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Analysis of interdecadal trends in chlorophyll and temperature in the Central Basin of Long Island Sound

Edward Rice [1], Gillian Stewart*

School of Earth and Environmental Sciences, Queens College, CUNY, Flushing, NY 11367, USA

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ABSTRACT

Few coastal systems have time series data that allow researchers to examine the impact of two important stressors on estuarine ecosystems: climate change and eutrophication. The Central Basin of Long Island Sound (LIS), between New York and Connecticut, is one such system. LIS has seen annual average surface temperatures increase at a rate of 0.03 °C/yr since 1976, with increases most pronounced during summer and early fall. Over the past 15 years, annual stratification (difference between mean annual surface and bottom temperatures) has also increased at the same rate. Despite expansion of waste-water treatment and declining point-source nutrient input, LIS remains eutrophic. An increase toward historic mean annual chlorophyll concentration has occurred since a minimum in the early 1990s, driven in part by higher fall chlorophyll values. There is also an apparent shift in the seasonality of phytoplankton blooms, with more frequent fall chlorophyll peaks and reduced early spring peaks relative to the 1950s. Non-metric Multidimensional Scaling (NMDS) analysis of phytoplankton communities from fall and summer 2002–8 indicated that cyanobacteria and flagellates are associated with higher amounts of chlorophyll at higher temperatures during these two seasons. These results suggest that as surface temperatures continue to increase, smaller cells and flagellates may maintain chlorophyll values at higher levels despite decreased or static surface nutrient concentrations in this system.

1. Introduction

A common paradigm for understanding the impact of climate change, based on observations of the tropical ocean, is that higher surface ocean temperatures will reduce productivity via increased stratification and nutrient limitation (Behrenfeld et al., 2006). However, the interaction between temperature, nutrients and productivity in coastal systems is not necessarily constrained by this paradigm (e.g. Richardson and Schoeman, 2004). Instead, temperature changes can result in a changing phytoplankton community, which in turn utilize nutrients differently. For example, Morán et al. (2009) predicts that as the North Atlantic warms, picoplankton can be expected to become more dominant, independent of nutrient availability and stratification. Hilligsøe et al. (2011) also found that temperature exerted a more significant effect than nutrient availability on interannual variation in phytoplankton community structure at open ocean stations. This group also found that smaller phytoplankton groups dominated at higher temperatures. For 28 coastal systems over 3 to 4 decades, Carstensen et al. (2011) found the ratio of chlorophyll (Chl *a*) concentration to total nitrogen (TN) in the water column was increasing with time. While the relationship between nutrients and phytoplankton biomass was complicated by other factors such as light availability, other limiting nutrients, and hydrodynamic and community differences, the only consistent trend across all systems was a near-doubling of the Chl *a*/TN ratio. Carstensen et al. (2011) suggested that this doubling was due to shifts in phytoplankton communities, as a result of climate change or anthropogenic impacts. The implication of these studies is that climate change could promote a community shift toward smaller phytoplankton with higher nutrient utilization efficiency, frustrating efforts by managers to decrease eutrophication by limiting nitrogen input.

To understand Chl *a* trends in warming coastal systems, studying the impact of reducing nutrient levels alone may be insufficient. Changes in community structure should also be included. This paper will examine the interaction of temperature, community structure, and Chl *a* levels in a major estuarine system, Long Island Sound (LIS), which is influenced by eutrophication and undergoing warming. LIS is a semi-enclosed, partially-mixed estuary with

* Corresponding author.
E-mail addresses: ricedward@gmail.com (E. Rice), gstewart@qc.cuny.edu (G. Stewart).
[1] Tel.: +1 718 997 3104.

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Western, Central, and Eastern basins (Fig. 1). The Central Basin of LIS was not included in the Carstensen et al. (2011) review, but is undergoing a long-term warming trend while managers strive to reduce point-source nutrient inputs and control summertime hypoxia – a persistent phenomenon in the Western and Central Basins. Geostrophic forces, semidiurnal tidal currents and complex bathymetry result in weak but distinct gyres in the Western and Central Basins – increasing residence time of nutrients and organic matter in these basins (Schimmel et al., 1999). Despite these gyres and freshwater inputs entering the northern shore in each basin, salinity gradient decreases from 35 in the east to 23 in the west (Schimmel et al., 1999). An opposite trend occurs with productivity, which increases from 32 ± 14 mol O_2/m^2-yr in the east to 82 ± 25 mol O_2/m^2-yr in the west (Goebel et al., 2006). The Western and Central Basin of LIS continue to experience periods of eutrophication and hypoxia. Unlike eutrophication, hypoxia is primarily a seasonal phenomenon – but also influenced by a number of factors. During fall, winter, and spring, dissolved oxygen concentrations are primarily determined by water temperature and stratification. During summer, wind stress, the size of the previous spring bloom, nutrients, and river discharge appear to be more important factors in predicting hypoxia extent and intensity (Lee and Lwiza, 2008).

To quantify and understand extensive summertime hypoxia, the Connecticut Department of Energy and Environmental Protection (CT DEEP) has been conducting surveys of surface and bottom temperature, salinity, dissolved oxygen (DO), total suspended solids, major nutrients and Chl *a* in LIS since 1991 (http://www.depdata.ct.gov/maps/lis/liswqmap.htm). Seventeen stations are typically visited monthly. During summer months, an additional 31 stations are visited bi-weekly and only CTD-based measurements are taken (i.e "hypoxia surveys"). The Millstone Power Station Environmental Laboratory has been keeping temperature records for the Eastern Basin of LIS since 1976 (DNC, 2010). The National Oceanic and Atmospheric Administration (NOAA) laboratory at Milford, CT has been keeping temperature records from Milford Harbor, in the Central Basin of LIS, since 1948. Several additional smaller scale surveys are described in Table 1.

The goal of this paper is to examine recent trends in LIS Central Basin Chl *a* in the context of climate change and nutrient reduction via expansion of secondary wastewater treatment. Earlier historic surveys from the 1930s, 50s, and 80s are referenced for context. Surface salinity, dissolved oxygen, photosynthetically available radiation (PAR), temperature, nutrient, Chl *a* and pigment data from the CT DEEP survey are analyzed with linear trend analysis and non-linear non-metric multidimensional scaling (NMDS). These analyses highlight possible relationships between warming temperatures, Chl *a* and community structure in the Central Basin of LIS.

2. Methods

2.1. Surveys

To establish the historical context for the trend analysis of physical and biological parameters of LIS, previous surveys of the Central Basin (Fig. 1) were obtained from archival and published sources. Temporal coverage of the Riley (1941), Riley and Conover (1956), Vishniac and Riley (1961), and Peterson (1985) surveys was annual and varied in intensity, scope, and specific location, but these studies provide the only baseline data to compare to current trends (Table 1). Although highly relevant and informative, we did not include the data from Capriulo et al. (2002) in our analysis since the time range (1993–5) is contemporaneous with the longer CT DEEP (1991–2010) dataset. The earliest survey (Riley, 1941) was conducted from June 1938–August 1939, generally offshore of the NOAA laboratory in Milford, CT. The next survey by Riley and Conover (1956) occurred between March 1952 and March 1954. Half of the stations were visited weekly, the other half were visited bi-weekly. Vishniac and Riley (1961) surveyed monthly temperature and Chl *a* from March 1958–April 1959 from 3 stations near Stony Brook, NY. Peterson (1985) also surveyed the waters near Stony Brook, monthly from March 1982–July 1983.

From January 1991 to April 2010, the CT DEEP stations were typically visited monthly, except for summertime hypoxia surveys when a bi-weekly schedule was followed. For all surveys, surface measurements of Chl *a*, temperature and nutrients were made at least 2 m from the surface of the water and bottom measurements were made at most 2 m above the bottom. Pigment data, derived from High Performance Liquid Chromatography (HPLC) analysis by Liu and Lin (2008) was provided by the CT DEEP and derived from stations H4, I2 and J2. These stations span the Central Basin (depth typically 10–20 m) from its western end (H4) to its eastern end (J2), with I2 being roughly located in the center. This data is only

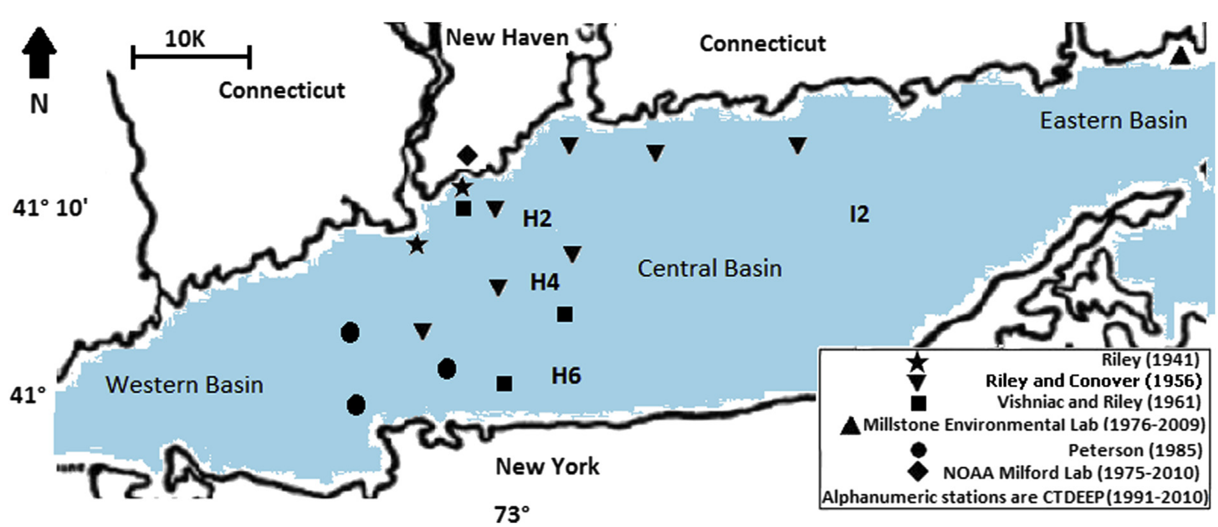

Fig. 1. Map showing location of historical and current surveys of the Central Basin of Long Island Sound. Western and Eastern Basins are also shown with the location of the long-term temperature survey in the Eastern Basin.