Four decades of water quality change in the upper San Francisco Estuary

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Abstract

Recent methods for trend analysis have been developed that leverage the descriptive potential of long-term time series. Combined with these methods, multi-decadal datasets of water quality in coastal systems can provide valuable opportunities to gain insights into ecosystem properties and drivers of change. This study describes use of an estuarine adaptation of the Weighted Regressions on Time, Discharge, and Season (WRTDS) model to describe water quality trends over four decades in the Delta region of the San Francisco Estuary (SFE). This region is a complex mosaic of inflows that are primary sources of nutrients into the larger Bay. To date, a comprehensive evaluation of the long-term monitoring dataset at multiple stations in the Delta has not been conducted despite the importance of nutrient transport from the region for water quality in the entire bay. The WRTDS technique is data-driven where the parameterization of the functional model changes smoothly over time following dynamic patterns of season and flow. Water quality trends that have not been previously quantified can be described, including variation in flow-normalized concentrations, frequency occurrence of extreme events, and response to historical changes in the watershed, all of which are important needs for understanding changes in the SFE. Model results from multiple stations in the Delta provided novel descriptions of historical trends and relationships between key species of dissolved inorganic nitrogen (ammonium, nitrate/nitrite, total). This variation was described in the context of varying contributions of input flows from the Sacramento and San Joaquin rivers, as well as tidal exchange with the central SFE. Conceptual relationships between water quality and drivers of change were used to generate and test hypotheses of mechanistic relationships using selected examples from the trend descriptions. Overall, this analysis provides an ecological and management-based understanding of historical trends in the SFE as a means to interpret potential impacts of recent changes and expected trends in this dynamic system. An argument is also made for more comprehensive evaluations of long-term monitoring datasets to understand relationships between response endpoints and causal mechanisms in coastal waters.

1 Introduction

1. How and why are trends interpreted - assessment of raw data, surrogates, various methods (kendall, GAM, WRTDS), what have been implications of using different approaches, see Kratzer USGS report http://pubs.usgs.gov/sir/2010/5228/pdf/sir20105228.pdf and data

http://pubs.usgs.gov/sir/2010/5228/, need to interpret eutrophication trends in estuaries - it's confusing (Cloern and Jassby 2010)

2. WRTDS, original method (Hirsch et al. 2010, 2015)
3. WRTDS application to Tampa Bay as test set (Beck and Hagy III 2015), further validation in Patuxent and other tidal waters Beck et al. (2015)
4. SF estuary, unique and prominent location, full story is complex (historical context and recent changes) (Cloern and Jassby 2012), why is the delta important (a vigorous biogeochemical reactor) (Jassby and Cloern 2000, Jassby et al. 2002, Jassby 2008), no one has empirically described the data in the delta using data-intensive methods
5. Study goal and objectives
    - Provide a description of trends - annual, seasonal, spatial, response to flow, change by analytes
    - Detailed description of selected sites in the context of conceptual relationships - 1) nonlinear or extreme quantile changes, site TBD, 2) P8 and WWTP improvements, 3) Suisun DIN, SiO2, Chla, and clams
    - What this means for understanding other systems

2 Methods

2.1 Study location and data

The San Francisco Estuary (SFE)... The delta...

2.2 Analysis method and application

$$\ln(N) = \beta_0 + \beta_1 t + \beta_2 \ln(Q) + \beta_3 \sin(2\pi t) + \beta_4 \cos(2\pi t) \tag{1}$$

2.3 Case studies

2.3.1 Disaggregating observed nitrogen time series

Hypothesis: Because multiple factors influence nutrient concentrations at different times, relationships between nutrients, time, and flow/salinity are non-linear, so we expect 1) annual trend independent of seasonal trend, 2) changes in seasonal amplitudes and quantile trends over time, 3) varying flow contribution, either as difference between predicted/flow-normalized results or changes in nutrient v flow scatterplots at different annual periods.

2.3.2 Effects of wastewater treatment

Hypothesis: Modal response of nutrient concentrations at P8 over time is result of WWTP upgrades, so we expect 1) a shift in load contributions before/after upgrade, 2) a flow-normalized annual trend at P8 to show a change concurrent with WWTP upgrades, and 3) shift in the flow/nutrient relatinship before and after upgrade related to change in load contributions.

2.3.3 Effects of biological invasions

Hypothesis: Biological invasions by benthic filter feeders have shifted abundance and composition of phytoplankton communities in Suisun Bay, so we expect 1) decline in annual, flow-normalized chlorophyll concentrations over time coincident with increase in abundance of invaders, 2) changes in stoichiometric ratios of limiting nutrients (nitrogen, SiO2) suggesting different uptake rates with shift in community composition, and 3) seasonal shifts in limiting nutrients based on changes in community composition and relative abundances with seasonal succession.

3 Results

3.1 Trends

3.2 Selected examples

3.2.1 Clam invasion in Suisun Bay

Data from (Crauder et al. 2016), Jassby (2008) describes phytoplankton community changes in the upper estuary, including chlorophyll response to flow. Figure 10 in Jassby (2008) showed that chlorophyll generally decreased with flow in 1980 but inreased with flow in 2000. Fig. 2, Table 1

4 Discussion

References

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$$\ln(DIN) = \beta_0 + \beta_1 t + \beta_2 \ln(Q) + \beta_3 \sin(2\pi t) + \beta_4 \cos(2\pi t) + \varepsilon$$

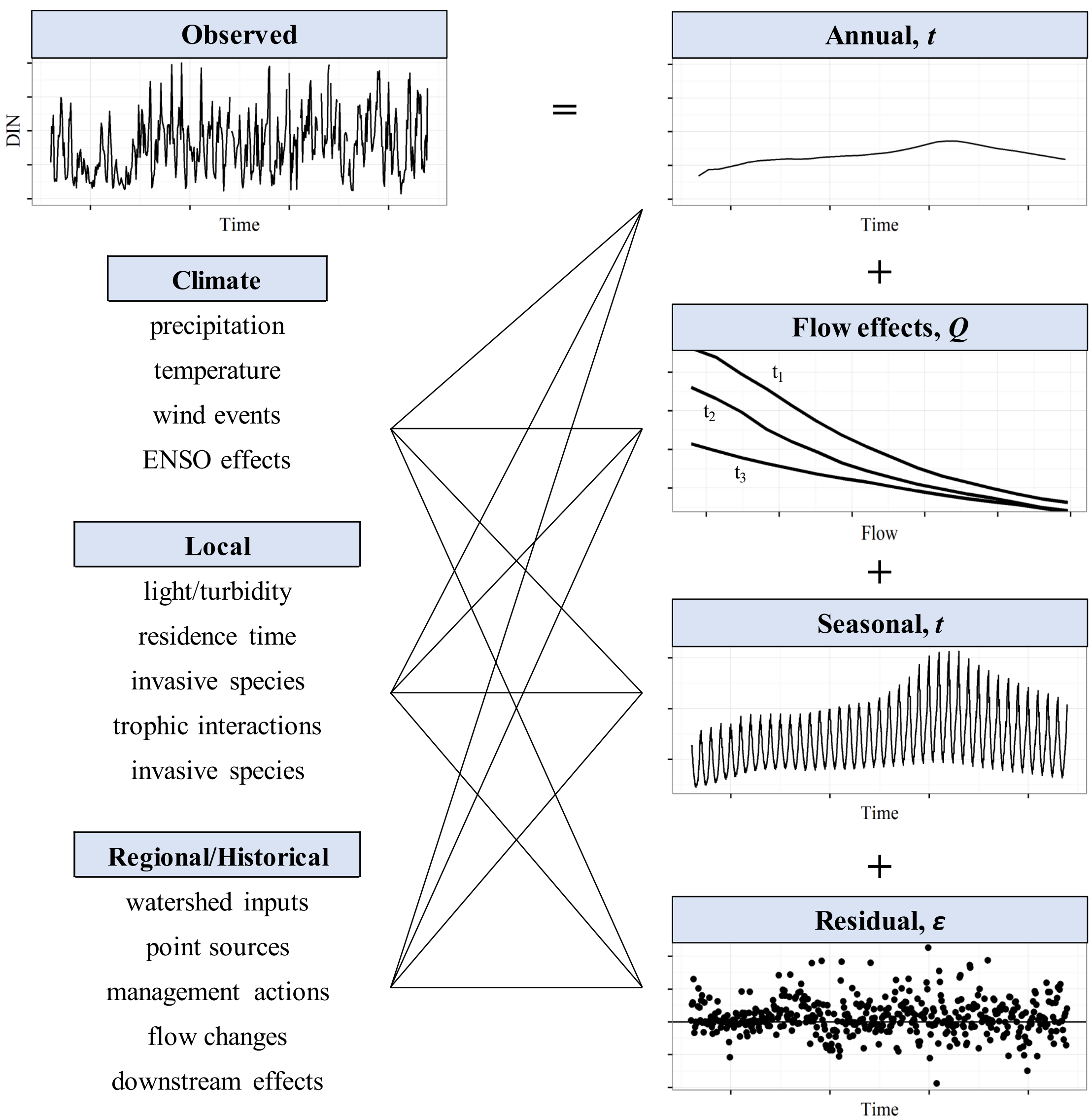

Fig. 1: Conceptual diagram illustrating use of WRTDS to decompose trends in observed nitrogen time series and potential forcing factors that can explain model output. Results from the model are described as annual and seasonal trends, changes in flow-nutrient dynamics for different time periods, and residual variation independent of time, flow, and season. Relationships between environmental factors (climate, local, regional/historical) and nitrogen trends are more easily related to the separate components of the observed time series using results from the model.

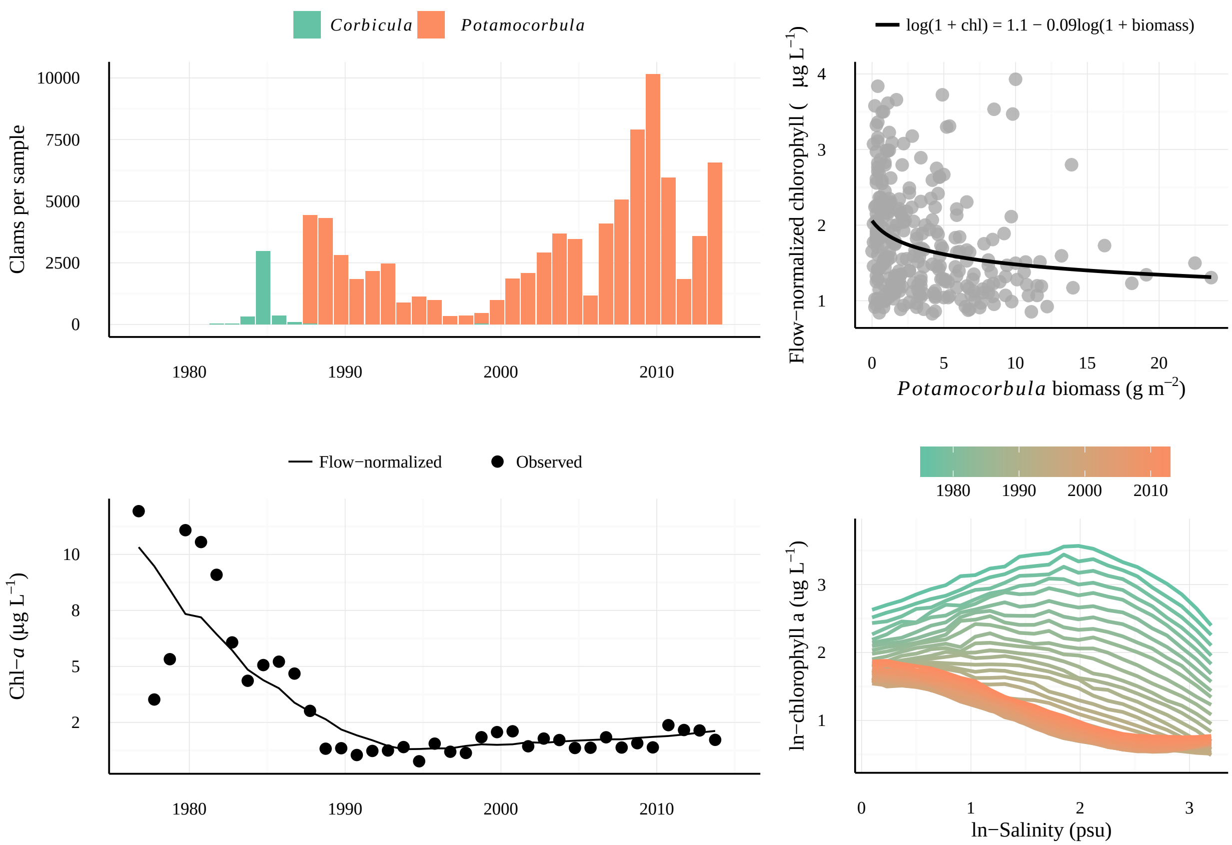

Fig. 2: Trends in clam abundance and chl-*a* concentration from 1976 to 2014 at station D7 in Suisun Bay. Invasion by *Potamocorbula amurensis* clams in the late 1980s and displacement of *Corbicula fluminea* was shown by changes in clam density (top left, annual means). A coincident decrease in chl-*a* concentration was also observed (bottom left). A weak but significant ($p < 0.001$) relationship between clam biomass and chl-*a* concentration is shown in the top right. Flow relationships with chl-*a* concentration have also changed over time (bottom right, observations from June). Chlorophyll shows a slight positive then dominantly negative association with increasing flow (decreasing salinity) early in the time series, whereas the trend is reversed in recent years.

Table 1: Summaries of flow-normalized trends in chlorophyll and silicon dioxide concentrations for different time periods. Summaries are means and percent changes based on annual means within the time periods. Increasing values are in bold-italics.

Period	**Chl-*a***		**SiO_2**	
	Mean	% change	Mean	% change
All				
1976-2013	3.5	-80.1	12.5	***33.6***
Annual				
1976-1985	7.8	-62.3	10.5	***8.9***
1986-1994	2.2	-62.1	12.4	***15.6***
1995-2003	1.6	***20.2***	13.7	***4.5***
2004-2013	2	***31.3***	13.6	-2
Seasonal				
JFM	1.9	-43.2	14.8	***7.3***
AMJ	4.3	-72.8	12.9	***25.7***
JAS	4.8	-88.4	11.1	***70.8***
OND	2.1	-79.4	11.7	***41.7***