Four Decades of Water Quality Changes in the Upper San Francisco Estuary

Marcus W. Beck[1], David Senn[2], Emily Novick[2], Phil Bresnahan[2], James D. Hagy III[1], Thomas Jabusch[2]

[1]US Environmental Protection Agency ORD NHEERL, Gulf Ecology Division, Gulf Breeze, FL

[2]San Francisco Estuary Institute, Richmond, CA

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 the San Francisco Estuary (SFE) could provide a valuable opportunity to gain insight into ecosystem properties and drivers of change in estuaries. This study explores the use of an estuarine adaptation of the Weighted Regression on Time, Discharge, and Season (WRTDS) approach to describe nutrient trends in the northern region of SFE (Suisun Bay and the Delta), a primary source of nutrients into the system. This novel technique is data-driven where the parameterization of the functional model changes smoothly over time following dynamic patterns of season and flow. By doing so, changes over time 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 trends in the northern SFE. The goal of the analysis is to apply the WRTDS model at multiple stations in the Delta and Suisun Bay regions of SFE to describe variation over time and relationships between key species of dissolved inorganic nitrogen (ammonium, nitrate/nitrite, total). This variation is considered 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. Overall, this analysis is expected to further an ecological and management-based understanding of dynamics in SFE, with implications for water quality restoration and protection of this prominent system.

Analysis Components

- Weighted Regressions on Time, Discharge, and Season (WRTDS) were applied to nine stations in the upper SFE
- Models were developed for three nitrogen analytes: dissolved inorganic nitrogen (DIN), nitrite/nitrate, and ammonium
- Trends were evaluated by monthly and annual periods using flow-normalized predictions from WRTDS

Water Quality and Flow Data

- Data from 1976 to 2012 for nine nutrient stations and daily flow estimates from major inflows were modelled

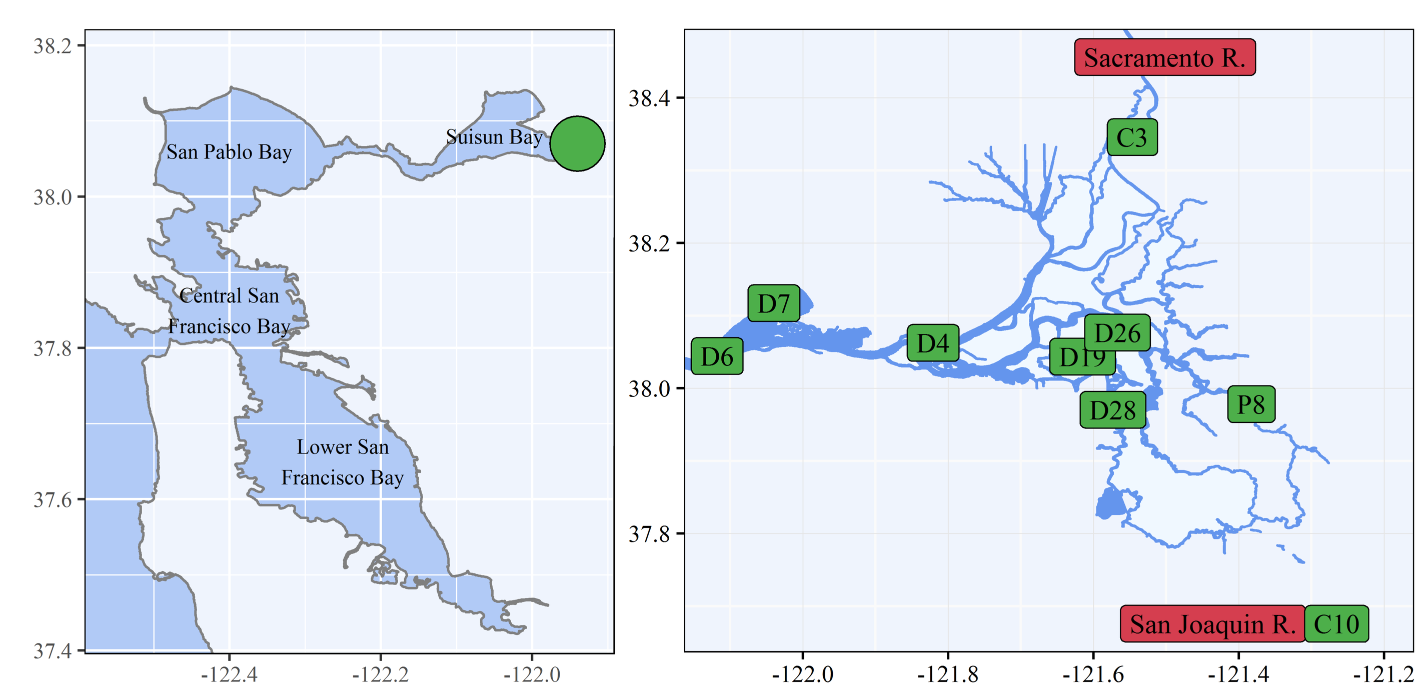


Figure : Locations of bimonthly nutrient (green) and daily flow (red) stations in upper SFE.

Applying Weighted Regression on Time, Discharge, and Season (WRTDS)

WRTDS models were applied to nutrient observations in relation to time, discharge, and season

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

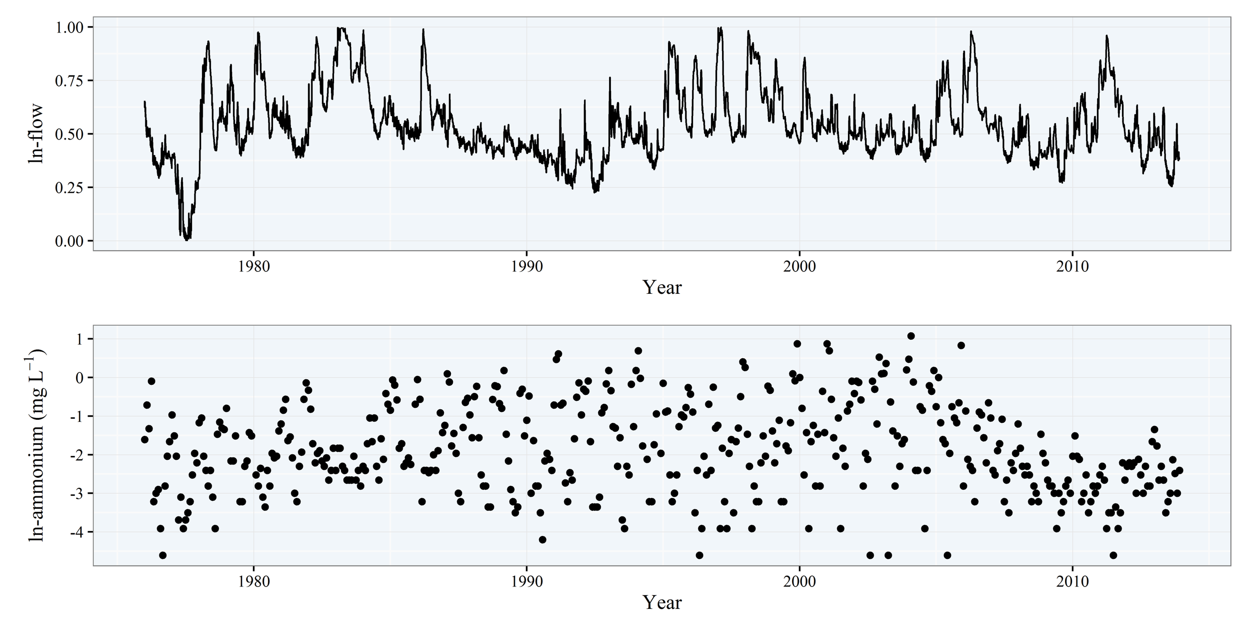


Figure : Example of raw flow and nitrogen data at P8 used with WRTDS. The model was fit to matched flow and nutrient data at a bimonthly time step and then results were predicted at a daily time step.

WRTDS output showed seasonal variation, response to flow changes, and different conditional quantile distributions of nutrients

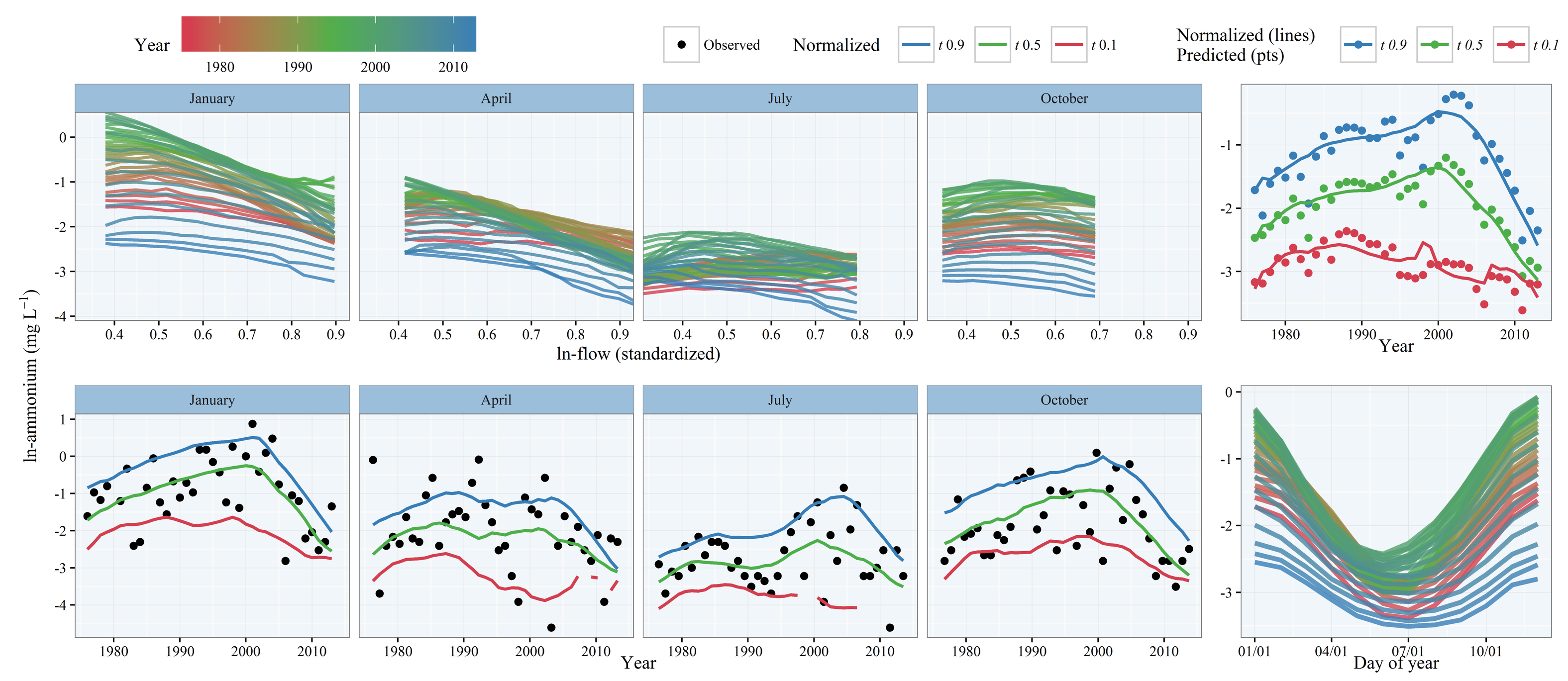


Figure : Examples of model results at P8 showing monthly and annual response to flow changes (top left), monthly quantile (τ) distributions of flow-normalized predictions (bottom left), quantile distributions of annual trends (top right), and annual changes in seasonal variation (bottom right).

Trend Analyses with WRTDS Results

Results for nine delta stations and three nitrogen analytes were used to evaluate annual and monthly trends over time and space

Table : Percent changes in DIN by years/months.

Site	1976-1988	1989-2000	2001-2012	JFMA	MJJA	SOND
C10	***28.3***	***17.4***	-41.7	-25.7	-10.1	***1.7***
C3	***23.9***	***26.8***	-13.9	***30.7***	***54.8***	***42.8***
D19	-19.8	***3.3***	-15.3	-28.6	-35.1	-15.6
D26	-5.2	***10.9***	-19.4	-10.9	-3.4	-2.6
D28	-21.7	***3.9***	-37.3	-32.9	-53.3	-48.8
D4	-10.9	***20.3***	-7.1	***11.4***	***4.8***	***10.7***
D6	-7.4	***21.6***	-8.5	-4.7	***45.6***	***34.7***
D7	-24.2	***17***	-6.1	-6.9	***19***	***21.4***
P8	***49.9***	***38.4***	-35.7	***31.6***	***52.8***	***45.4***

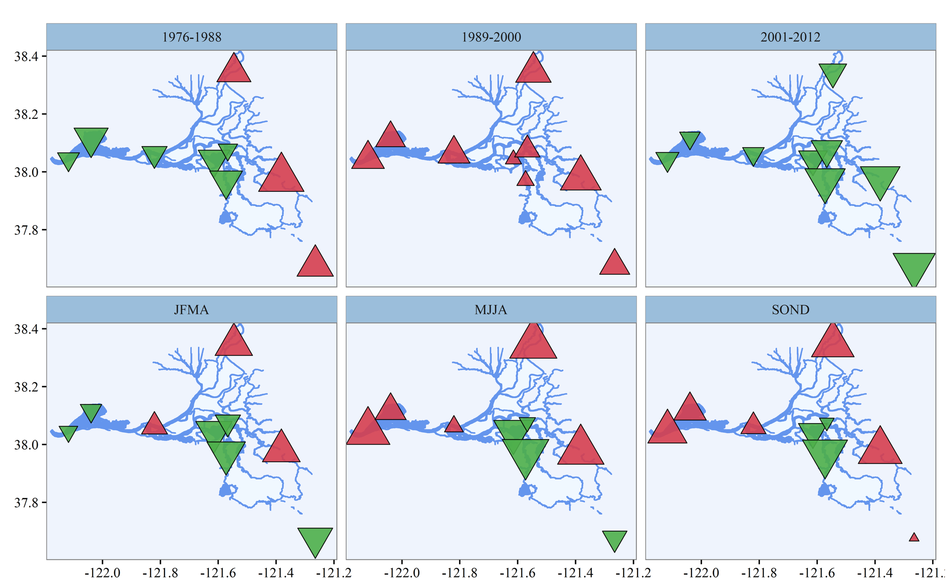


Table : Percent changes in ammonium by years/months.

Site	1976-1988	1989-2000	2001-2012	JFMA	MJJA	SOND
C10	-39	-59	-44.5	-78	-95.8	-91.7
C3	***53.6***	***41.6***	-18.1	***81.8***	***95.8***	***74.6***
D19	***8.8***	-5.6	-7.5	-16	-21.8	-4.8
D26	***22.8***	***8.4***	-20.9	-0.9	***7.9***	***18.7***
D28	-10.7	-17.7	-18.2	-42.3	-24.7	-34.7
D4	***5.3***	***46.8***	-5.1	***66.9***	***33.6***	***68.3***
D6	***11.8***	***33***	-9.7	***36***	***56.4***	***45.3***
D7	-20.8	***25.2***	-11.6	***21.2***	-16	***34***
P8	***143.1***	***46.7***	-86.5	-52.7	-23.9	-61.1

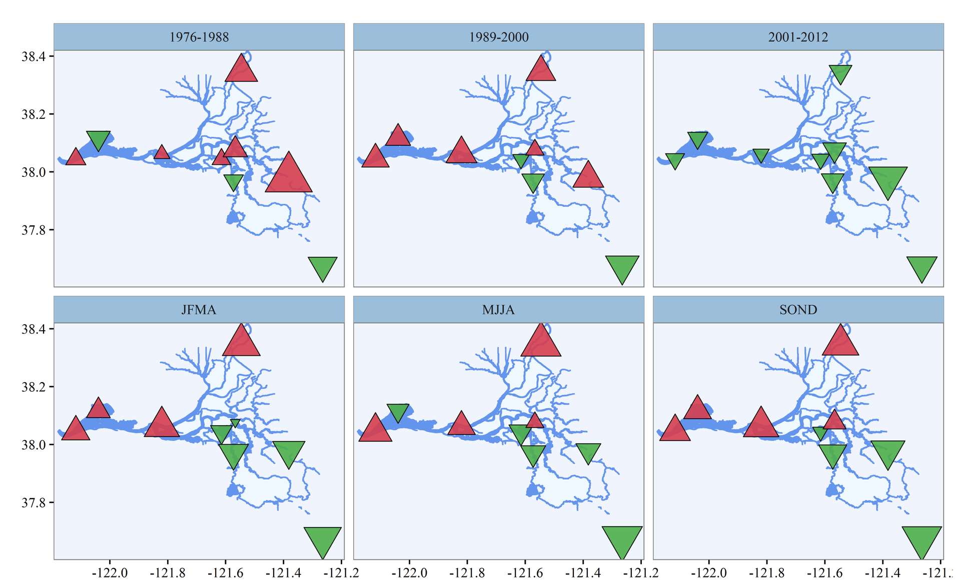
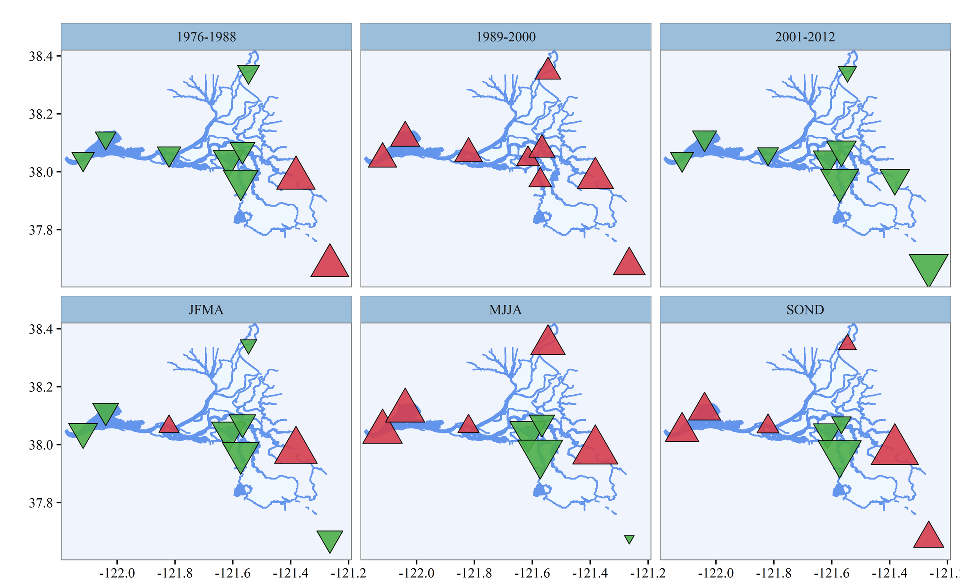


Table : Percent changes in nitrite/nitrate by years/months.

Site	1976-1988	1989-2000	2001-2012	JFMA	MJJA	SOND
C10	***38.7***	***23.7***	-40.8	-12.5	-0.2	***20.4***
C3	-7.2	***11.9***	-3.6	-2.3	***29.4***	***3.3***
D19	-21.8	***8.7***	-16.5	-28.6	-34	-16.3
D26	-11	***12.9***	-18.9	-13.4	-11.8	-4.7
D28	-30.2	***7.9***	-39.1	-34.5	-59.1	-53.8
D4	-9.2	***15.9***	-6.0	***5.4***	***6.6***	***7.3***
D6	-7.8	***16.7***	-8.8	-17.9	***42.6***	***27.6***
D7	-6	***18***	-9.9	-12.7	***41.9***	***24.4***
P8	***39.1***	***33.9***	-18.8	***52.2***	***60.6***	***67.3***



Evaluation of Additional Indicators

Covariation among indicators can provide mechanistic clues

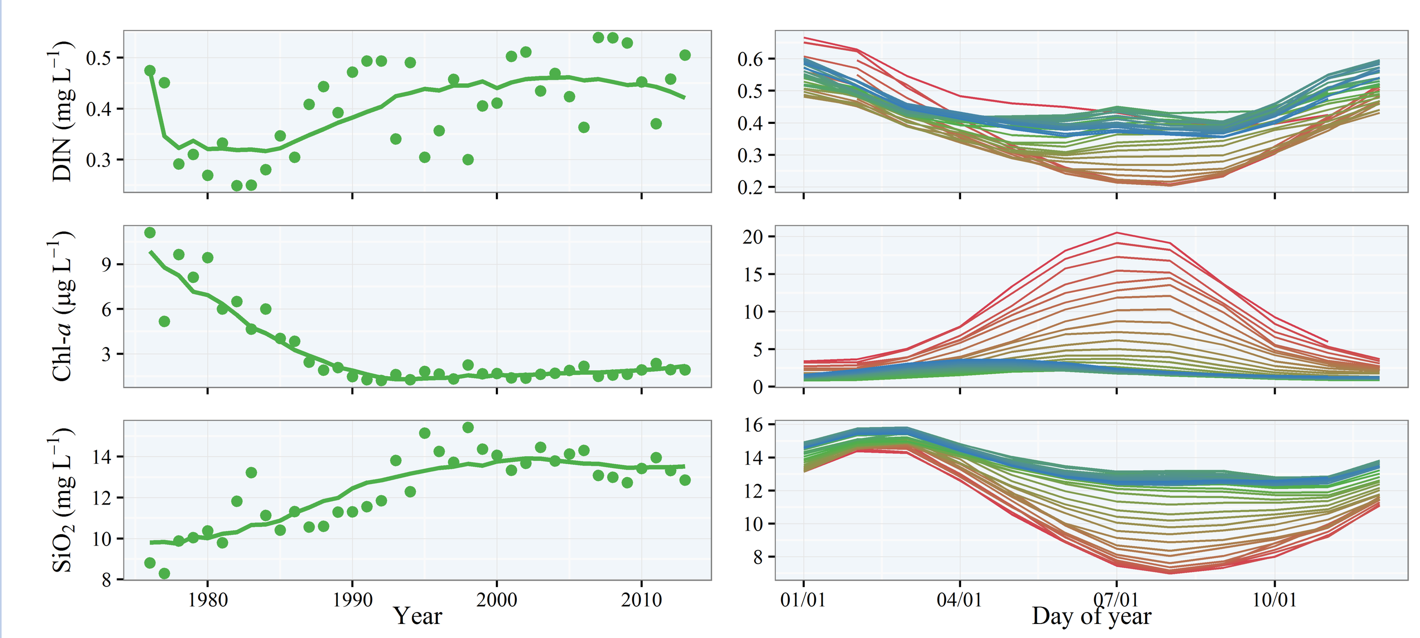


Figure : Flow-normalized trends of annual (left) and seasonal (right) variation in DIN, Chl-*a*, and SiO_2 at D7. RGB colors indicate a unique year from 1976 to 2012 (see above).

Conclusions

- WRTDS analyses on four decades of nutrient data revealed undescribed spatiotemporal variation, e.g., large, nonmonotonic changes in NH^{4+} at P8
- Trends among stations differed dramatically among different quantiles, long term change was more dynamic in the upper quantiles
- Long-term changes were observed in seasonal NH^{4+} distributions, eg., concentration reductions during winter

We acknowledge the significant efforts of the California Department of Water Resources Environmental Monitoring Program in providing access to data.

Interactive data app of full results: https://beckmw.shinyapps.io/sf_trends/

WRTDStidal R package: https://github.com/fawda123/WRTDStidal

USEPA ORD NHEERL - Gulf Ecology Division - Gulf Breeze, FL

Mail: beck.marcus@epa.gov

WWW: http://fawda123.github.io/sf_trends/README