Increasing nutrients, changes in algal biomass, and large Noctiluca blooms in Puget Sound: Is eutrophication fueling the microbial food web?

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The Story

Because of its proximity to the cold, nutrient-rich Pacific Ocean, Puget Sound is considered to have a diatom-based food web with a relatively short food chain supporting higher trophic levels. Phytoplankton respond to nutrient availability, composition, and the physical character of the water column. Through our long-term monitoring program (Fig. 1) and aerial surveys, we found that nutrient concentrations in Puget Sound have significantly increased and nutrient ratios have steadily changed over the last 13 years (Fig. 3) despite the strong influence of the ocean on Puget Sound water quality (Fig. 2).

We frequently document extensive algal blooms, Noctiluca blooms, and jellyfish masses at the surface (Fig. 4). Many of the phytoplankton blooms show high abundances of autotrophic flagellates. In contrast, depth-integrated algal biomass (chlorophyll *a*) shows a significant steady decline from 1999 to 2011 (Fig. 3C). These seemingly opposing observations - high algal biomass and Noctiluca at the surface and decreasing biomass below the surface - could be clues to a shifting food-web structure and nutrient fluxes in Puget Sound. The cause and impacts of these trends are discussed in the context of human pressures, climatic and oceanic boundary conditions, and planktonic food-web structure.

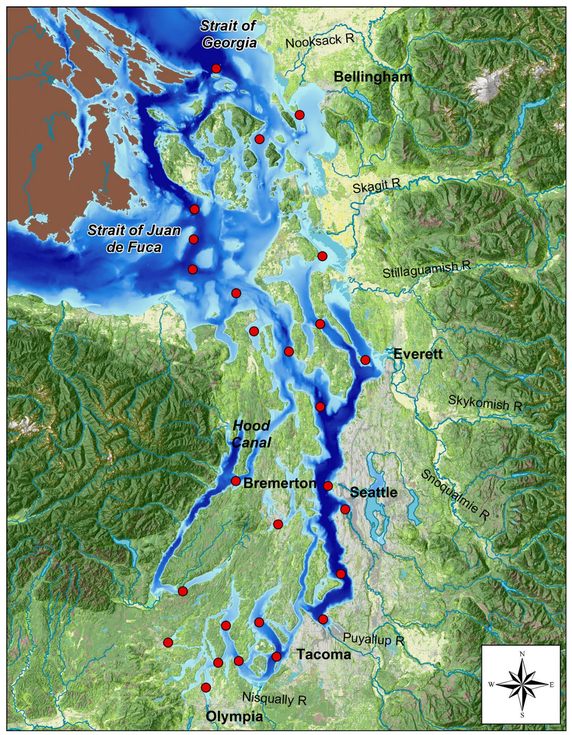

Figure 1. Long-term monitoring stations in Puget Sound.

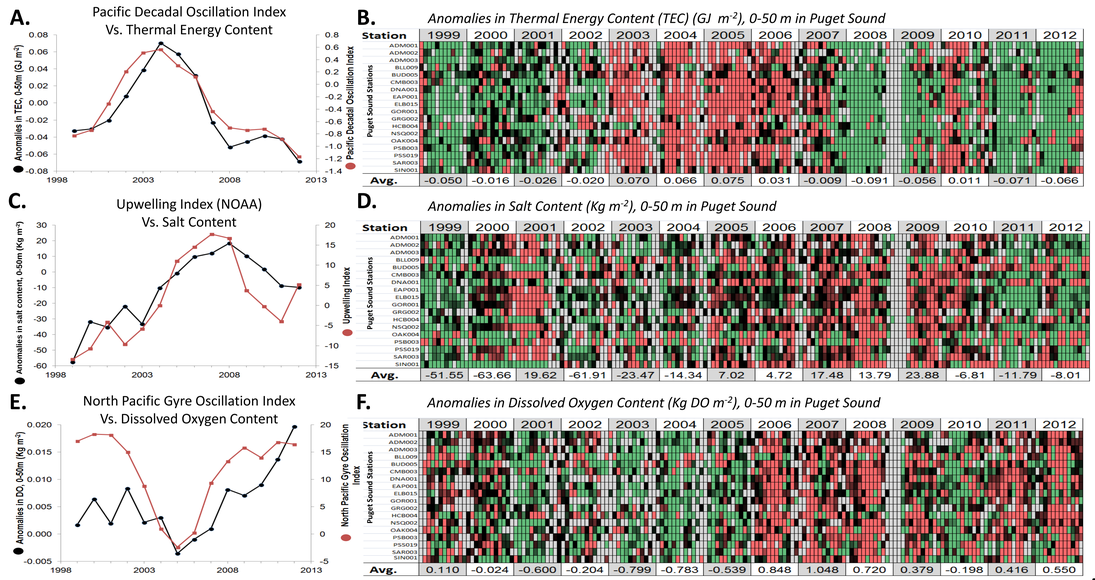

Figure 2. The influence of ocean boundary conditions on Puget Sound water quality variables. Depth aggregated results are presented as anomalies relative to site-specific median baselines established from 1999 to 2008. A) Yearly Puget Sound-wide averaged anomalies for thermal energy content from 0-50 m correlate with the Pacific Decadal Oscillation Index (series shown as 3-year running averages). B) Monthly anomalies for thermal energy content at individual stations; red denotes anomalies > 75th percentile; green denotes anomalies < 25th percentile; black values are near the median; and gray denotes no data. C) Correlation of the Upwelling Index with yearly averaged anomalies for salt content. D) Monthly anomalies for salt content at individual stations. E) Correlation of the North Pacific Gyre Oscillation Index with yearly averaged anomalies for dissolved oxygen content. F) Monthly anomalies for dissolved oxygen content at individual stations.

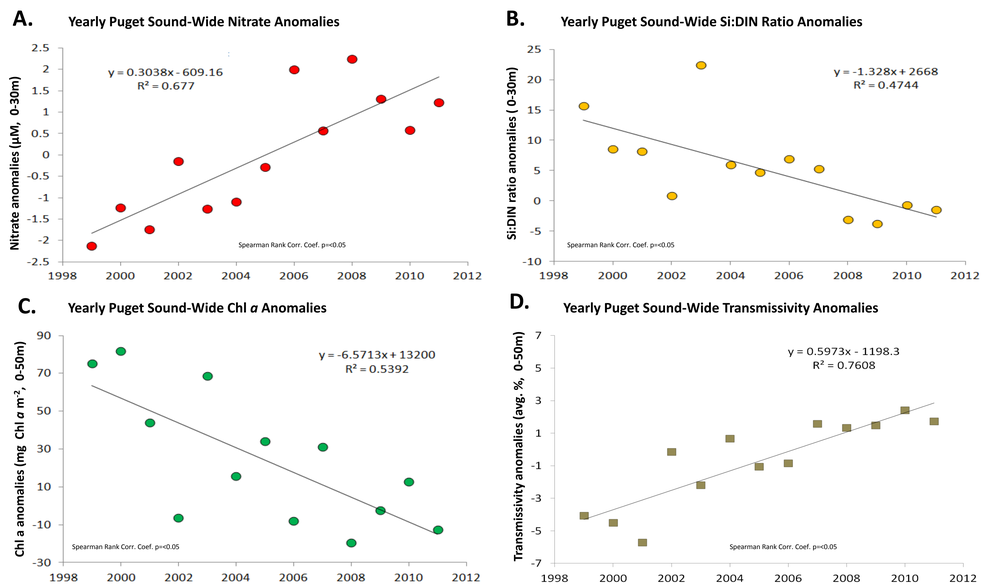

Figure 3. Long-term trends in yearly Puget Sound-wide anomalies. Nitrate (A) significantly increased at a rate of 3 µM per decade resulting in a significant decrease of ~10 units per decade in the Si:DIN ratio (B), yet overall sub-surface chlorophyll a (C) has declined by 65 mg per square meter. Transmissivity measurements (D) independently confirm the decline of chlorophyll a with a significant increase in water clarity.

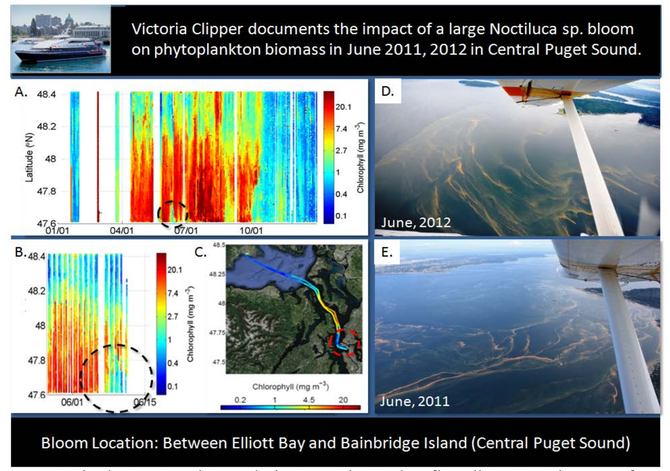

Figure 4. The heterotrophic and photosynthetic dinoflagellate Noctiluca *sp. formed intense blooms in June 2011 (E) and 2012 (D) causing a rapid decline of* in situ *chlorophyll a concentrations measured by surface sensors on the Victoria Clipper ferry (A). The more localized and intense bloom in 2012 reduced chlorophyll a concentrations between 47.6° and 47.8° North (B) along the ferry transect (C).*

Findings and Summary

- Ocean boundary conditions significantly drive water quality in Puget Sound (Fig. 2), yet macro-nutrients continued to steadily increase independent of ocean variability (Fig. 3A).
- Changes in the Si:DIN ratio are considered a sign of human nutrient inputs (Harashima, 2007).
- A decline in the silicate to dissolved inorganic nitrogen (Si:DIN) ratio (Fig. 3B) paired with an increase in nitrate (Fig. 3A) will increasingly favor the growth of non-silicified phytoplankton species such as the dinoflagellate *Noctiluca*.
- Over the last two years, the Department of Ecology's Eyes Over Puget Sound reports (EOPS) have documented extensive near-surface blooms of *Noctiluca* and other dinoflagellates in Puget Sound (Fig. 4D, E).
- *Noctiluca* is frequently associated with eutrophication of coastal environments (Vasas et al., 2007)
- *Noctiluca* blooms reduce chlorophyll *a* concentrations in the water column. The impact of *Noctiluca* grazing on phytoplankton biomass appears in Ecology's Victoria Clipper ferry transect data (Fig. 4A, B).
- Despite large, frequent surface blooms of dinoflagellates, chlorophyll *a* concentrations have significantly declined (Fig. 3C) and sub-surface clarity has significantly increased (Fig. 3D).
- Changes in the lower food web structure may have much larger implications for ecosystem functioning.

References

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