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*)

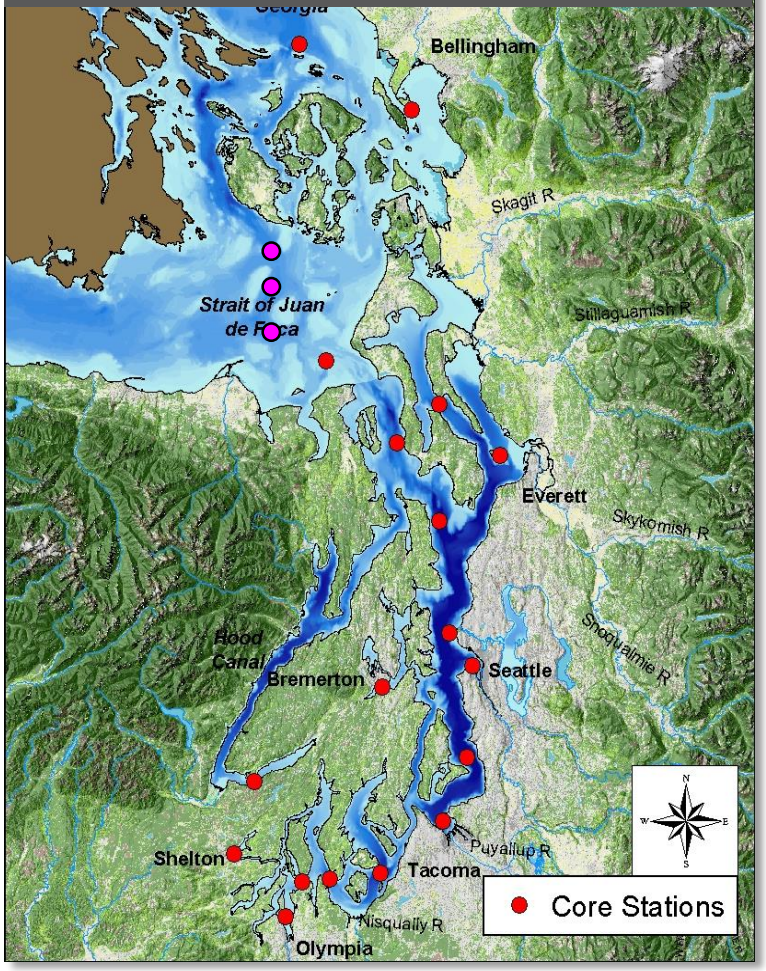
C. Maloy, C. Krembs, J. Bos, S. Albertson, S. Pool, M. Keyzers, A. Brownlee

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

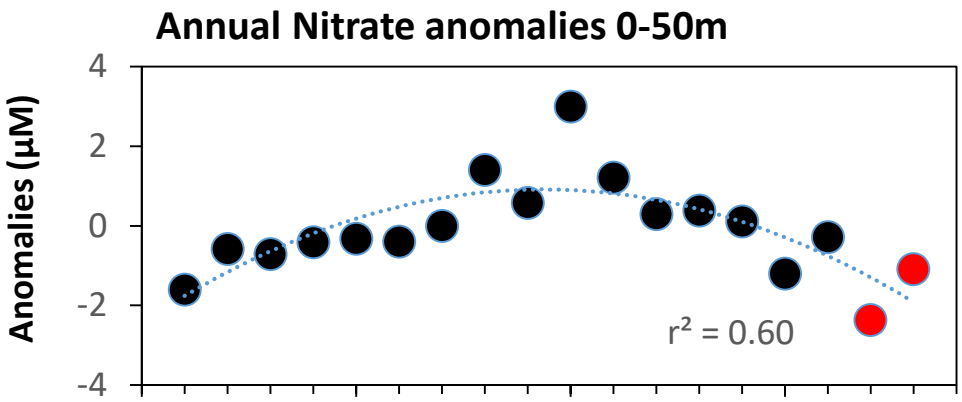
Are improving indicators a result of changes in…

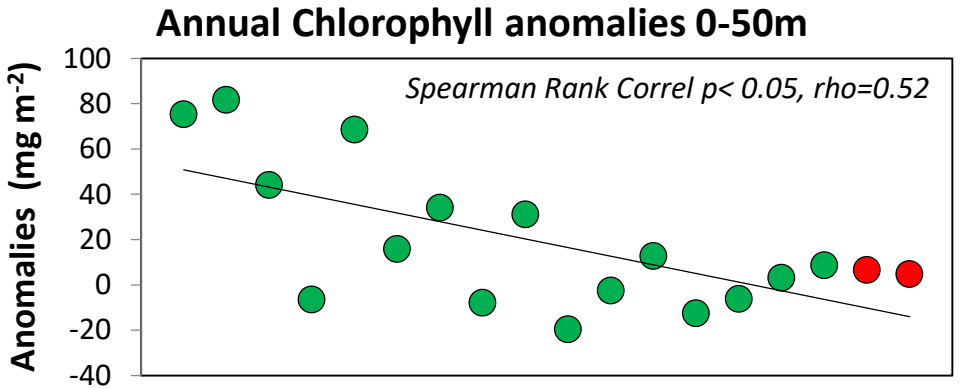
- Physical processes?
- Ecosystems processes?
- Human success?

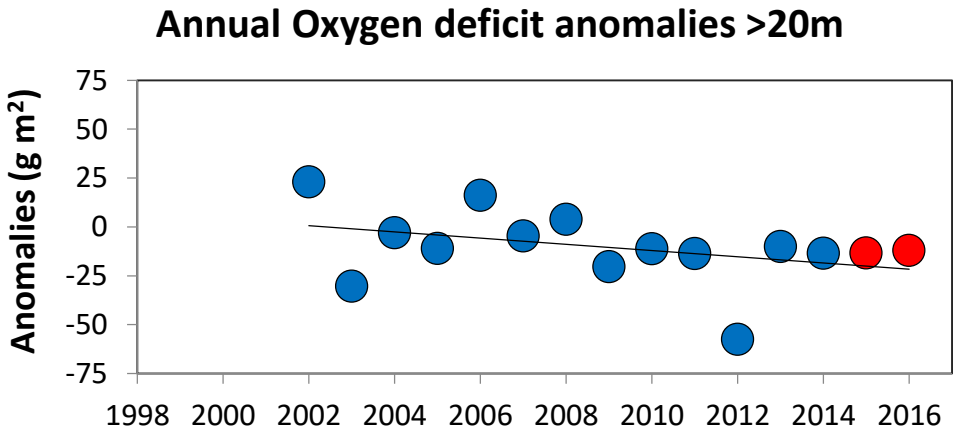
Anomalies

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

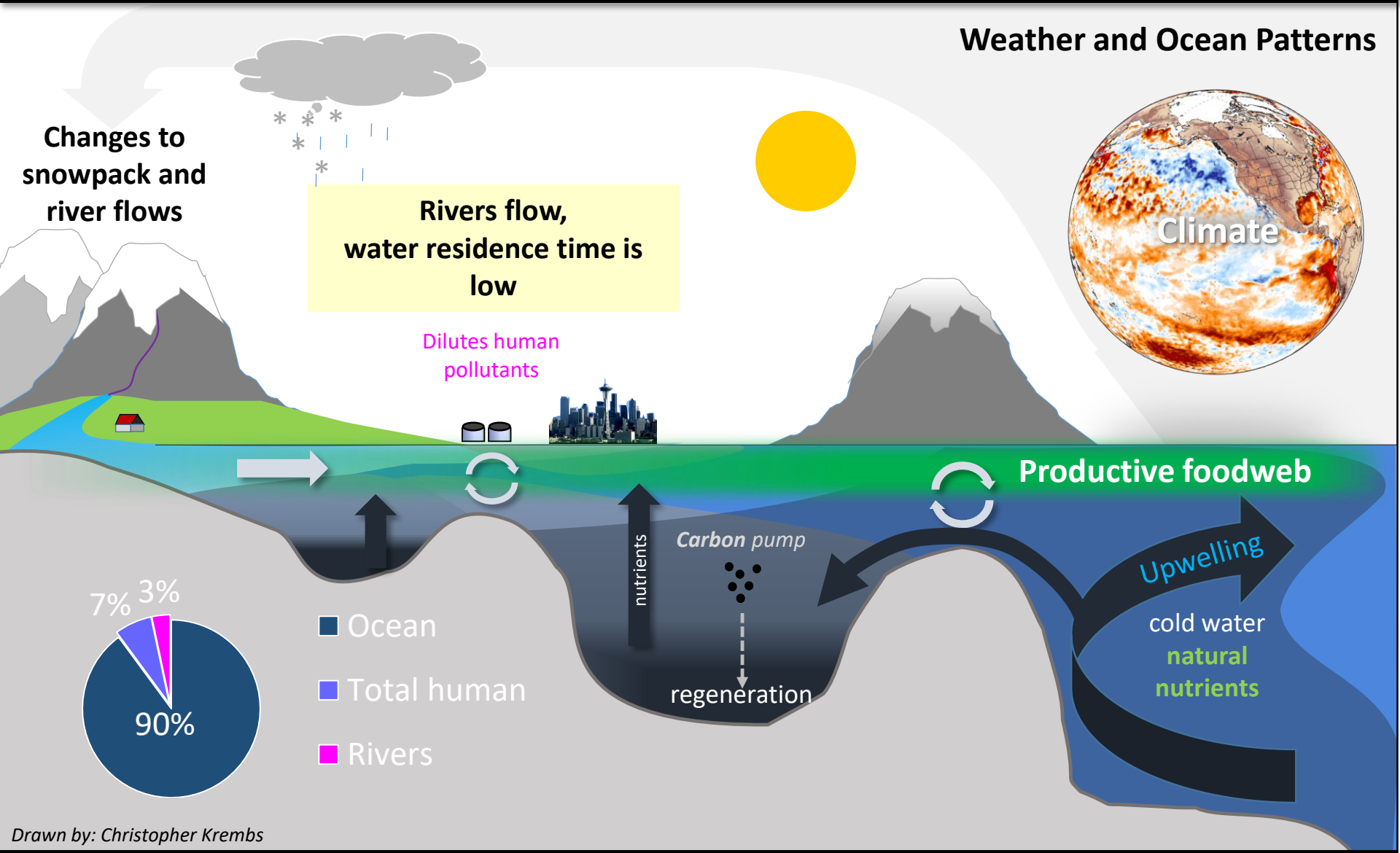
➢ The **oxygen deficit,** amount of dissolved oxygen needed to go from below to a 100% O_2 sat. (>20m)



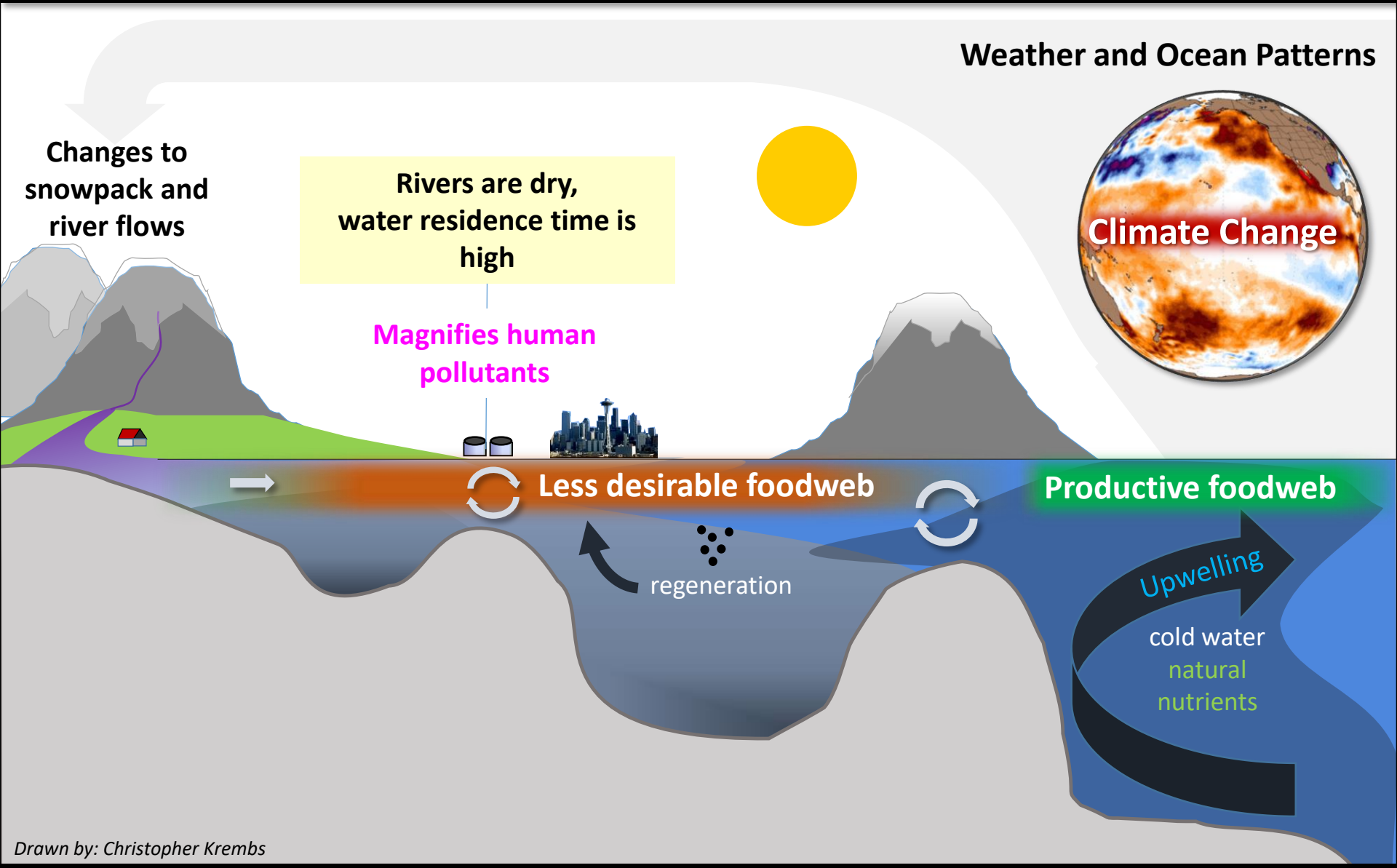




The timing of processes will be affected by future climate



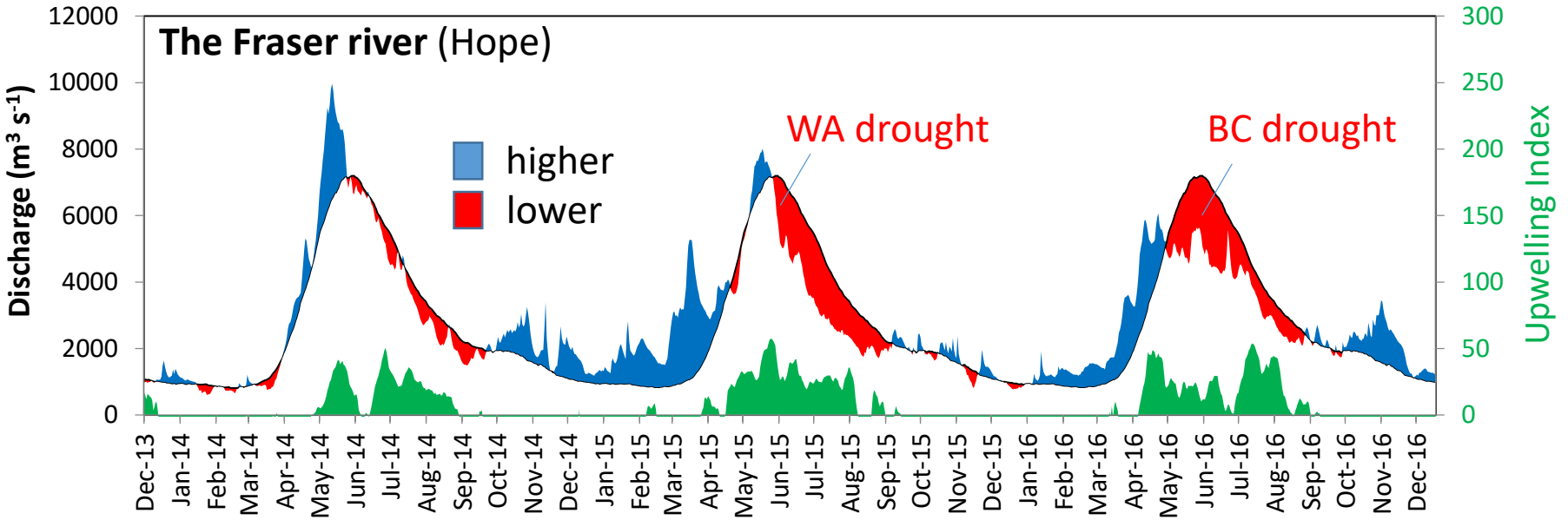
Summer droughts increase the human burden on water quality



Estuaries and Bays | Basins | Ocean

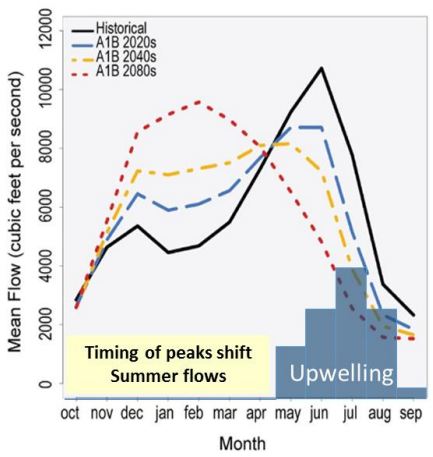
Recent years gave us an insight into projected climate scenarios

Historically peaks of coastal upwelling and the freshet are in sync

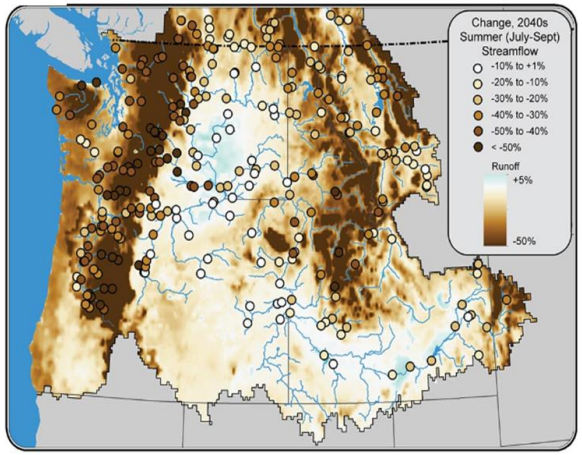


Source:
Climate Change Impacts in the United States, 2014

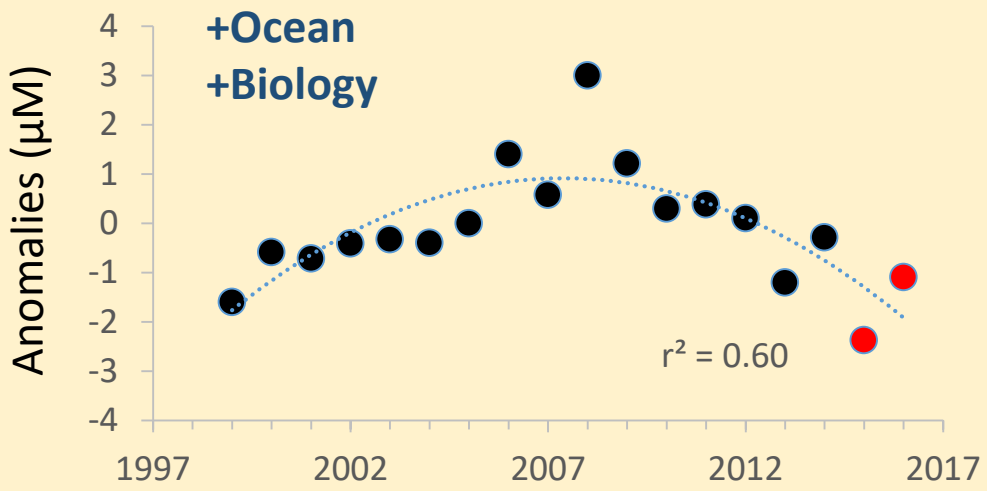
Future shift in timing of streamflow peaks



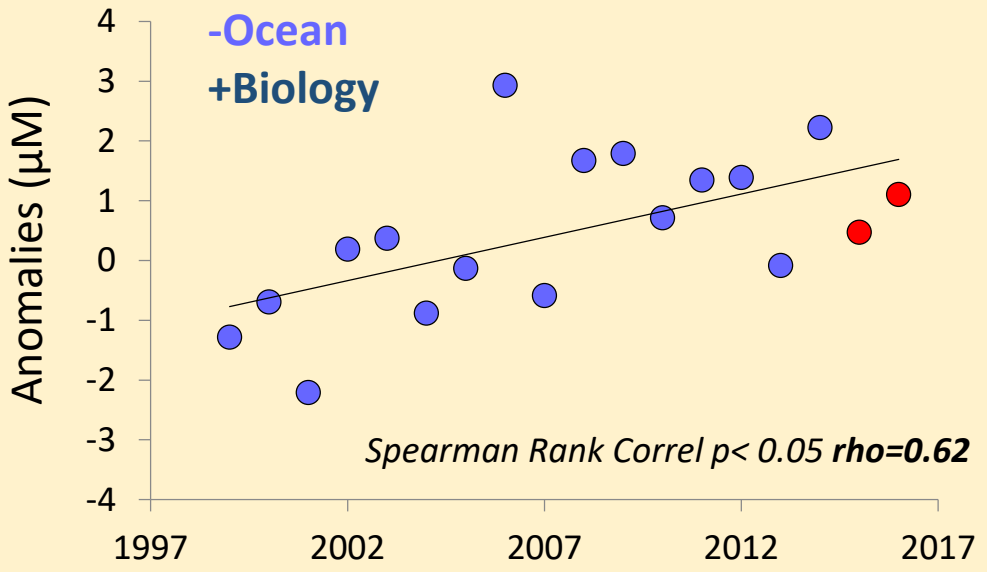
50% reduced summer flows by 2040

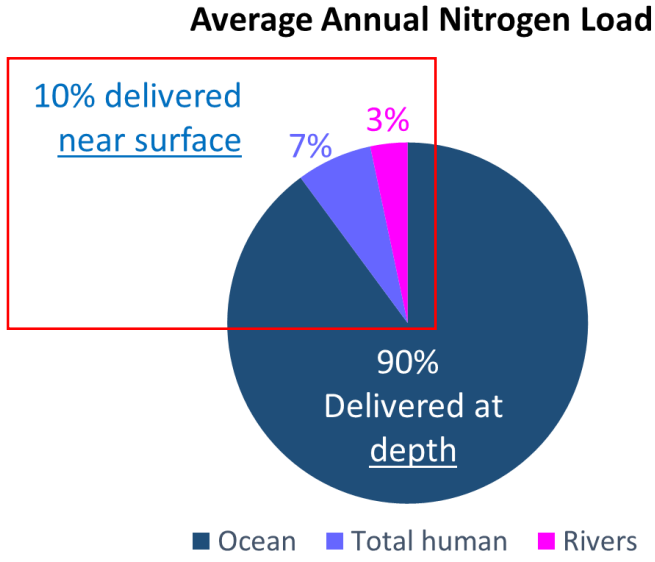


Yearly variation in nitrate 0-50m



Nitrate : Salt ratio relative to source water

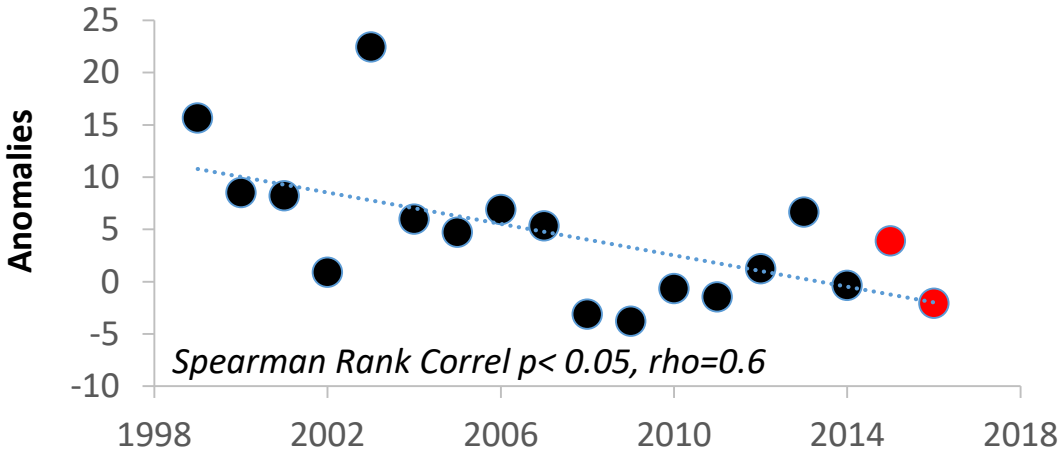




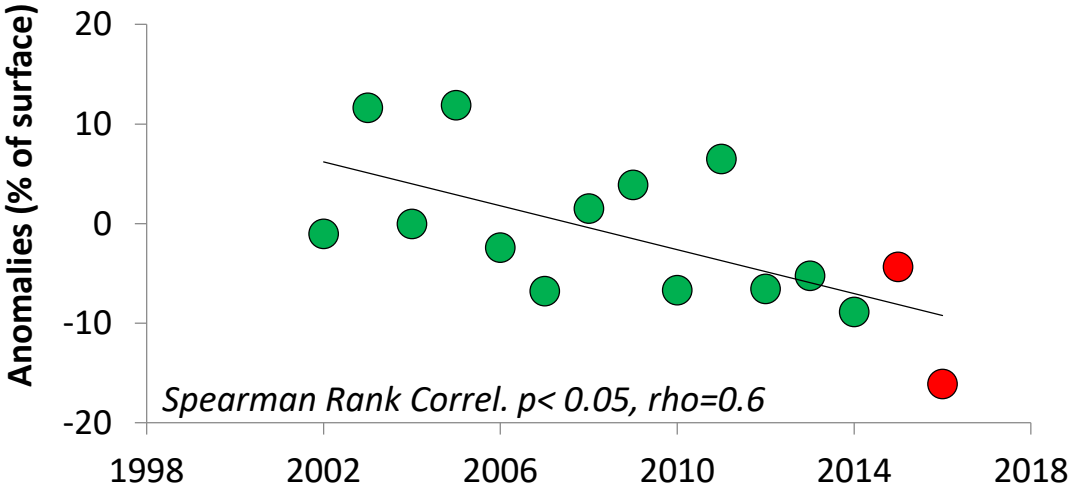
- Only the ocean is bringing salt into Puget Sound
- We can calculate out nitrogen from ocean to get at "human" nitrogen sources

Eutrophication indicator for nutrients, ratios…

Silicate: DIN *(dissolved inorganic nitrogen)*

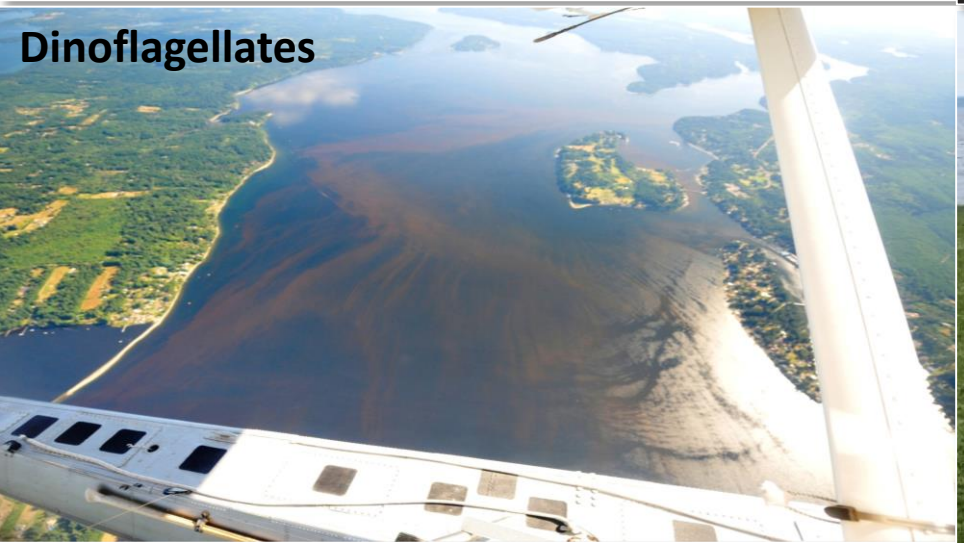


Near-bottom : surface Chl a



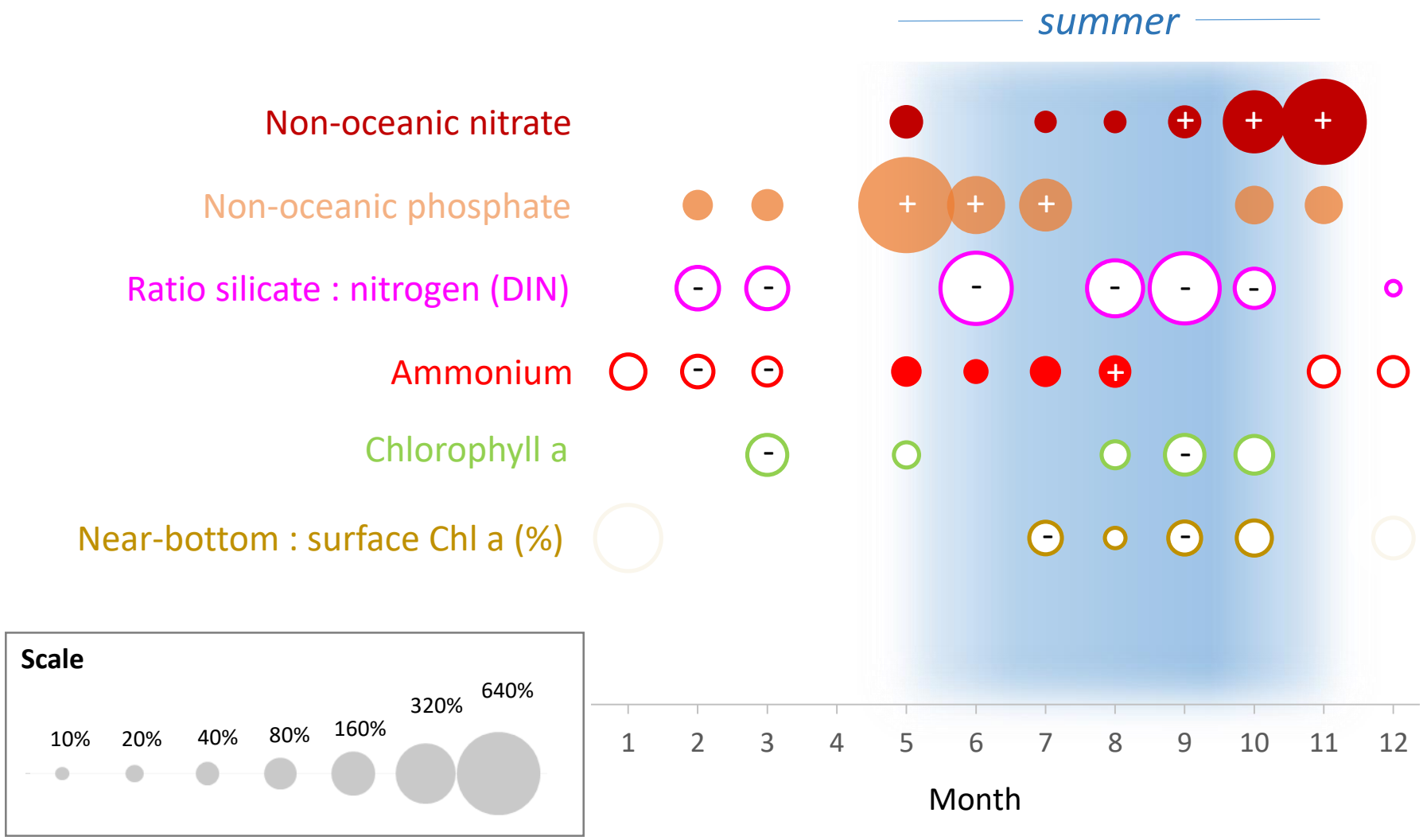
- Si:DIN is a eutrophication indicator
- Nutrient balance can change the base of the food web fostering nuisance species
- Organic particle export can change

Undesirable species that tend to float (qualitative observations, Eyes Over Puget Sound)

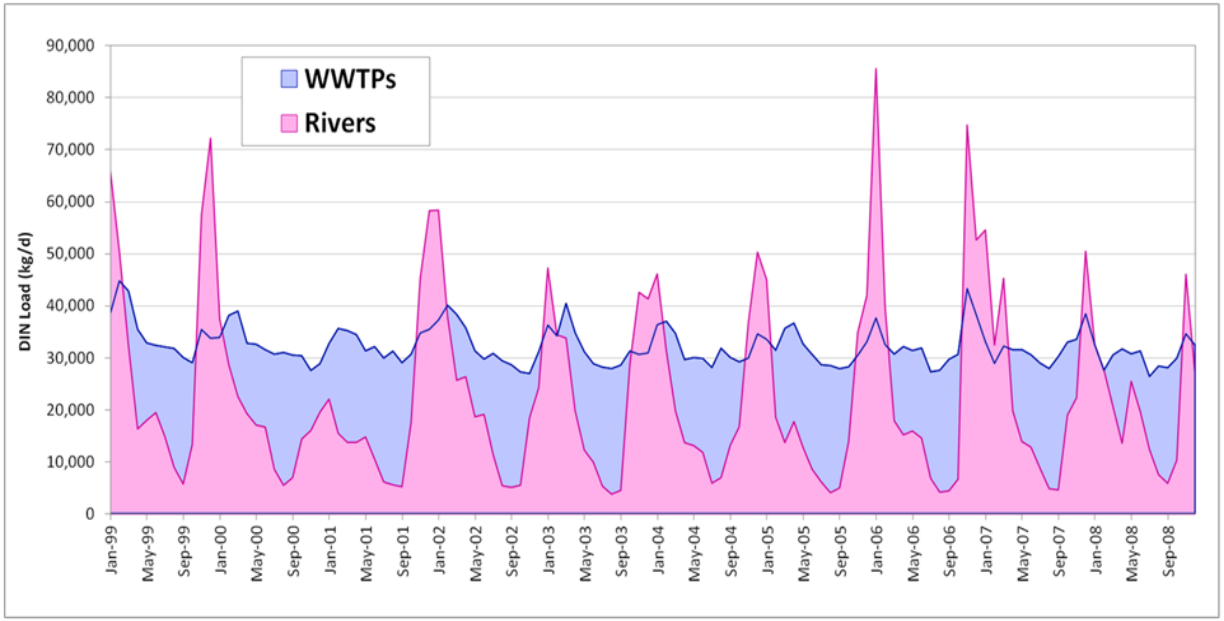


Percent significant change since 1999

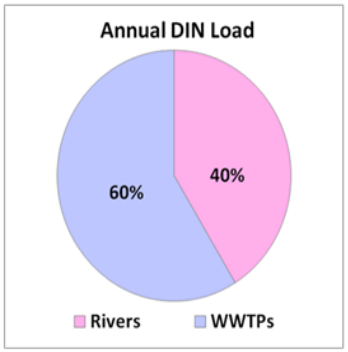
(Spearman Rank Correl., n=17 years, 10% sign level)

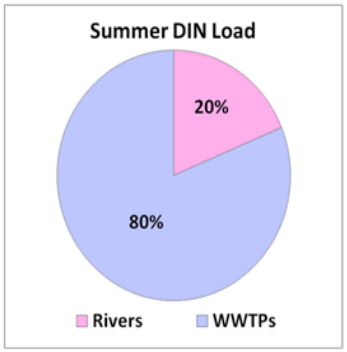


In summer, the relative contributions of WWTPs are highest, and sluggish water exchange can further increase pollutants



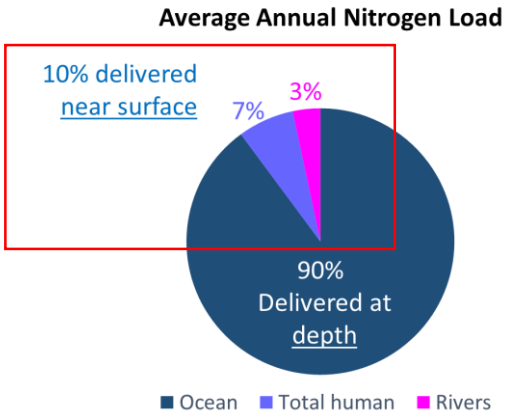
Source: Mohamedali et al., 2011a .





	Annual DIN Load	SUMMER DIN Load
Rivers	22,630 kg/d	6,760 kg/d
WWTPs	32,210 kg/d	29,320 kg/d

60% WWTP **80% WWTP**



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.

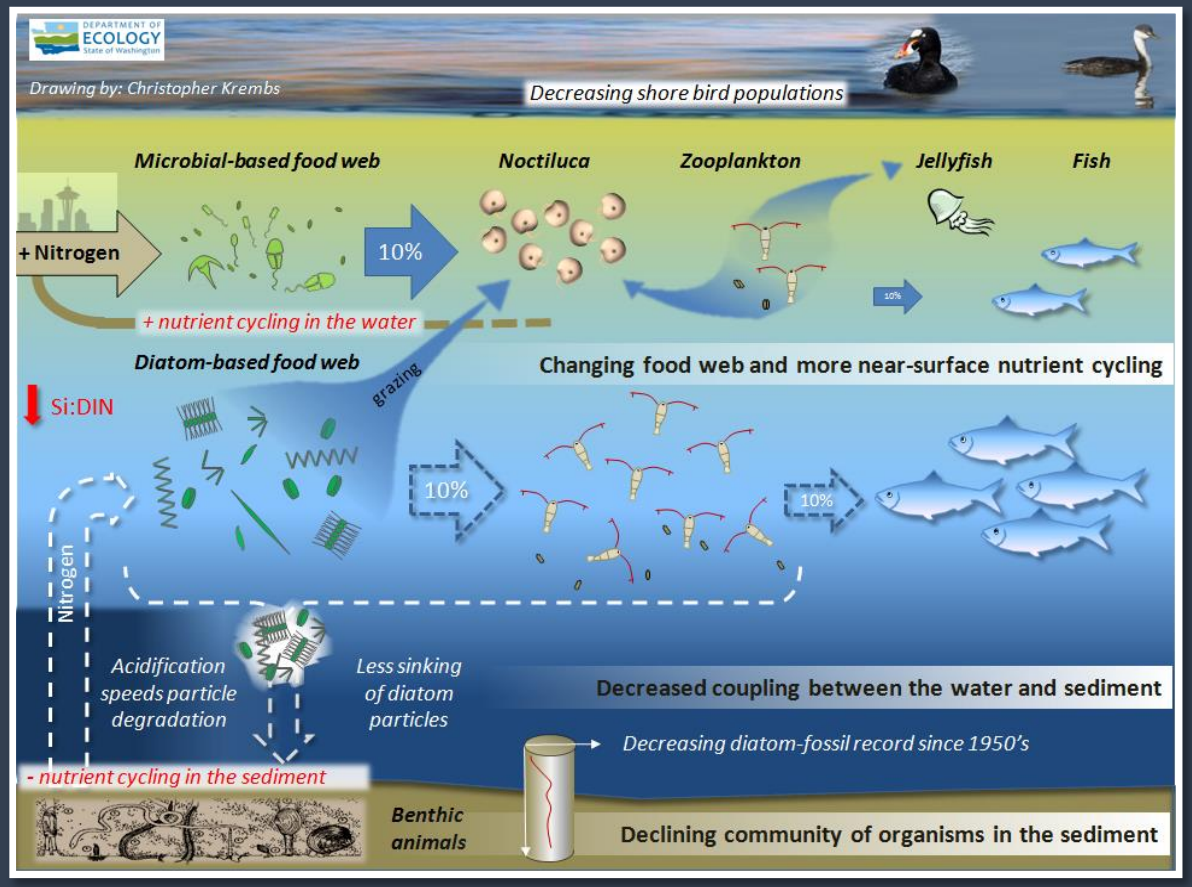
It is time to revisit and rethink what is going on in Puget Sound…

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.

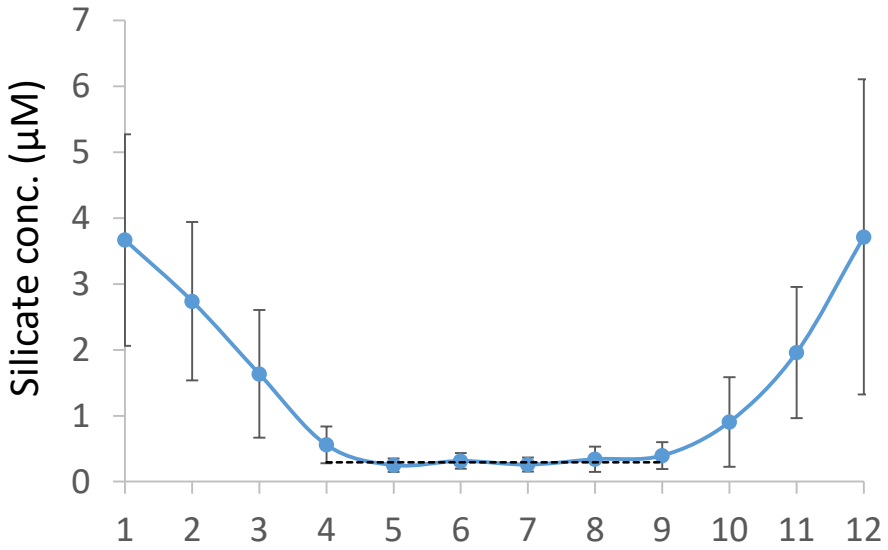
Strength of Science supporting hypothesis

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

The Silicate to Chl a Relationship

Addition information

Silicate : Chl a ratio seasonal climatology



Silicate : Chl a trend 0-30m