Combining Routine Monitoring and Research to Understand Estuarine Biogeochemistry

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2010 National Monitoring Conference
Session K1 - 29 April 2010

Recent Cooperative Efforts to Re-think Management of Estuarine Eutrophication

NOAA – National Estuarine Eutrophication Assessment Update
Edited by: Suzanne Bricker, Ben Longstaff, William Dennison, Adrian Jones, Kate Boicourt, and Caroline Wicks (2007)

US EPA – Estuarine Nutrient Criteria Development : Edited by
Patricia M. Glibert, Christopher Madden, Walter Boynton, David Flemer, Cynthia Heil, and Jonathan Sharp (not published in 2008)

- Estuarine typology – not all behave the same way
- Ecosystem response should be evaluated, not nutrient loading or concentration

Important Considerations

- **Oxygen depletion in bottom region of stratified waters is not only form or hypoxia, also both anthropogenic and "natural" drivers can cause hypoxia**

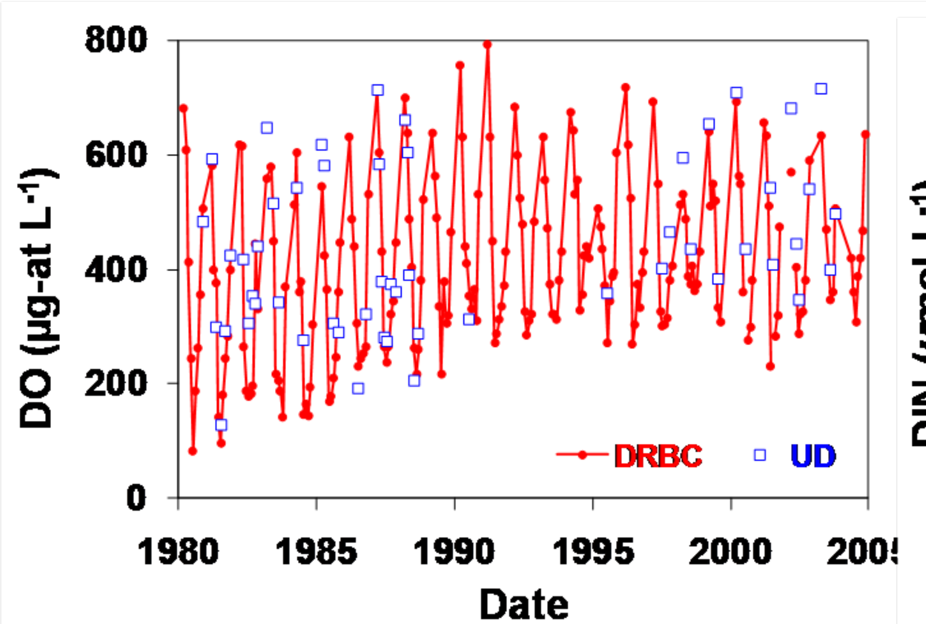
- **Excess labile organic matter is not only reductant for oxygen demand in natural and altered waters**

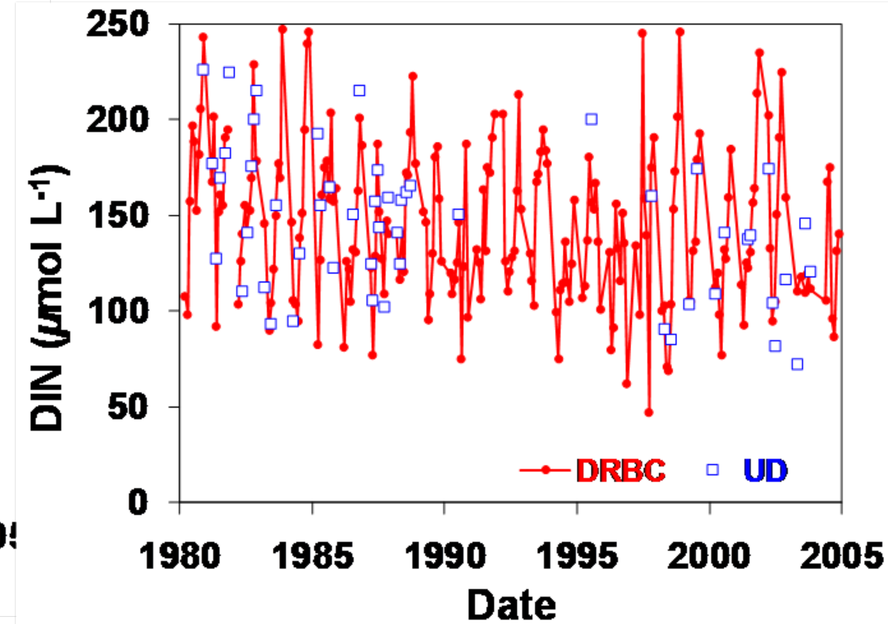
- **Top-down, as well as bottom-up controls of primary production must be understood**

- **We must recognize "shifting baselines" in assessing estuarine conditions**

Research/Monitoring Compatibility

- **Delaware River – home of first major municipal water system in the US with good assessment of quality of drinking water intake back to at least the 1880s**
- **Delaware River Basin Commission (DRBC) – good monitoring along the length of Delaware River and Bay estuary starting in 1967 and continuing to present – monitoring for management of estuary**
- **My University of Delaware (UD) research with consistent sampling along length of estuary starting in 1978**
- **Same sampling stations between DBRC and UD**
- **Some similar parameters measured compatibly**





Regular DRBC sampling data compared to less regular UD data for dissolved oxygen (DO) and total dissolved inorganic nitrogen (DIN) at same station – independent sampling, usually within a week or two of each other.

All graphs with molar units – 71.4 µM N = 1 mg N L^{-1}; 1 µg-at L^{-1} O = 0.5 µM O_2 L^{-1}. Molar units used to avoid confusion and for stoichiometric comparisons.

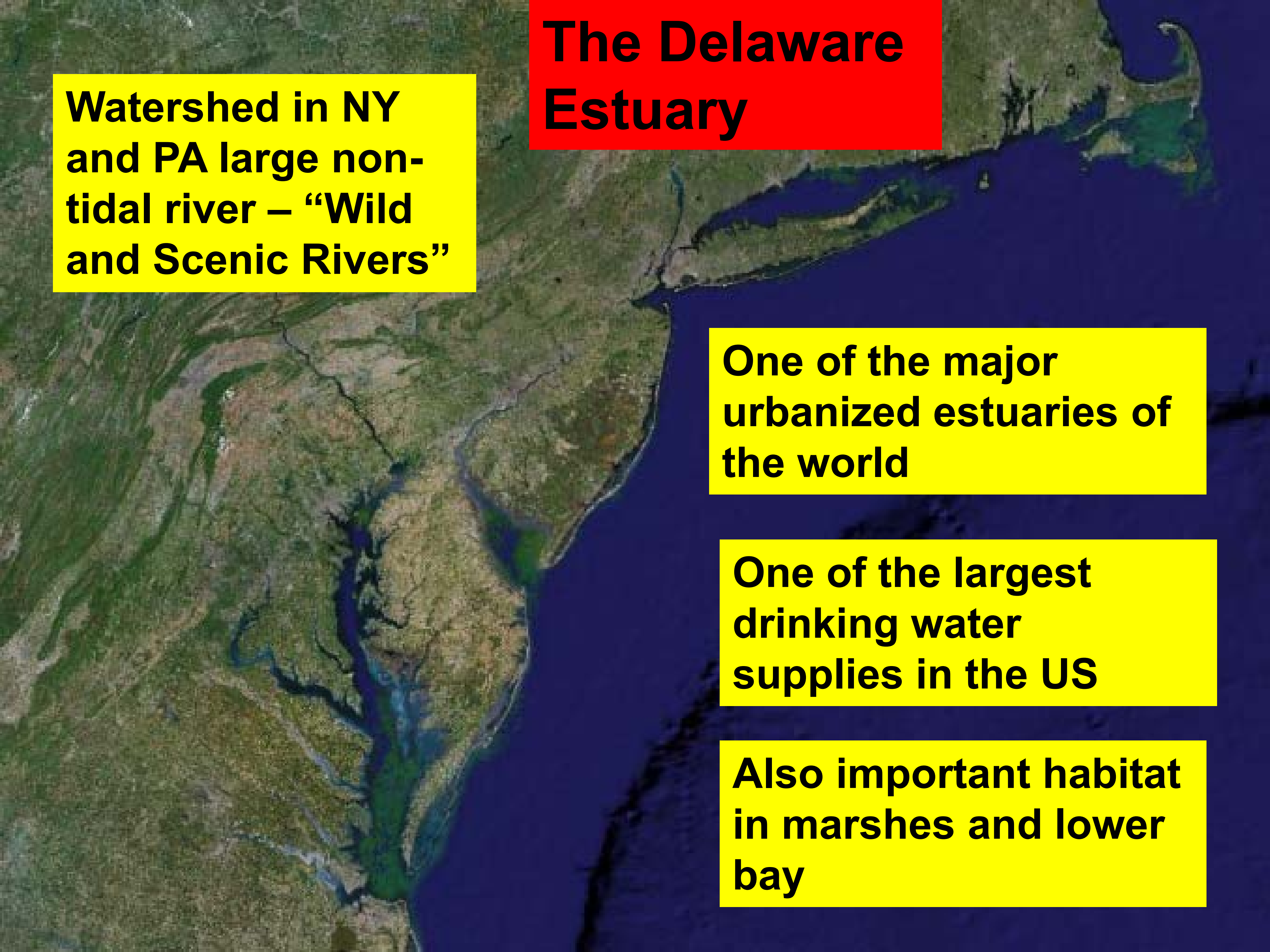
Generic Lessons from Delaware Estuary Biogeochemistry

- Estuary of Delaware River and Bay – dominated by single river, relatively rapidly flushing

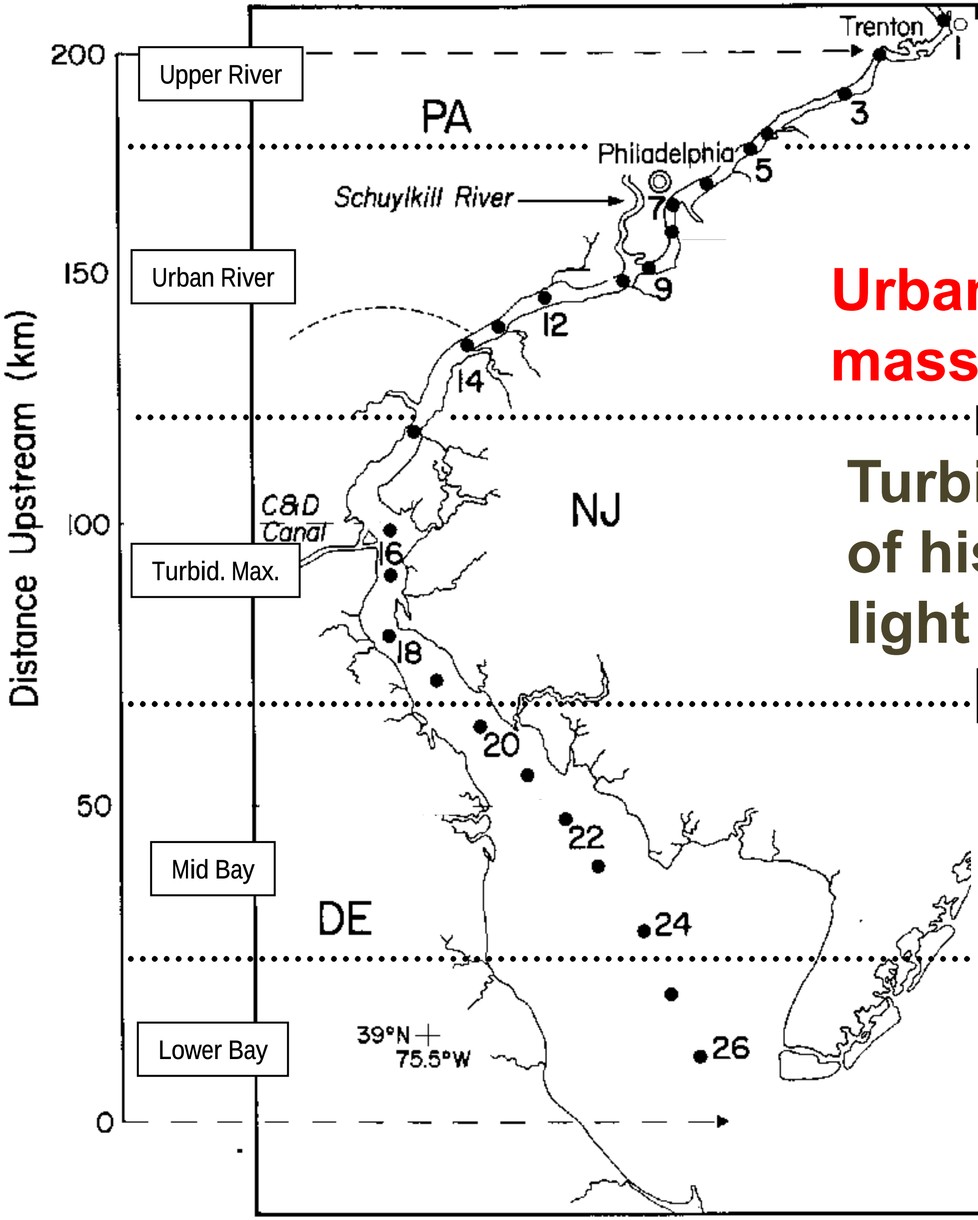
- Similar to many US and European estuaries – Chesapeake Bay and Long Island Sound are embayments with multiple river inputs and retarded flushing

- Most estuaries probably do not fit single mixing category (salt wedge, partially stratified, well-mixed)

- Most estuaries have strong spatial, as well as, temporal variability


The Delaware Estuary
Watershed in NY and PA large non-tidal river – “Wild and Scenic Rivers”
One of the major urbanized estuaries of the world
One of the largest drinking water supplies in the US
Also important habitat in marshes and lower bay


Trenton
Philadelphia
Wilmington
Long tidal river from Trenton through Philadelphia
Salty Delaware Bay – Wilmington to Lewes
“Discovered” by Hudson in 1609, settled in 1631
Lewes



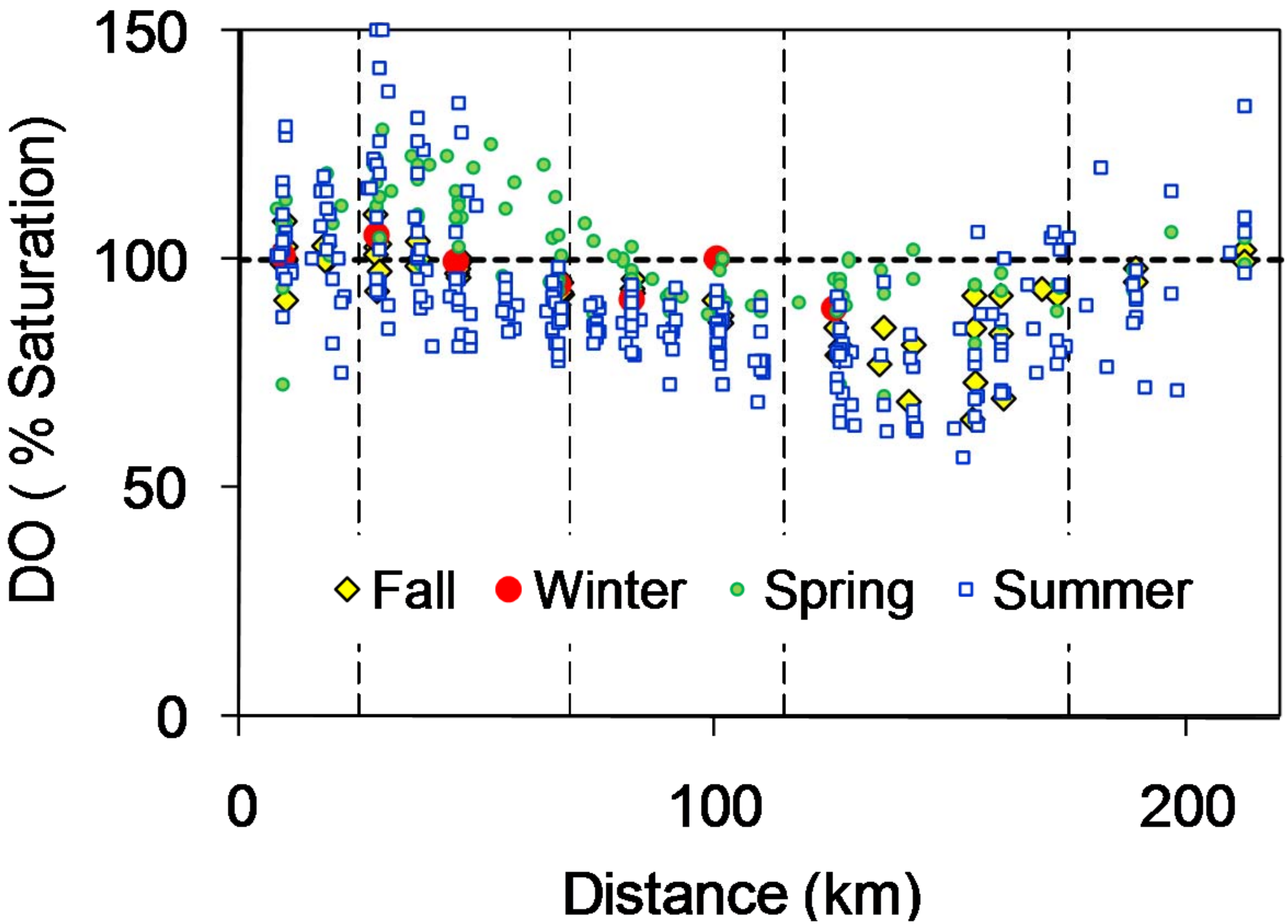
Upper tidal river – clear, composite agricultural and municipal inputs from fall line

Urban river – relatively clear, local massive municipal inputs

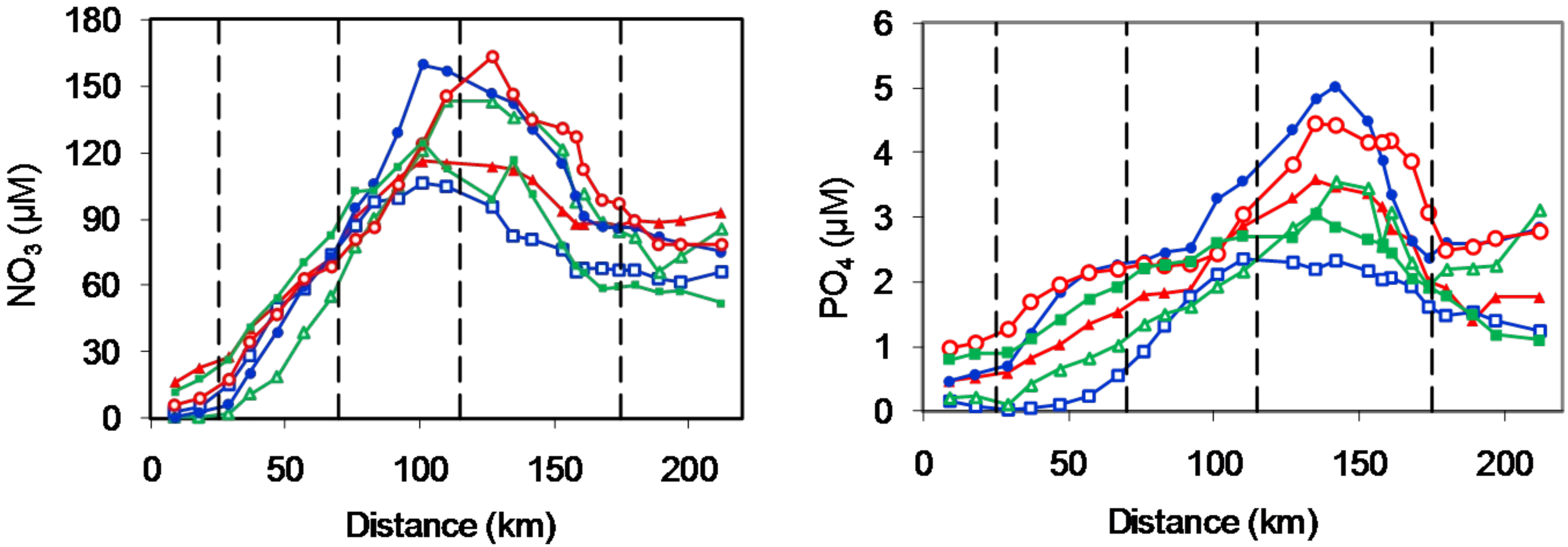
Turbidity maximum – resuspension of historical TSS inputs – strong light limitation

Mid-bay – grading from turbid to clear, relatively high nutrients grading to low

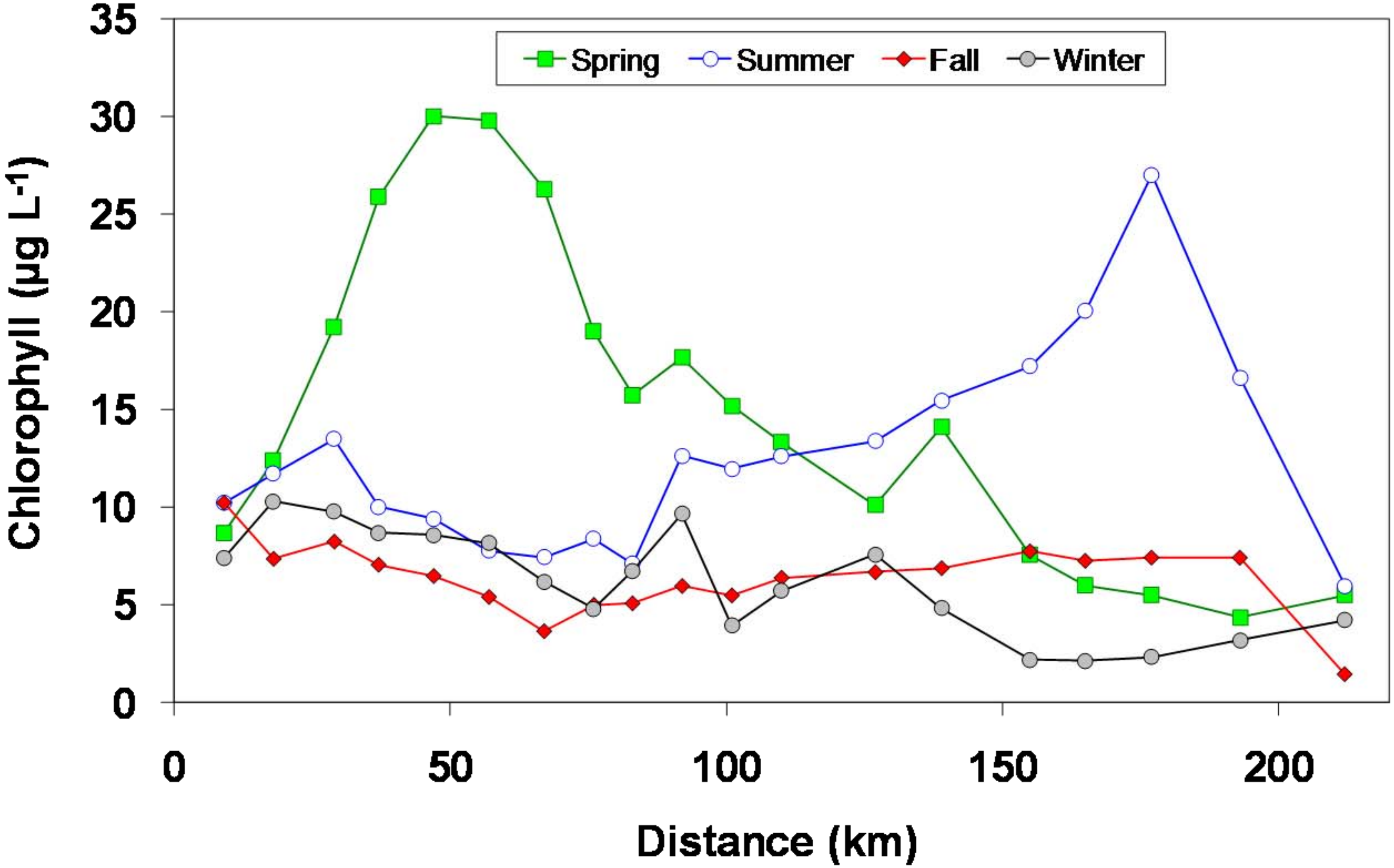
Lower bay – relatively clear, nutrient-limited



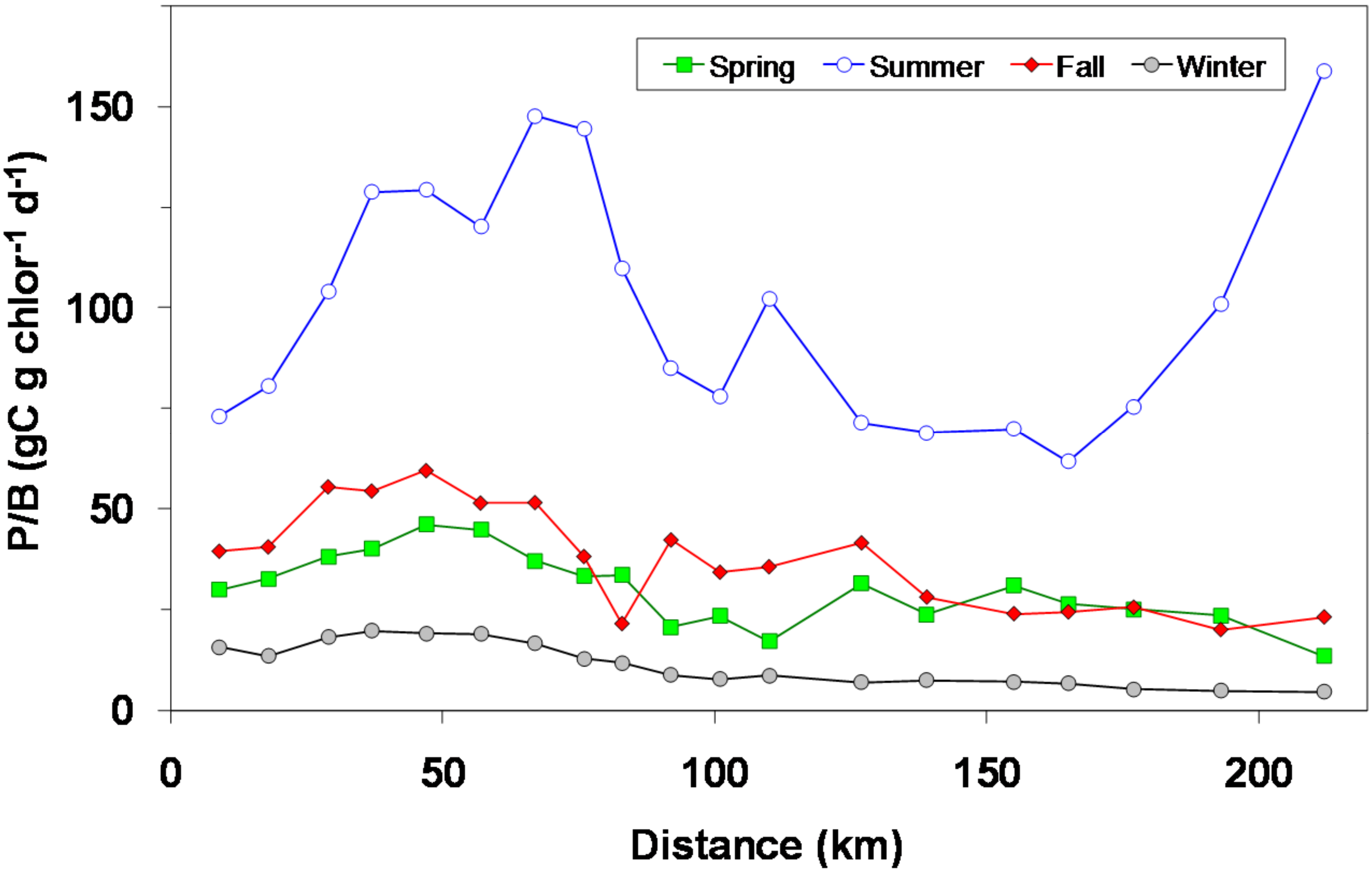
Present day dissolved oxygen (DO) along the axis of the Delaware Estuary separated by seasons (data from 1990-2003 period) – surface water data – very little depth difference



Modern seasonal concentrations of nitrate (NO_3) and phosphate (PO_4) along the length of the Delaware Estuary: Jan-Feb (▲), Mar-Apr (□), May-June (∆), July-Aug (●), Sept-Oct (○), Nov-Dec (■)



Chlorophyll biomass along the length of the Delaware Estuary separated into seasons – because of minimal trend, averages for period of 1980-2003



Primary production (from depth-integrated ^{14}C measurements) normalized to biomass along length of Delaware Estuary separated into seasons – also averages for 1980-2003

The Delaware Estuary Today

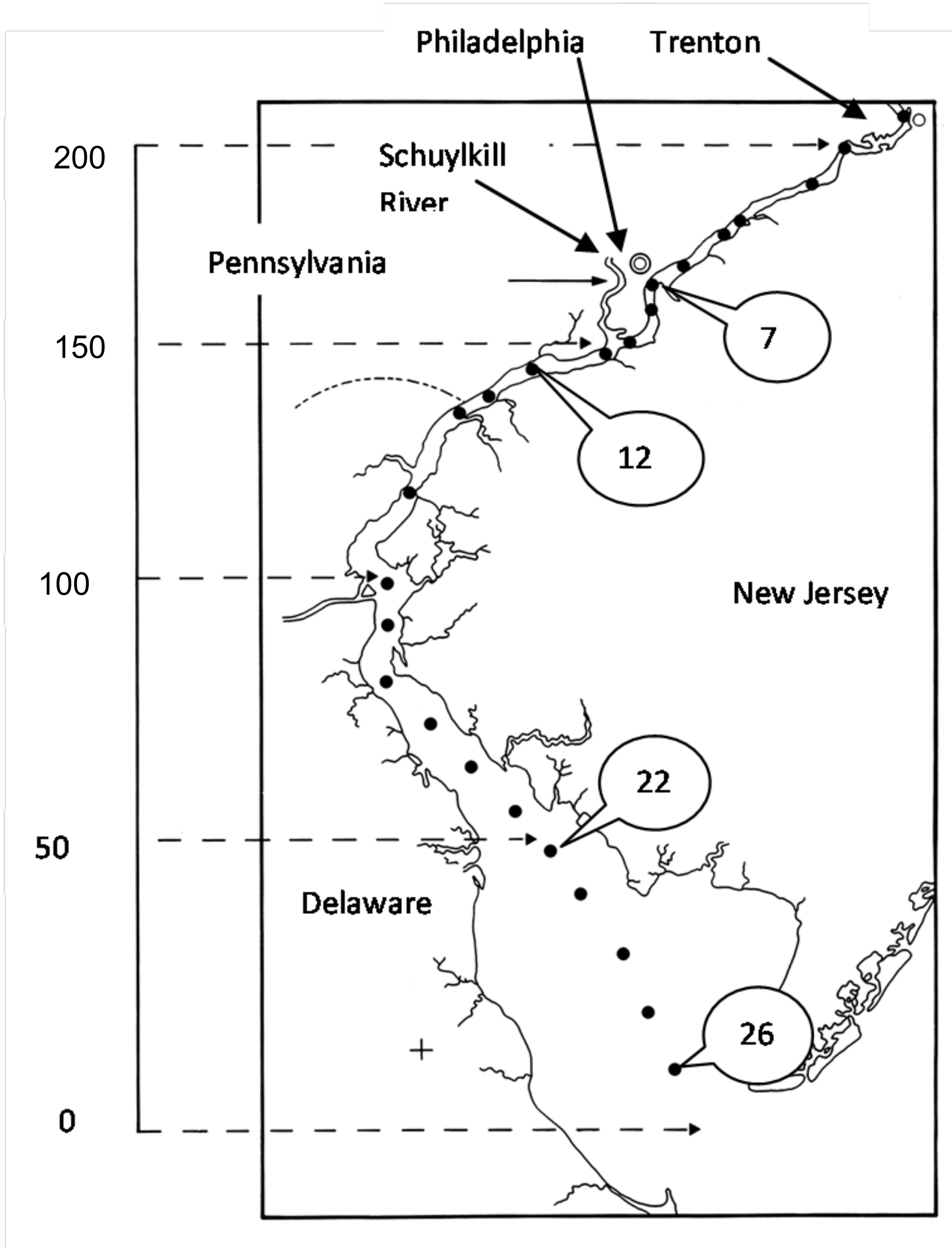
- **Very high nutrient concentrations in the urban tidal river region – no adverse local response to nutrients; dilution of nutrients through salinity gradient of Delaware Bay**

- **Highest primary production and chlorophyll in mid bay, where nutrients are diluted eventually to limitation levels**

- **No bottom water hypoxia in mid to lower bay today – possible change in future with climate change**

- **Present conditions relatively constant since 1990, slight differences in DO, nutrients, and dissolved organic carbon from late 1970s to 1990**

What about longer recent trends?



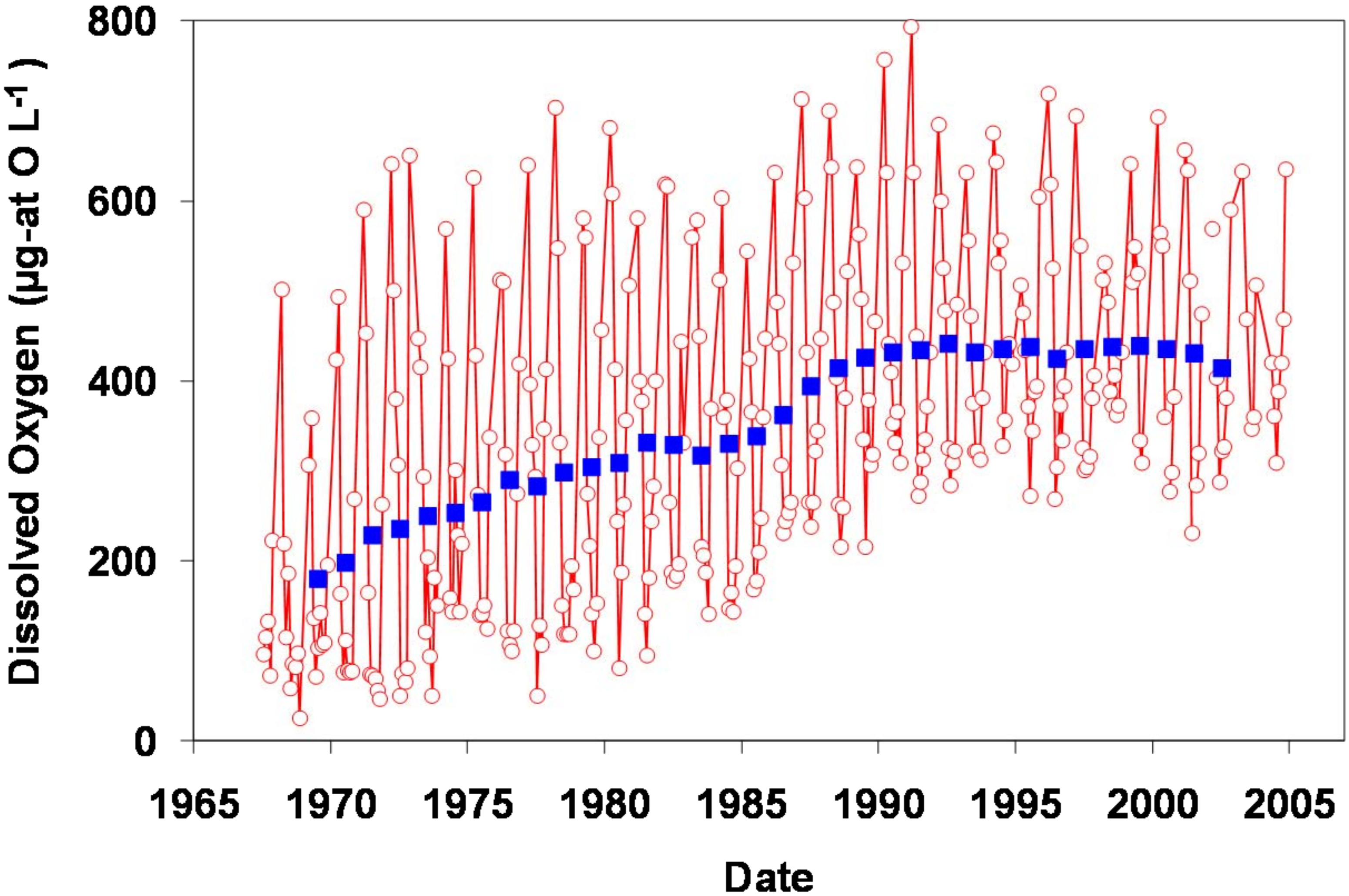
The Delaware Estuary with specific sampling stations

UD research stations from 1 at head of tide to 26 near mouth of Delaware Bay – distance up estuary from mouth in km

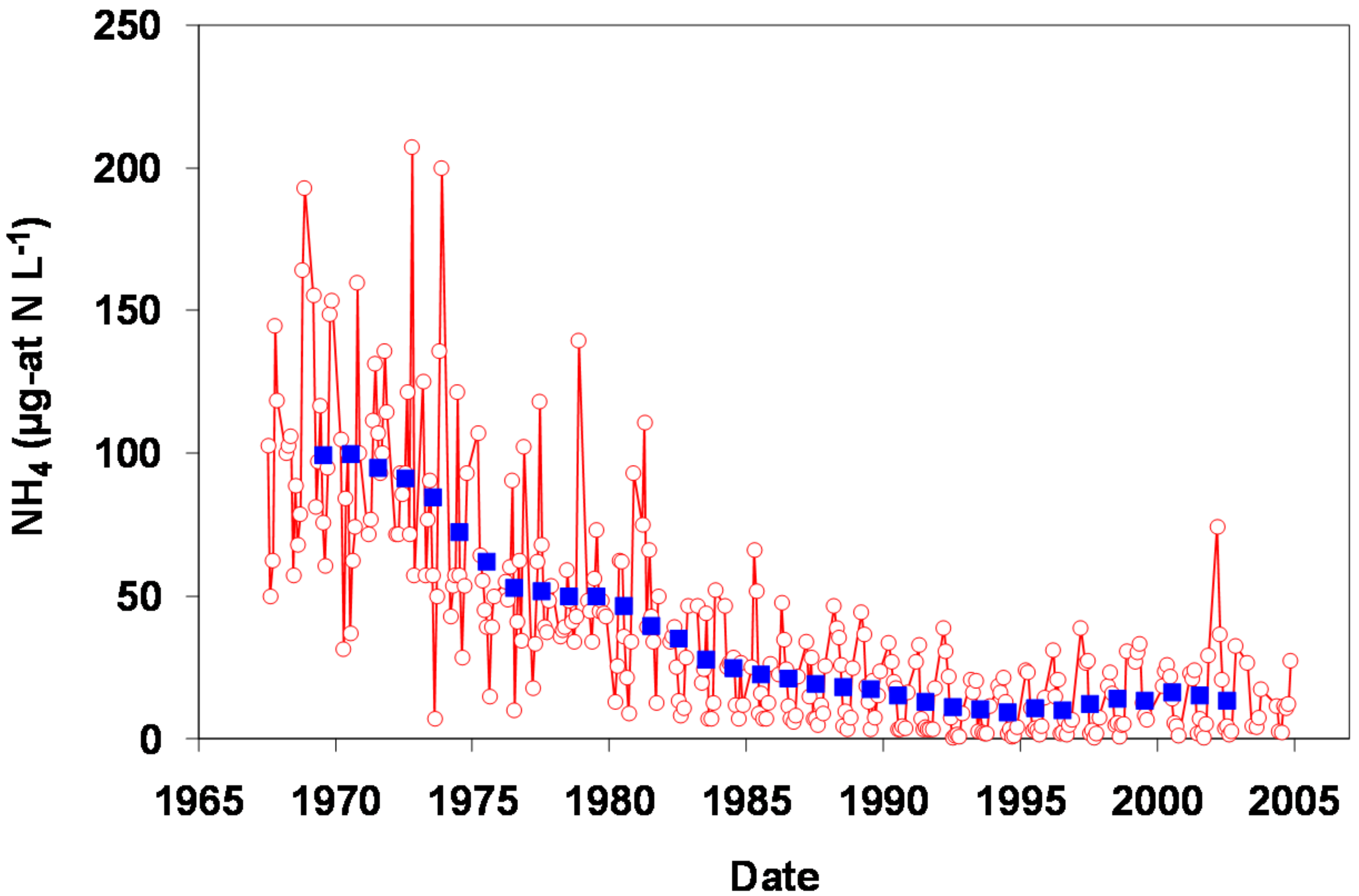
7 – PWD (Philadelphia Water Department) Torresdale intake

12 – DRBC Paulsboro station

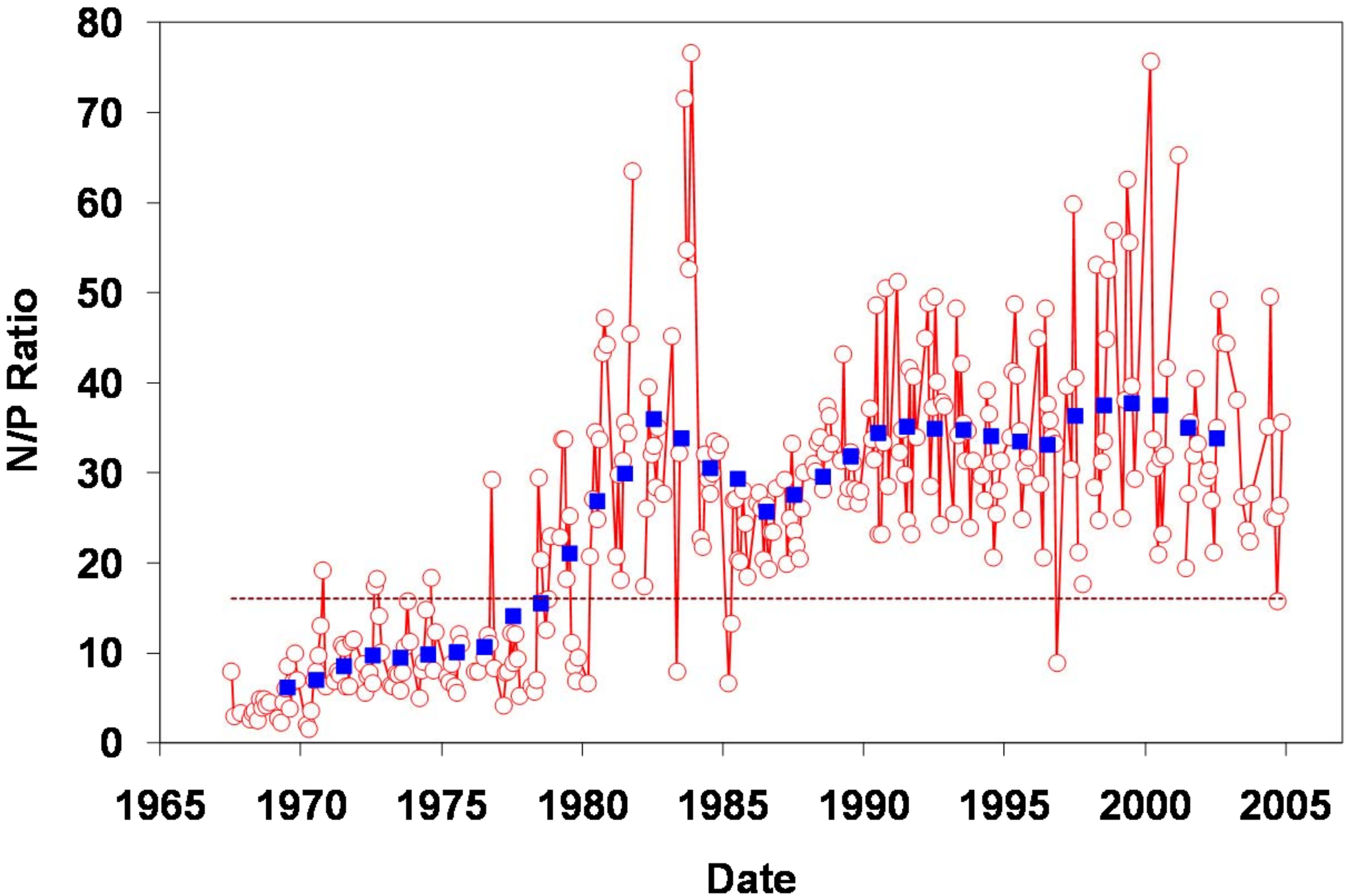
22 – DRBC Mahon River station



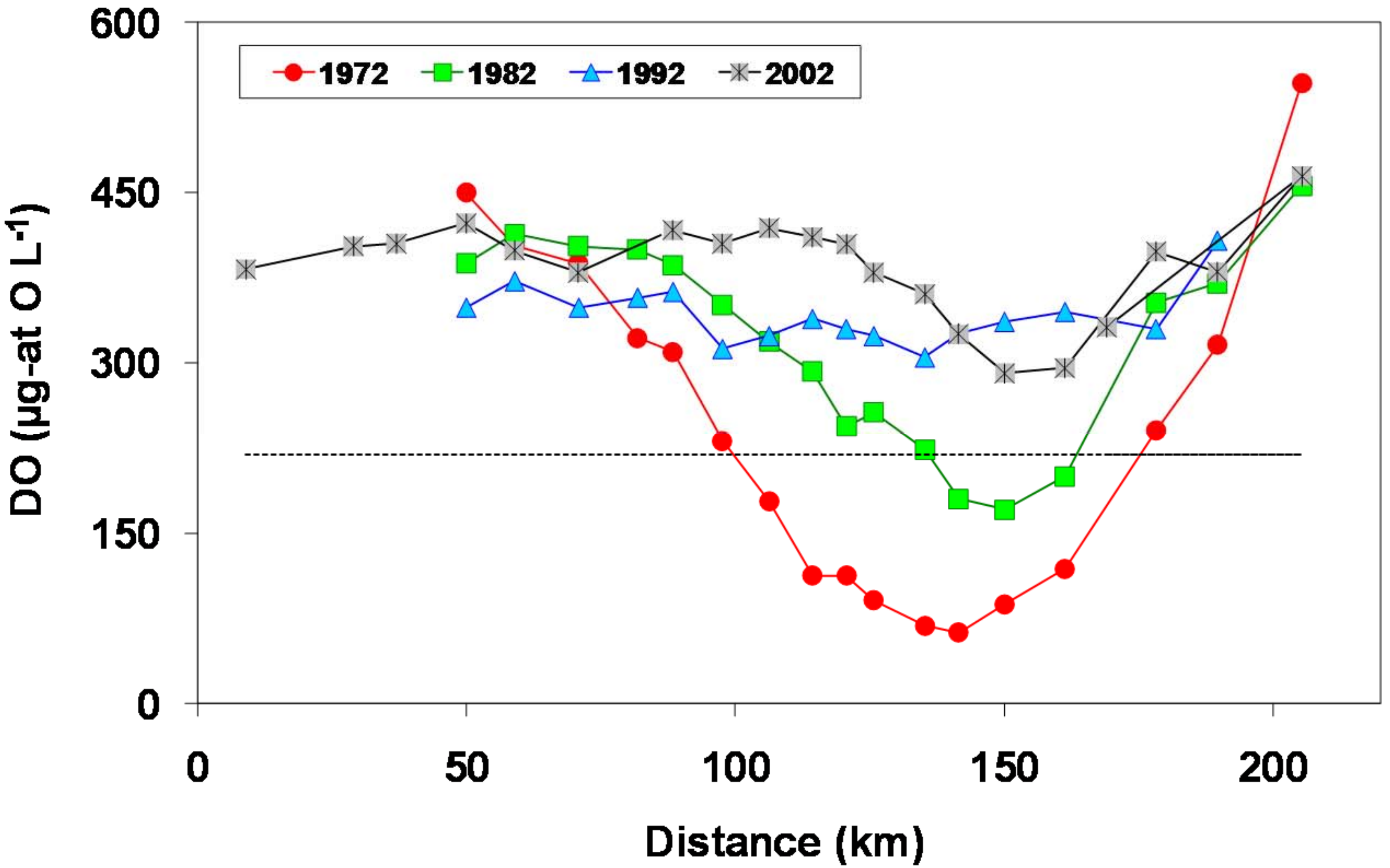
Dissolved oxygen at station 12 from 1967-2005: ○ average monthly values, ■ 5-year running averages. Extreme hypoxia in summer in past. Increase from 1970-1990 equals 10 µg-at O L^{-1} yr^{-1}



Ammonium N at station 12 from 1967-2005: ○ average monthly values, ■ 5-yr running averages. Decrease from small decrease in total dissolved nitrogen, primarily from oxidation to nitrate (nitrification – chemoautrophic process). With nitrification stoichiometry, NH_4 decrease equivalent to 9.2 µg-at O $L^{-1}yr^{-1}$



Ratio of total dissolved nitrogen to total phosphorus at station 12 from 1967-2005: ○ average monthly values, ■ 5-yr running averages, dashed line is Redfield ratio (stoichiometric biological demand of 16/1).



High summer (July-August) oxygen demand in past extended into upper bay; now much improved throughout estuary

Changes in Past 40 Years

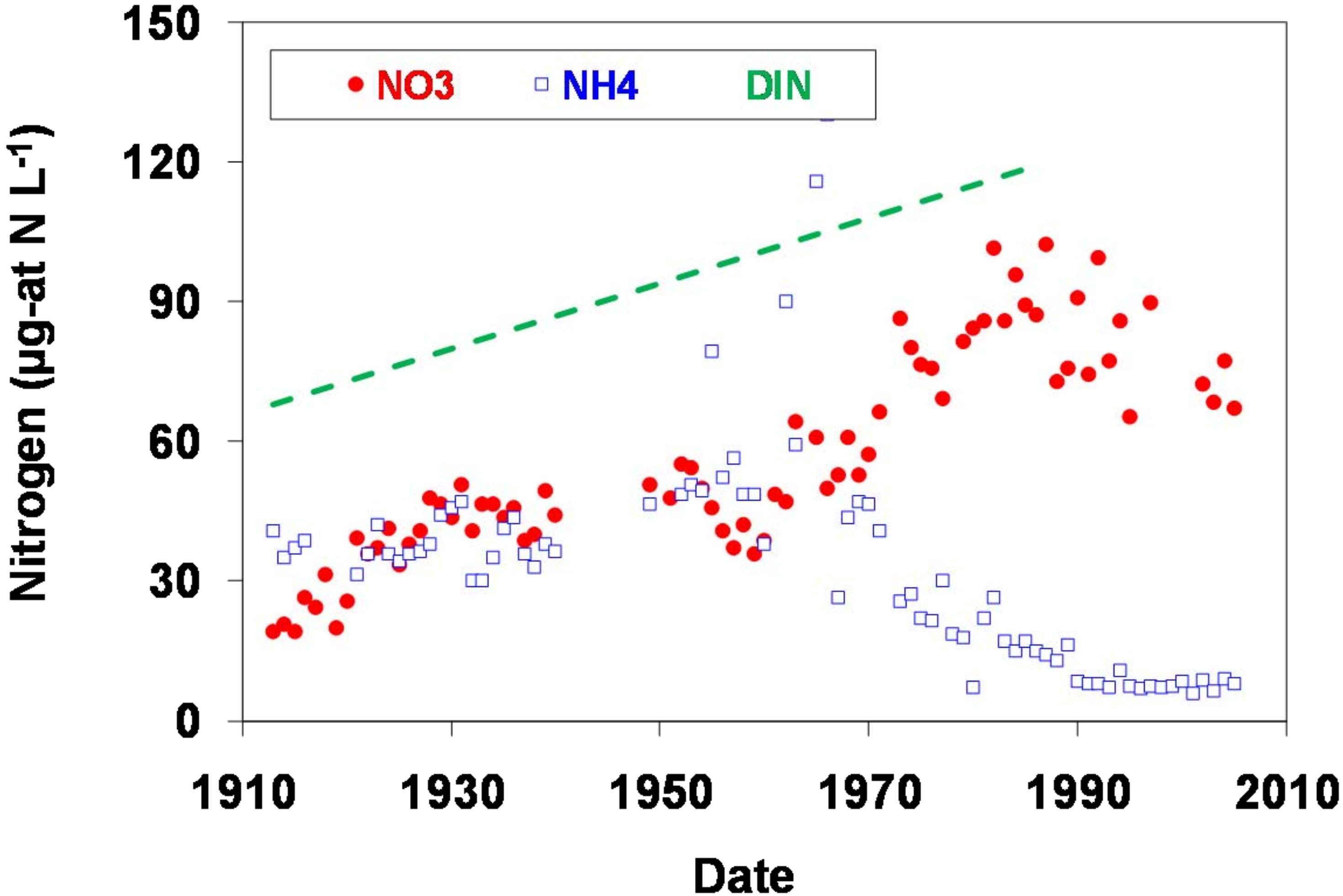
- **Large water quality improvement in tidal river and upper bay from upgraded sewage treatment plant effluents**

- **Summer hypoxia removed – but this was not hypoxia from excess algal production and probably was mainly due to chemoautotrophy, not heterotrophy**

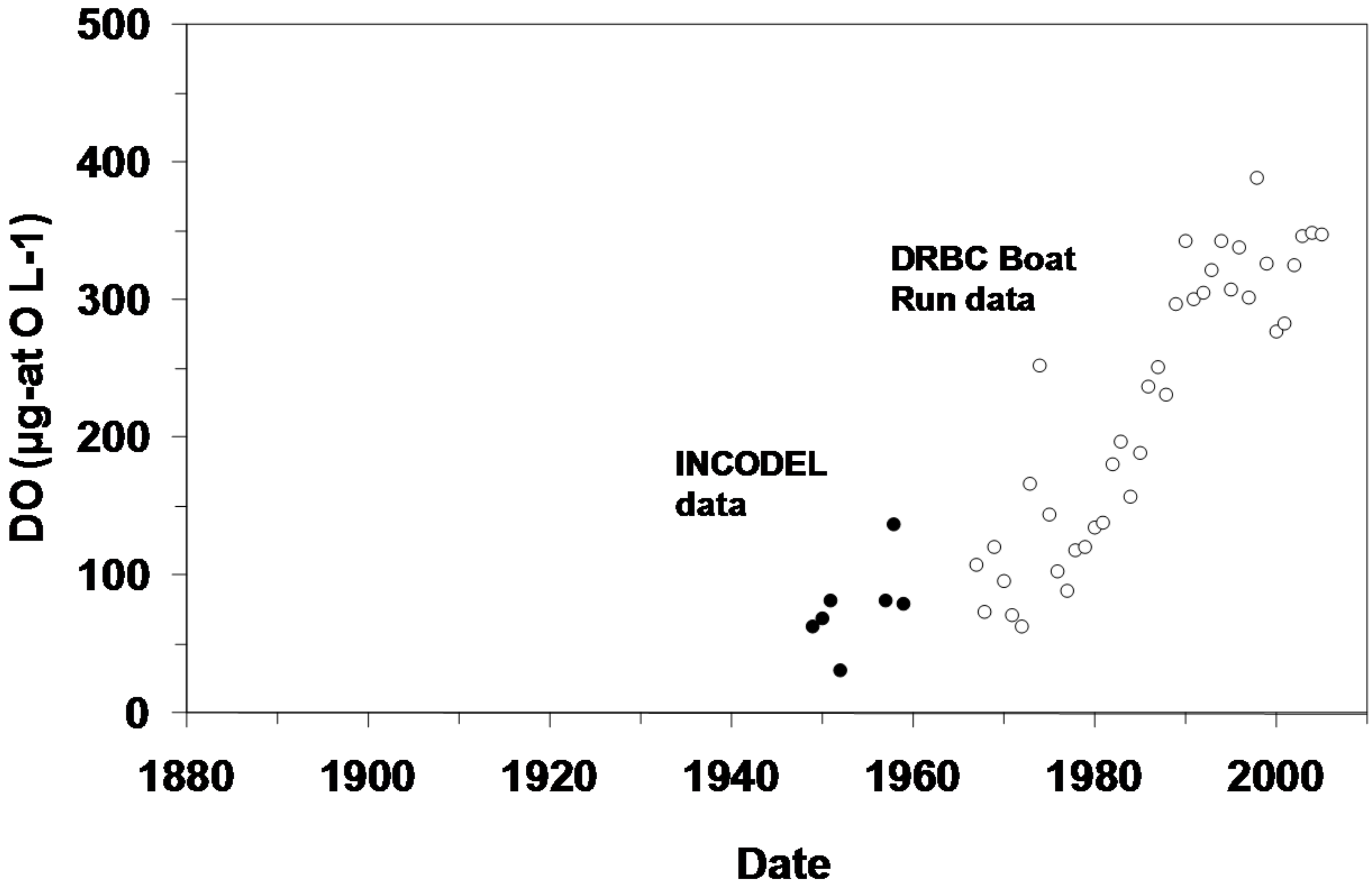
- **Large change in nitrogen speciation, but still very high N today – NO_3 at 150 µg-at N L^{-1} level**

- **Very large decrease in P resulting in large change in N/P and nominal shift from N-limitation to P-limitation**

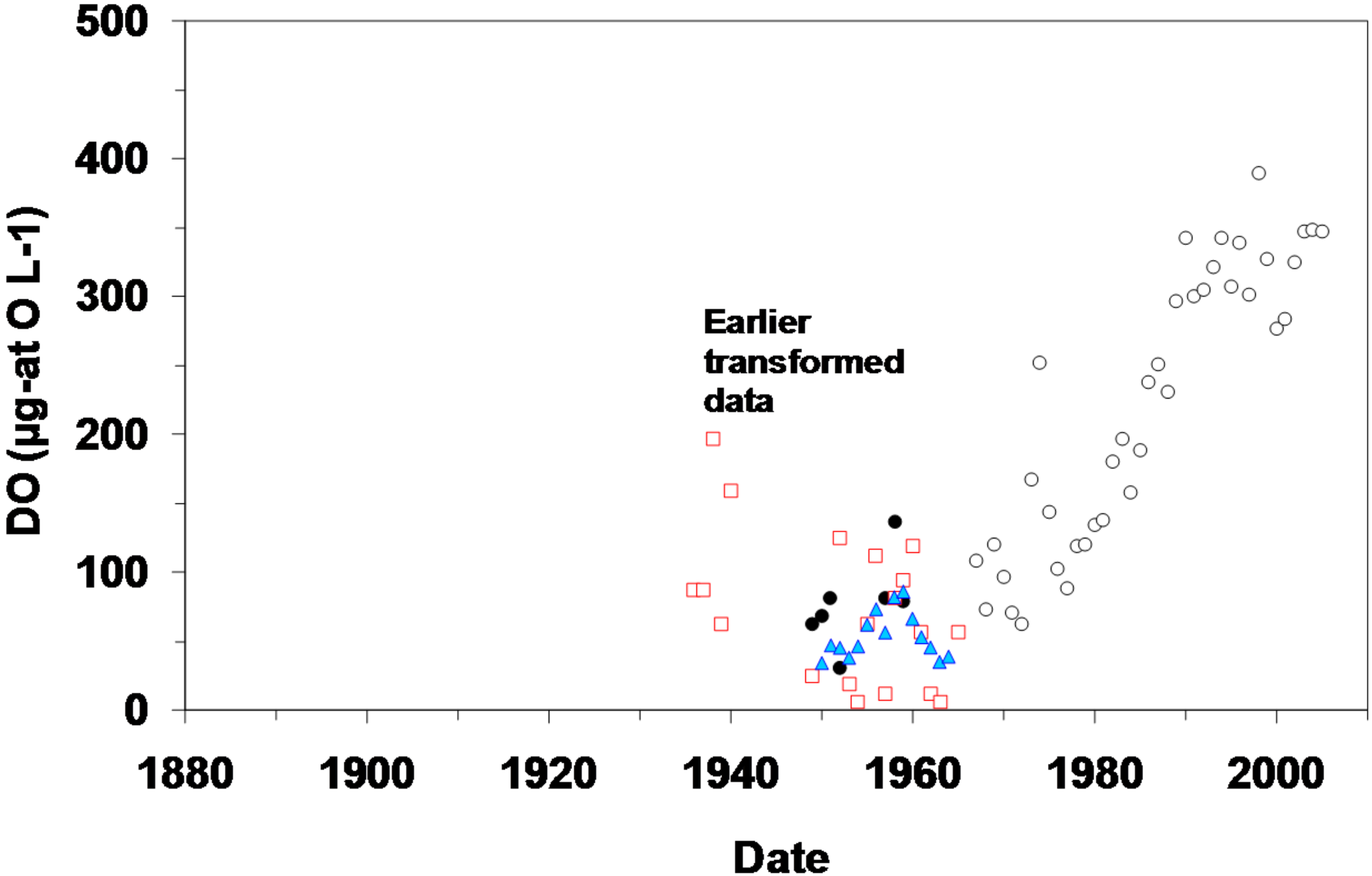
Can we look back further and look at biological impact?



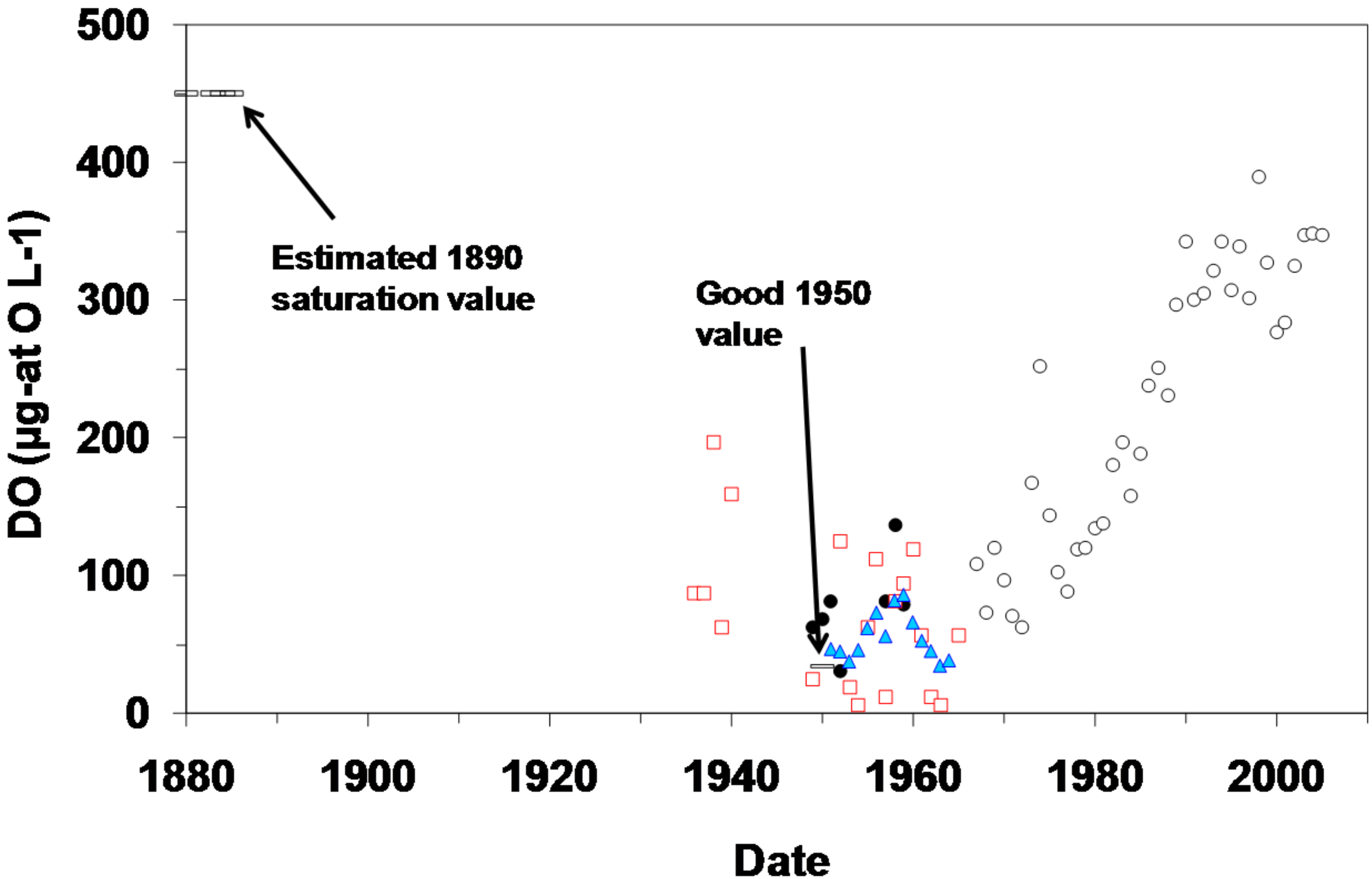
PWD data for NO_3 and NH_4 at station 7 in Delaware River from 1913 – 2005 (from N. Jaworski). Large drop in NH_4 with increase in NO_3 as seen in DRBC data at station 12 – station 7 concentrations lower than at station 12. Increase of DIN from 1913 -1985 ≈ 0.7 µg-at N L^{-1} yr^{-1}.



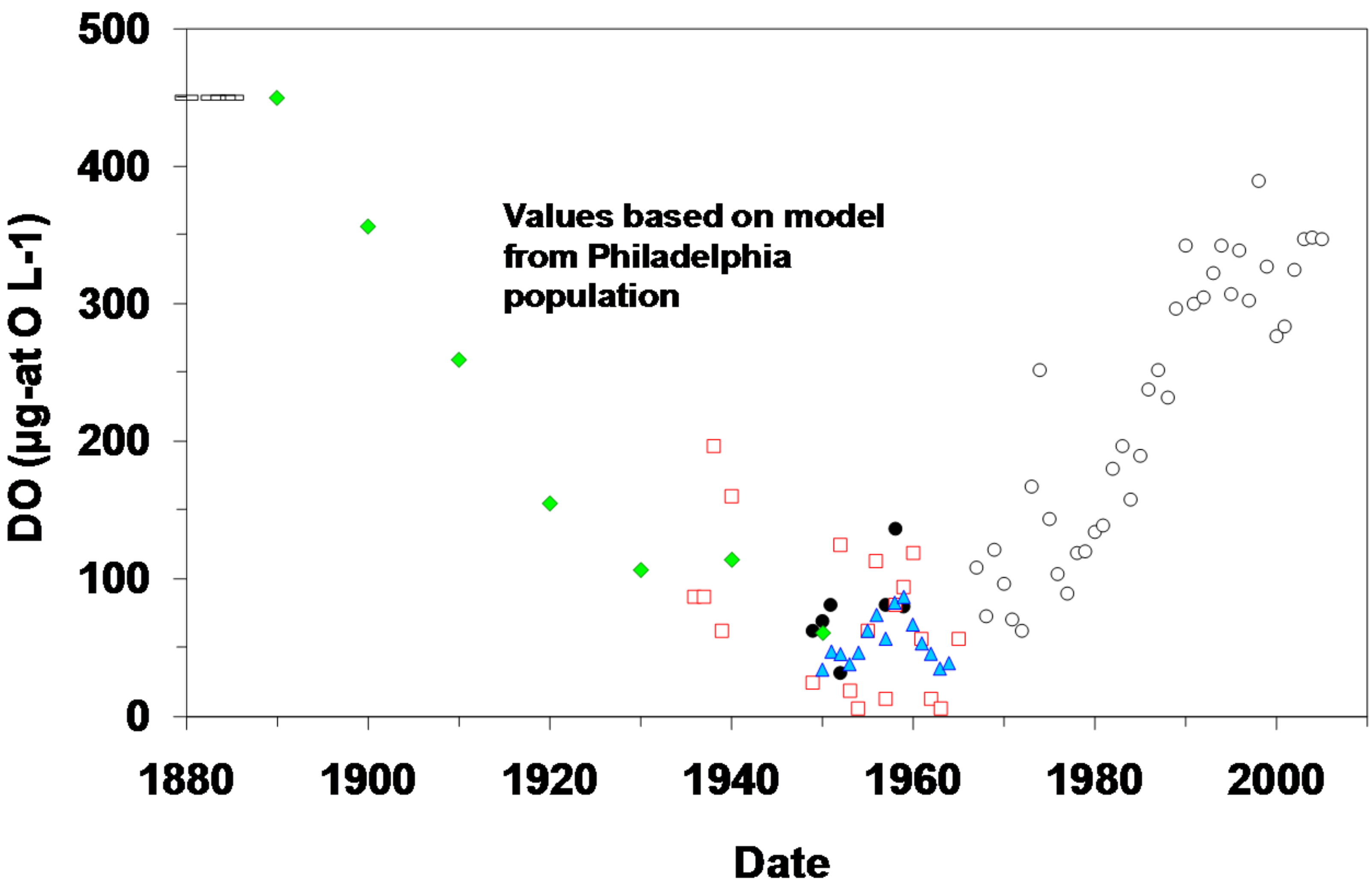
Long-time DO record for Delaware River in summer at station 12. Start with good direct DRBC data from 1967; add some direct data from precursor organization from 1950s



Data from 1930s – 60s from slightly different summer periods and from upstream in river (station 7) transformed to station 12 for July-August



Assume saturation for 1890 from shad fishery records. Regression of greater Philadelphia population vs DO for 1890 and 1950



Add population-modeled values for 1900 – 1940. Rapid drop in DO after 1910 – shad landings plummeted between 1910-1920. Sulfurous "stinkin" river during WWII

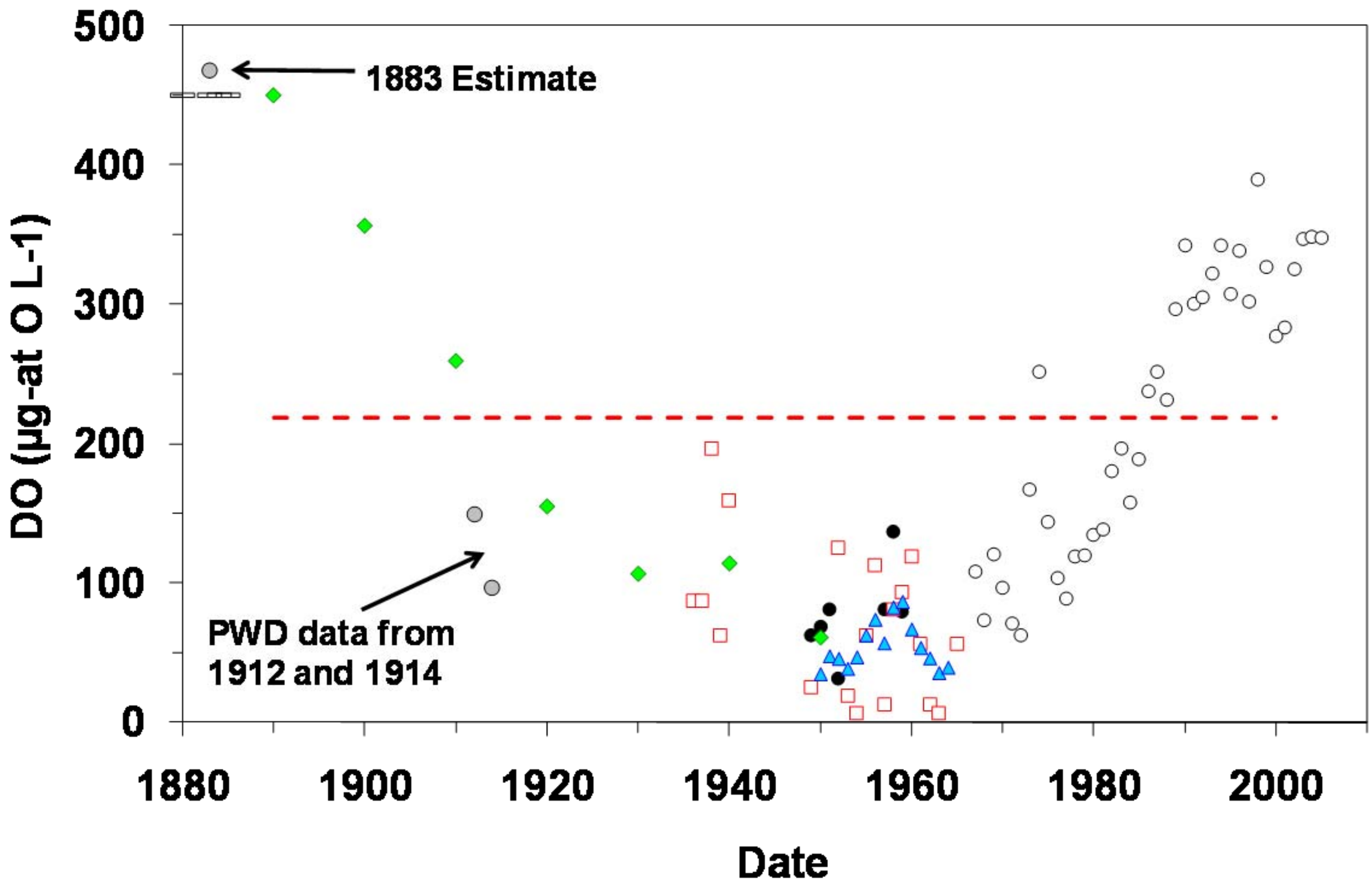
Coleridge, 1815 poem, Cologne:

“I counted two and seventy stenches,
All well defined, and several stinks!
The river Rhine, it is well known,
Doth wash your city of Cologne;
But tell me, nymphs! what power divine
Shall henceforth wash the river Rhine?”

anecdotal olfactory data

H_2S

CH_4



Data found at PWD from 1912 and 1914; thorough estimate from 1893 – pre-Winkler. Dashed red line is clean water act standard of 3.5 mg L^{-1}.

In Past Century

- **Demand from allochthonous sources drove urban river hypoxic (anoxic) in summer from about 1920-1980**

- **Nutrient buildup from moderate at beginning of record to very high at same time greater Philadelphia municipal area population grew**

- **In 1890s, oxygen demand not large, but human mortality from water-borne diseases was large until filtration of drinking water in 1920s**

- **By 1920s or 30s, high chemoautotrophic and heterotrophic activity as biological response**

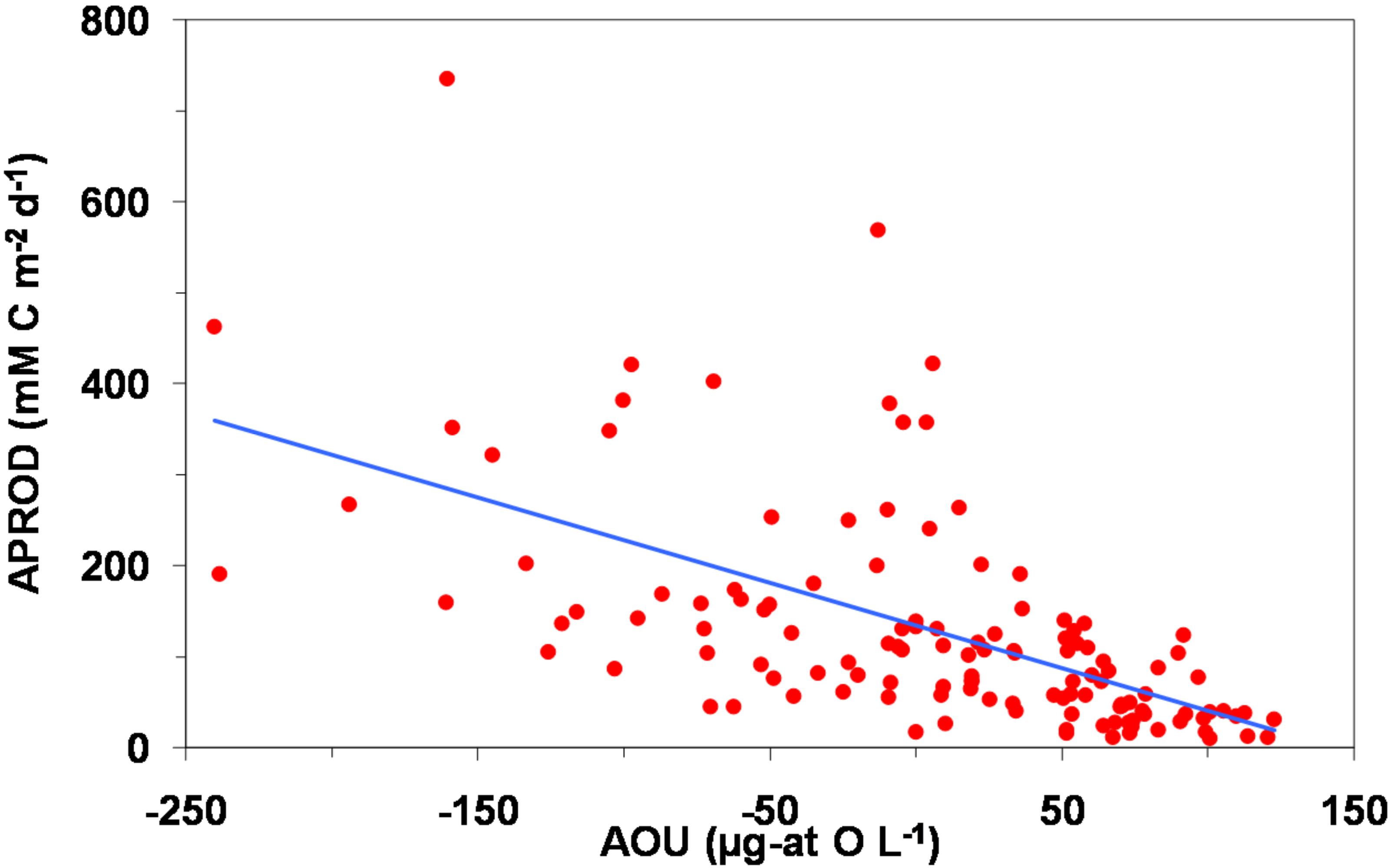
What do we know about ecosystem response in bay?

Ecosystem Response as Primary Production

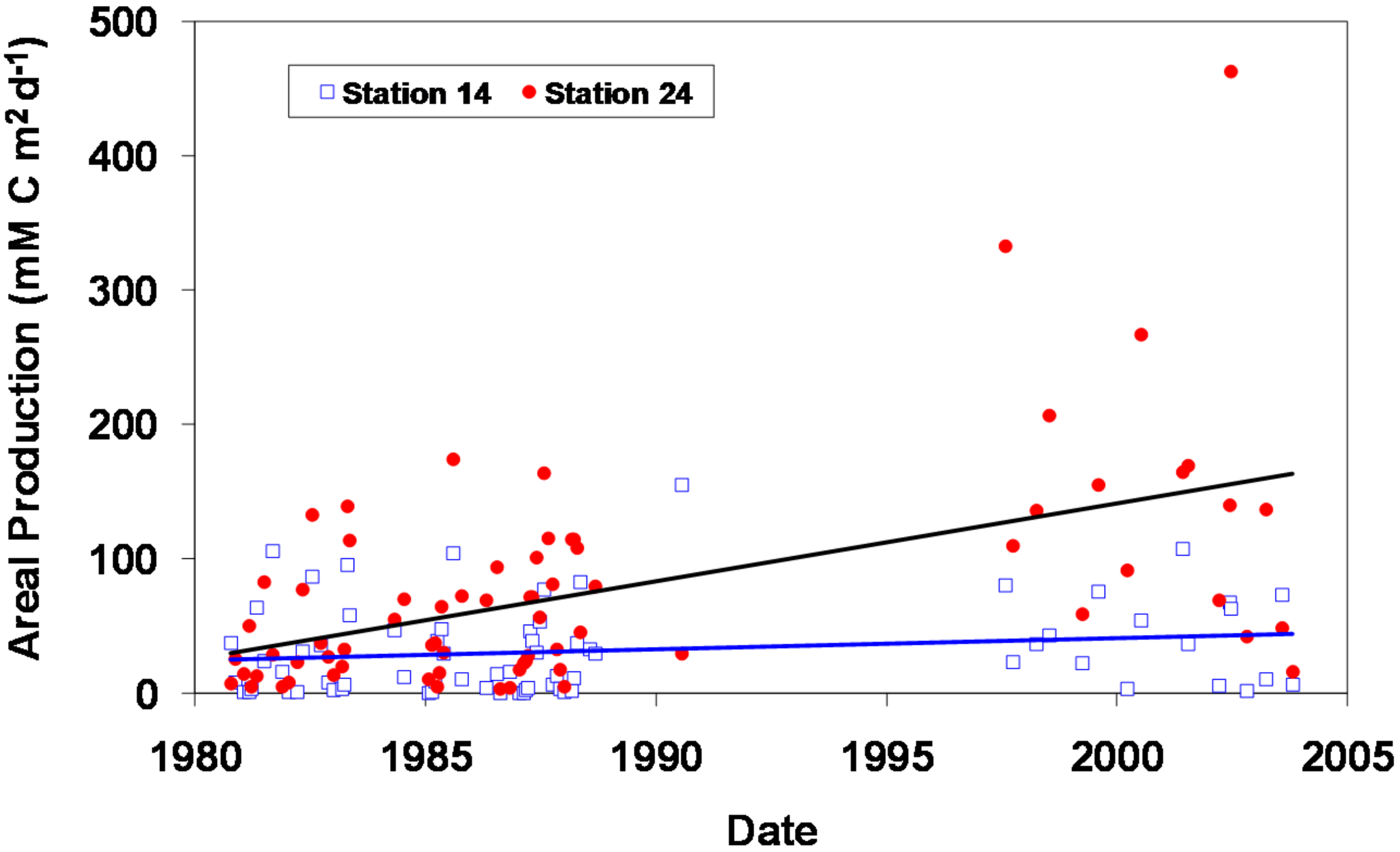
Primary production measured for past 25 years using depth-integrated ^{14}C simulated *in-situ* incubations, but only since 1980

Estimate earlier primary production using AOU model

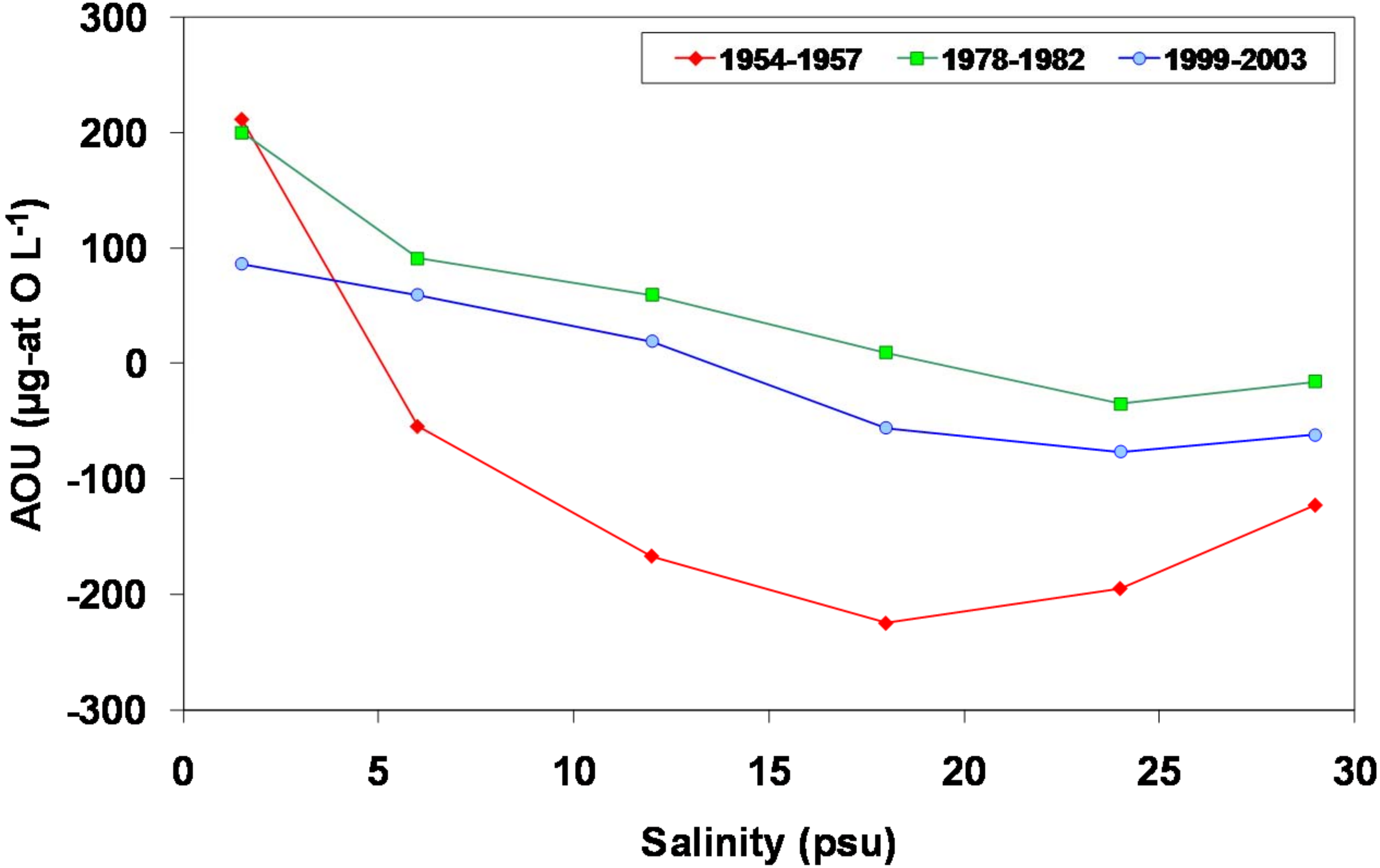
- AOU – apparent oxygen utilization
- AOU concept and stoichiometry from Redfield et al for isolated subsurface ocean waters
- Difference between measured DO and that expected from T and S – microbial DO used or produced
- Positive AOU = oxygen demand, great enough to not be offset by air-water exchange
- Negative AOU = oxygen production above exchange



Comparison of areal primary production (APROD) and AOU from measurements 1980-2003 – net oxygen use at low APROD, excess oxygen produced at high APROD



No trend in chlorophyll at river (14) or lower bay (24) stations, no trend in primary production at station 14, slight increase over time at station 24 – increased PO_4 advected to bay in recent years



High AOU at lowest salinity for 1950s and late 1970s – consistent with oxygen demand in river, lower AOU in early 2000s. More negative AOU in 2000s vs late 1970s in mid-bay, much more negative AOU in 1950s than today

Conclusions

- In 1950s, higher primary production, greater fish yields in Delaware Bay at time when nutrients were equal to or higher than today (no hypoxia in mid-bay)
- Severe hypoxia in urban river to upper bay in past was from allochthonous inputs, not excess algal production
- High nutrients in Delaware Estuary do not cause eutrophication problems due to physics of this estuary – Delaware is not unique, many well-mixed, highly flushed estuaries do not have hypoxia from autochthonous sources
- Since allochthonous hypoxia is no longer a problem and there is no secondary BOD problem, can focus on other water quality problems