In: Pollock NW, Godfrey JM, eds. Diving for Science 2007.
Proceedings of the American Academy of Underwater Sciences 26th Symposium.Dauphin Island, AL: AAUS; 2007.

Deploying Benthic Chambers to Measure Sediment Oxygen Demand in Long Island Sound

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Abstract

In order to address the need for high-quality sediment oxygen demand (SOD) measurements, diver deployed benthic flux chambers equipped with sondes were used to assess SOD (aerobic uptake) and the sediment-water fluxes of constituents in regions of Long Island Sound (LIS) characterized by periods of summer hypoxia/anoxia. Procedures were developed for deploying chambers from small vessels, and our sampling techniques employed equipment custom designed at our laboratory. SOD measurements in western LIS during both winter (850 µmol O_2 m^{-2} h^{-1}) and summer hypoxic conditions (870 µmol O_2 m^{-2} h^{-1}) showed good agreement over small spatial scales. Although the benthic oxygen utilization constant (k) was 6-7 times higher in the summer, low ambient DO (hypoxia) in western LIS bottom waters at this time accounted for reduced SOD rates.

Introduction

The goal of the Long Island Sound (LIS) Integrated Coastal Observing System, LISICOS, is the development of a sustained capability to observe the LIS ecosystem, and to understand and predict its response to natural and anthropogenic changes (LISICOS, 2007). Efforts are specifically focused on combining real-time data (monitoring buoys) with a numerical model to predict dissolved oxygen (DO) concentrations and the occurrence of summer hypoxia. Our primary objective was to determine benthic oxygen demand, a key unknown in water quality models of hypoxia in LIS, at LISICOS sampling stations (Figure 1). Benthic chambers were used to assess sediment oxygen demand (SOD; aerobic uptake) in regions of LIS characterized by periods of summer hypoxia/anoxia. The apparatus is oceanographically robust and user friendly and, therefore, does not require a specialist for its deployment. Aerobic and anaerobic bacterially mediated sedimentary processes (*i.e.*, diagenesis) and infaunal activities, especially in coastal regions, have a major role in the cycling of oxygen, carbon, nutrients, essential and toxic trace metals, and organics (Warnken *et al.*, 2000, 2001; Mason *et al.*, 2006). Fluxes of these biologically active constituents into and out of the sediment provide essential process information needed for understanding the eutrophication dynamics in the water column and sediments.

Benthic *in situ* flux chambers have had wide application (Tengberg *et al.*, 1995, 2004, 2005) and are integral to the essential tasks of this project. Based on a design provided by Dr. Gary Gill and colleagues (Warnken *et al.*, 2000; 2001) we have built an innovative apparatus equipped with an oxygen electrode/data logger for time sequenced measurements of oxygen. The design also allows manual sampling of waters from the flux chamber by syringe. Development of the chambers required creative designing, engineering, and numerous field and laboratory tests. The benthic chambers yield high quality time series information on sediment-water exchanges.

Methods

Benthic *in situ* flux chambers were developed and tested during this study. Chambers were deployed at LISICOS sampling stations in western Long Island Sound (WLIS; LISICOS, 2007) to measure spatial and temporal variations in sediment/benthic oxygen demand (SOD) during March and August 2005. Deployments were done at the FB1 buoy (40.994°N, 73.678°W; 13.7 m. depth) and the WLIS buoy (40.950°N, 73.567°W; 18.3 m. depth; Figure 1).

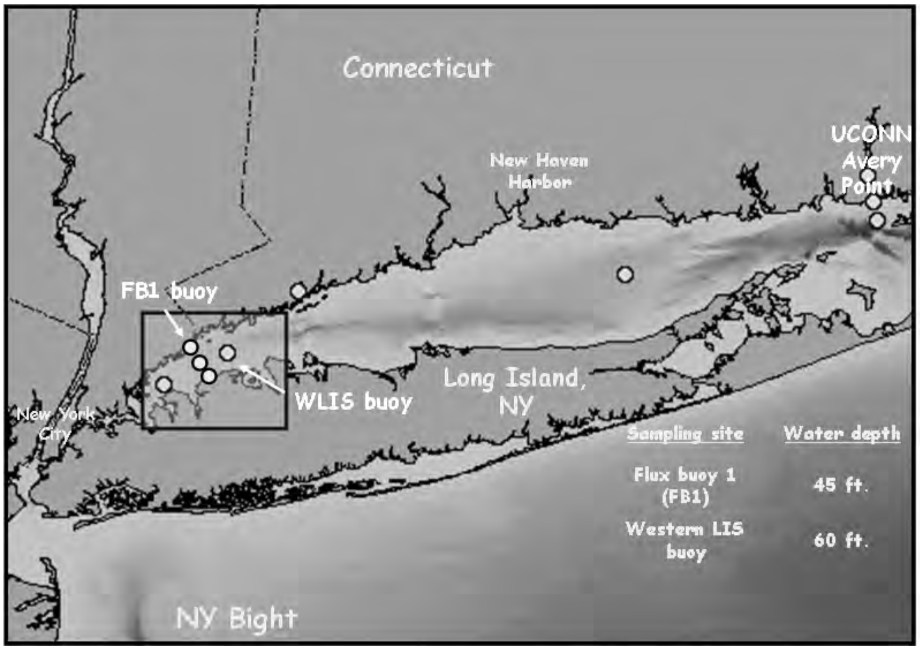

Figure 1. LISICOS monitoring buoy sites in LIS. The five primary sampling sites for LISICOS process studies are enclosed by the square (figure adapted from LISICOS, 2007).

The devices are dual chambered (Figure 2), offering a variety of flexible sampling protocols (*e.g.*, replication, short spatial variability tests, time series water sampling). Each chamber has an internal volume of 13L and covers a 0.1 m^2 area of surface sediment. The chambers were built at the UCONN Marine Science and Technology Center (MSTC) using sheet polycarbonate (Modern Plastics), and only teflon and polycarbonate components (McMaster-Carr) came in contact with the water in the chambers. Dissolved oxygen was measured at 15 minute intervals using Yellow Springs Instruments (YSI) 600 series sondes, and other standard hydrographic data (temperature, salinity, depth) were also measured by these instruments. An Ikellite submersible battery powers a stirring motor (Hankscraft; 25 rpm) inside a watertight polycarbonate housing on each chamber. The motor rotates a floating stir bar inside the chamber, keeping oxygen and other constituents uniformly distributed throughout the chambers (Figure 2).

Benthic chambers were manually deployed by davit from the UCONN MSTC vessel *R/V Challenger* (25 ft. hull). During deployment, the chambers were attached to a subsurface float located 3 meters from the bottom of a deployment shot-line (Figure 3). This prevented the chambers from sitting on the bottom during deployment, and allowed for diver placement on undisturbed sediment. Prior to deployment, the legs are extended to add stability once the chambers are on the sediment (Figure 2). The side ports are open during deployment on the shot-line to assist with removal of trapped air, and closed once the chambers are in position. Due to heavy commercial and recreational boat traffic in the deployment area, the chambers were not left attached to the deployment shot-line. Gear attached to surface marker buoys is often dragged off by boats after being snagged, or removed intentionally by user groups that feel the gear will impede their use of LIS. To prevent this, a tether (2m) and weight (4.0 kg) was attached to the shot-line weight (23-45 kg) before deployment. After the divers had placed the benthic chamber in undisturbed sediment, the tether weight was detached from the shot-line weight and attached to the chambers (Figure 3). The two weights sat next to each other, providing a continuous guideline from the surface to the chambers. This aided the divers in locating the chambers in the zero to three foot visibility water without the risk of the equipment being removed if the shot-line was snagged. Sonic tags (pingers) were also used to allow divers to locate the chambers with an underwater acoustic receiver if the surface marker buoy was removed. To recover the chambers at the end of the deployment, the divers attached the chambers to the subsurface buoy and the tether to the shot-line weight. The entire apparatus could then be hoisted aboard the boat.

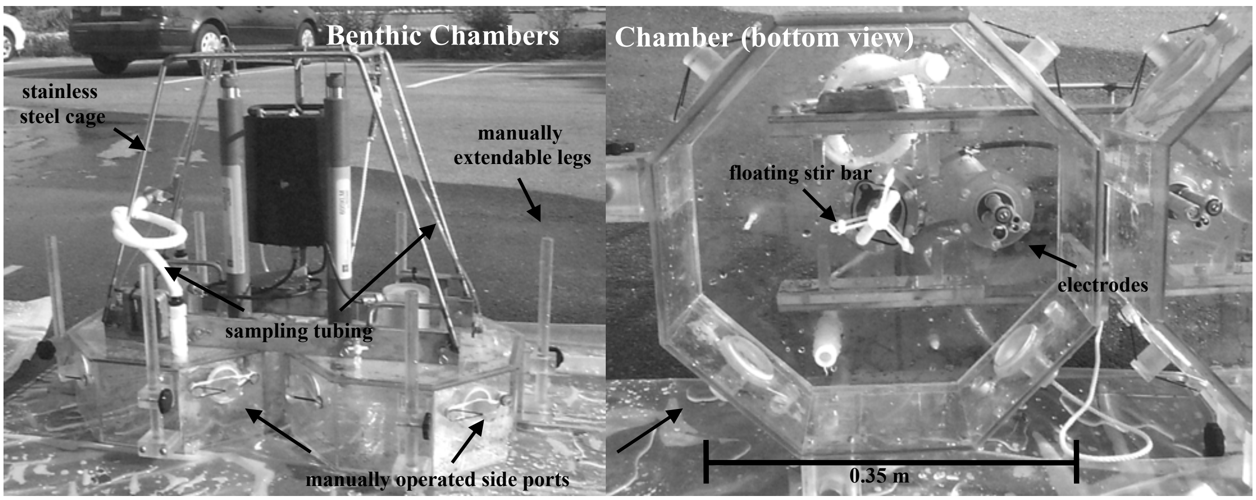

Figure 2. Benthic chambers used for sediment oxygen demand measurements. The stainless steel cage is an aid to divers during deployment and protects the sondes once deployed. The two-chamber configuration measures 0.9 x 0.5 x 0.6 m (L x W x H).

The power supply for externally-powered sondes was modified using submersible 5-pin SeaCon fittings (Brantner & Associates; Figure 4). A similar battery-powered calibration cable was also used in the field prior to deployment. These power/calibration cables were designed by David Cohen for use on the LISICOS monitoring buoys, and wiring was done by UCONN MSTC. This system allows the user to avoid buying and modifying YSI field cables, and sondes can be changed out underwater when using SeaCon fittings.

Divers sampled water from chambers at deployment and retrieval using syringes (60 ml polypropylene luer-lock or 1L acrylic/polycarbonate; Figure 5). Sample water used for Winkler DO titrations was added without disturbance to 60 ml BOD (biological oxygen demand) bottles. Water was sampled through either polypropylene luer-lock tubing or large inner diameter silicone tubing (Figure 2). Winkler titration (APHA, 1995; Strickland and Parsons, 1968) comparisons to sonde DO readings were made in the laboratory following calibration, and with samples collected from the chambers in the field. In August 2005, water samples were collected as a test of the procedures and techniques for the determination of biogeochemically important chemical constituents. The suite of measurements included dissolved organic carbon, nutrients, total mercury, and monomethylmercury (results not presented here).

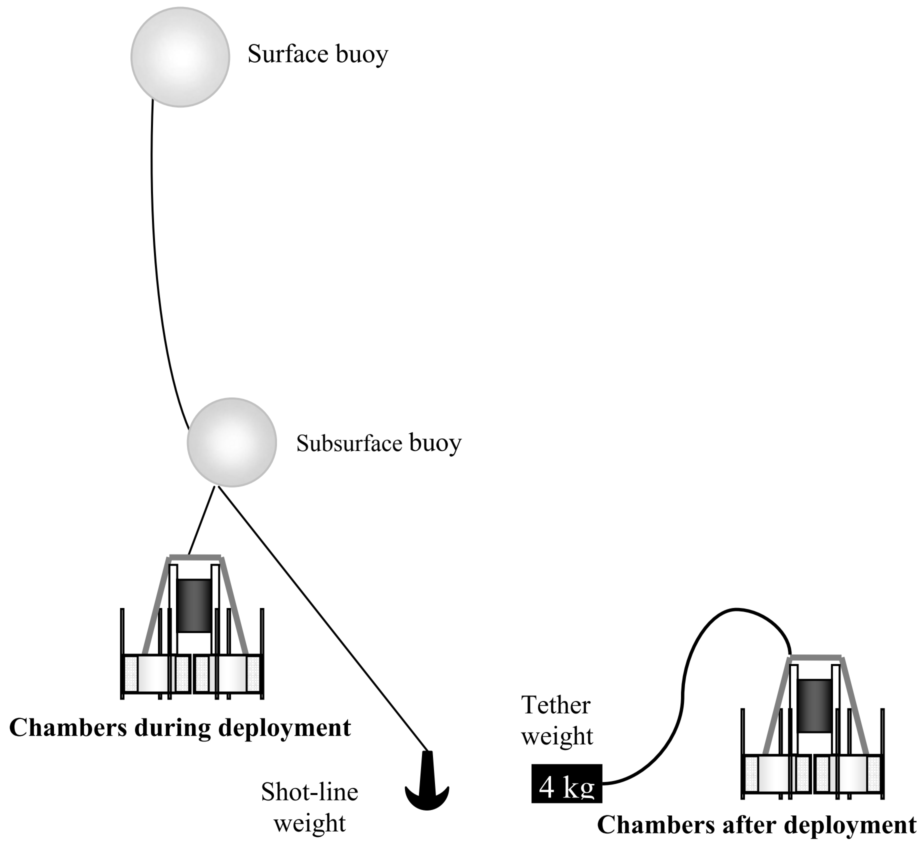

Figure 3. Schematic of benthic chamber deployment using a shot-line, and position of the tether weight and chambers on sediment relative to the shot-line weight after deployment.

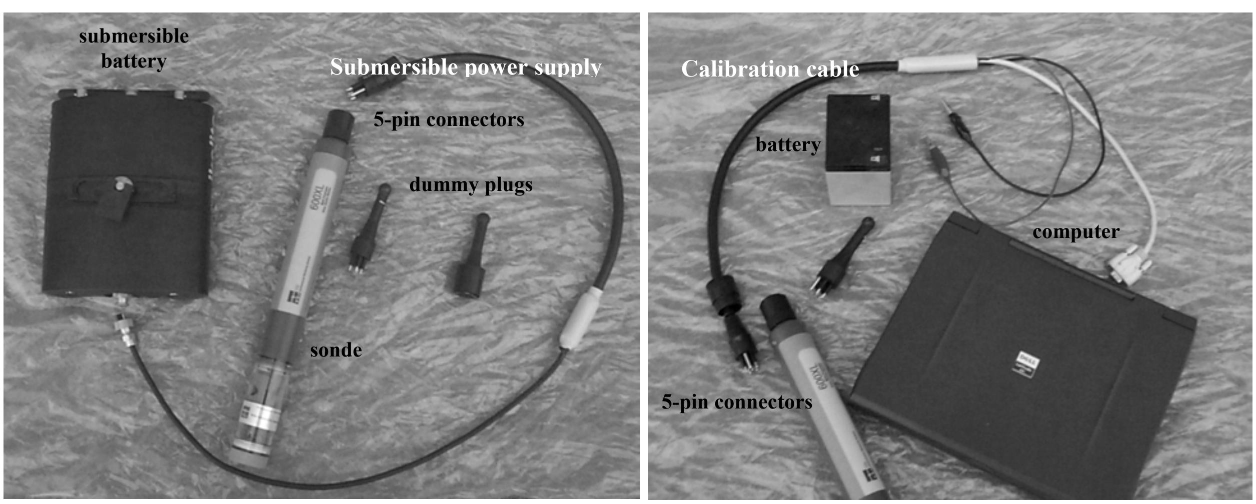

Figure 4. Externally-powered sonde shown with submersible 5-pin power cable and 5-pin battery-powered calibration cable.

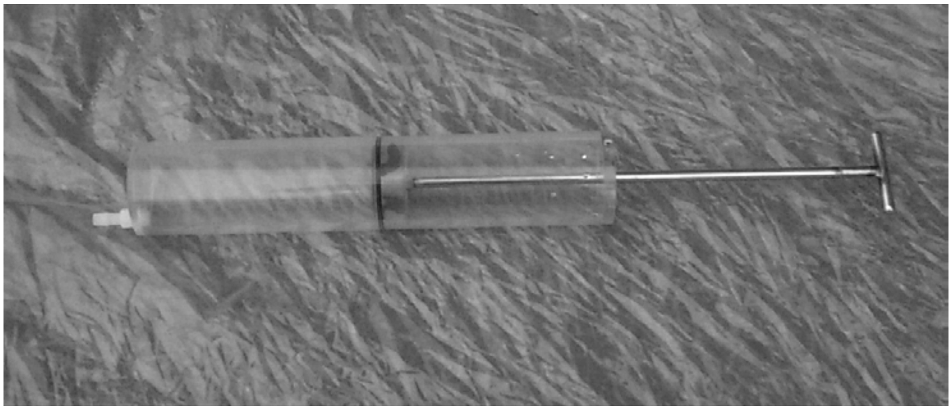

Figure 5. 1L syringe used to sample water from the chambers for Winkler titrations and biogeochemically important chemical constituents.

Results and Discussion

An oxygen utilization constant (*k*) is estimated from a linear regression of the log of the scaled DO observations (c_t/c_0) and time (c_t and c_0 are the DO content of the chamber at time *t* and initial deployment), and was used to estimate SOD (kc_0; James O'Donnell, personal communication). Since the exponential decline is substantial (Figure 6), the initial phase (four hours) of the oxygen record that was not influenced by start-up transients was chosen to estimate these rates.

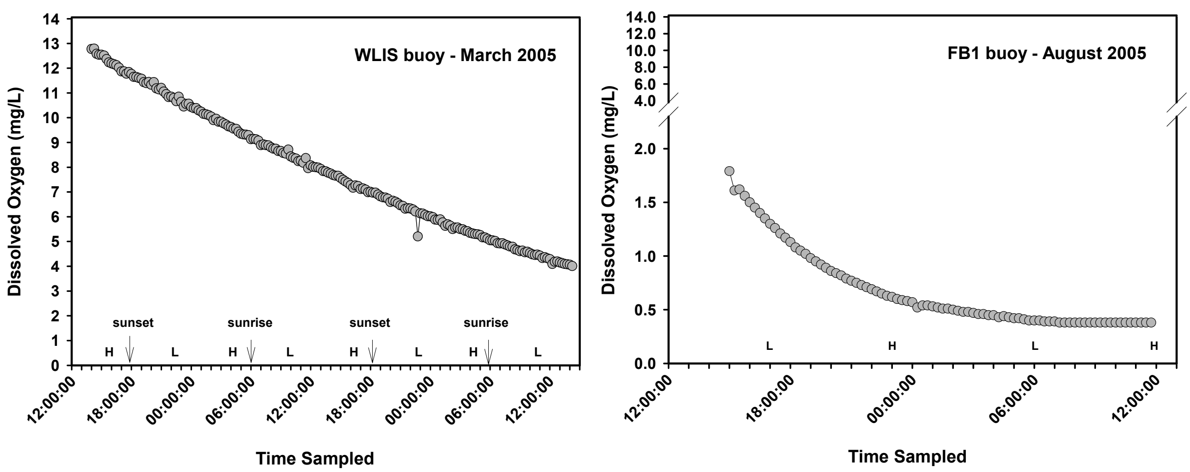

Figure 6. Benthic chamber dissolved oxygen measurements (YSI sondes) from March and August 2005. Each plot shows one of the duplicate chambers deployed at each site. Approximate times of high (H) and low (L) tides are indicated.

The calculated SOD rates from duplicate chambers at the WLIS buoy in March 2005 (Figure 6) were 834 and 871 µmol O_2 m^{-2} h^{-1}, indicating good agreement (4% relative difference; [difference/average]*100) over small spatial scales, and *k* ranged from 0.018 to 0.022 h^{-1}. The deployment of duplicate chambers at the FB1 buoy in August 2005 (Figure 6) produced SOD estimates of 928 µmol O_2 m^{-2} h^{-1} ($k = 0.148$ h^{-1}) and 824 µmol O_2 m^{-2} h^{-1} ($k = 0.120$ h^{-1}), indicating slightly greater variability (12% relative difference) on a small spatial scale. Although the SOD estimates are similar in March (2°C) and August (19°C), *k* values were 6-7 times higher in August. The low ambient DO (hypoxia) in the bottom waters of WLIS in August (22% oxygen saturation) accounted for reduced SOD rates, even at elevated values of *k*. This suggested that enhanced SOD fluxes would be evident in the early summer and fall when aeration processes produce substantially higher benthic water column DO in WLIS.

In the laboratory, the difference between sonde oxygen measurements and Winkler determined DO levels was small (0-4% relative difference) in March and August 2005. Winkler samples collected from benthic chambers deployed in March 2005 (average ambient DO 400 µM or 12.8 mg L^{-1}) differed from the sonde reading by 7%. Oxygen measurements agreed within 1-4% in August 2005 (average ambient DO 56 µM or 1.8 mg L^{-1}).

The instrument deployment and recovery method was effective. A significant amount of time was saved by having a continuous guideline to the chambers, and the divers required the use of an underwater acoustic receiver to find an instrument only once. The polycarbonate construction proved to be robust enough for deployment by shot-line from a small boat. The threaded connection between sonde and chamber failed once during a deployment, and the problem was resolved by removing the bails (lifting wire) from the sondes as they proved to be a snag point. The initial results show that the dual benthic *in situ* flux chambers yield high quality time series information on sediment-water exchanges and allow for manual sampling of waters from the chambers. Our procedures for deploying and recovering the chambers were reliable, and became easier in subsequent deployments (2006) from a larger, more stable platform, the UCONN MSTC vessel *R/V Lowell Weicker* (36 ft. hull, A-frame).

Additional surveys were conducted in 2006 and have addressed the seasonal component to SOD rates and estimating *k*. Concurrent deployments (duplicate chambers) at several of the LISICOS sampling stations have allowed us to examine spatial variability in SOD over a larger area. Although successful, the current approach where the chambers are deployed and sampled entirely by divers, is labor intensive and ultimately limits the spatial and temporal coverage. Therefore, longer term plans include adapting the apparatus to a benthic lander and development of an automated version that will provide timed water sampling. These modifications may allow benthic chambers to be deployed from a boat without diving.

Acknowledgments

Many thanks to Peter Boardman, Turner Cabaniss, Bob Dziomba, Adam Houk, Kay Howard-Strobel, Marco Liebig, Nathalie Morata, Dr. James O'Donnell, and Brennan Phillips (UCONN Marine Sciences) and Dr. Gary Gill (Battelle Marine Sciences Laboratory, WA). This research was partially funded by NOAA through grants to LISICOS.

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