Changes in nutrient ratios drive changes in pelagic and benthic assemblages, and benthic-pelagic coupling in Puget Sound: A compelling hypothesis linking water quality and the benthos.

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Introduction:
Analyses of Ecology’s long-term monitoring data indicate that changes in the cycling of organic material might occur that could affect phytoplankton, micro-zooplankton, and benthic communities. The long-term change has potential implications for marine food web structure, energy transfer, particle export, and higher trophic levels such as fish. A tentative hypothesis is presented combining observations about the significance of energy flow through the microbial food web that determines the outcome of energy available for higher trophic levels.

Results and Discussion:
Long-term increases in nitrogen concentrations (Fig. 1 A) and shifting nutrient ratios (Fig. 1 B) suggest human nitrogen inputs to Puget Sound. Yet, decreasing phytoplankton biomass (Fig. 2) in our monitoring network (Fig. 3) suggests large-scale changes in lower trophic levels of the pelagic food web that match a decline in the marine benthos (Fig. 4 A, B).

- Monitoring of lower food web dynamics remains a knowledge gap in Puget Sound and is indispensable to connect water quality to the marine food web!

Hypothesis: Nitrogen additions to Puget Sound cause nutrient ratios Si:N:P to change and indirectly might create a larger energy transfer through the microbial food web by promoting conditions for increased micro-zooplankton grazing. This has consequences for overall phytoplankton species composition, biogeochemical cycles, higher trophic levels food availability, and benthic-pelagic coupling.

Water Column

A. Nitrate anomalies (µM, 0-30m)

B. Si:DIN

EOPS, Aerial photography 6-17-2013

Fig. 1. Inter-annual changes in (A) nitrate and (B) the ratio of silicate to dissolved inorganic nitrogen (Si:DIN) to be a result of anthropogenic nitrogen additions to the system. From 1999 to 2003, inter-annual patterns of nitrate (A) changed in the surface waters. Averaged, this level of dissolved inorganic nitrogen (Si:DIN) decreased. Nearshore stations were calculated by the difference between maximum (blue line) seasonal baseline by dissolved inorganic nitrogen levels at the different stations. The regression line is calculated from the 10-year mean of the year and station location (17 core stations) (see map Fig. 3).

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Results and Discussion:
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Human pollution causes nutrient imbalances (Fig. 1 B) and plays a role in the shift from diatom to flagellate assemblies [1]. Large blooms of the dinoflagellate Noctiluca (Fig. 5) in our marine network (2) are consistent with the increase in nitrogen (Fig. 1 A). In contrast, a decrease in sub-surface phytoplankton biomass (Fig. 6), particularly in the late summer (Fig. 7), contradicts nitrogren trends.

- Could long-term observations indicate that food web dynamics alter nitrogen concentrations in the water?

A tentative correlation between nitrate and phytoplankton biomass** implies that phytoplankton can control nitrate levels in Puget Sound. Therefore, mechanisms that control phytoplankton biomass could increase nutrient concentrations.

- We present several observations that could indicate changes in the microbial food web in Puget Sound.

Micro-phytoplankton grazers (>30µm) control phytoplankton biomass in the central and Hood Canal (1) and can consume the diatom biomass once per day (6). We confirm that phytoplankton biomass and ammonium track each other following blooms (Fig. 7). We propose that findings in central Puget Sound may apply to the larger Puget Sound region.

- A shift from a copepod - to a micro-zooplankton-dominated food web can reduce the energy flow to higher trophic levels (more trophic levels) and reduce carbon export to depth.

- The export of organic material from a micro-grazer-dominated food web retains nutrients near the surface (6), it differs from the organic-carbon-rich, and fast-sinking fecal pellets of a copepod-dominated food web.

- Evidence of a potentially reduced carbon export to depth comes from Ecology’s long-term benthic monitoring program. Puget Sound-wide evidence of reduced phytoplankton biomass and strong micro-zooplankton grazing could explain the increased carbon increase via increased top-down grazing control on

- Reduced phytoplankton biomass and strong micro-zooplankton grazing could explain the increase in organic material for the marine food web. The trend is found on site and seasonal anomalies calculated as in Figs. 1-3.

Fig. 2. Marine long-term monitoring locations in Puget Sound (a) and Puget Sound-wide averages over the period 1999 to 2013. Aerial photography April 12, 2013. (©) EOPS. All 6 Regions = significant. Regions Sampled using random sampling design

References:
[1] Carey et al., 2014
[4] Verity et al., 1996a; Nejstgaard et al., 1997; Landry et al., 2000a; Calvet, 2001; Suzuki et al., 2002
[7] Carey et al., 2014

Fig. 3. Changes in benthic macro-invertebrate total abundance and taxa richness (both % of Whidbey Basin) across Puget Sound between the years 1970 and 2012. Data are presented in a bar graph format, with the bars indicating the relative abundance and richness of taxa across the 6 regions of Puget Sound.

Fig. 4. (A) Changes in benthic macro-invertebrate total abundance and taxa richness (both % of Whidbey Basin) across Puget Sound between the years 1970 and 2012. Data are presented in a bar graph format, with the bars indicating the relative abundance and richness of taxa across the 6 regions of Puget Sound.

Fig. 5. Changes in the relative importance of spring and late summer phytoplankton biomass. Long-term trends in chlorophyll a (sping bloom) are decreasing (red). The decrease is partially driven by a decline in the late summer phytoplankton biomass (blue), yet spring blooms are unchanged (black). Data were calculated as in Fig. 1.

Fig. 6. Nitrate anomalies (µM, 0-30m)

Fig. 7. Seasonal patterns of sub-surface phytoplankton, ammonium, and Noctiluca. Seasonal patterns of sub-surface phytoplankton, ammonium, and Noctiluca (red) concentration across Puget Sound (in the water column) and in the Hood Canal (in the water column). Both phytoplankton and ammonium are proxies for algal standing stock and ammonium export by sinking fecal pellets. Noctiluca blooms (spring and late summer bloom) are tracked by peaks in ammonium. Seasonal data are plotted on 10-year Puget Sound-wide average over the period 1999 to 2012. Data were sampled at 31 stations, 15 days per year at targeted stations.

Fig. 8. Hypothesis: Changes in the Marine Food Web and Energy Transfer in Puget Sound

Fig. 9. Noctiluca blooms at surface in very long-living location: Between North Hood Island and Whidbey Island (April 12, 2013). (©) EOPS. All 6 Regions = significant. Regions Sampled using random sampling design

Fig. 10. Nitrate anomalies (µM, 0-30m)

Fig. 11. Changes in benthic macro-invertebrate total abundance and taxa richness (both % of Whidbey Basin) across Puget Sound between the years 1970 and 2012. Data are presented in a bar graph format, with the bars indicating the relative abundance and richness of taxa across the 6 regions of Puget Sound.

Fig. 12. Nitrate anomalies (µM, 0-30m)

Fig. 13. Changes in benthic macro-invertebrate total abundance and taxa richness (both % of Whidbey Basin) across Puget Sound between the years 1970 and 2012. Data are presented in a bar graph format, with the bars indicating the relative abundance and richness of taxa across the 6 regions of Puget Sound.