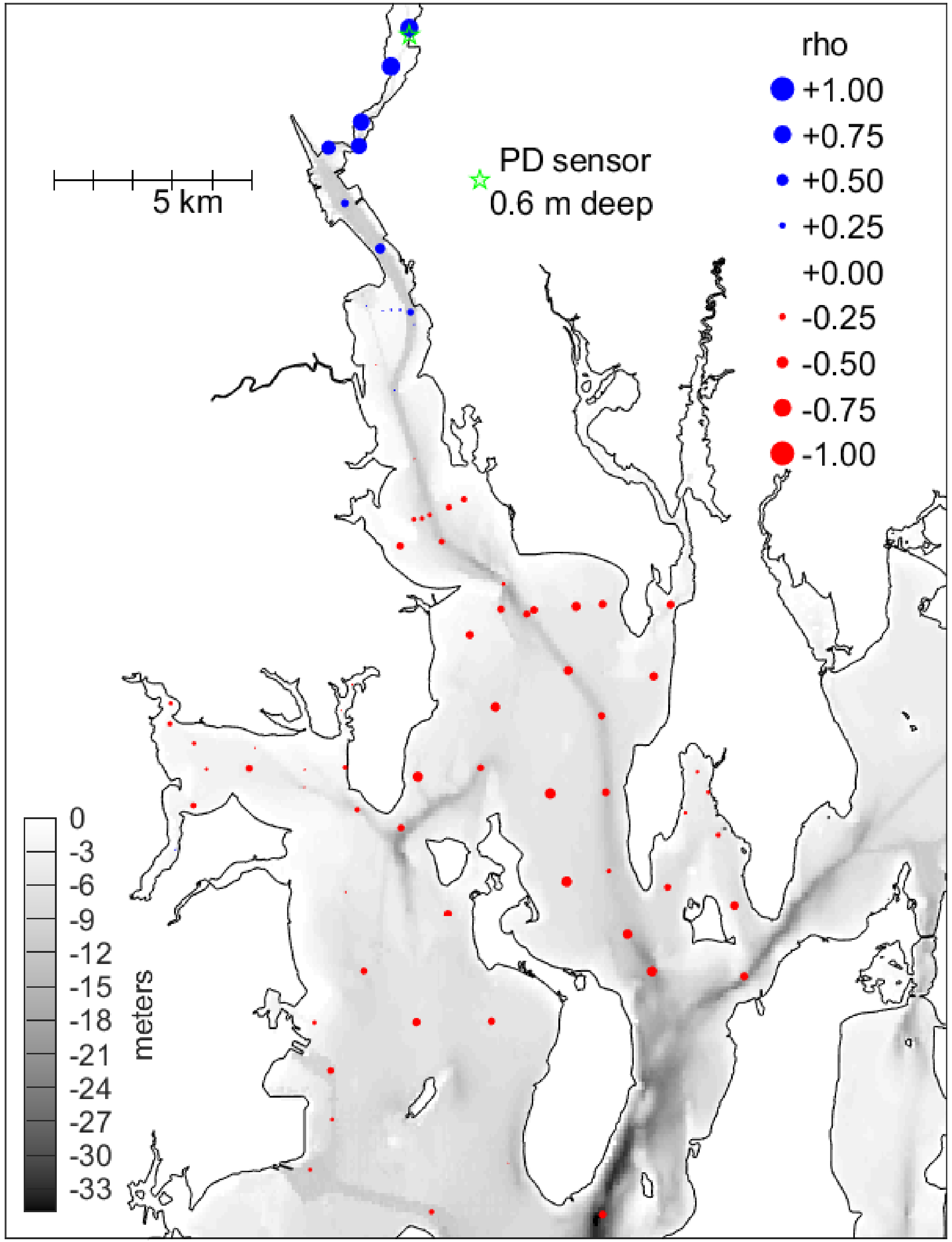
- Positive correlations
- Highest nearest to BR
- Higher at deeper locations

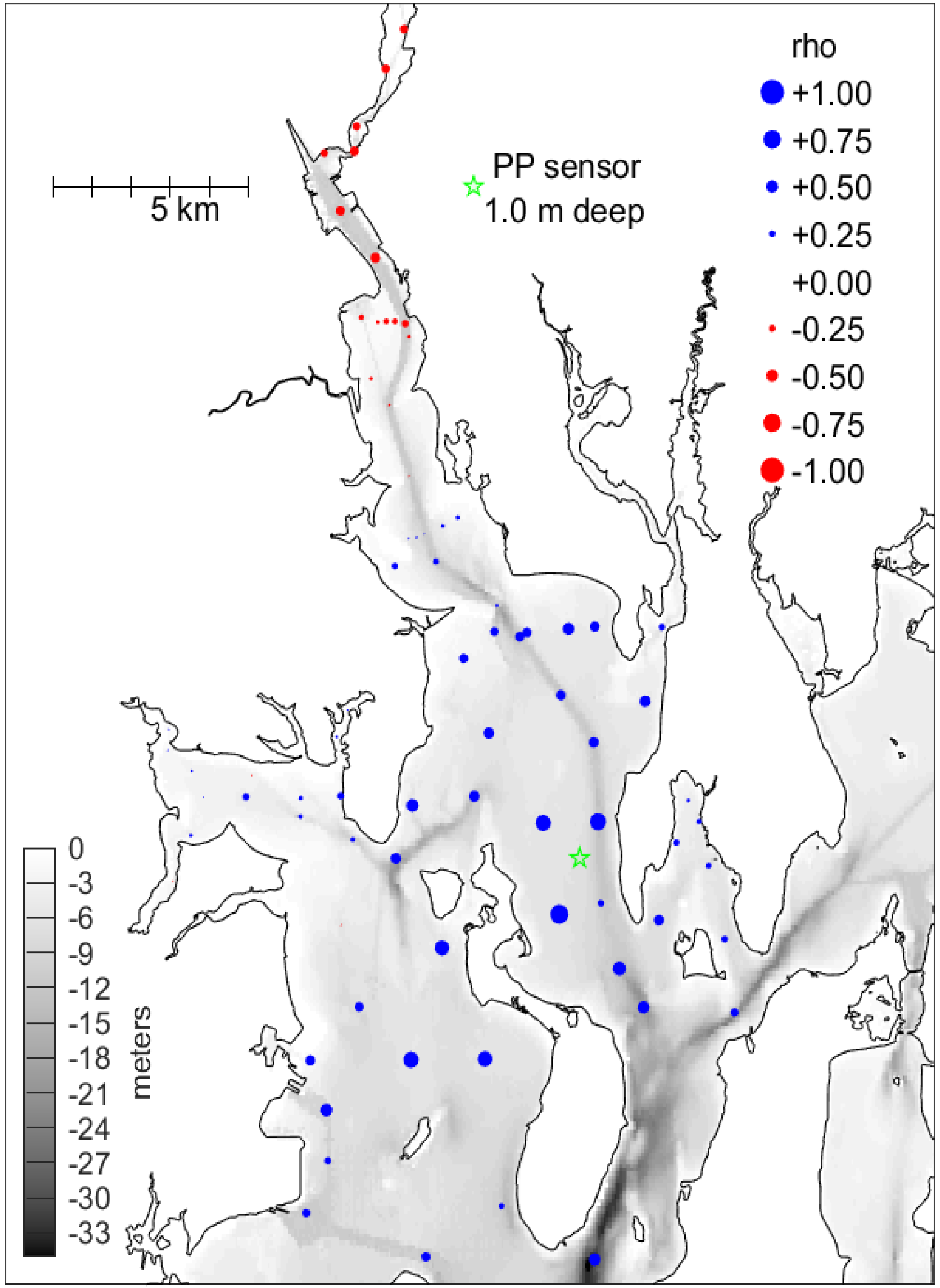


Decorrelation spatial scale (from surveys) and time scale (from time series):

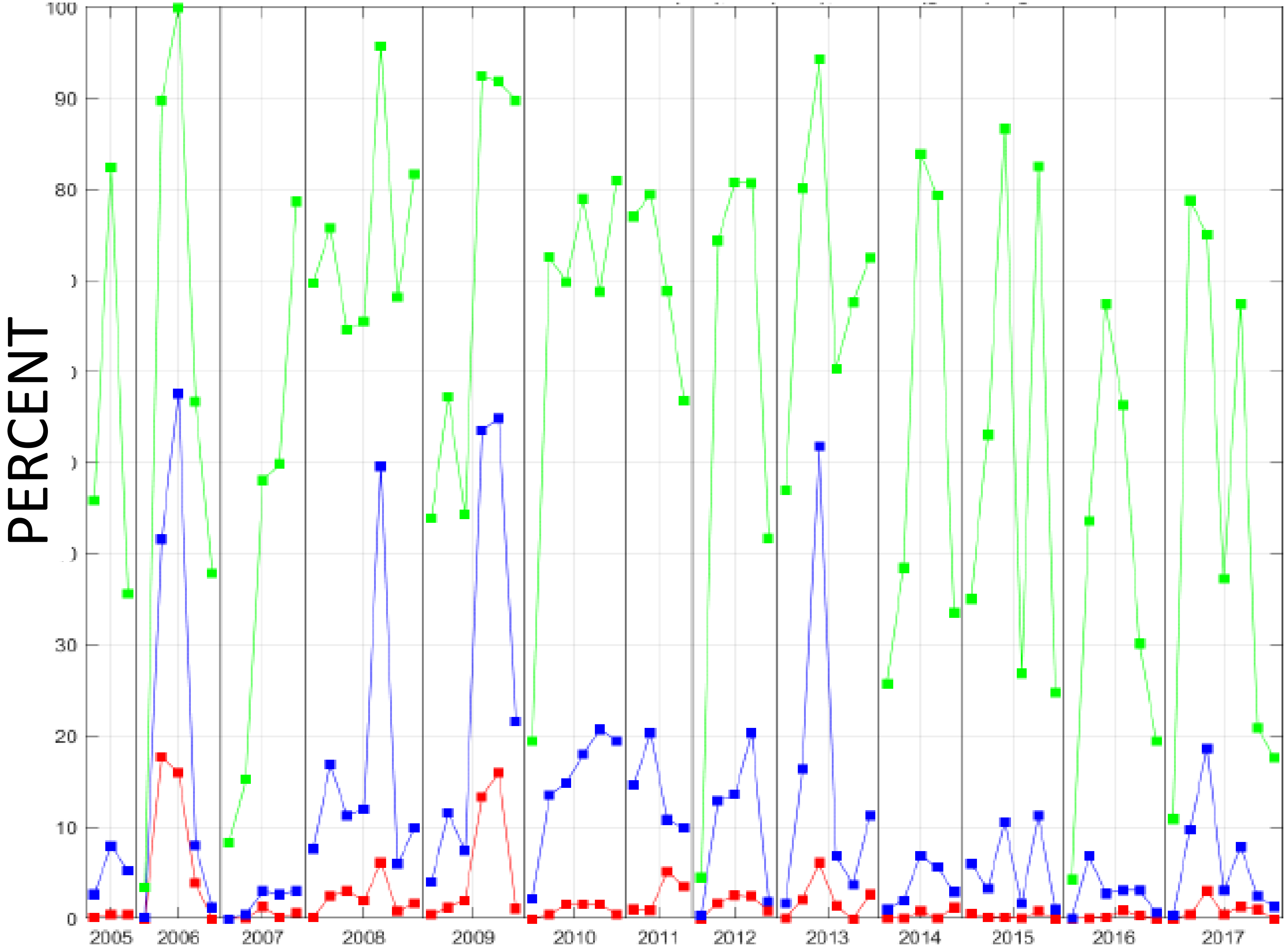
- Larger/longer for oxygen than for chlorophyll
- Larger/longer at depth than near surface

Decorrelation scale	**Oxygen**		**Chlorophyll**	
	Shallower	Deeper	Shallower	Deeper
Spatial	**~5 km**	**~10 km**	**~4 km**	**~7 km**
Temporal	**~3 days**	**~5 days**	**~1.5 days**	**~3 days**





Negative north/south surface chlorophyll correlation suggests alternating timing of blooms and post-bloom declines



Percent hypoxic area

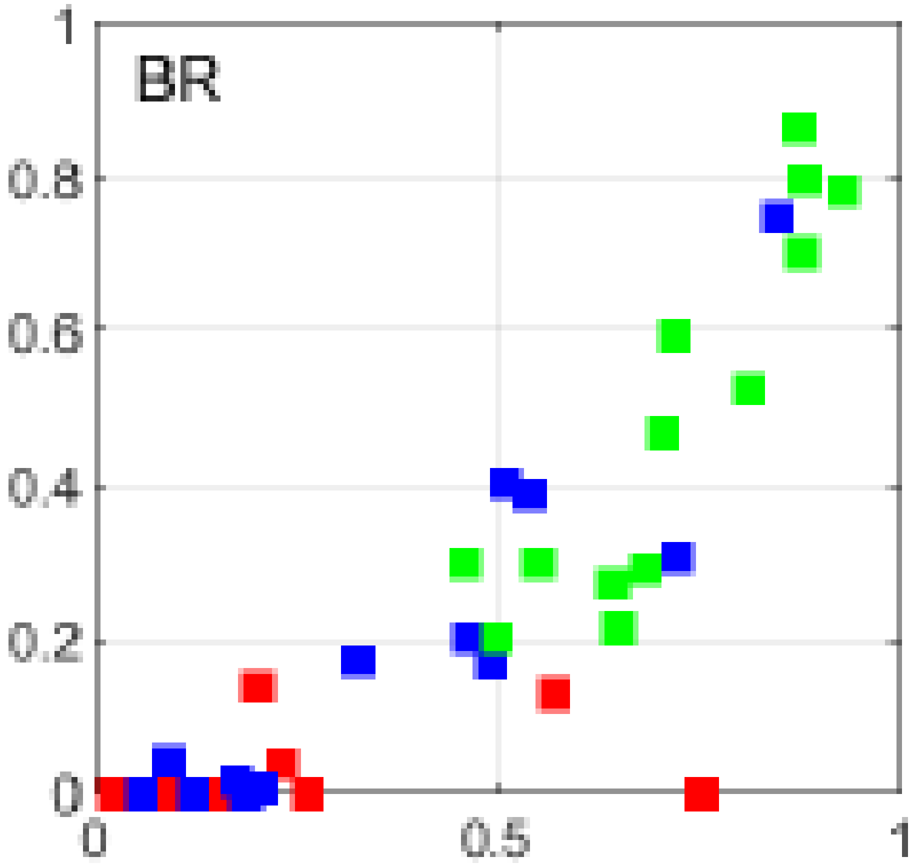
Spatial surveys (bott. D.O. each station)

- Map to regular grid, compute area below threshold
  - 4.8 mg L^{-1}
  - 2.9 mg L^{-1}
  - 1.4 mg L^{-1}

Long-term decline rel. 4.8 and 2.9 mg L^{-1}

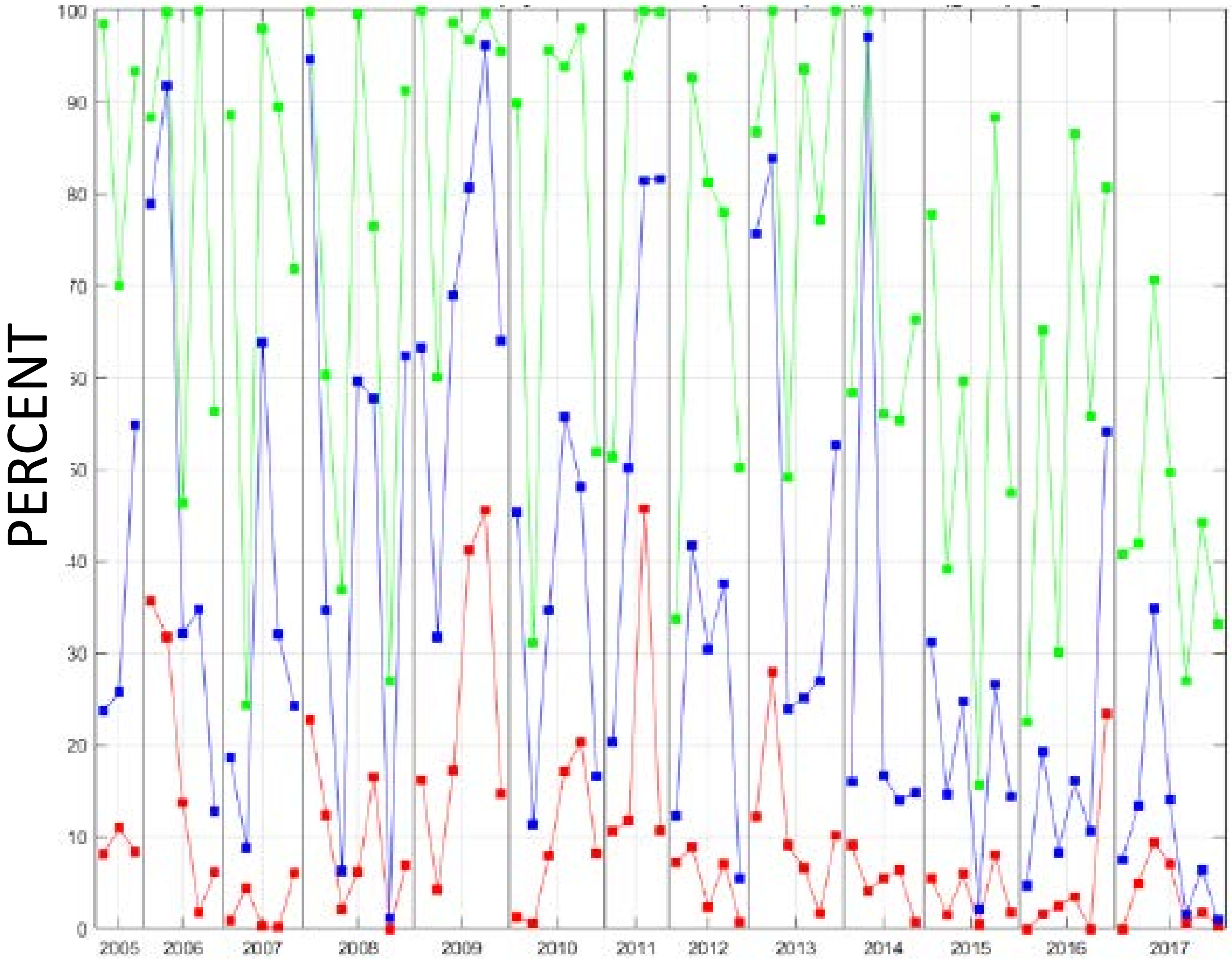
Hypoxia Index (time series) at Bullocks Reach vs Seasonally-averaged **Percent Hypoxic Area** (surveys)

Hypoxia Index (rel. 1.4, 2.9, 4.8 mg L^{-1}) normalized by 12, 70, 210 mg L^{-1} day, resp.



- **High r^2 (0.83 and 0.79 resp.) for 2.9 and 4.8 mg L^{-1} thresholds**
- **Correlations weaker at other stations**

Seasonal-mean percent hypoxic area (rel. 1.4, 2.9, 4.8 mg L^{-1}) normalized by 10%, 30%, and 80%, resp.



Percent high-chlorophyll area
Spatial surveys (surf. chl each station)

4.9 ug L^{-1}

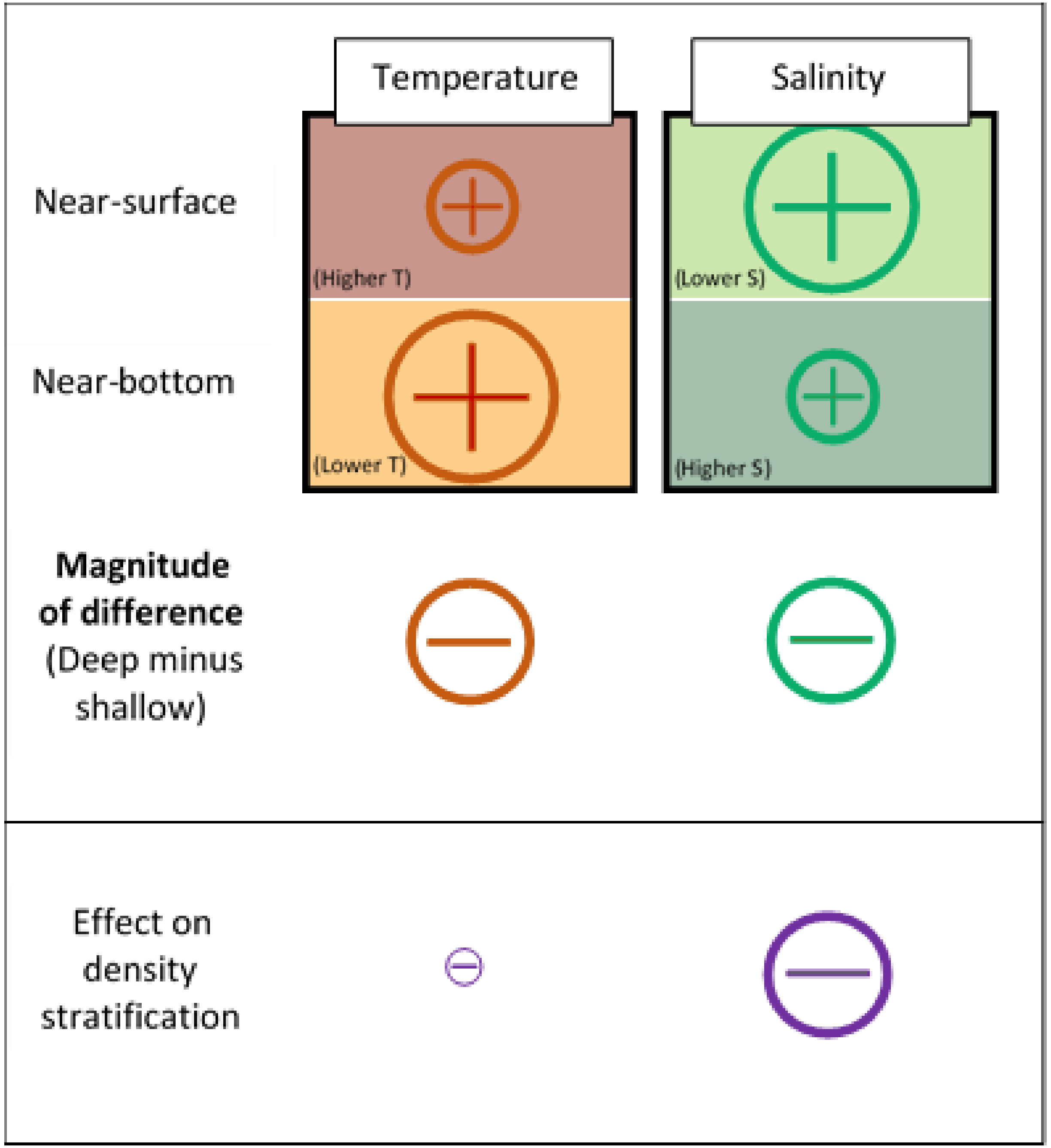
8 ug L^{-1}

27.5 ug L^{-1}

Long-term declines more clear than in chlorophyll index (which is from time series, stations mostly in deeper channelized locations)

Long-term trends:
temperature, salinity, stratification

- Fixed site moorings, 2001 or 2004/5 to 2017, May-Oct, near-surface and near-bottom
- Surface warming about 0.5°/decade
  - Consistent with other prior studies
- Deep warming ~2X faster
  - Probably due to offshore warming
- Salinity increasing
  - Stronger at surface: ~1.6 PSU/decade
  - Probably due to many recent dry years
  - Unlikely to continue (precip. increases)
- Stratification decreasing
  - Dominantly due to salinity
- Warming likely more impact on hypoxia (metabolic rates) than stratification decline



Questions?