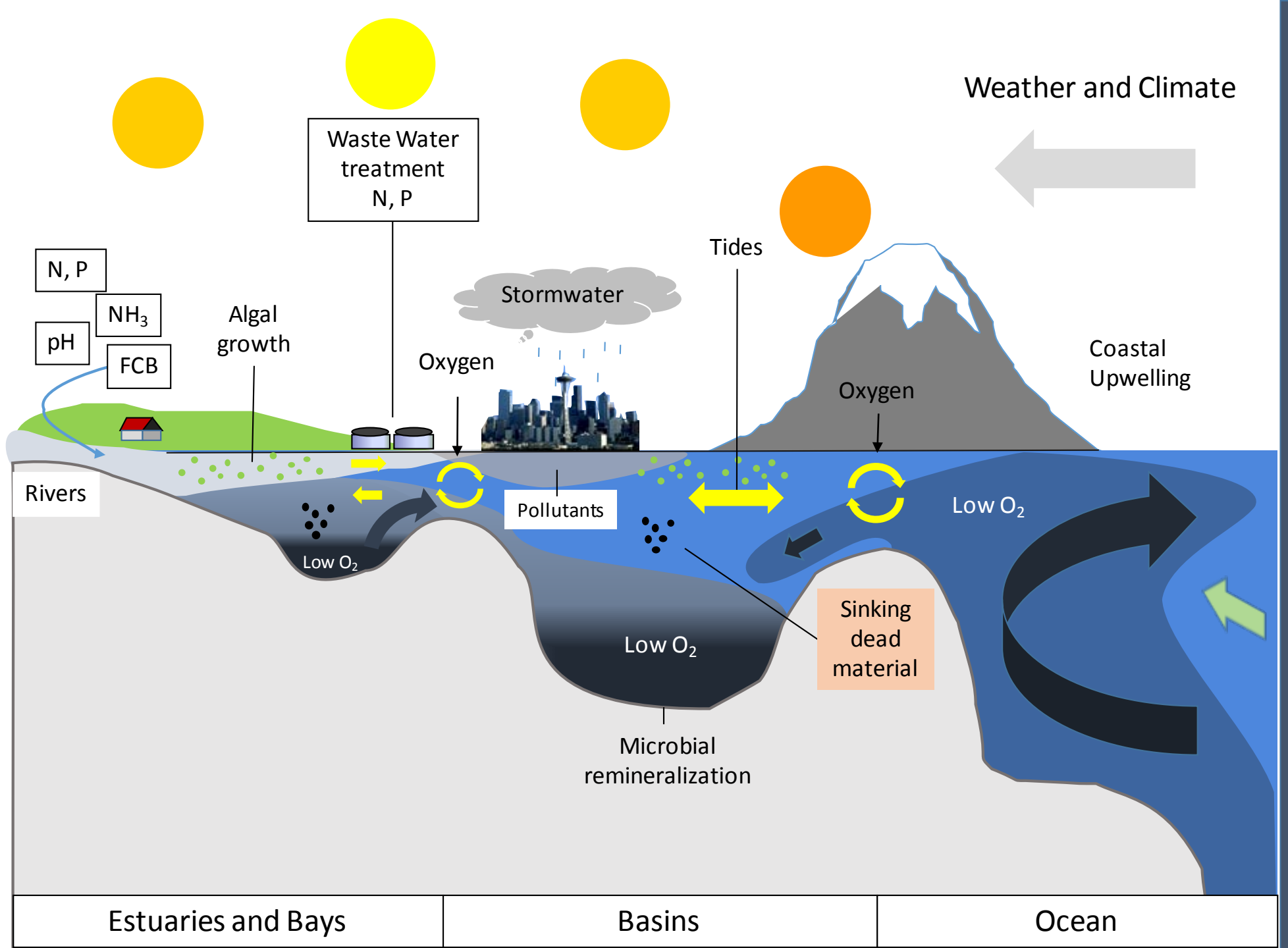
Long-term trends and the role of eutrophication in Puget Sound

Dr. Christopher Krembs, Marine Monitoring Unit, Ecology

EPA Region 10, 3/29/2016

http://www.underwatersculpture.com/

Are we loosing the benefits of the sediment?



Puget Sound is

a deep fjord

(avg 60m)

Changes in sinking particles matters more than in other places!

Eyes Over Puget Sound, monthly condition report

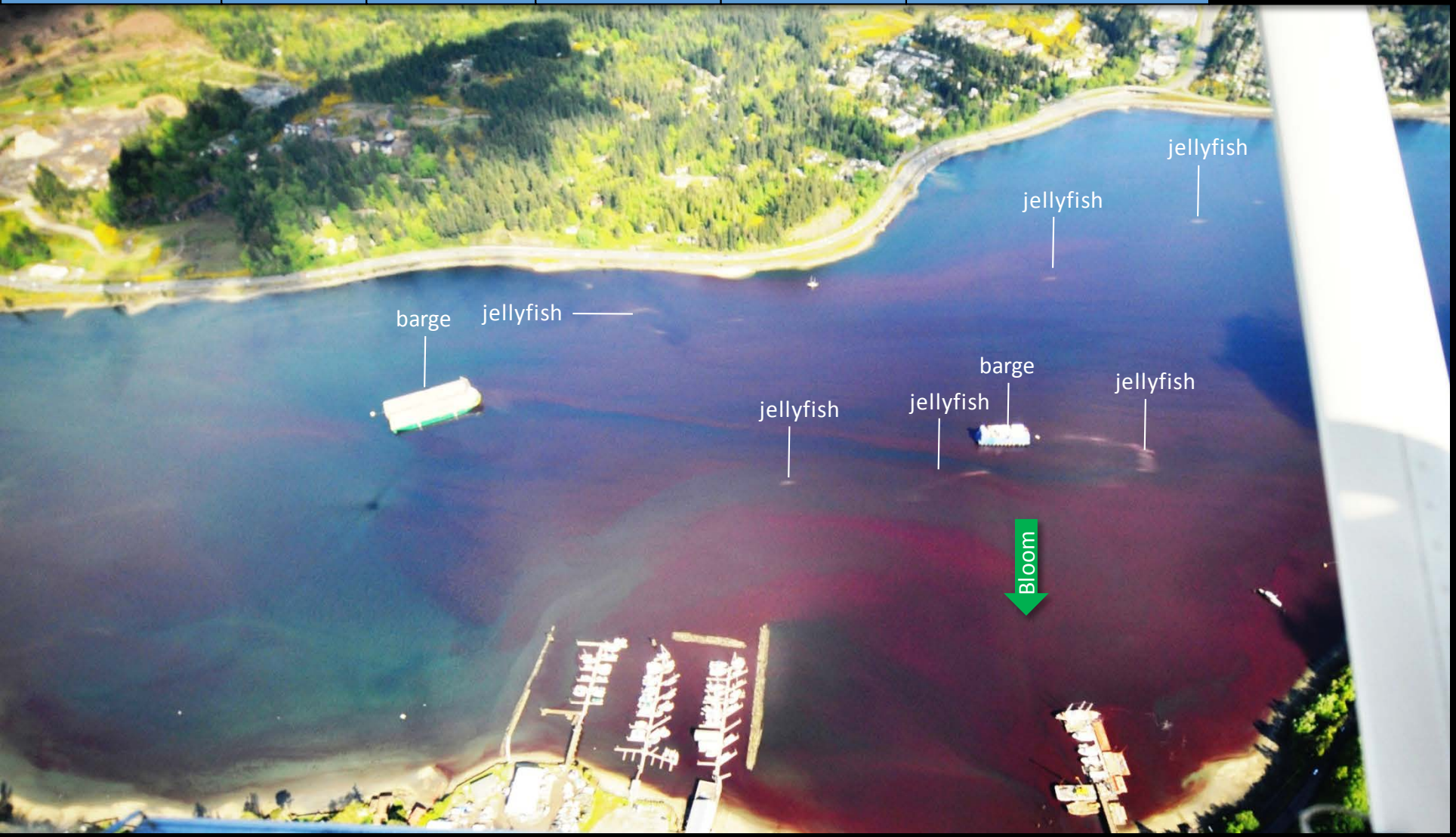
Field log	Weather	Water column	Aerial photos	Ferry and Satellite	Moorings

Red-brown bloom mixed into sediment-rich river plume. Jellyfish patches.
Location: Deepwater Point, Totten Inlet (South Sound), 10:27 AM.

Flagellates thrive in water:

- rich in organic molecules
- stratified

Aerial photography 4-29-2015



Red bloom and patches of jellyfish.
Location: Kitsap Marina, Sinclair Inlet (Bremerton), 9:52 AM.

Flagellates thrive in water:

- rich in organic molecules
- stratified
- flagellates are auto, mixo or heterotrophic
- opportunistic

Eyes Over Puget Sound

DEPARTMENT OF ECOLOGY State of Washington

Flight log	Weather	Water column	Aerial photos	Ferry and Satellite	Moorings

Up-to-date observations of visible water quality conditions in Puget Sound and the Strait of Juan de Fuca

Noctiluca has an impact on:

- food web structure
- biogeo-chemical processes
- considered a eutrophication indicator

Aerial photography 6-8-2015

Large Noctiluca bloom surfacing and gathering in large quantities at tidal front.
Location: Commencement Bay (Central Sound), 3:32 PM.

Noctiluca has an impact on:

- food web structure
- biogeo-chemical processes
- considered a eutrophication indicator

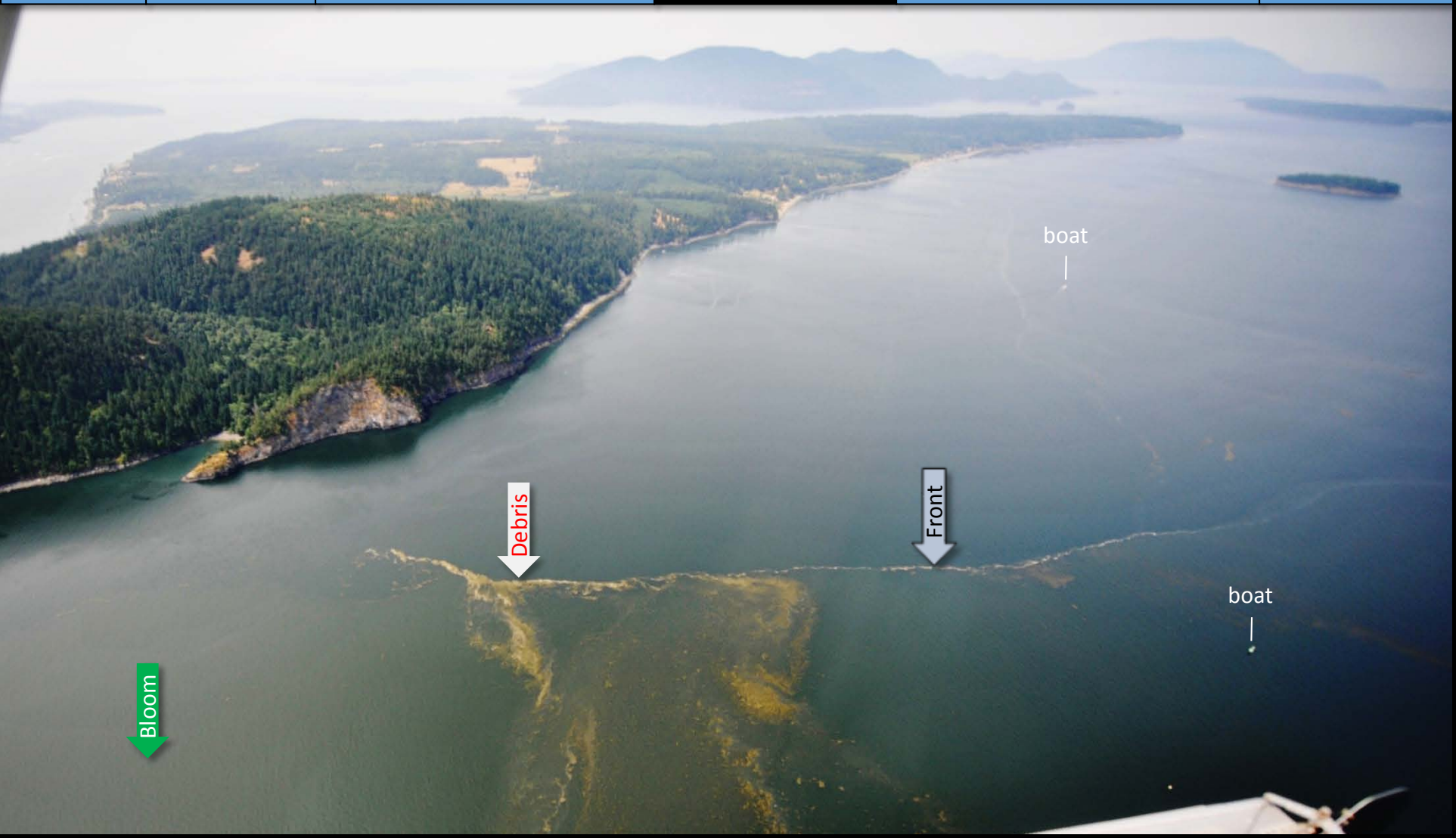
Aerial photography 7-6-2015

Extensive accumulations of organic debris, a brown algal bloom, and a large oil sheen.
Location: Between Port Madison and Shilshole (Central Sound), 3:05 PM.

Macro-algae:

- Eutrophication indicator

Aerial photography 7-6-2015



Large islands of organic material drifting at the surface off Guemes Island.
Location: Padilla Bay (North Sound), 1:05 PM.

Macro-algae:

- Eutrophication indicator
- occur in summer
- poor food for plankton species

Publication No. 14-03-078

DEPARTMENT OF ECOLOGY State of Washington

Eyes Over Puget Sound

Field log | Climate | Water column | Aerial photos | Ferry and Satellite | Moorings

Surface Conditions Report

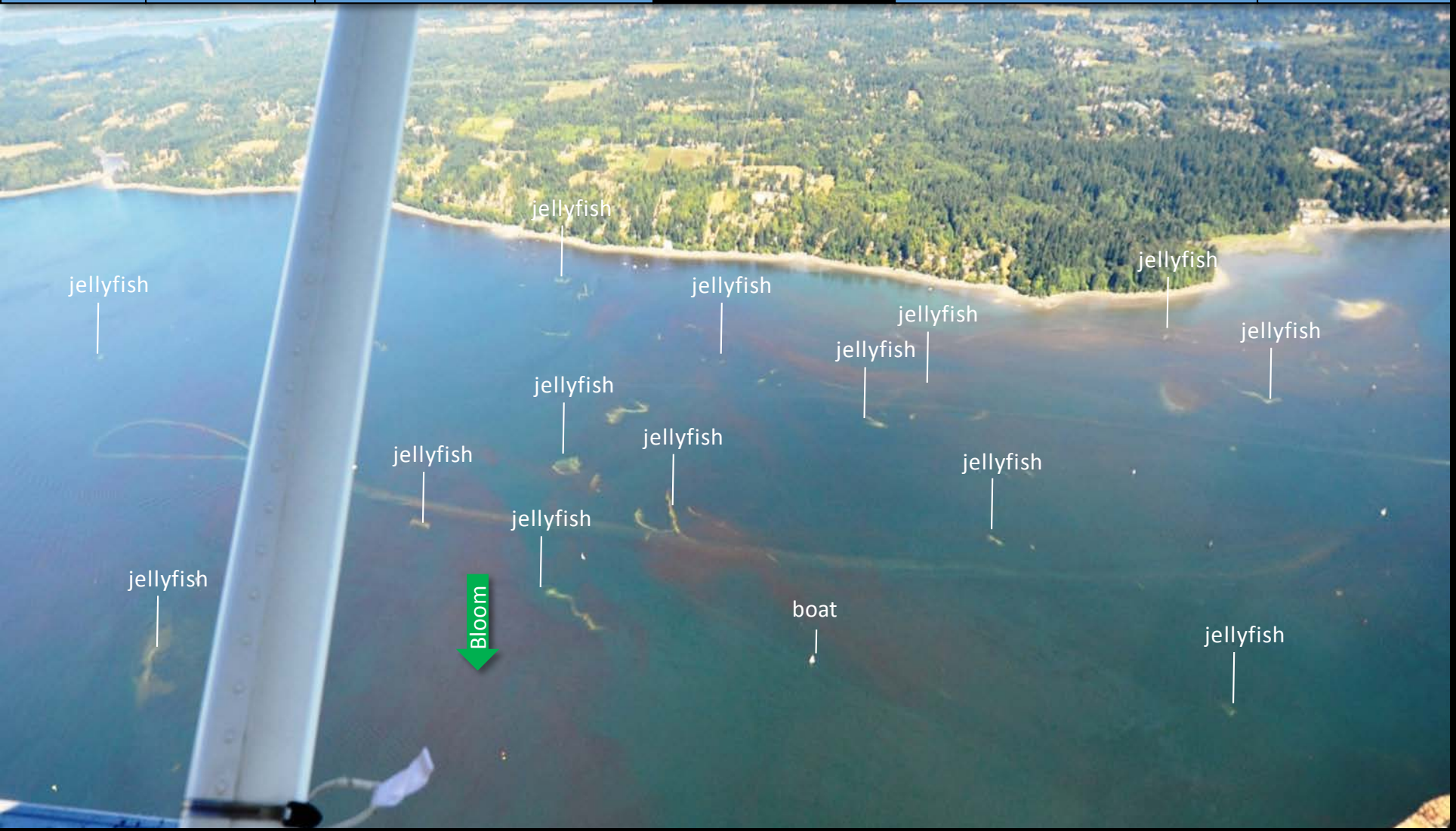
October 29, 2014

Guest: Gabriela Hannach

Start here

Up-to-date observations of visible water quality conditions in Puget Sound and the Strait of Juan de Fuca

Aerial photography 8-4-2015

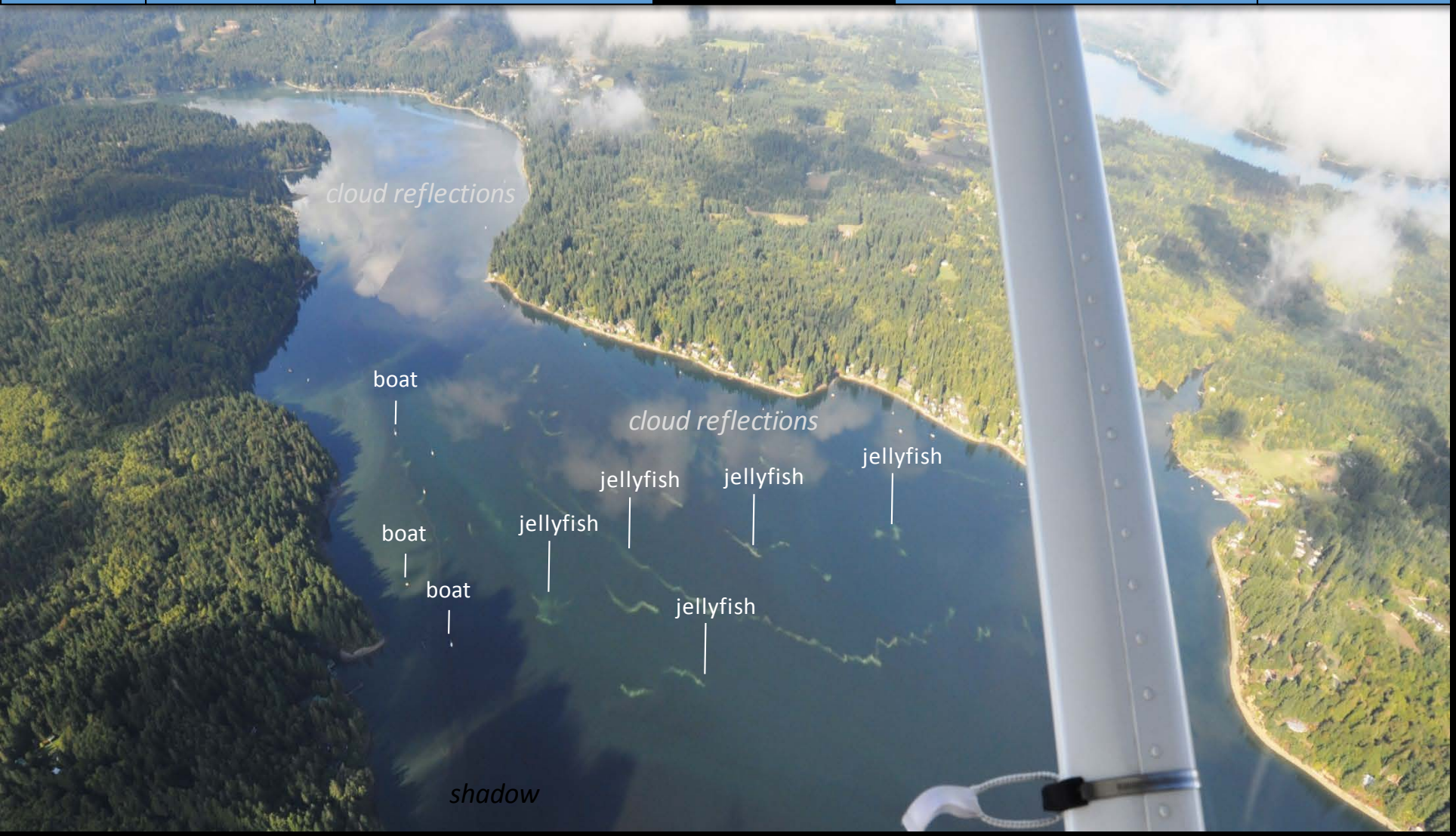


Numerous large patches of jellyfish in water containing red-brown algal bloom.
Location: Budd Inlet (South Sound), 3:12 PM.

Jellyfish:

- Eutrophication indicator

Aerial photography 9-21-2015

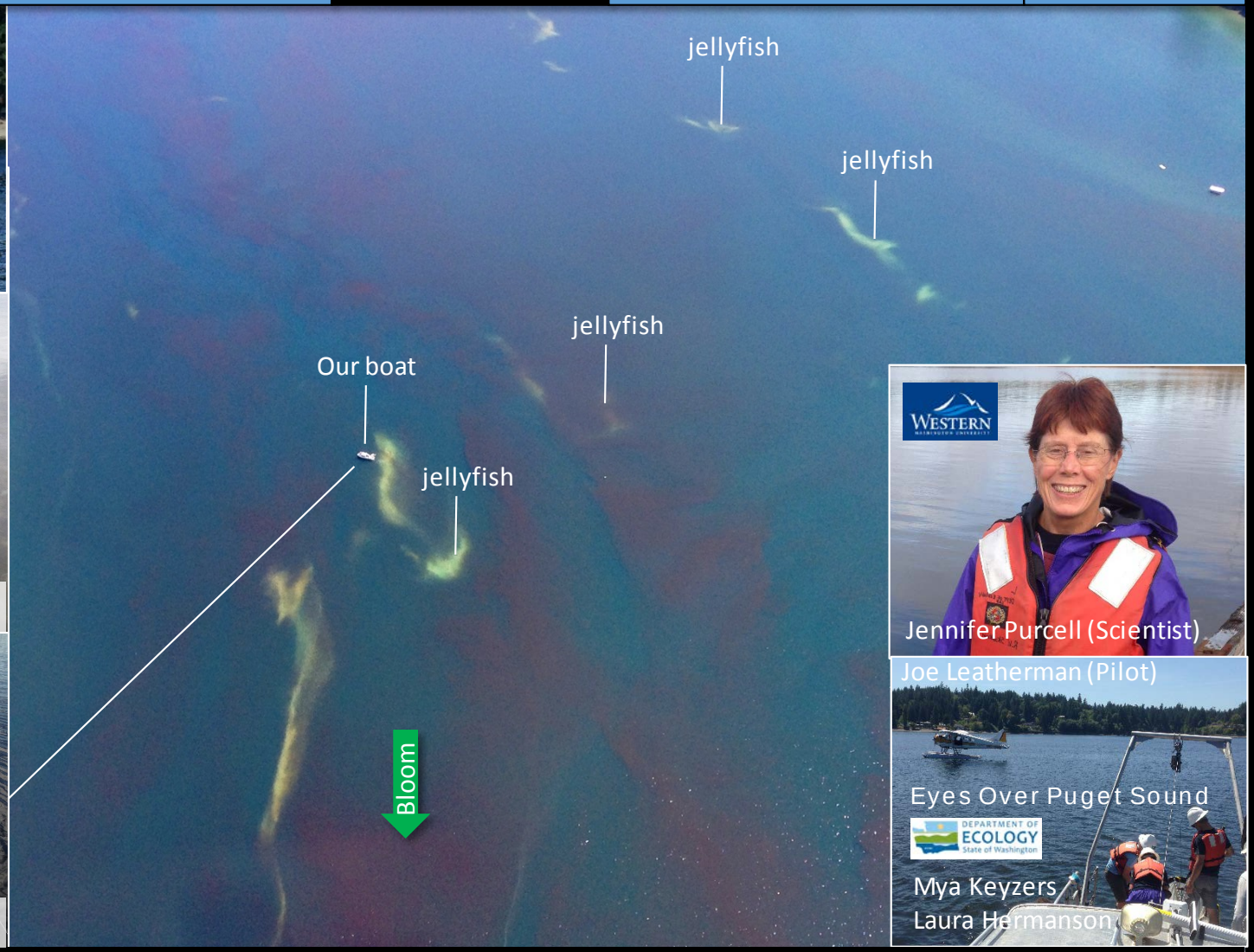


Large jellyfish patches in water containing fading red-brown algal bloom.
Location: Eld Inlet (South Sound), 10:24 AM.

Jellyfish:

- Eutrophication indicator
- occur abundantly in summer-fall
- poor food

Aerial photography 8-4-2015



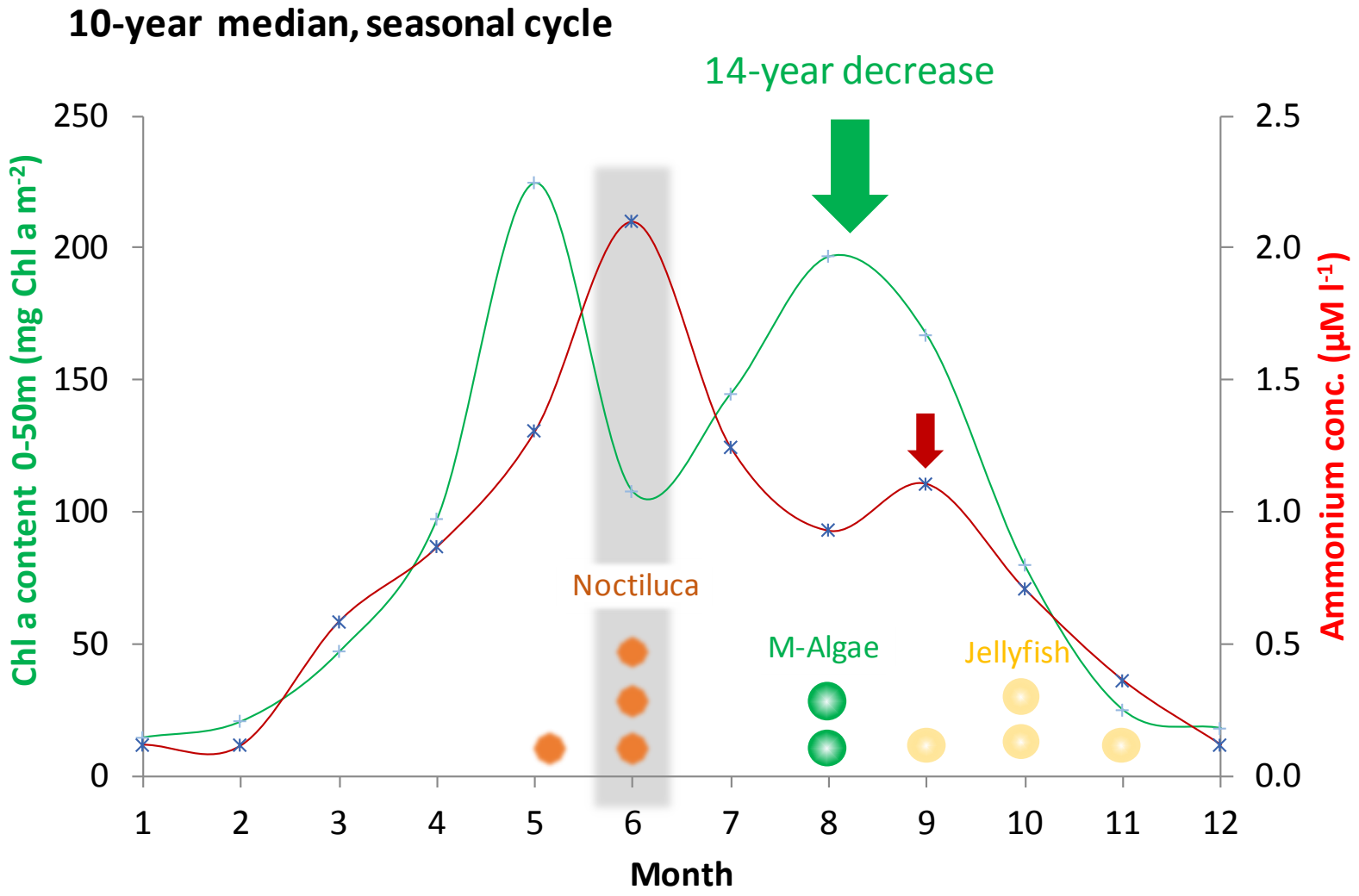
Collaborating on air to ground measurements of jellyfish super smacks (this one is > 2 million individuals)

Location: Eld Inlet (South Sound, 1400 ft), 1:10 PM.

Jellyfish:

- Eutrophication indicator
- occur abundantly in summer fall
- poor food

Grazing is reflected in the seasonality of phytoplankton biomass (and NH_4) in Puget Sound (15 year median)

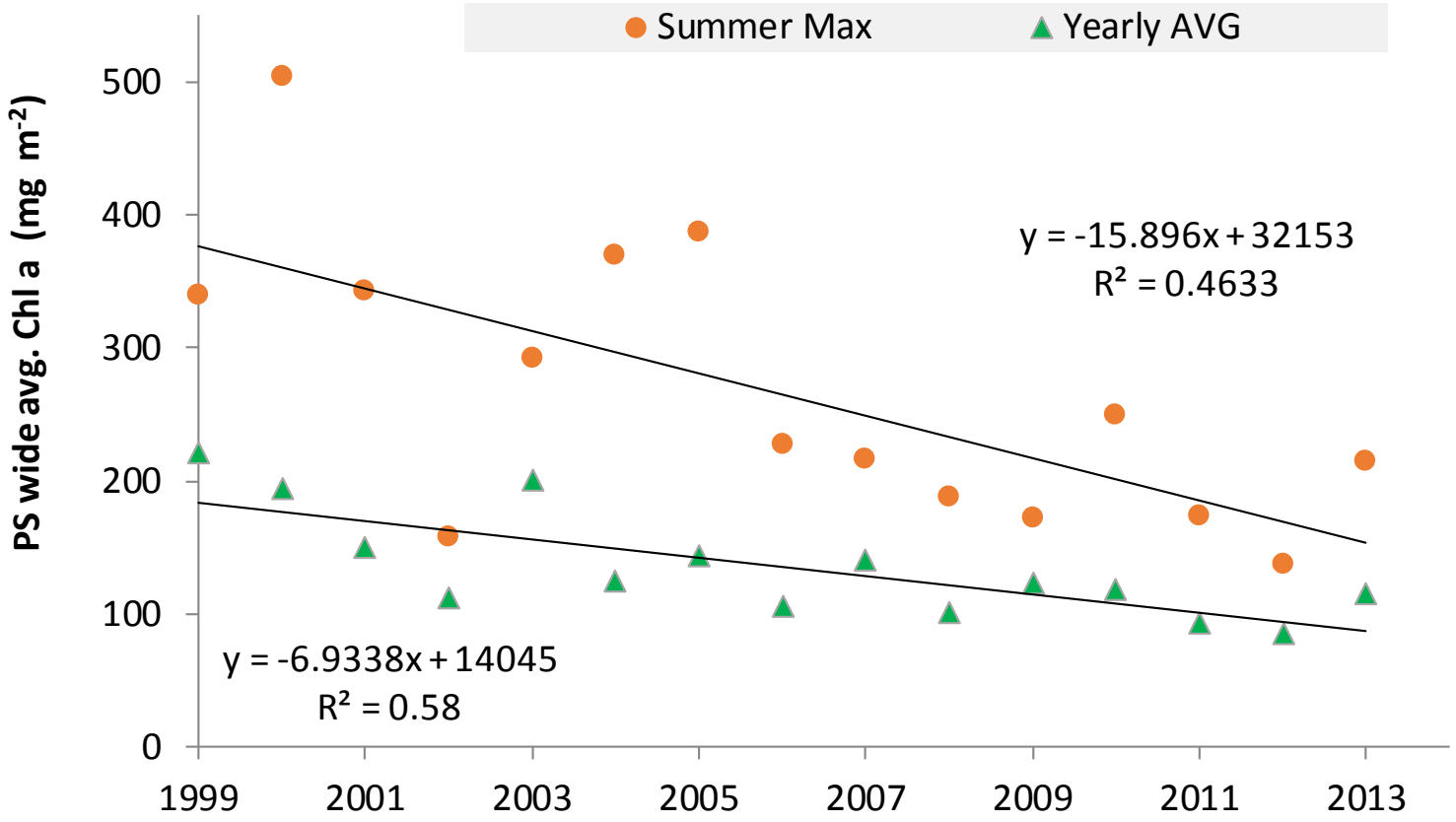


Phytoplankton dynamics change in summer

The spring bloom characteristics remain similar over the last 15 years

Chl a summer peak looses its strength

Note: NH_4 max also decreases in late summer; average is unchanged



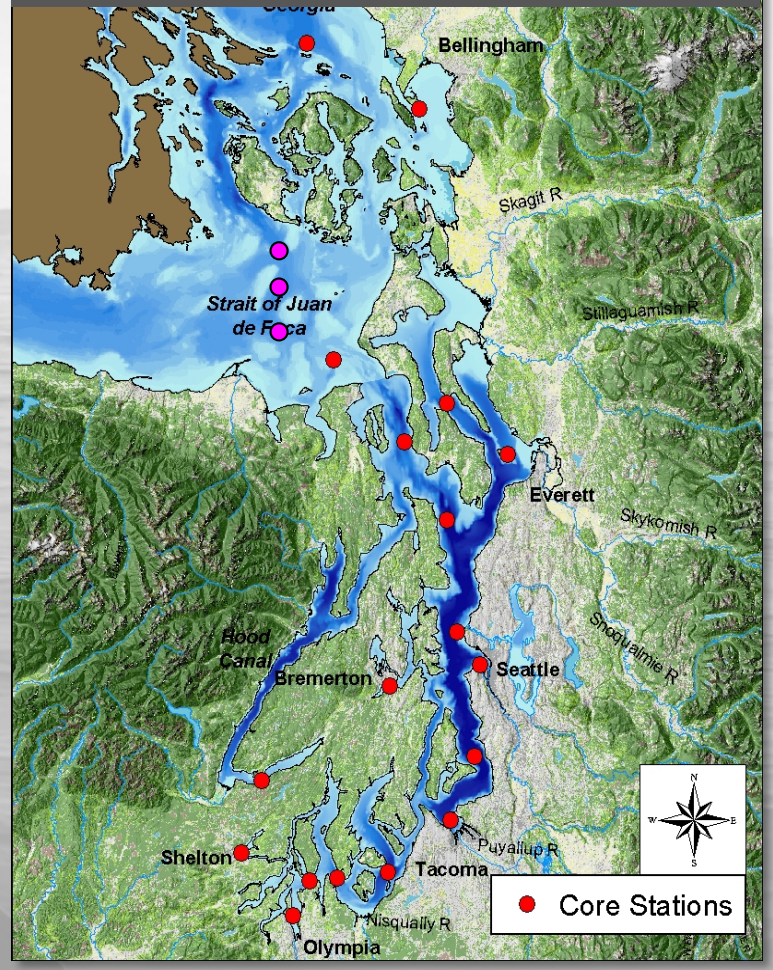
Phytoplankton dynamics change in summer

The spring bloom characteristics remain similar

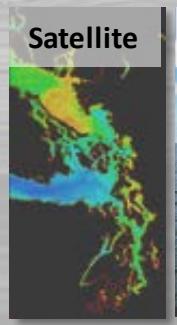
A response to changing nutrient supply of glacier-fed rivers?

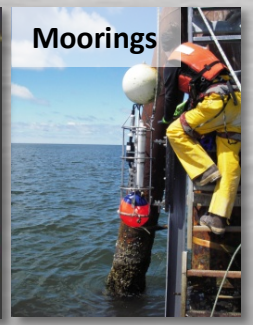
Measuring long-term trends in eutrophication, dissolved oxygen and physical variables

Greater Puget Sound region



Water Quality variables measured monthly 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

Monthly Baselines 1999-2008

"The Holy Grail"

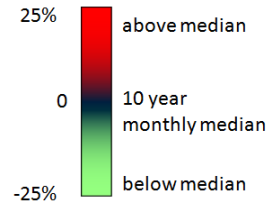
How much are humans influencing water quality

If natural influences are known, human influences can be scaled

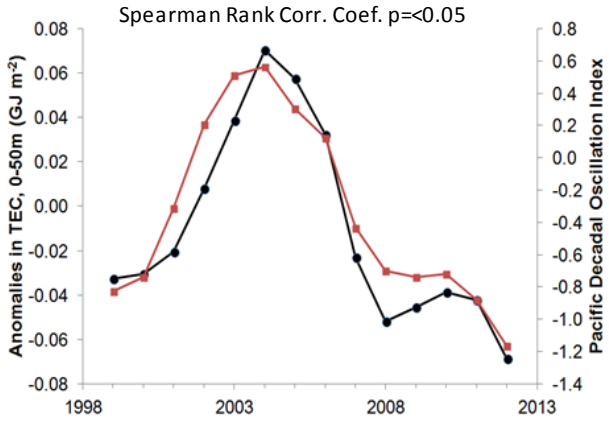
Ocean boundary conditions impact PS water quality

A-B **Sea Surface Temperature -** Pacific Decadal Oscillations Index

C-D **Upwelling -** Upwelling Index (anomalies)

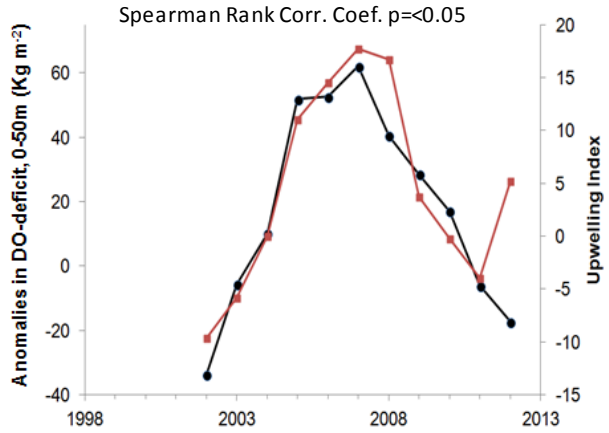


A. Pacific Decadal Oscillation Index

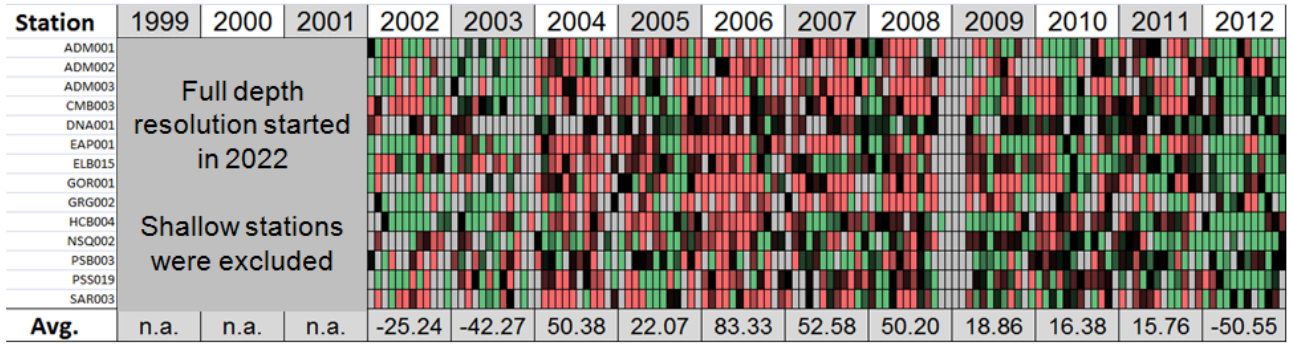


B. *Anomalies in Thermal Energy Content, 0-50m*

C. Upwelling Index (NOAA)

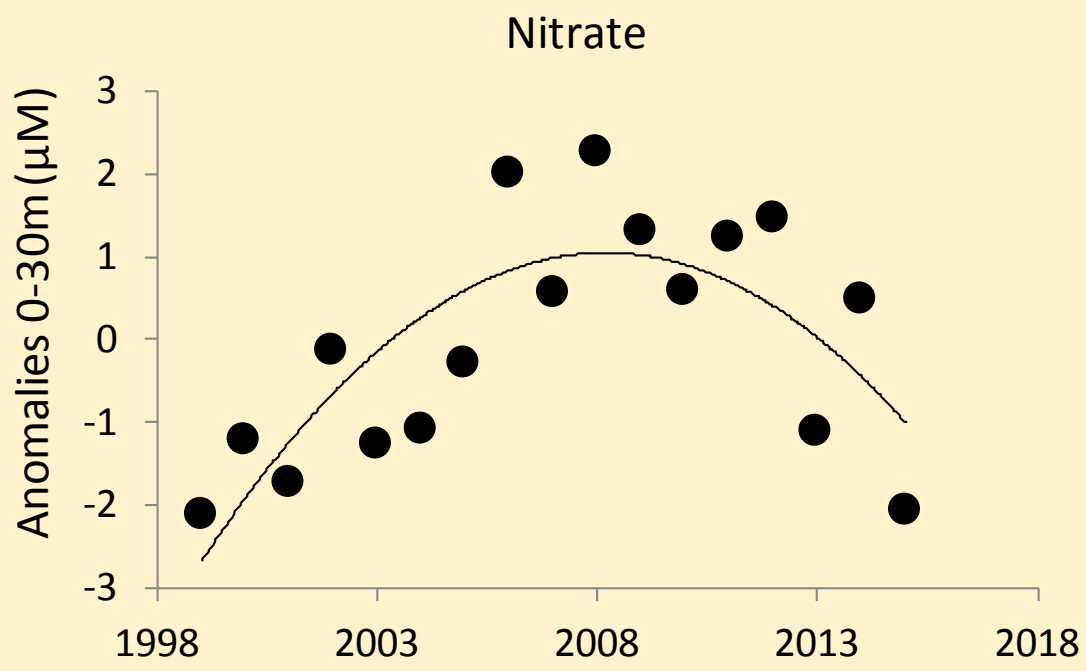


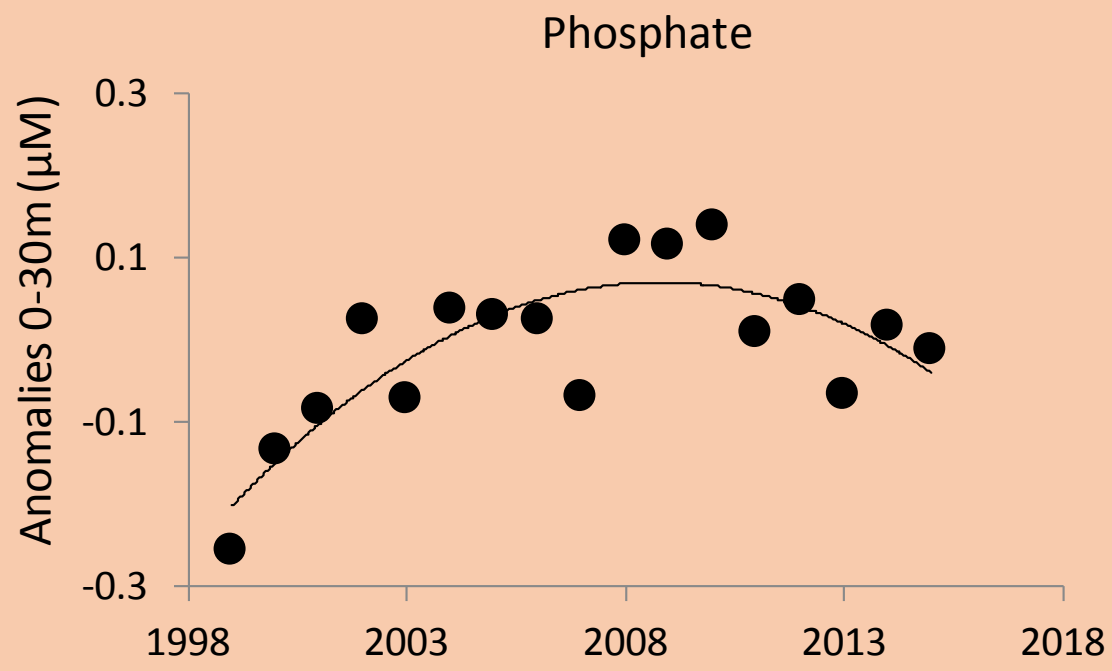
D. *Anomalies in Dissolved Oxygen Deficit, >50 m*

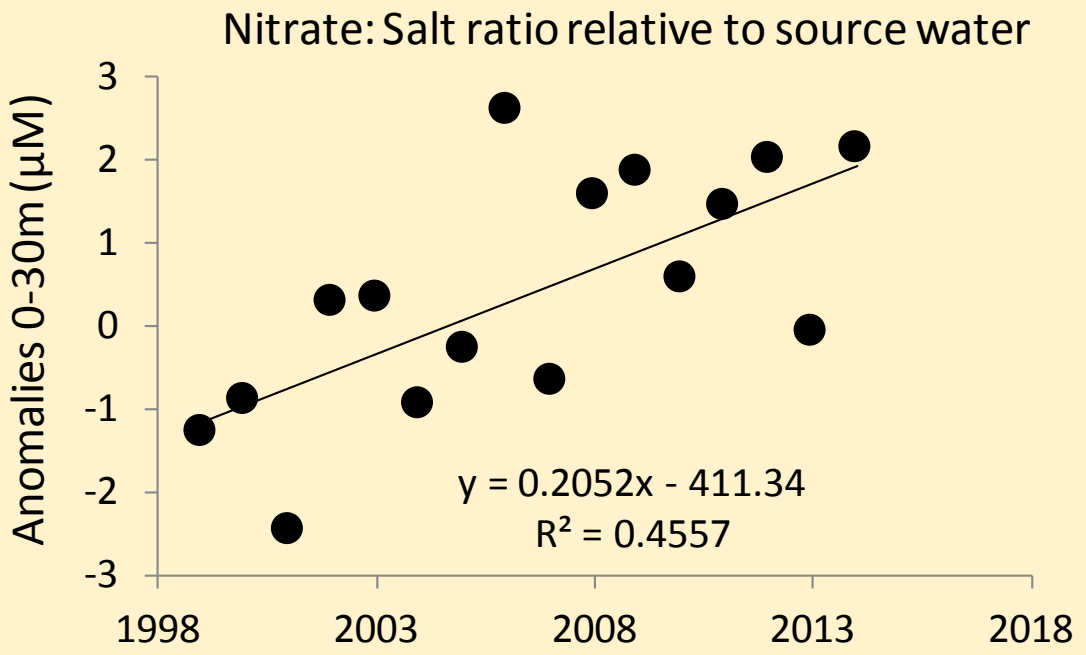


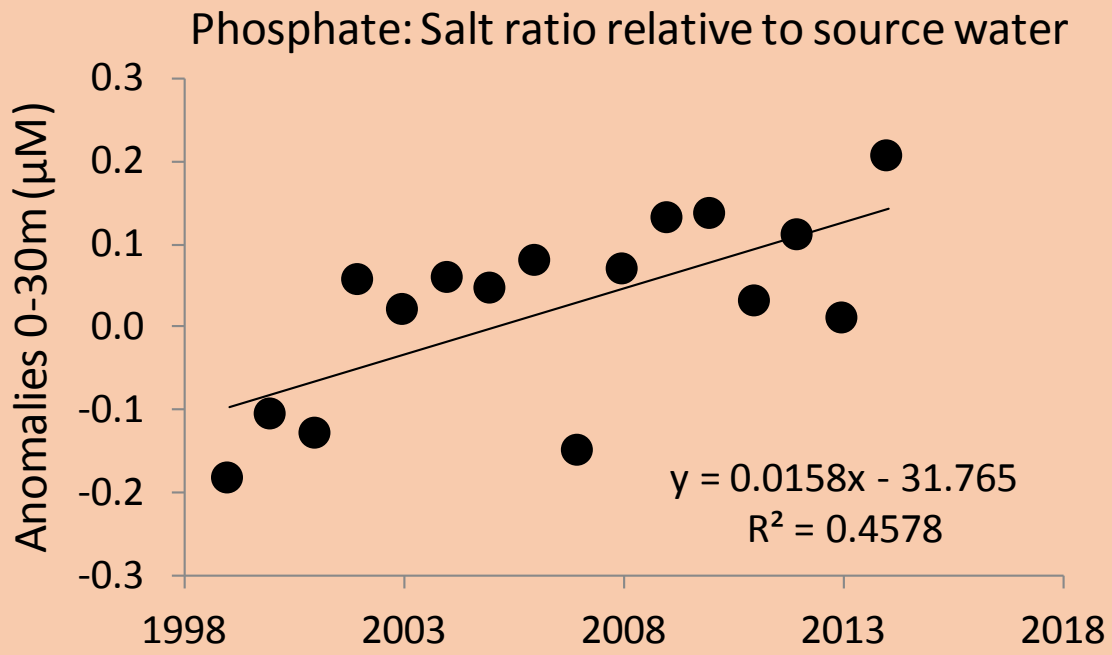
PS responds to ocean conditions at the surface

Physical variables at depth respond also to coastal variations

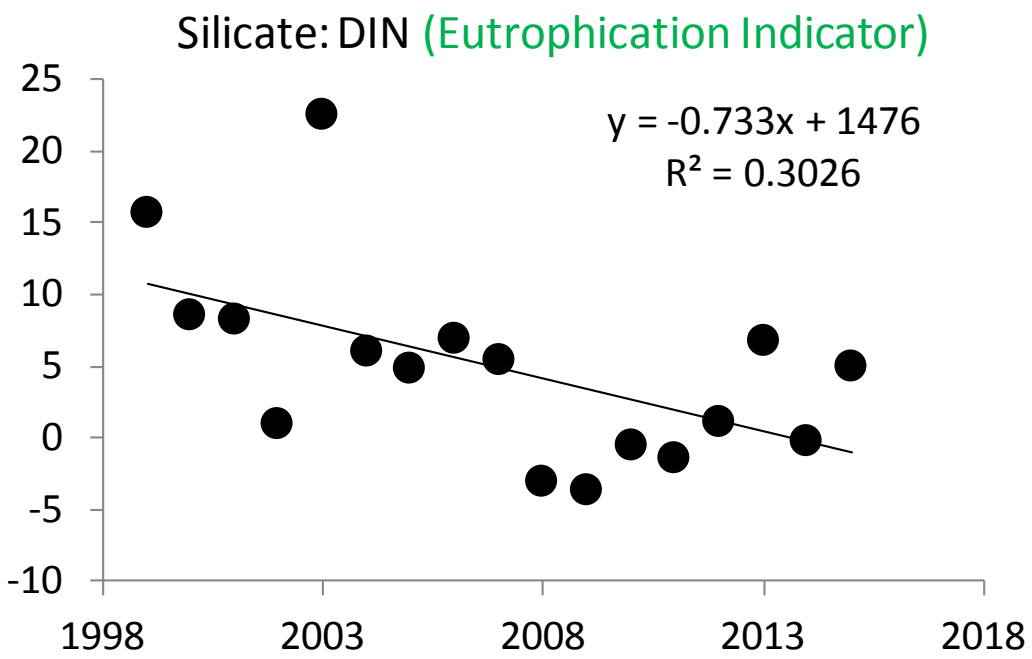

Nitrate
Anomalies 0-30m (µM)
3
2
1
0
-1
-2
-3
1998
2003
2008
2013
2018


Phosphate
Anomalies 0-30m (µM)
0.3
0.1
-0.1
-0.3
1998
2003
2008
2013
2018


Nitrate: Salt ratio relative to source water
Anomalies 0-30m (µM)
3
2
1
0
-1
-2
-3
y = 0.2052x - 411.34
R² = 0.4557
1998
2003
2008
2013
2018


Phosphate: Salt ratio relative to source water
Anomalies 0-30m (µM)
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
y = 0.0158x - 31.765
R² = 0.4578
1998
2003
2008
2013
2018

Nutrient balance is changing at the base of the food web



Si:DIN variations in ocean source water is 1-2 orders of magnitude lower (ocean not a driver)

Dilemma: Nutrients in PS are increasing?

- Nitrogen loading from rivers are relatively unchanged.
  - Hallock, D., 2008. River and Stream Water Quality Monitoring Report, Water Year 2008.

    Washington State Department of Ecology, Olympia, WA.
  - Von Prause, M., 2014. River and Stream Water Quality Monitoring Report, Water Year 2013.

    Washington State Department of Ecology, Olympia, WA.
- Nitrogen loading from sewage treatment plants, unchanged.
  - Mohamedali, T., M. Roberts, B. Sackmann, and A. Kolosseus. 2011. Puget Sound Dissolved Oxygen Model Nutrient Load Summary for 1999-2008.

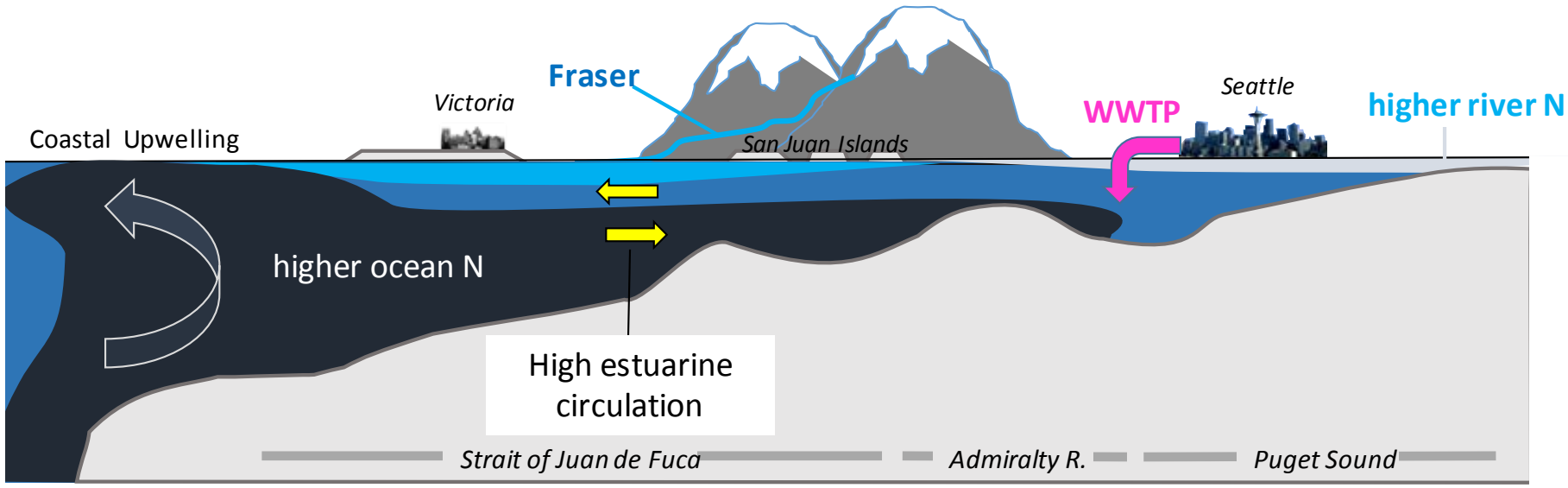
    Washington State Department of Ecology, Olympia, Washington.
- Nitrogen trends not visible in ocean source water to Puget Sound

Status and trends of organically-bound nutrients are missing!

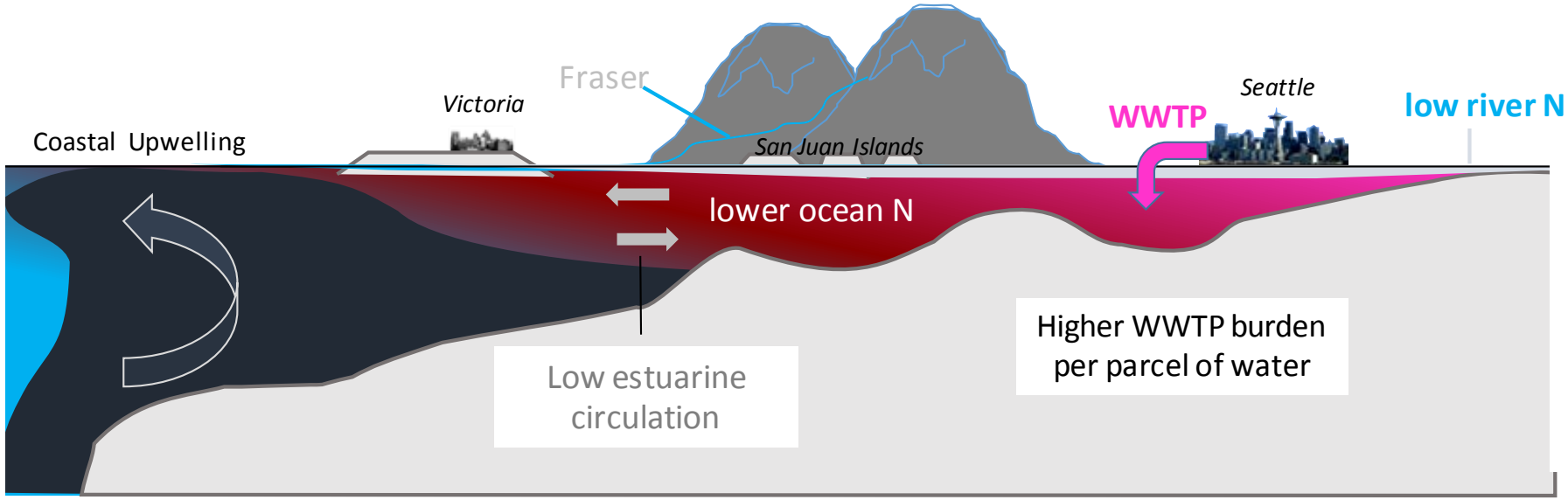
River flows drive “natural” nutrient inputs directly and indirectly.

Low river flows promote qualitative nutrient differences.

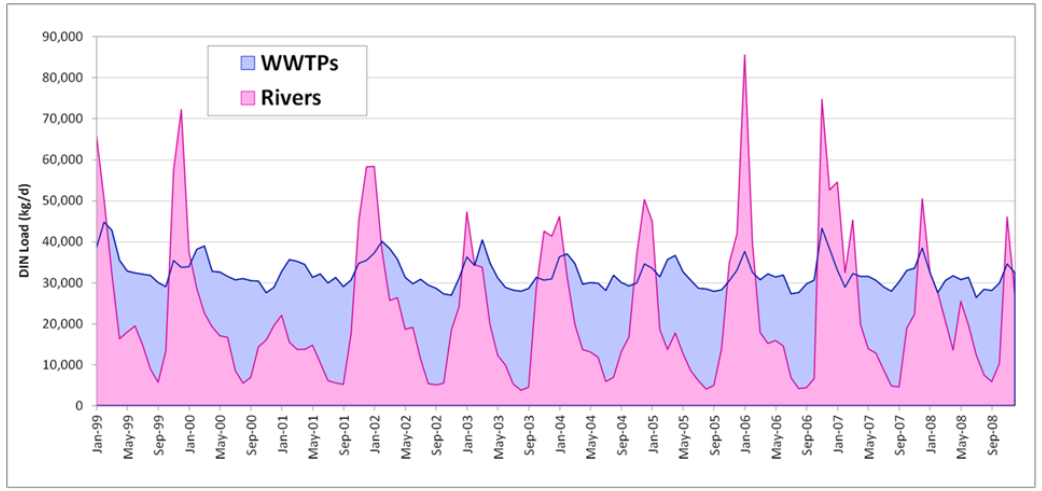
Short surface water residence time normal snowpack

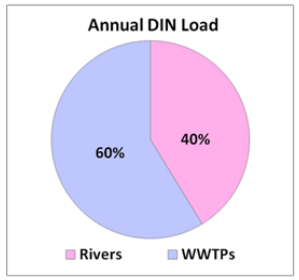


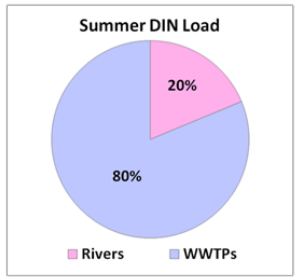
Long surface water residence time reduced snowpack



In summer the relative contributions of WWTP is highest, higher water residence time might promote nuisance species



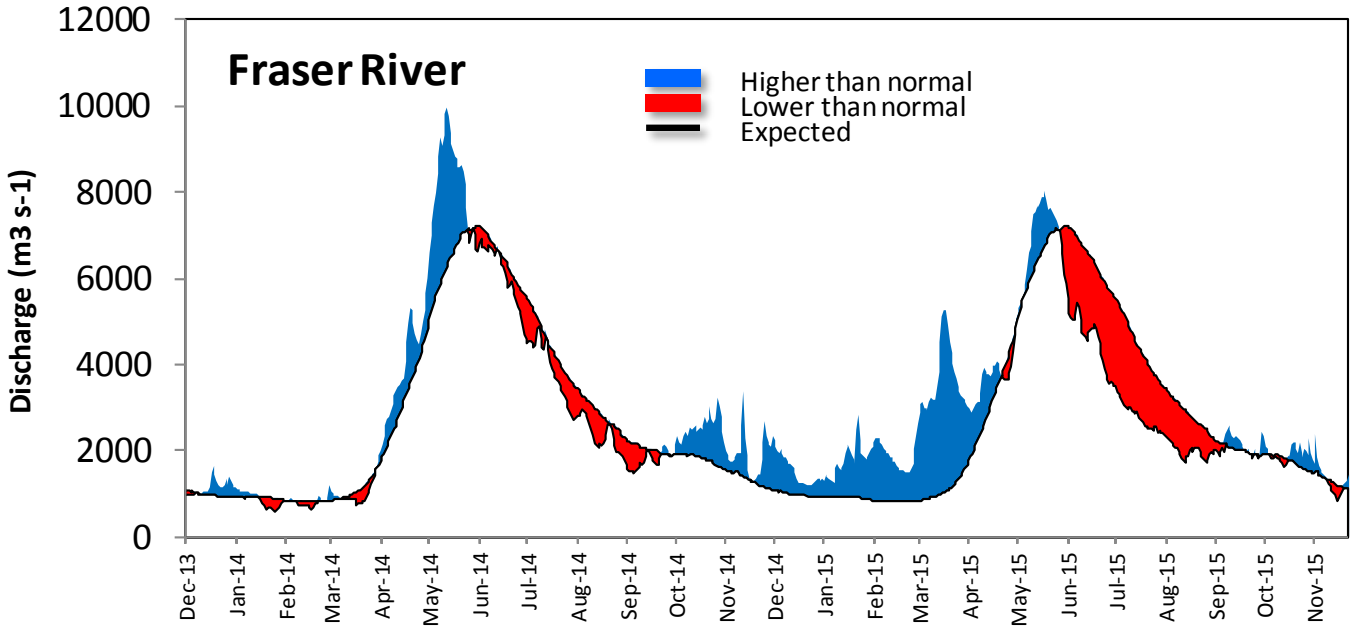




	Annual DIN Load	SUMMER DIN Load
Rivers	22,630 kg/d	6,760 kg/d
WWTPs	32,210 kg/d	29,320 kg/d

Comparison of dissolved inorganic nitrogen (DIN) load from rivers (pink) and wastewater treatment plants (blue) into Puget Sound (Source: Mohamedali et al., 2011a).

Low summer flows coincide with eutrophication indicator species and the marine foodweb patterns



SUMMER (June to Sept)

Climate → Snow-fed rivers

- Water residence time could have profound indirect effects on WQ

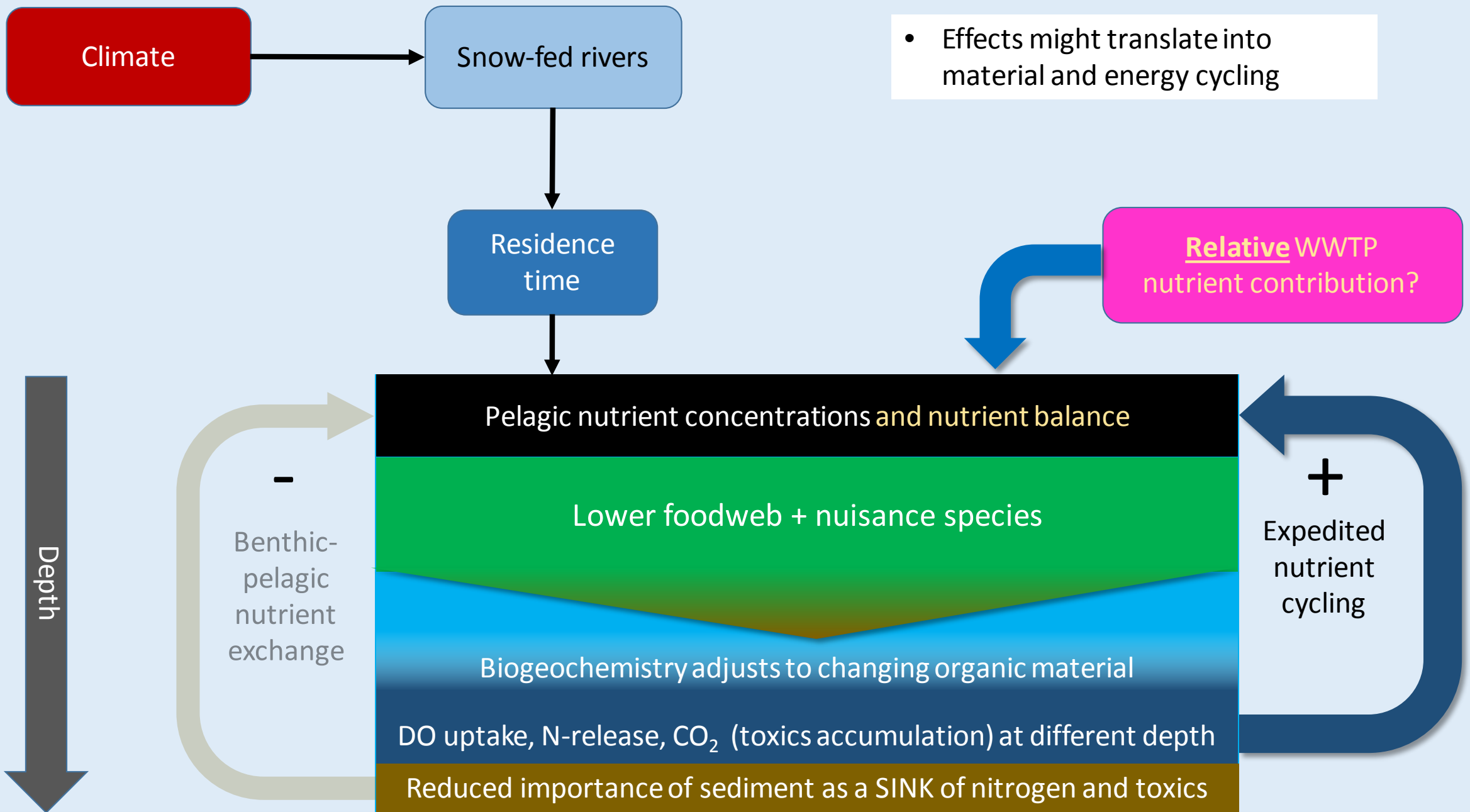
variable

Residence time

static

Relative WWTP nutrient contribution?

SUMMER (June to Sept)



- Effects might translate into material and energy cycling

Unexplained changes in the sediment. Food supply?

Ecology's Benthic Index categories

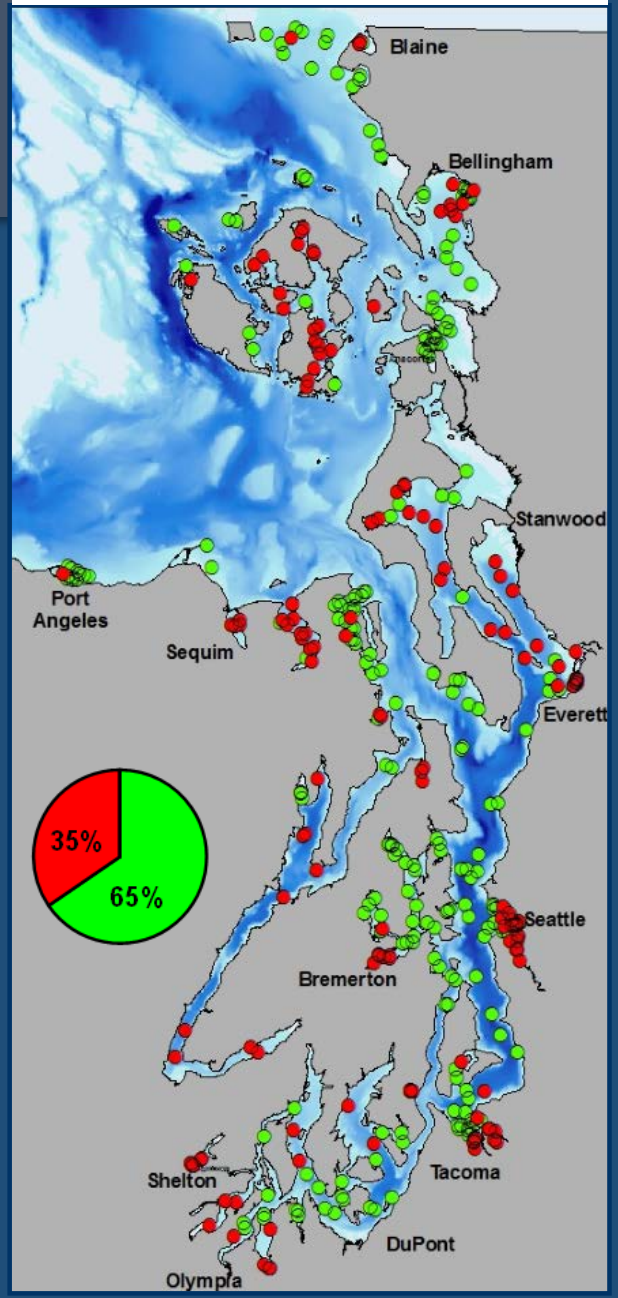
Unaffected Adversely affected

Increase in the areas with *adversely affected* benthos

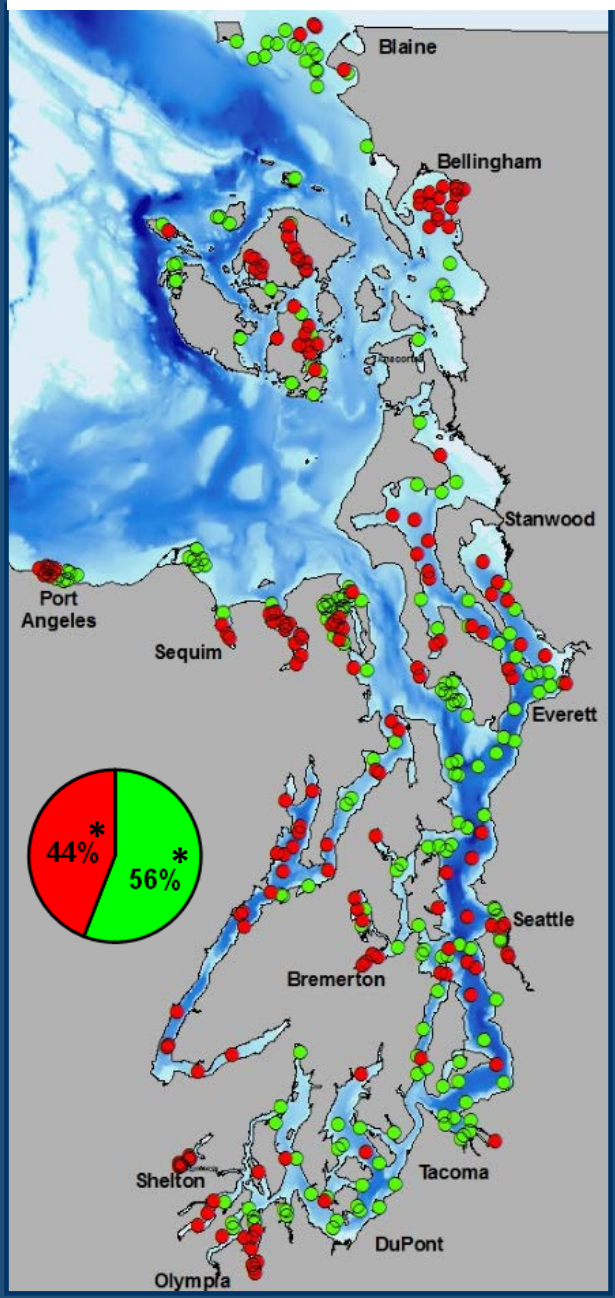
- Decadal decline in benthic abundance and taxa richness
- Detritivores most affected

Are these potentially signs of a reduced food supply (particle export) to the benthos?

Baseline

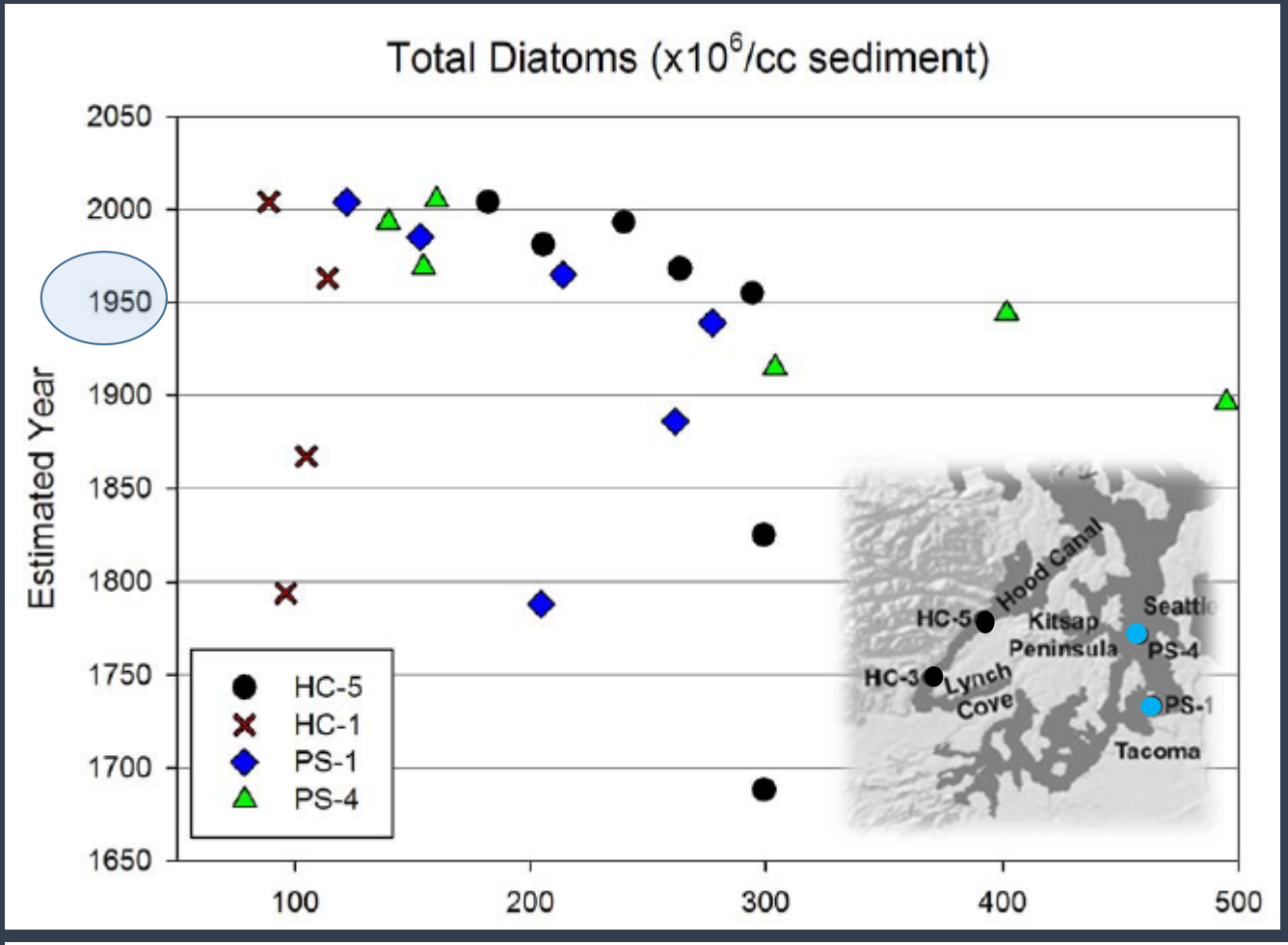


Second Round



Trends in the sediment record before 1999?

Brandenberger et al. 2008



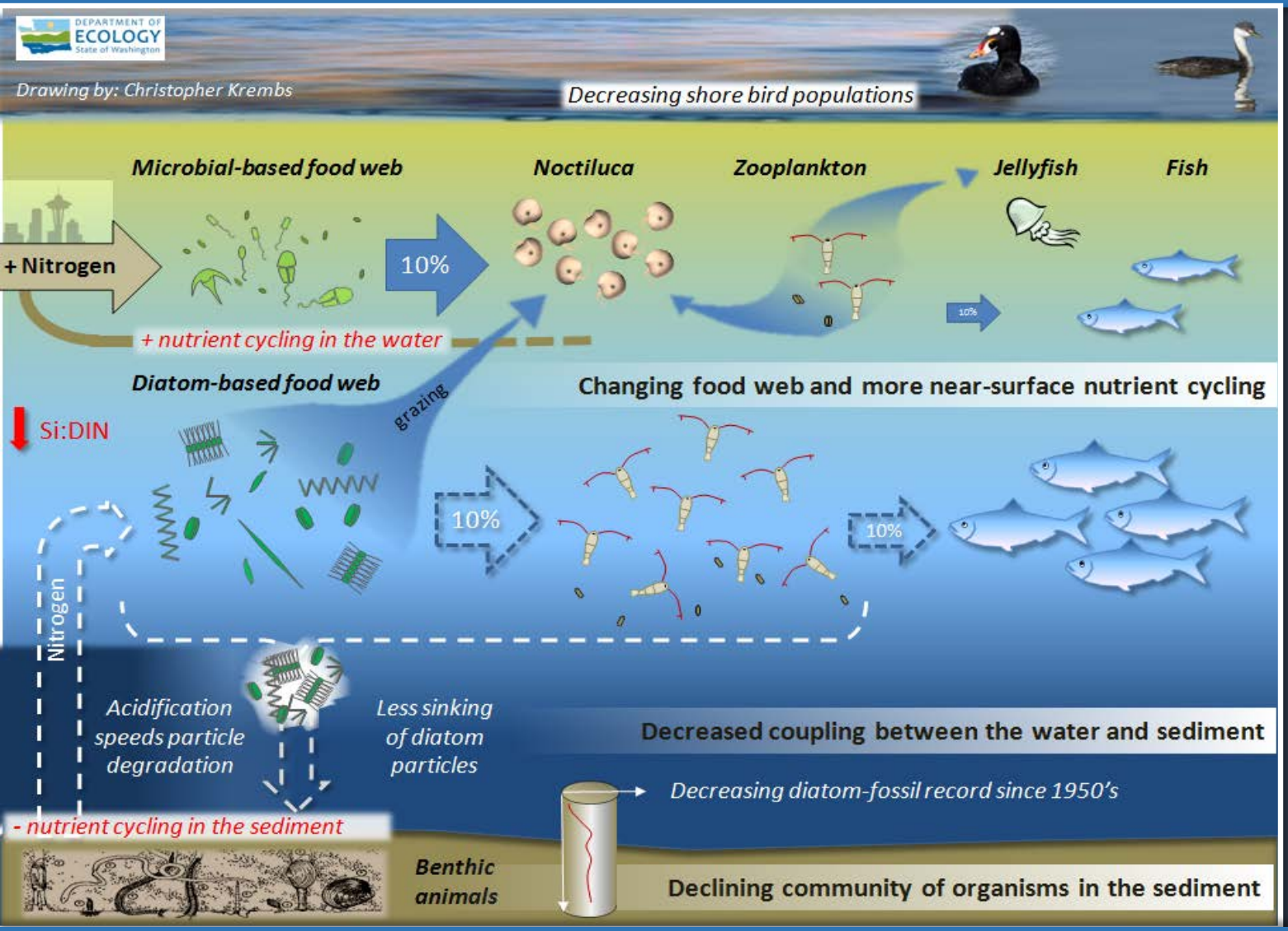
Reconstructing Trends in Hypoxia Using Multiple Paleoecological Indicators Recorded in Sediment Cores from Puget Sound, WA.

NOAA Coastal Hypoxia Research Grant

Diatoms have been declining since they 1950 in Puget Sound

Report, Figure 39. Diatom valve abundance in each cubic centimeter of wet sediment (shown in millions of valves) for Puget Sound (PS-1 and PS-4) and Hood Canal (HC-1 and HC-5) sediment cores. The y-axis indicates estimated year of samples determined by ^{210}Pb chronology.

Hypothesis: Changes in the lower foodweb



The energy and material cycling through the lower and intermediate food web of Puget Sound are changing.

Natural oceanic variability and known nitrogen loads cannot explain the observed patterns.

The big unknowns are microbial foodweb, PP, grazing, and particle export (rates, dynamics, trends, composition)

Important Topic

Vasas et al. 2007

HAB-forming species and Noctiluca **stimulate the microbial network**, but reduce higher trophic levels (fish).

The loss of planktivorous fishes acts together with nutrient enrichment in promoting **HAB species, Noctiluca and jellyfish.**

Vol. 336: 1–14, 2007 | MARINE ECOLOGY PROGRESS SERIES Mar Ecol Prog Ser | Published April 27

OPEN ACCESS

FEATURE ARTICLE

Eutrophication and overfishing in temperate nearshore pelagic food webs: a network perspective

Vera Vasas[1, 4,*], Christiane Lancelot[1], Véronique Rousseau[1], Ferenc Jordán[2, 3]

[1]Ecologie des Systèmes Aquatiques, Université Libre de Bruxelles, Campus Plaine CP 221, Boulevard du Triomphe, 1050 Bruxelles, Belgium

[2]Collegium Budapest, Institute for Advanced Study, Szentháromság u. 2, 1014 Budapest, Hungary

[3]Animal Ecology Research Group, Hungarian Academy of Sciences, Hungarian Natural History Museum, Ludovika t. 2, 1083 Budapest, Hungary

[4]*Present address:* Department of Plant Taxonomy and Ecology, Eötvös Loránd University, Pázmány Péter s. 1/C, 1117 Budapest, Hungary

ABSTRACT: We investigated the effects of human activities on the pelagic food web structure of nearshore marine ecosystems. Their generic structure was established on the basis of literature review and analyzed by qualitative structural network analysis. Two main issues were addressed: (1) the role of species capable of forming harmful algal blooms (HABs) and red tides (*Noctiluca* spp.), as well as the role of jellyfish, in eutrophicated systems; (2) the contribution of human influences on food webs, focusing on bottom-up (increased nutrient loading) and top-down (overfishing) effects. Results suggest that HAB-forming species and *Noctiluca* stimulate the microbial network, but reduce higher trophic levels such as commercially important fish species. Jellyfish act as a buffer in eutrophicated and overfished systems, as they retain nutrients from the water column, but their blooms lead to a massive accumulation of large phytoplankton organisms. Anthropogenic nutrient enrichment favors undesirable species because of their specific position in the food web, and this crucial position may explain their far-reaching effects. Finally, while it appears that overfishing of piscivorous fishes inhibited HABs and supported blooms of diatoms and other large algae in the past, the present-day loss of planktivorous fishes acts synergistically with nutrient enrichment in promoting HAB species, *Noctiluca* and jellyfish. These fundamental constraints, which are inherent in the generic structure of pelagic food webs, thus largely determine community dynamics in marine coastal ecosystems.

KEY WORDS: Food web · Eutrophication · Overfishing · Network analysis · Coastal ecosystem · Indirect effects · Harmful algal blooms · Gelatinous plankton

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Eutrophication and overfishing are threatening marine coastal communities worldwide. Visible consequences are harmful algal blooms and jellyfish outbreaks. The analysis of the pelagic food web structure by Vasas et al. (diagrammatically idealized above) helps us to understand the mechanisms by which eutrophication and overfishing can generate ecosystem shifts.

Illustration: Sándor Snepp; background from Google Earth™

INTRODUCTION

Coastal waters receive large amounts of anthropogenic nutrients from domestic and industrial effluents and agricultural runoff. Effects of coastal eutrophication are discernible at all trophic levels (Cloern 2001) and appear as direct and indirect qualitative changes in pelagic food webs, e.g. proliferation of harmful algal blooms (HABs), extinction of species at higher trophic levels, and reduced yields of harvestable fishes and invertebrates. These alterations of the food web struc-

*Email: vvasas@yahoo.com

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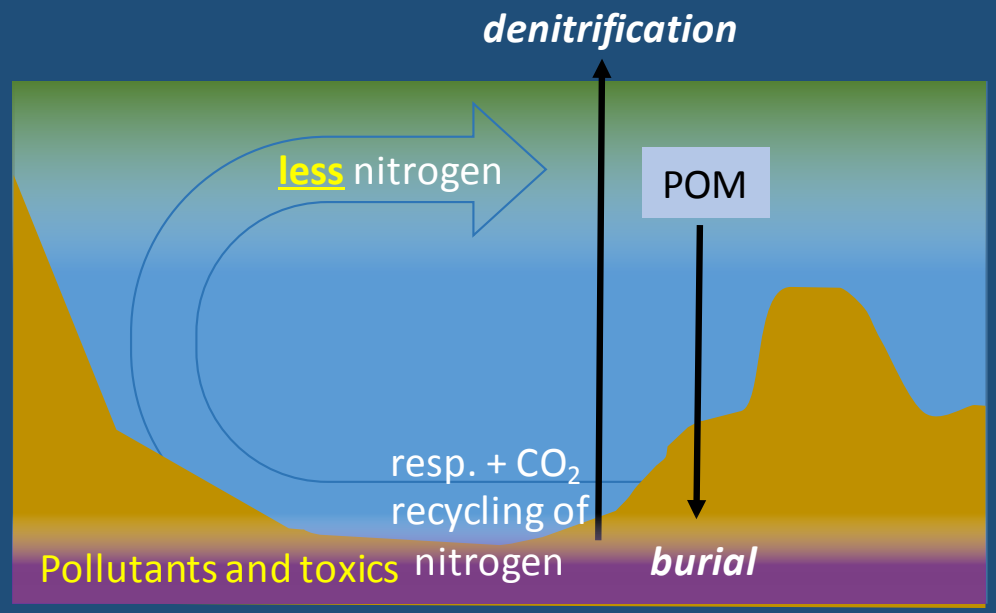
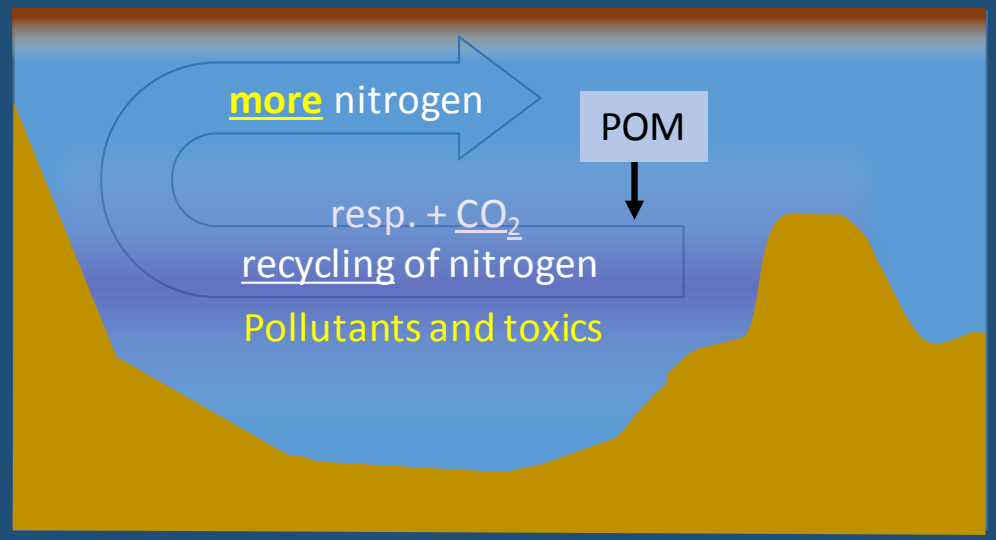


Fast sinking:
Diatom based food web,
recycling and burial at bottom



Slow sinking:
Microbial based food web,
recycling mid-water

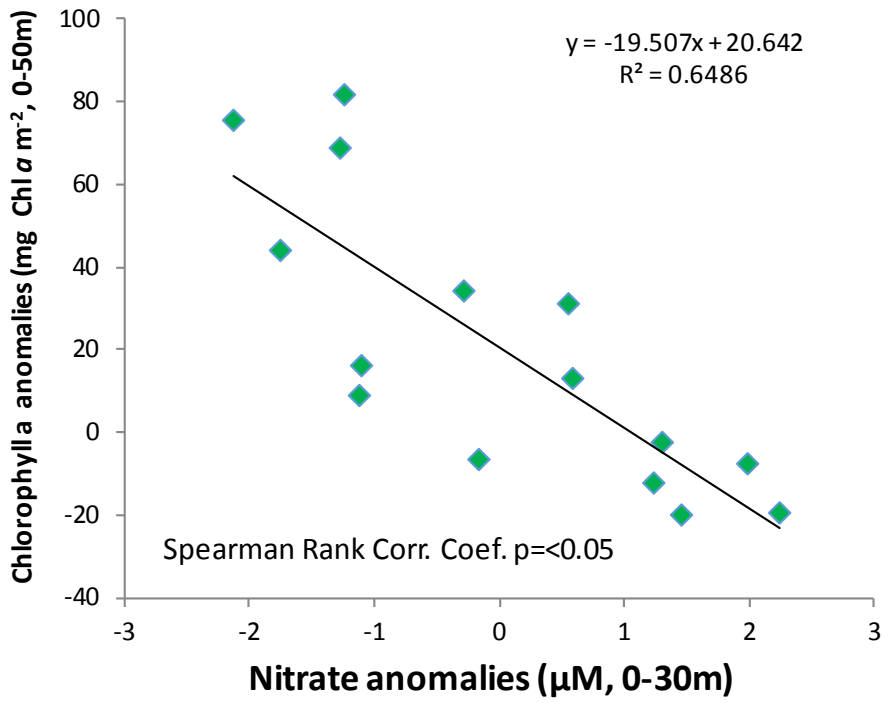
A different particle flux increases pelagic pollution/toxics and diminishes loss terms via the sediment

Can that increase nutrients at surface?

Upward shift of phytoplankton and remineralization in the water column. This results in loss of nitrogen losses (burial and denitrification)

Inter-annual variability in phytoplankton biomass could explain changes in macro-nutrients?

Nitrate and Chl *a*



Micro-zooplankton (<200 µm)

Micro-zooplankton grazers can remove the entire diatom standing stock each day!

Balance between microzooplankton grazing and phytoplankton growth in Dabob Bay (Hood Canal)…

Leising et al., 2005. The balance between microzooplankton grazing and phytoplankton growth in a highly productive estuarine fjord. Progress in Oceanography 67:366–383.

Predator-prey balance

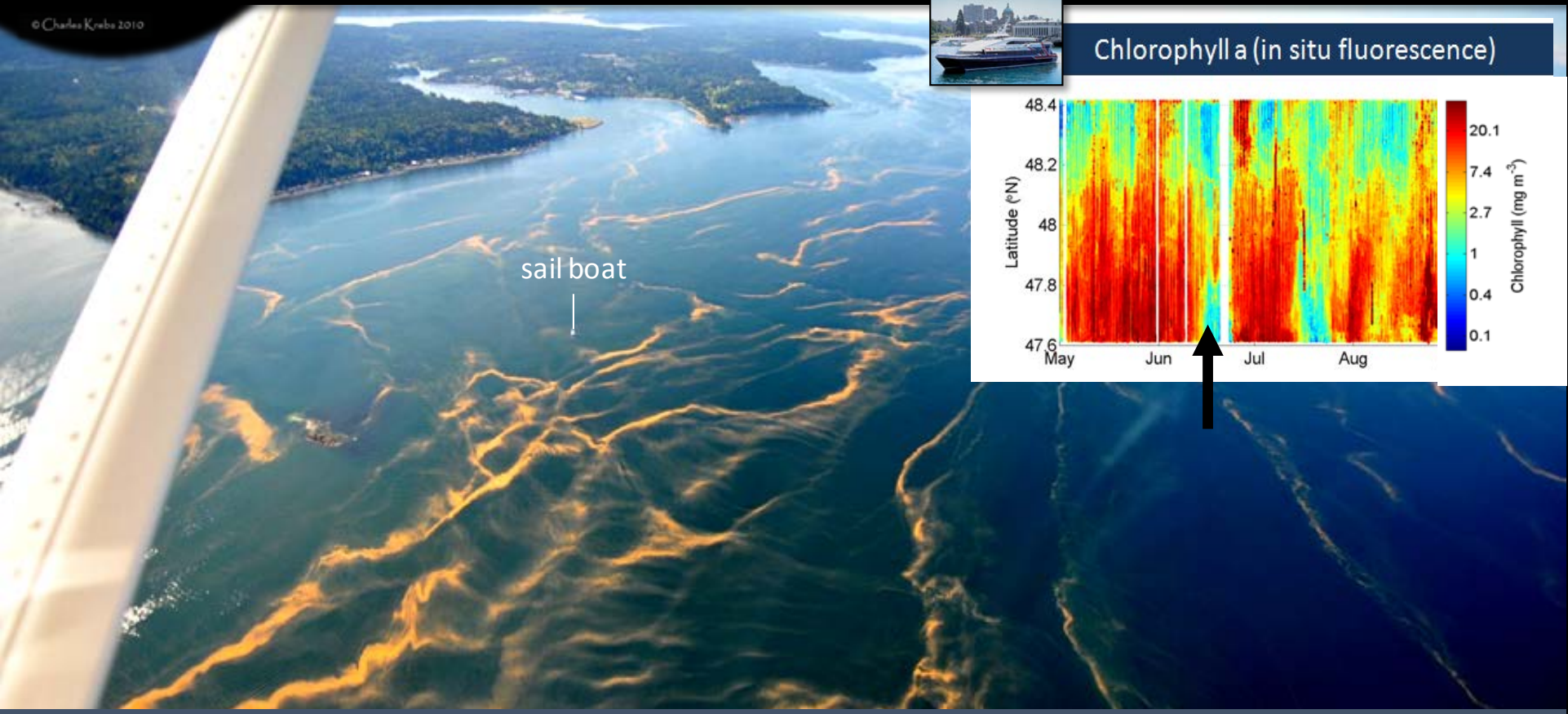
Shift could have significant effects that ripple through the foodweb

What controls phytoplankton inter-annual variability could also control nutrients in Puget Sound?

Noctiluca blooms are large (eutrophication indicator)

A strong competitor to copepods that feed on diatoms!

Food : <u>No food preference!</u> (*Diatoms, flagellates, detritus, nauplii, copepod and fish eggs…)*

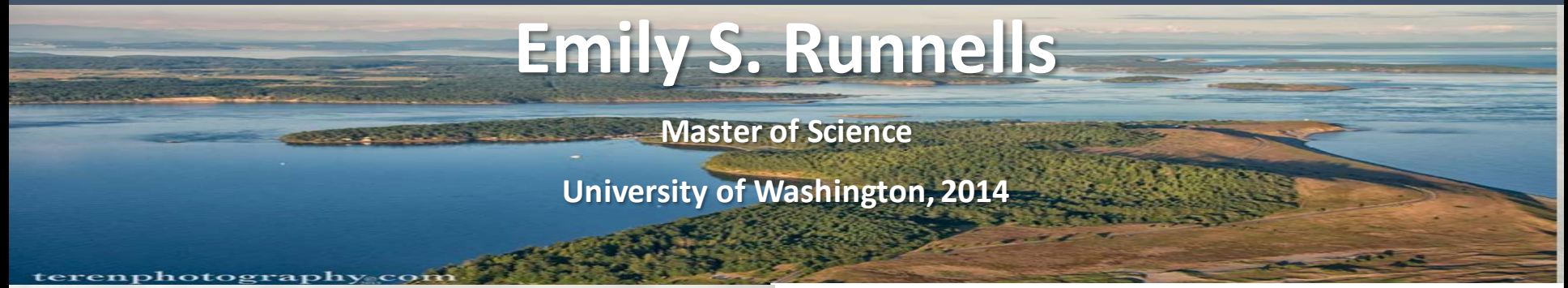


Noctiluca rapidly recycles sinking fecal pellets and retains nutrients in the surface.

(Kiørboe, Thomas 2003)

Noctiluca is occurring on a scale that is very visible to the naked eye

Decadal Changes in Seabird Foraging Activity, Forage Fish, and Plankton in Cattle Pass, San Juan Islands



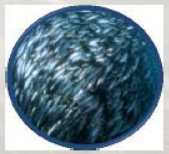
Emily S. Runnells

Master of Science

University of Washington, 2014

In Conclusion

1990s > 2010s

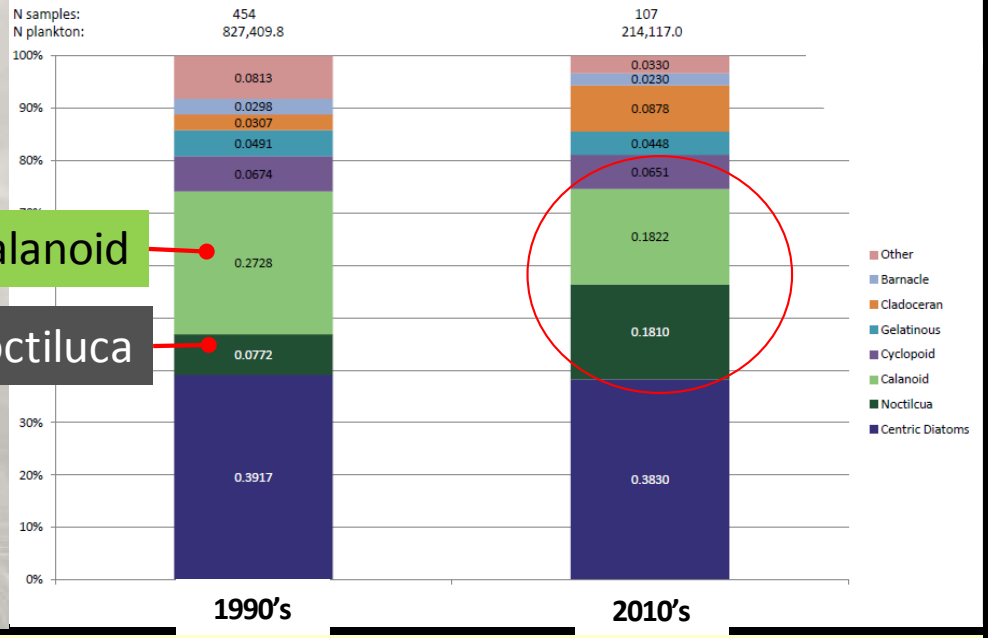


1990s > 2010s

1990s > 2010s for Calanoid Copepods

Shift in community composition

Plankton Community Composition



Calanoid ↓

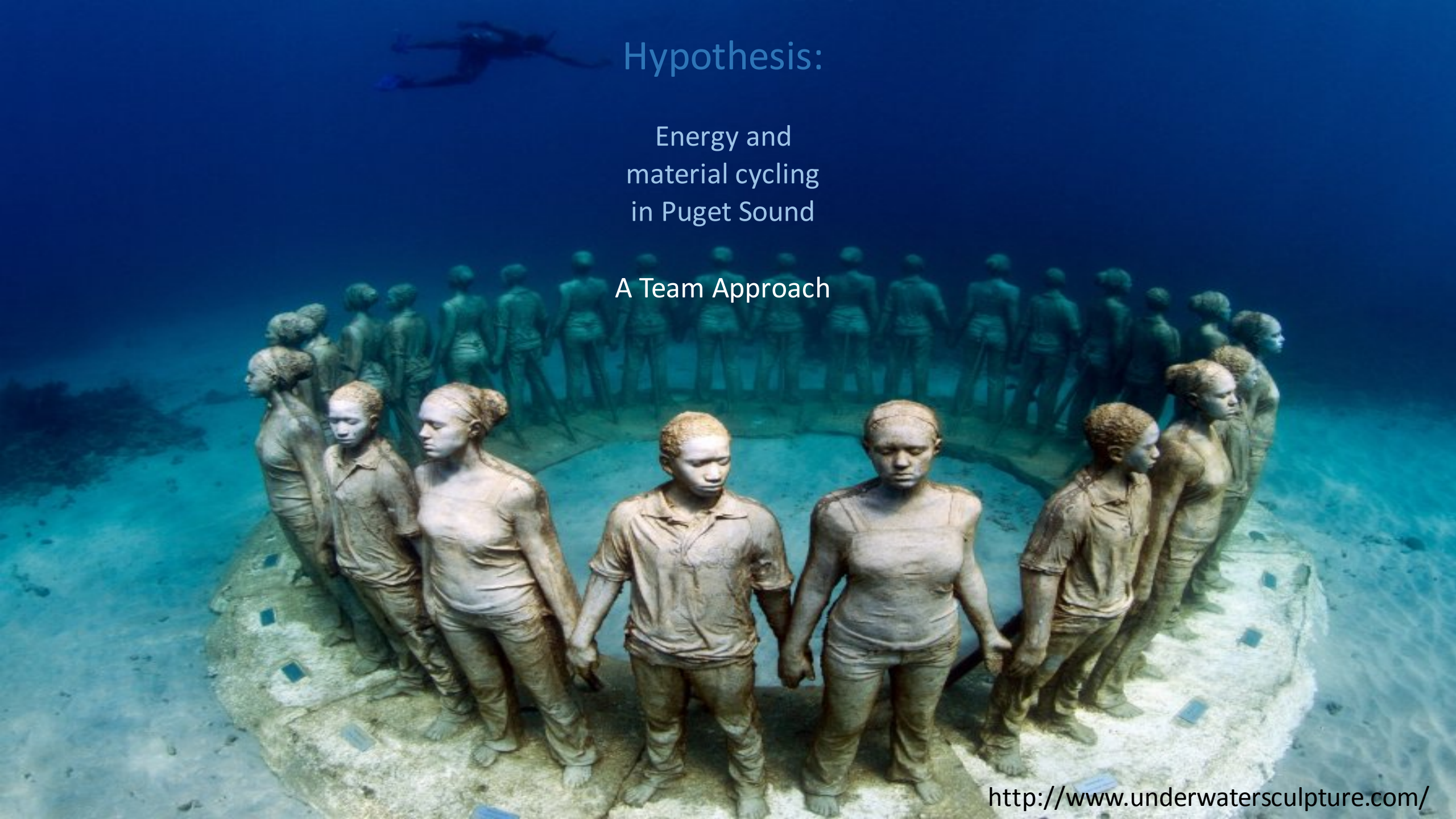
Noctiluca ↑

1) Change not limited to Puget Sound. 2) The effect potentially cascading to higher tropic levels.

Hypothesis:

Energy and
material cycling
in Puget Sound

A Team Approach



http://www.underwatersculpture.com/

R. flows, biogeochemistry and lower food web are relevant to the understanding of water quality trends in Puget Sound.

1. Changes in river summer flows affect the growth conditions of the lower levels of the marine food web.
   - Water retention time in Puget Sound
   - Nutrient quality, nutrient balance, nutrient dilution (WWTP gain in relative importance)

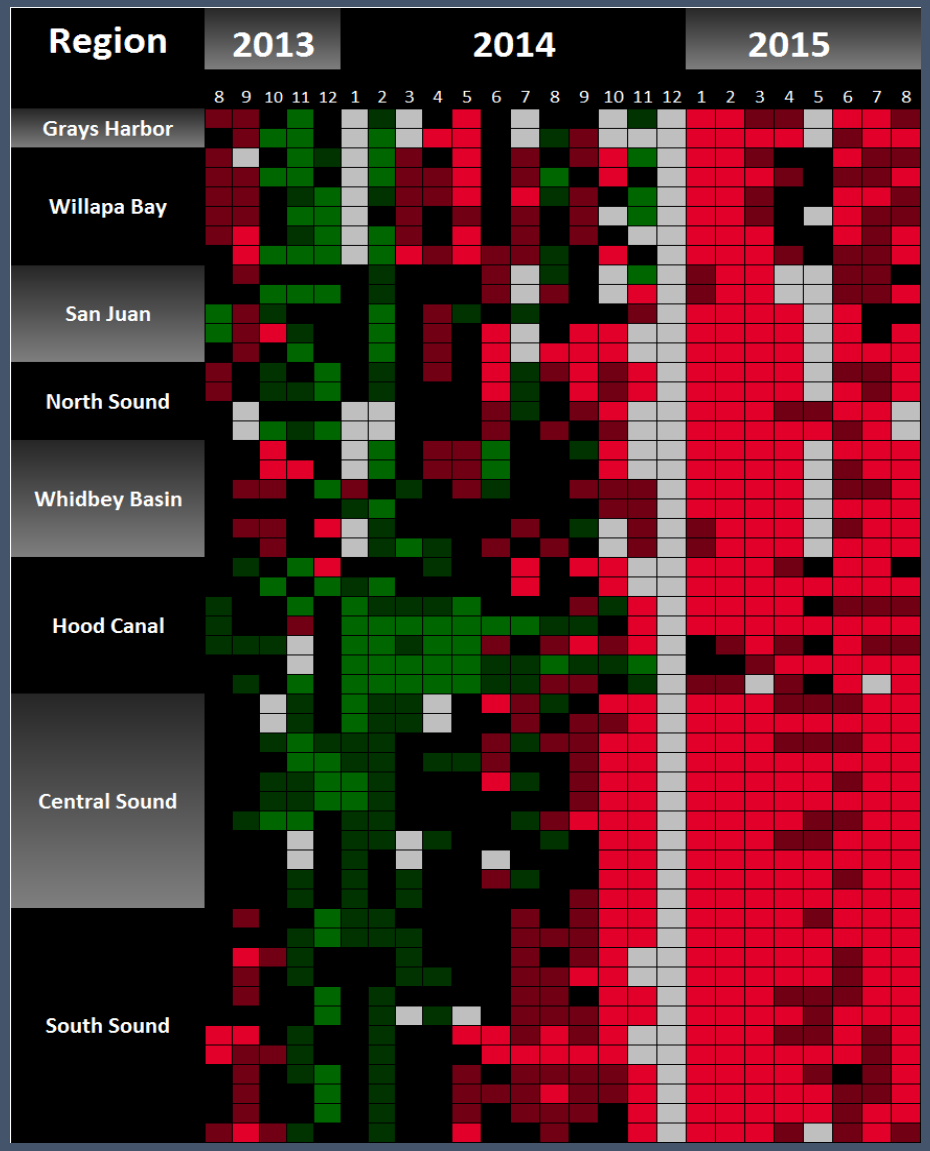
2. In summer, the microbial network has gained importance relative to the linear productive diatom-based food chain.

3. The org particle export to deeper water changed qualitatively and quantitatively in response to shifts in the lower-tropic levels of the foodweb.

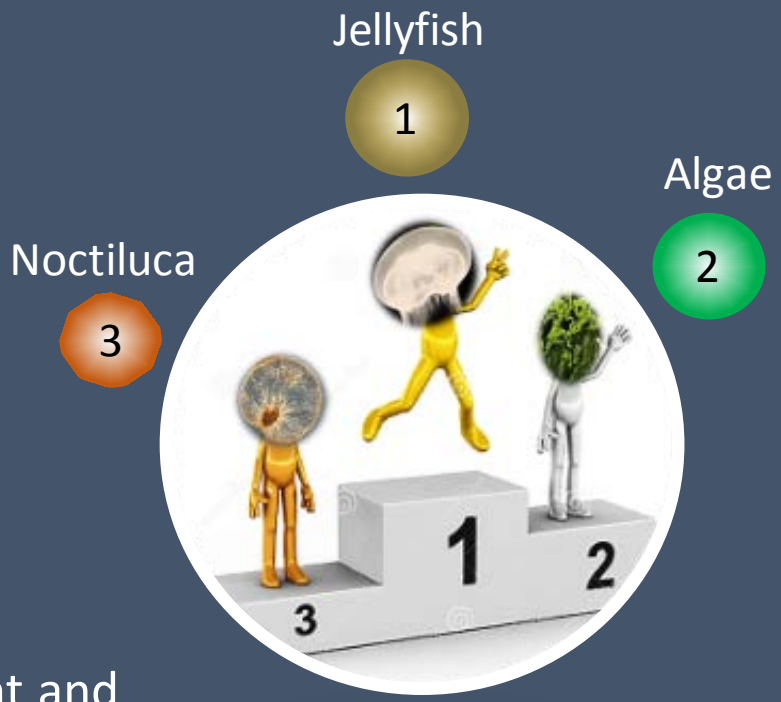
4. Mid-water biogeochemical processes increase while those of the sediment decrease (DO and toxics uptake, release of nutrient + CO_2 at intermediate depths).

Qualitative assessment of the effect of recent warm water on Puget Sound's food web.

Water temperature very high in 2015



The "Blob" and the future?



- Jellyfish were very abundant and frequent and persisted through the year.
- Macro-algae patches were extensive.
- Noctiluca & dinoflagellate blooms were sizable, but comparable to recent years.
- Events overlapped.

Picture by Mya Keyzers

Eyes Over Puget Sound:

We will continue to provide updates on developing conditions