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Sasha Kramer, 2016

Phytoplankton require certain essential nutrients for growth. The Redfield ratio (Redfield, 1934) dictates an ideal element proportion of 106 carbon: 16 nitrogen: 1 phosphorus in order to maintain balanced phytoplankton growth through photosynthesis (Li et al., 2008). Under typical conditions, the concentration of nutrients present in the water directly controls the attainable phytoplankton yield (i.e. one inorganic nitrogen from nitrate yields one organic nitrogen in cellular form). While plankton that are starved of nutrients tend to die off quickly, plankton that are simply nutrient limited can adjust to constant but low levels of nutrient concentration (Cullen et al., 1992), often by adjusting their Redfield ratio. As an essential nutrient, nitrogen is a limiting factor for phytoplankton growth in the ocean (Dugdale, 1967). In oceanic and coastal ecosystems, dissolved nitrate (NO_3^-) is the most commonly available form of nitrogen (Zielinski et al., 2011). The formation of nutrients through microbial processes such as denitrification in deep water creates a source of nitrogen in the deep ocean (Arrigo, 2005). Phytoplankton growth is limited by both light and nutrients: therefore, the transport of nitrate into the euphotic zone controls the rate of primary production. In the Gulf of Maine, nitrate concentration varies with depth and season. Water density is determined by temperature and salinity; these qualities in turn control the depth of mixing and stratification, and thus the depth of the nitracline, the depth at which the high-nutrient deep waters are found (Townsend, 1998).

An instrument known as the *In Situ* Ultraviolet Spectrophotometer (ISUS by Satlantic, Inc.) offers the ability to quantify nitrate concentrations based on optical properties. The instrument specifically measures the magnitude of absorption of ultraviolet light by dissolved nitrate molecules in the water. The concentration is determined from the ratio of the measured absorption coefficient to the molar absorption coefficient of nitrate. The ISUS is placed directly into the water at a site of specific interest—it measures the absorption and computes the nitrate concentration at this site every hour.

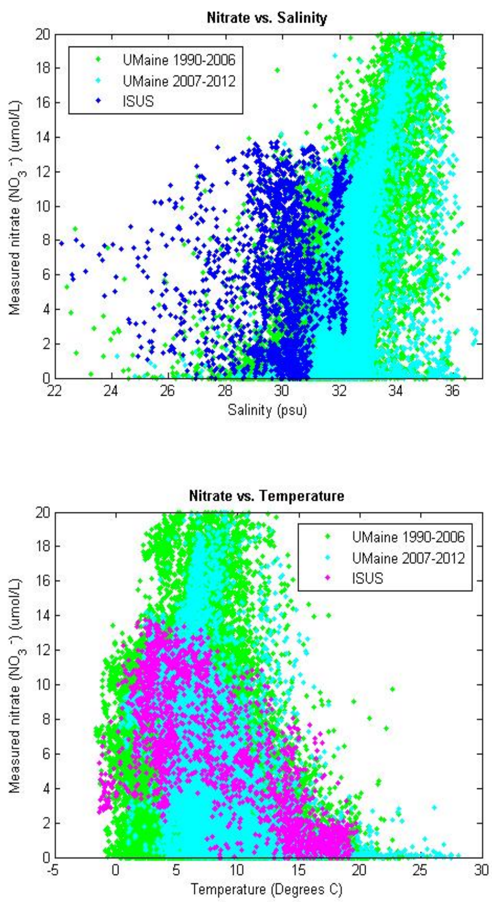

Figure 1. Nitrate vs. salinity and nitrate vs. temperature. Data for the Gulf of Maine 1990-2006 in green, 2007-2012 in cyan, and data for Harpswell Sound 2007-2012 in blue (salinity) or pink (temperature). (*Gulf of Maine data from Rebuck et al., 2009*).

This method of analysis gives superior stability, precision, and accuracy in data compared to a typical water sample analysis in a laboratory setting (Johnson & Coletti, 2002). For the past 4 years, an ISUS sensor has been deployed on the Bowdoin Buoy in Harpswell Sound collecting hourly observations of nitrate concentration concurrent with hourly observations of chlorophyll fluorescence (which can be used as a proxy for phytoplankton biomass).

Once per week between May 21, 2014 and June 18, 2014, measurements of the depth distribution of salinity, temperature, density, chlorophyll fluorescence, and dissolved oxygen content were taken at the Bowdoin Buoy. Water samples were collected at five discrete depths each week, and were returned to the lab for analysis of chlorophyll concentration on the Turner fluorometer and nutrient concentration on the SmartChem. These laboratory analyses were used to calibrate and validate the buoy- and boat-based optical observations.

The analysis of nitrate observations was performed in two phases. First, the variability in nitrate measured on the buoy since 2007 along with co-located discrete water samples was compared to a published historical dataset in order to place Harpswell Sound in the broader context of the Gulf of Maine. Second, the timeseries buoy observations of nitrate and chlorophyll were analyzed to determine temporal covariability.

The historical nutrient and water quality data for the Gulf of Maine gathered by Rebuck et al. 2009 for 1990-2009 (in addition to unpublished data from 2010-2012) provided a broader spatial and temporal range for comparison with data from the Bowdoin Buoy in Harpswell Sound, Maine from 2007-2012. The historical nutrient data for the Gulf of Maine were measured in the lab; the nutrient data for Harpswell Sound was measured by the ISUS. There are relatively few match-ups for validation, but these points did show the correlation between the two methods. However, the similarity of the distribution of measured nitrate from water samples in lab and the *in situ* temperature and salinity characteristics of the sampled waters were very coherent with those measured by the ISUS, providing some quantitative validation. Future analysis of the ISUS data from summer 2014, in comparison to nutrient data from the water samples taken over the course of this summer, will further justify the validity of the ISUS data.

A clear relationship between nitrate concentration and water temperature and nitrate concentration and salinity for both the Gulf of Maine and Harpswell Sound emerged (Figure 1). The highest concentrations of nitrate are found in the saltiest water (between 30-34 psu) and coldest water (between 3 and 12 degrees Celsius). This pattern was observed both generally in the Gulf of Maine and more specifically in Harpswell Sound, indicating that processes observed in Harpswell Sound are connected to broader scale oceanographic processes. These results also indicate that nutrients generated by deep ocean processes are dominant and river sources are negligible, a result that is not found in most areas.

For both chlorophyll data and ISUS nitrate data, 2010 proved to be a model year with a clear and thorough timeseries from early February to late November. After analysis, the relationship between nitrate and chlorophyll showed a strong preliminary correlation of chlorophyll concentration (once again, as a proxy for phytoplankton biomass) increasing as nitrate concentration decreases (Figure 2). The low levels of phytoplankton consume the high levels of nitrate and therefore, as the bloom grows, the concentration of nitrate decreases proportionally.

The expected dependence of chlorophyll concentration on nitrate concentration becomes incredibly clear through these results, similar to the results presented in Li et al., 2010. The ISUS data from 2007-2012 requires further processing in order to fully explore the relationship between chlorophyll and nitrate concentration on a pertinent timescale to bloom growth dynamics. While it is possible to construct a full time-series from the newly manipulated ISUS dataset after this summer work, it would be important and interesting to further examine the relationship between chlorophyll concentration and nitrate concentration in Harpswell Sound on daily, weekly, seasonal, and yearly timescales. This next step of investigation will require more time for data processing, but the work done this summer to validate the ISUS data and show the correlation between Harpswell Sound and the Gulf of Maine is incredibly promising for future work.

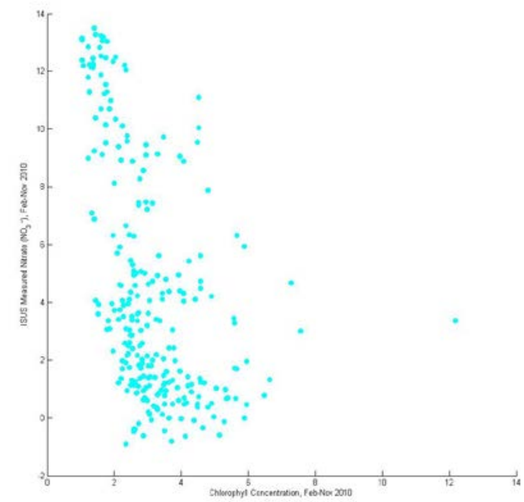

Figure 2. Chlorophyll concentration vs. ISUS measured nitrate concentration for the year 2010.

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