Changes in Puget Sound from Ecology’s long-term marine water quality monitoring program

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- Ecological systems show variability on different spatial, temporal and organizational scales. (Levin 2003: The Problem of patterns and scale in Ecology)

C. Maloy, C. Krembs, J. Bos, S. Albertson, S. Pool, M. Keyzers, A. Brownlee
Status and trends in water quality indicators
(collected monthly at 27 stations and compared to baselines)
“We work a lot in anomaly space”

Greater Puget Sound region

Water Quality variables at 27 stations

Physical variables
- Temperature
- Salinity
- Density

Chemical variables
- Oxygen
- Nitrate
- Silicate
- Phosphate
- Ammonium
- Nutrient ratios
- pH

Bio-optical variables
- Water clarity
- Chlorophyll a
- Euphotic depth
Are improving indicators a result of changes in...
- Physical processes?
- Ecosystems processes?
- Human success?

**Anomalies**
- Change from baseline
- Seasonal and geographical variation removed
- Annual anomalies averaged over all stations

➢ The **oxygen deficit**, amount of dissolved oxygen needed to go from below to a 100% O₂ sat. (>20m)
The timing of processes will be affected by future climate.

Changes to snowpack and river flows

Rivers flow, water residence time is low

Dilutes human pollutants

Weather and Ocean Patterns

Productive foodweb

Carbon pump

Upwelling

cold water natural nutrients

Estuaries and Bays

Basins

Ocean

90%
7%
3%

Ocean
Total human
Rivers

Drawn by: Christopher Krembs
Summer droughts increase the human burden on water quality

- Rivers are dry, water residence time is high
- Magnifies human pollutants

Changes to snowpack and river flows

Drawn by: Christopher Krembs
Recent years gave us an insight into projected climate scenarios. Historically peaks of coastal upwelling and the freshet are in sync.

**The Fraser river (Hope)**

Discharge ($m^3\cdot s^{-1}$)

- **higher**
- **lower**

WA drought

BC drought

Source: Climate Change Impacts in the United States, 2014
Yearly variation in nitrate 0-50m

- Only the ocean is bringing salt into Puget Sound
- We can calculate out nitrogen from ocean to get at “human” nitrogen sources
Eutrophication indicator for nutrients, ratios...

**Silicate: DIN** *(dissolved inorganic nitrogen)*

- **Si:DIN** is a eutrophication indicator
- Nutrient balance can change the base of the food web fostering nuisance species
- Organic particle export can change

![Graph showing anomalies in Silicate and DIN](image)

**Near-bottom: surface Chl a**

- Spearman Rank Correl. $p < 0.05$, $\rho = 0.6$

![Graph showing anomalies in near-bottom Chl a](image)
Undesirable species that tend to float
(qualitative observations, Eyes Over Puget Sound)

Noctiluca

Credit: Jim Devereaux

Jellyfish

Dinoflagellates

Macro-algae
Percent significant change since 1999

(Spearman Rank Correl., n=17 years, 10% sign level)

- Non-oceanic nitrate
- Non-oceanic phosphate
- Ratio silicate : nitrogen (DIN)
- Ammonium
- Chlorophyll a
- Near-bottom : surface Chl a (%)
In summer, the relative contributions of WWTPs are highest, and sluggish water exchange can further increase pollutants.

Source: Mohamedali et al., 2011a.
Summary

• The relative timing of Fraser river and upwelling matters for Salish Sea water quality. **Land-Ocean-Climate Connection.**

• The ocean drives nitrogen. When the ocean is removed, nitrate is still increasing.

• In summer **eutrophication indicators are prevalent: nuisance species, nutrient ratios...**

• Export production during summer appears to change towards a more regenerative microbial food web (**big data gap**).

• **Humans** could have an increasing impact on WQ during summers.
It is time to revisit and rethink what is going on in Puget Sound...

Correlation does not prove causation
Hypothesis: Changes in the lower food web

“Supporting science varies in strength. See last slide for details on each topic”.

**HS-1:** Climate change has the effect of magnifying human nutrient contribution to Puget Sound and shifts the food web in the summer months.

**HS-2:** Changes in the nutrient balance affect the growth conditions of the lower levels of the marine food web.

**HS-3:** In summer, the microbial food web has gained importance relative to the productive, diatom-based food chain.

**HS-4:** The organic particle export to deeper water changed in response to shifts in the lower-trophic levels of the food web.
## Strength of Science supporting hypothesis

### Hypothesis:

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Data volume</th>
<th>Data Strength</th>
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</thead>
<tbody>
<tr>
<td><strong>HS-1:</strong> Climate change has the effect of magnifying human nutrient contribution to Puget Sound and shifts the food web in the summer months.</td>
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<tr>
<td>Summer river flow trends and predictions</td>
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<td>Water residence time and ocean connection</td>
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<td>Ocean, river and WWTP nitrogen loadings</td>
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<td>Eutrophication indicator for nutrients (Si:DIN ratio)</td>
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<td><strong>HS-2:</strong> Changes in the nutrient balance affect the growth conditions of the lower levels of the marine food web.</td>
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<td>Nutrient trends (nitrate, ammonium) and trends in nutrient balance</td>
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<td>Phytoplankton biomass trends, and silicate limitation on phytoplankton</td>
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<td>Macro-algae floating and washing up on beaches</td>
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<td><strong>HS-3:</strong> In summer, the microbial food web has gained importance relative to the productive, diatom-based food chain.</td>
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<td>Aerial observation on timing and scale of microbial food web (Noctiluca,)</td>
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<tr>
<td>Phytoplankton decrease coinciding with Noctiluca bloom and ammonium</td>
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<td>Historical newspaper record on Noctiluca</td>
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<td><strong>HS-4:</strong> The organic particle export to deeper water changed in response to shifts in the lower-trophic levels of the food web.</td>
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<td>Microfossil profiles in sediment cores</td>
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<td>Decreasing benthic-pelagic coupling</td>
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<td>Decreasing benthic species</td>
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<td>Increasing water clarity and decrease in silt fraction in sediment</td>
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<td>PCR accumulation via pelagic food web</td>
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The Silicate to Chl a Relationship

Addition information

Silicate : Chl a ratio seasonal climatology

Silicate : Chl a trend 0-30m

Spearman Rank Correl. $p<0.05$, $\rho=0.7$