NYSG Completion Report

Report Written By: Darcy J. Lonsdale, Christopher J. Gobler, and Jennifer George **Date**: August 6, 2012

A. Project Number and Title: R/CMB-36-NYCT, Impacts of Climate Change on the Export of the Spring Bloom in Long Island Sound

B. Project Personnel: Co-P.I.s Darcy J. Lonsdale and Christopher Gobler; NYSG Scholars Jennifer George, Xiaodong Jiang, and Laura Treible

C. Project Results::

C1. Meeting the Objectives:

Objective 1. To conduct field studies of the physical and chemical characteristics, phytoplankton and zooplankton species composition and abundance, primary productivity and grazer-induced mortality rates of phytoplankton, and organic matter export in LIS during winter and spring.

Plankton characteristics: Field sampling was conducted in the central Long Island Sound (41˚ 3.572 N, 73˚ 8.674 W) weekly to bi-monthly during the months of December through April in 2010 and 2011. In 2011, additional cruises (n = 4) were extended to western Long Island Sound (Execution Rocks, 40^{o} 52.32 N, 73^{o} 44.04 W) with a third station between the two stations (40^{o} 59.085 N, 73^{o} 27.083 W). On station, the vertical profiles of temperature, salinity and photosynthetically-active radiation (PAR) were generated using a Seabird 19*plus* CTD. Seawater samples were analyzed for dissolved nutrient concentrations, including silicate, nitrate, nitrite, ammonium, and inorganic phosphate and size-fractionated phytoplankton biomass. Whole seawater samples were preserved for microscopic enumeration of microplankton (autotrophic flagellates, dinoflagellates, diatoms, non-loricate ciliates and tintinnids), nanoplankton (heterotrophic and autotrophic flagellates, heterotrophic and autotrophic dinoflagellates and cilites. Other seawater samples were analyzed by flow cytometry to assess picoplankton densities (heterotrophic bacteria, phycoerythrin-containing picocyanobacteria, and photosynthetic picoeukaryotes). Mesozooplankton samples were obtained from oblique net tows using 64-µm and 202-µm nets fitted with flowmeters. Whole seawater samples for measurements of primary productivity were obtained with minimal aeration from the upper mixed layer and transferred into 300-ml borosilicate clear or opaque bottles (n = 6 for each) and incubated for 24 hours. Measurements of initial and final dissolved oxygen concentrations were converted to primary productivity measurements using the Redfield ratio of oxygen to carbon (138:106).

Both the 2010 and 2011 bloom peaks coincided with the lowest surface seawater temperature of the year, occurring around 1.0 ºC. In 2010, the Long Island Sound (LIS) spring phytoplankton bloom occurred in early February, with chlorophyll *a* concentrations reaching 11 µg L^{-1} and primary production rates of 0.51 ± 0.08 mg C L^{-1} d^{-1} during the bloom peak. Chlorophyll *a* concentrations averaged 3 µg L^{-1} prior to the bloom in late January and dropped to less than 2 µg L^{-1} after the bloom demise in late February. The bloom community was comprised of a mix of picophytoplankton (36%), nanophytoplankton (30%) and microphytoplankton (35%). Diatoms dominated the autotrophic component during the bloom, with densities increasing from approximately 100 cells mL^{-1} before the bloom to ~7,000 cells mL^{-1} during the bloom peak. Other autotrophs such as dinoflagellates, picoeukaryotes, and picocyanobacteria were less abundant (63 ± 58 cells mL^{-1}, 1,310 ± 226 cells mL^{-1} and 159 ± 5 cells mL^{-1}, respectively) whereas heterotrophic bacterial densities averaged 3.68 ± 0.46 x 10^{5} cells mL^{-1} and increased after the bloom. The zooplankton population during the 2010 bloom was numerically dominated by heterotrophic nanoflagellates which increased from concentrations of 400 cells mL^{-1} before the bloom, to more than 5,000 cells mL^{-1} during the bloom, and decreased to 3,000 cells mL^{-1} at its end. In contrast, heterotrophic dinoflagellate abundances (0 – 413 cells mL^{-1}) were low during January and early February but peaked in late February and March whereas ciliate densities remained constant throughout the bloom but decreased after the bloom collapse (concentrations ranged from 5 – 9 cells mL^{-1}. Copepods comprised 86% of the mesoplankton community in 2010 and densities averaged 3 ± 1 individuals L^{-1} during

January and early February but increased to 8 ±2 individuals L^{-1} in late February and March during the bloom demise.

Similar to 2010, the 2011 spring phytoplankton bloom occurred in early February, reaching 15 µg chl *a* L^{-1} and primary production rates reached 0.74 ± 0.05 mg C L^{-1} d^{-1} during the peak of the bloom. Chlorophyll *a* concentrations (2.0 – 4.0 µg L^{-1}) and primary productivity rates (0.05 – 0.09 mg C L^{-1} d^{-1}) were low before and after the bloom occurred. The 2011 bloom community was comprised of 12%, 28%, and 60%, pico-, nano- and microphytoplankton, respectively. Diatoms dominated the nano- and microplankton communities of the bloom, with densities increasing from < 100 cells mL^{-1} before the bloom to approximately 9,000 cells mL^{-1} during the bloom peak and decreasing to 2,000 cells mL^{-1} during the bloom demise. Picoeukaryotes, picocyanobacteria, and autotrophic dinoflagellates were minor components of the bloom (2.67 ± 2.57 x 10^3, 131 ± 114, and 19 ± 22 cells mL^{-1}, respectively. Heterotrophic bacteria densities averaged 3.00 ± 0.32 x 10^5 cells mL^{-1}, and increased during the bloom demise. The grazer population during the 2011 bloom was numerically dominated by heterotrophic nanoflagellates, which increased from concentrations of 800 cells mL^{-1} before the bloom to over 3,200 cells mL^{-1} at the peak of the bloom. Copepods comprised 76% of the mesoplankton community between January and March, and densities were 2 ± 1 individuals L^{-1} during January and early February, and increased to 4 ± 1 individuals L^{-1} in during the bloom demise.

Nutrient dynamics: Experiments were performed to determine if nutrients influenced the net growth rates of phytoplankton in LIS. Triplicate sets of bottles containing whole seawater were amended with nitrate (20 µM), silicate (20 µM), or phosphate (1.25 µM), a combination of all three (N+P+Si), or unamended. The spring phytoplankton bloom in both years had a strong effect on nutrient concentrations in LIS as dissolved inorganic nitrogen, orthophosphate, and silicate were reduced by 98%, 84%, and 96%, respectively in 2010 and 92%, 64%, and 86% in 2011. In both years during the peak of the bloom, the experimental addition of nitrate significantly increased growth rates of phytoplankton relative to the control and all other treatments ($p<0.05$; Tukey test). On other dates, nutrient levels were higher and the addition of nutrients did not alter the net growth rates of phytoplankton.

Phytoplankton grazing mortality and growth rates: The dilution technique was used to estimate *in situ* microzooplankton grazing (g; d^{-1}) and phytoplankton intrinsic growth rates (k; d^{-1}) (Landry et al. 1995). Seawater collected from the upper mixed layer in LIS during field sampling was used to create a dilution series. In addition to chlorophyll *a*, flow cytometric characterization of the phytoplankton community was performed to evaluate growth and grazing mortality rates of picoplankton. Microzooplankton grazing and phytoplankton intrinsic growth rates were successfully detected using the dilution technique throughout this project, even when surface temperature was 1.0 ºC. In 2010, intrinsic growth rates of phytoplankton averaged 0.40 ± 0.11 d^{-1} during the initiation and peak of the 2010 bloom, but declined sharply during the bloom collapse. Microzooplankton grazing rates were low during the bloom initiation period (0.15 ± 0.03 d^{-1}), but rose significantly during the peak and demise of the bloom ($p<0.05$; 0.62 ± 0.11 d^{-1}) when grazing rates exceeded phytoplankton intrinsic growth rates and resulted in 100 – 400% of primary production being consumed daily. Microzooplankton grazing rates of picoplankton (heterotrophic bacteria, picoeukaryotes, and picocyanobacteria) were generally similar to those of chlorophyll *a* in pattern (peaking during the bloom demise) and magnitude (0.27 ± 0.13 d^{-1}, 0.39 ± 0.33 d^{-1}, 0.40 ± 0.24 d^{-1}, respectively).

In 2011, the intrinsic growth rates of phytoplankton were low prior to the spring bloom (0.21 ± 0.04 d^{-1}), increased three-fold during bloom initiation (0.60 ± 0.02 d^{-1}) and then decreased to pre-bloom levels during the peak and demise of the bloom (0.23 ± 0.08 d^{-1}; 7-24 Feb. Microzooplankton grazing rates followed a pattern similar to those of phytoplankton intrinsic growth rates, but were offset by ~ two weeks. The highest grazing rate occurred during the bloom peak (0.35 ± 0.04 d^{-1}) which resulted in 100 - 340% of primary production being consumed per day. Size-fractionated chlorophyll *a* grazing rates revealed significantly higher grazing on microphytoplankton (0.54 ± 0.06 d^{-1} on cells > 20 µm) during the bloom compared to pico- and nanophytoplankton ($p<0.05$; Tukey test). Microzooplankton grazing rates on heterotrophic bacteria remained

constant throughout the bloom, while grazing on picocyanobacteria increased during the peak and collapse of the bloom, and grazing on picoeukaryotes increased at the end of the bloom. Mean grazing rates of microzooplankton on heterotrophic bacteria, picocyanobacteria, and picoeukaryotes were 0.32 ± 0.14 d^{-1}, 0.39 ± 0.26 d^{-1}, and 0.13 ± 0.08 d^{-1}, respectively.

A highly significant multivariate linear regression model **(**$r^2 = 0.81$, $p = 0.002$**)** predicted *in situ* growth rates of phytoplankton in LIS during the spring bloom were inversely correlated with the percent primary production consumed by the microzooplankton and positively correlated with concentrations of dissolved silicate (net growth rate = 0.0666-(0.127*log(primary production grazed) + (0.148*log[Si]). Using this model and concentration of chlorophyll *a* measured on the first sampling date each year the timing and magnitude of the 2010 and 2011 spring blooms were hindcasted within 10% of values measured on any given date.

Objective 2. To experimentally elucidate the impact of higher and lower winter seawater temperatures on the magnitude and composition of the spring bloom, zooplankton grazing rates, and organic matter export in LIS.

Mesocosm experiments: To evaluate the effects of water temperature on the plankton community, mesocosm experiments were conducted during the initiation of the spring bloom each year at ambient and enhanced (+3.0 ºC) water temperatures. The mesocosms (300-L, translucent, polyethylene tanks, n=4 per temperature) were maintained at a desired temperature by being placed in 2 m^3 tanks, each set to a specific temperature level. At the beginning of each experiment, ambient temperature was measured and the two temperature levels were set accordingly. Seawater was transferred from the surface mixed layer at the entrance of Stony Brook Harbor, located along the southern shores of LIS 14 km from the primary sampling site, an hour before high tide into a 5,000-L tank. Initial plankton communities, nutrient levels, temperature, and salinity of the seawater used for mesocosm experiments were not significantly different from those found at the primary sampling site in LIS.

The 2010 mesocosm experiment was conducted for two weeks, at two temperature levels, 1.0 ºC and 4.0 ºC. During this experiment chlorophyll *a* levels averaged 9.5 µg L^{-1} during the first week, and showed a separation between the two temperature treatments by the end of the experiment, with the 1 ºC mesocosms harboring significantly higher levels of chlorophyll *a* ($p<0.05$; t-test). The 1 ºC mesocosms also had significantly higher levels of diatoms and significantly lower levels of ciliates compared to the 4 ºC mesocosms (1 ºC and 4 ºC diatoms levels = $6,710 \pm 361$ and $3,505 \pm 497$ cells mL^{-1} respectively; $p< 0.01$; t-test); ciliate levels = 13 ± 3 and 30 ± 5 cell mL^{-1} respectively; $p<0.05$; t-test). Microzooplankton grazing coefficients (g; d^{-1}) and phytoplankton growth coefficients (k; d^{-1}) were lower in the 1 ºC mesocosms compared to the 4 ºC mesocosm (mean grazing rates of 0.17 ± 0.03 and 0.26 ± 0.07 d^{-1} respectively; and mean growth rates of 0.19 ± 0.13 and 0.30 ± 0.20 d^{-1} respectively) but the overall grazing impacts of zooplankton on phytoplankton growth [i.e., (g/k) x 100] were similar (89.5% and 86.7%, respectively). Heterotrophic nanoflagellate abundances increased slightly by the end of the experiment, but were similar for both temperature treatments ($4.51 \pm 0.61 \times 10^3$ and $4.80 \pm 0.23 \times 10^3$ cells mL^{-1} for 1 ºC and 4 ºC).

The 2011 experiment was conducted for three weeks again at 1 ºC and 4 ºC. During this experiment chlorophyll *a* levels decreased during the first week, remained constant during the second week, and displayed separation between treatments during the third week, with the 1 ºC mesocosms showing significantly higher levels of chlorophyll *a* (1 ºC and 4 ºC chlorophyll *a* levels = 5.66 ± 0.20 and 4.47 ± 0.25 µg L^{-1} respectively; $p<0.01$; t-test). The 1 ºC mesocosms also had significantly higher levels of diatoms compared to the 4 ºC mesocosm (diatom levels = $3,122 \pm 791$ and $1,108 \pm 222$ cells mL^{-1} respectively; $p<0.01$; t-test). Unlike 2010, ciliate densities were similar between the 1 ºC and 4 ºC temperature treatments (74 ± 16 and 78 ± 11 cells mL^{-1}, respectively). Heterotrophic nanoflagellate abundances increased slightly by the end of the experiment, and were similar for both treatments ($3.64 \pm 0.29 \times 10^3$ and $3.83 \pm 0.59 \times 10^3$ cells mL^{-1} for 1 ºC and 4 ºC). Microzooplankton grazing rates and phytoplankton intrinsic growth rates were similar in the treatments (mean grazing rates of 0.35 ± 0.04 and 0.33 ± 0.04 d^{-1}; mean growth rates of 0.32 ± 0.02 and 0.26 ± 0.11 d^{-1} respectively). A comparison of percent primary production grazed, however, indicated a difference between the

two temperature treatments, with lower levels of consumption in the 1 ºC mesocosm (106% compared to 133%).

Objective 3. To identify those components of the LIS pelagic food web altered by winter/spring temperature.

Statistical analyses of the mesocosms experiments (described above) indicated that one of the most temperature-sensitive components of the plankton community was the diatoms (also reflected in total chlorophyll *a*) which had significantly lower abundances in the elevated-temperature treatments.

C2. Scientific Abstract:

The spring phytoplankton bloom is an ecologically-important event whose root cause has been studied for decades and continues to be debated. This study examined the biological and physical mechanisms controlling the onset and demise of the spring phytoplankton bloom in the third largest US estuary, Long Island Sound (LIS), during 2010 and 2011. The spring bloom in LIS initiated when there was no stratification of the water column (ΔT from surface to bottom = 0.05 °C and 0.24 °C, respectively), and peaked in early February when temperatures were at the annual minimum (1.0 °C and 0.8 °C, respectively). The bloom magnitude and duration were a function of phytoplankton growth and zooplankton grazing, with the bloom initiation occurring when intrinsic growth exceeded grazing and the bloom demise occurring when grazing exceeded growth (>100% of primary productivity grazed per day). During the bloom collapse, nutrients were drawn down and the phytoplankton community was nutrient-limited, suggesting the bloom demise was a function of both top-down and bottom-up effects. Over the entire study, a highly significant ($p<0.01$) multivariate linear regression model using the percentage of primary production consumed daily by microzooplankton and dissolved silicate concentrations was capable of hindcasting the timing and magnitude of the spring bloom within 10% of actual values during both study years. Mesocosm experiments performed during the spring bloom showed that experimentally increased seawater temperature (+3.0 ºC) was associated with decreased phytoplankton biomass (i.e., total chlorophyll *a* and diatom densities) compared to ambient temperature. Continued nutrient mitigation and climatic warming may lessen the intensity of the spring bloom.

C3. Problems Encountered: There were no major methodological difficulties in executing this project.

C4. New Research Directions: We did not take any new directions *per se* from the original objectives. However, the research took on additional relevancy given the recent debate in the literature over the ultimate cause(s) of spring blooms in the North Atlantic (i.e., the Critical Depth Hypothesis *versus* the Dilution-Recoupling Hypothesis; Sverdrup 1953 and Berenfeld 2010, respectively). Our findings in both 2010 and 2011 were that the winter-spring bloom occurred during the coldest water temperature of the season and when no stratification was apparent. Therefore, our work also does not support the notion that some stratification of the water column is necessary for a spring bloom to develop (Critical Depth Hypothesis).

C5. Interactions: Several of the presentations listed below were attended by various agency representatives (e.g., New York Sea Grant and Connecticut Sea Grant, Environmental Protection Agency, and the New York Department of Environmental Conservation).

.C6. Presentations and Publications:

Publications:

Copies of the two publications have previously been supplied to NYSG.

Jiang, X., D.J. Lonsdale, and C.J. Gobler. 2011. Rapid gain and loss of evolutionary resistance to the harmful dinoflagellates *Cochlodinium polykrikoides* in the copepod *Acartia tonsa*. Limnol. Oceanogr. 56:947-954

Jiang, X., D. Lonsdale, and C. Gobler. 2010. Grazers and vitamins shape chain formation in a bloom-forming dinoflagellate, *Cochlodinium polykrikoides*. Oecologia 164:455-464

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Presentations:

George, J. (2012) Impacts of climate change on the spring bloom in Long Island Sound, Long Island Sound Study Science and Technology Advisory Committee meeting, Stony Brook, NY, February (oral presentation)

George, J., C.J. Gobler, D.J. Lonsdale (2012) Effects of temperature on microzooplankton grazing and initiation of the spring bloom n Long Island Sound, Ocean Sciences Meeting, Salt Lake City, UT, February (abstract, poster)

George, J., C.J. Gobler, D.J. Lonsdale (2011) Impacts of climate change on the spring bloom in Long Island Sound, New England Estuarine Research Society Meeting, Port Jefferson, NY, May (abstract, oral presentation)

George, J., C.J. Gobler, D.J. Lonsdale (2010) Impacts of climate change on the spring bloom in Long Island Sound, Long Island Sound Biennial Research Conference, Stamford, CT, October (oral presentation)

Manuscripts:

George, J., D.J. Lonsdale, C.J. Gobler (in preparation) Testing the Critical Depth and Dilution-Recoupling Hypotheses to explain the winter-spring phytoplankton bloom in a coastal ecosystem, Long Island Sound

D. Accomplishments:

D1. Impacts & Effects: Our study demonstrated that the development of the winter-spring bloom in LIS is regulated by the interaction of phytoplankton growth and zooplankton grazing but not water-column stratification and thus does not support long-standing theory (i.e., the Critical Depth Hypothesis) and contributes significantly to the current scientific debate. Furthermore, during the bloom collapse, when zooplankton grazing exceeded growth (>100% of primary productivity was being grazed per day), dissolved nutrients were drawn down and the phytoplankton community growth was nitrogen-limited. This finding has relevance for resource managers given that one of the main goals of the LISS is to improve water quality and reduce the severity of hypoxia through the reduction of nitrogen loads. Our mesocosm experiments conducted using spring bloom water from LIS showed that after two or three weeks, a 3^{o}C increase in water temperature resulted in lower total chlorophyll *a* and diatom densities compared to ambient temperature but the role of grazing in these results was inconclusive. Overall, however, our study suggests that continued nutrient mitigation and climatic warming may lessen the intensity of the spring bloom in Long Island Sound and has implications for the management of hypoxia and fisheries in LIS

D2. Scholar(s) & Student(s) Status:

Xiaodong Jiang, Ph.D., completed May 2010. Thesis title "Ecological and evolutionary interactions between the copepod *Acartia tonsa* and the dinoflagelate *Cochlodinium polykrikoides*.
Currently an Associate Professor, at the School of Life Science, East China Normal University

Jennifer George, M.S. completed August 2012. Thesis title "The physical and biological mechanisms controlling the winter-spring bloom in Long Island Sound".

Laura Treible, M.S., expected date of thesis completion December 2012.

Lucas Merlo, B.S., May 2010, undergraduate, employed January – May 2010 and October 2010.

D3. Volunteers: None

D4. Patents: None

E. Stakeholder Summary: There is evidence that seawater temperatures in Long Island Sound (LIS) may be on the rise which is a pattern seen along the northeast U.S. coast. For example, in the nearby estuary, Narragansett Bay, Rhode Island, it was found that during warm-water winters, the winter-spring bloom of phytoplankton was suppressed relative to cold winters and the suppression was associated with higher abundances of phytoplankton grazers (i.e., zooplankton). A significant reduction in the magnitude of the spring bloom has implications for hypoxia in LIS as recent research has suggested that the flux of organic matter from the spring bloom is a major determinant of bottom oxygen levels (Lee and Lwiza 2008). A reduction in the magnitude of the spring bloom could therefore help ameliorate hypoxia, but on the other hand, also change the relative productivity of pelagic and benthic fisheries given that the latter are more dependent on the flux of organic matter originating in the surface waters.

Our study demonstrated that the development and demise of the winter-spring blooms in LIS in 2010 and 2011 were the direct result of the balance between phytoplankton growth and zooplankton grazing. Bloom initiation began when phytoplankton production exceeded consumption by zooplankton while the reverse was true during the bloom collapse. During the bloom collapse, nutrients essential for phytoplankton growth were significantly reduced and nutrient-manipulation experiments showed that dissolved nitrogen, in particular, limited the growth of the phytoplankton community at that time in both years. To better understand the impact that winter warming of LIS may have on the spring phytoplankton bloom, we conducted temperature-manipulation experiments using seawater collected from the Sound during the bloom and found that after two or three weeks, a $3^{o}C$ increase in water temperature resulted in lower phytoplankton biomass, including diatoms, compared to that experiencing ambient temperature. The role of zooplankton grazing in these experiments, however, was inconclusive. Overall, our study suggests that continued nutrient mitigation and climatic warming may lessen the intensity of the spring bloom in Long Island Sound and has important implications for the management of hypoxia and fisheries in LIS

F. Pictorial: Photos were previously forwarded to NYSG.

Literature Cited

Behrenfeld M.J. (2010) Abandoning Sverdrup's Critical Depth Hypothesis on phytoplankton blooms. Ecology 91:977-989

Landry M.R., Kirshtein J., Constantinou J. (1995) A refined dilution technique for measuring the community grazing impact of microzooplankton, with experimental tests in the central equatorial Pacific.Marine Ecology-Progress Series 120:53-63.

Lee, J.Y. and K.M.M. Lwiza. 2005. The role of horizontal exchange on interannual variability of temperature and salinity in estuaries. *J. Geophys. Res.* 110: C09022.

Sverdrup H.U. (1953) On conditions for the vernal blooming of phytoplankton. Journal du Conseil International pour I'Exploration de la Mer 18:287-295.