Report as of FY2006 for 2006PR29B: "DISSOLVED OXYGEN DYNAMICS IN TWO RESERVOIRS OF CONTRASTING TROPHIC STATUS IN PUERTO RICO"

Publications

- Dissertations:
  - Fernando Pantoja, 2007, Dinámica fisicoquímica y fitoplantónica del embalse Guajataca, MS Thesis, Departament of Biology, UPR Mayaguez, 190 pages.
- Other Publications:
  - Sotomayor-Ramírez, D. G.A. Martínez, L. Pérez-Alegría 2006. Nutrient management for improved agricultural production and environmental quality. Invited presentation at EXPOCHEM, November 2006. Mayagüez, PR.
  - Sotomayor-Ramírez, D. G.A. Martínez, L. Pérez-Alegría, C. Santos. 2007. Seasonal pattern of dissolved oxygen and stratification in two tropical reservoirs. 30th Congress of the International Association of Theoretical and Applied Limnogy. Montreal Canada, August 12 to 18, 2007. http://www.SIL2007.org/ (projected)
  - Pantoja F., C. Santos, D. Sotomayor-Ramírez, and G.A. Martínez. Physicochemical and planktonic dynamics in a tropical reservoir. 30th Congress of the International Association of Theoretical and Applied Limnogy. Montreal Canada, August 12 to 18, 2007. http://www.SIL2007.org/

Report Follows

Problem and Research Objectives:

Low dissolved oxygen (DO) has been identified as the cause of impairment in the principal reservoirs of Puerto Rico (PREQB, 2002). A proper understanding of the DO dynamics in reservoirs cannot be drawn from historical water quality data gathered in reservoirs by public agencies in Puerto Rico because measurements have been rather sporadic in a temporal and spatial scale (3 months apart in the best cases), in very rare occasions have these measurements consisted of depth profiles which could provide some insight as to the factors controlling DO dynamics, and concentrations have not been related to other water quality parameters. The eutrophic conditions due to inputs of sediments and nutrients were identified as the primary reason for the lakes not meeting the water quality standard for DO, yet the waters did not exceed the numeric standards for nutrients (PREQB, 2003). Numerical nutrient reference values for reservoirs of Puerto Rico suggests that the majority exhibit some impact from anthropogenic activities, with six classified in the mesotrophic category, twelve in the eutrophic category and one in the hypereutrophic category (Martínez et al. 2005).

The variations in trophic status across lakes can vary due to non-point source inputs, in-lake geomorphologic characteristics, and circulation patterns due to variations in thermal stability, that will affect DO content and dynamics. Most reservoirs consistently exhibit anoxia at some depth, which causes a significant drop in water column average values. It is unclear whether this is a natural phenomena characteristic of tropical systems or whether is a result of water impairment and thus require remediate actions to be implemented. There is substantial evidence that suggests that tropical reservoirs, even oligotrophic reservoirs, commonly experience temporal hypolimnion anoxia (Townsend, 1996). If this is the case in Puerto Rico, the USEPA criteria of 5 mg DO/L would have to be modified to be more sensitive to natural conditions. There appear to be substantial differences in DO dynamics between tropical reservoirs and temperate systems (Townsend, 1998; Townsend, 1999; Lewis, 2000) which demands a thorough characterization of tropical lake behavior prior to adopting management guidelines developed in temperate areas. The effect of stratification, short-term variations in DO concentrations, as well as the elucidation of natural conditions leading from hypoxic to anoxic conditions must be considered.

This on-going study is characterizing the DO dynamics in two reservoirs as a first step towards the future establishment of DO criteria for Puerto Rico and for providing baseline data for modeling DO dynamics in Puerto Rico. The overall objectives are to assess the limnoligical conditions of selected reservoirs as a means to provide a benchmark to gauge future change and by which to anticipate water quality management. The specific objectives are to:

1) Characterize the circulation and stratification status of two reservoirs, for determination of the degree of hypolimnetic anoxia.

2) Establish cause-effect relationships between causative (temperature, light, nutrients) and DO concentrations in the reservoirs.

3) Relate DO concentrations to variables relating lake productivity, nutrient dynamics, reservoir stratification, and morphometric criteria.

Methodology:

Study sites: Two stations have been established at damsite within Lago Guajataca and Lago Cerrillos (Table 1). Two additional stations were later added which consisted of the transitional zone in Lago Cerrillos and the entrance of Lago Dos Bocas. We have opted to modify the original sampling strategy which was to sample Lago Dos Bocas. We hypothesized that the large sediment loads entering that lake during runoff/storm events would confound interpretation of the data and evaluation of dissolved oxygen dynamics within the water column. Sediment blocks sunlight from reaching deeper depths of the water column thus primary production limitation is due to sediments and not algal biomass within the lake. In addition, the high sediment oxygen demand rates that may be exhibited in that lake may difficult the elucidation of natural mechanisms governing dissolved oxygen dynamics in tropical reservoirs. A preliminary survey of Lago dos bocas will be performed on 26 June 2007.
To date, eleven samplings have been performed in Guajataca and nine samplings have been performed in Cerrillos (Table 2). We expect to study Lago Cerrillos and Guajataca through July 2007, and will be making and will be making sporadic visits to Lago Dos Bocas.

Instrumentation and water quality data collection: Climatic variables for each lake are being gathered from corresponding climatologic stations administered by USGS, which include: mean daily temperature, daily precipitation, wind velocity, reservoir height. Water samples were collected with a 1-L Van Dorn sampler at (i) surface (i.e. approx. 20 cm from the surface), (ii) 1 m depth and (iii) at the extinction coefficient depth (1.7xSD) (Wetzel, 2001), and decanted to acid-washed polyethylene bottles. On 15 and 16 November 2006, sampling was performed within selected depths of Lago Cerrillos and Lago Guajataca, respectively. Samples were transported in ice coolers (<6$_o$C) to the Soil and Water Chemistry Laboratory at the University of Puerto Rico – Mayagüez Campus. A 250 mL portion of the sample was acidified with H_2SO_4 to pH <2 and stored frozen; a second 250 mL portion was filtered through glass-fiber filter for Chlorophyll-a analysis using Turner TD-700 Model fluorometer; and a third 250 mL portion was used for metal analysis or stored frozen in reserve.
Turbidity was quantified in the laboratory with a LaMotte portable turbidity meter. The parameters quantified were: total Kjeldahl nitrogen (TKN) (EPA method 351.2), dissolved nitrate (NO_3) (EPA method 353.1), total phosphorous (TP) (EPA method 365.4), dissolved phosphorus (DP) (365.2) and chlorophyll “a”(EPA method 445.0). Nutrients quantified in dissolved form were filtered through a 0.45 µm membrane. All nutrients were quantified using a BRAN+LUEBBE Ion Auto-Analyzer. Metals were quantified in water samples on selected dates (November profiles) and depths by Univ. of Georgia Soil, Plant and Water Testing Laboratory (http://aesl.ces.uga.edu/).
In situ measurements were pH, electrical conductivity, dissolved oxygen, water temperature, photosynthetically active radiation, and oxidation-reduction potential with a CTD-12 multiparameter probe (Applied Microsystems Inc.; Sidney, BC, Canada). The deployment depth was calculated after correcting the actual pressure for atmospheric pressure using the equation by Wetzel (2001, p. 152). The measured redox potentials were converted to potential in the system relative to standard H_2 electrode (Eh,actual) and corrected for pH and temperature. Electrical conductivity were expressed as that at 25$_o$C

(Radtke et al. 1998). Parameters were gathered in 1m intervals to the bottom in descending and ascending manner. All sensors were checked for proper functioning in the laboratory, prior to field sampling and calibrated as needed. Water transparency (Secchi depth) were determined with a 20-cm disk with alternating black and white quadrants in the shaded side of the boat.. Lake depth at the sampling point was determined with a marked tag-line.

The thermocline was determined from the maximum rate of change of temperature with depth and the top and bottom of the metalimnion was determined from the second derivative of the rate of change in temperature at two consecutive depths. The hypolimnetic volume was determined from the bottom of the metalimnion to estimated in-lake median depth. Hypolimnetic volume-weighted dissolved oxygen (VWDO) concentration were calculated from dissolved oxygen concentration and corresponding depth related water volume. The DO per unit area were computed from VWDO, hypolimnion depth and estimated hypolimnion area (Burns, 1995; Pelletier, 1998).

Principal Findings and Significance

Lake characteristics: Lago Guajataca has a greater drainage and lake area, but lower mean depth than Cerrillos; hence the latter has a greater volumetric capacity (Table 1). We hypothesize that Cerrillos has a greater proportion of anoxic sediment overlain by lake water hypolimnetic volume (hypolimnetic volume / mean anoxic sediment area) than Guajataca. Also, sediment load to Guajataca has historically been greater than in Cerillos. These two indicators suggest that the bottom sediments in Guajataca play a much more important role in recycling nutrients to the water column which could be used by phytoplankton during lake turnover (meromixis or holomixis).

Epilimnetic water quality characteristics: Sechi disk depths ranged from 1.5 to 4.0 m and from 1.8 to 3.0 m in Lago Guajataca and Cerrillos, respectively. Chlorophyll-a values (0 to 1 m) ranged from 2.5 to 5.8 µg/L from August 2006 to February 2007 in Guajataca, after which a large flush in chlorophyll-a values were observed on March 2007 (Figure 1). Values tended to be higher in the entrance than in the damsite of Guajataca. A similar pattern was observed in Cerrillos, but the peak in chlorophyll-a concentration in March 2007 was not as large. The peaks in chlorophyll-a values were coincident with those observed for turbidity (Figure 2), yet in general there was a poor association between chlorophyll-a and turbidity.

Similar nutrient (N and P) concentrations as those quantified by Martínez et al. (2005) were observed during the sampling period for both lakes.

Lake profile water quality characteristics: A depth profile taken on 14 November 2006, in Lago Cerrillos, showed that Chlorophyll-a increased from the surface to 6 m depth and thereafter did not change with depth increase. Profiles taken on February and March 2007, during the expected period of overturn, showed that maximum chlorophyll-a concentrations occurred from the surface to about 8 m, with higher values on the March 2007 sampling. On 16 November 2006, in Lago Guajataca, chlorophyll-a concentrations increased with depth from the surface and peaked at 8 m, thereafter decreasing with depth. On the Febraury sampling in Guajataca, maximum chlorophyll-a concentration was at 1 m. Profile concentrations increased for the March sampling, with maximum values of between 21 and 34 µg/L at between 1 and 4 m depth. A preliminary *in-situ* chlorophyll-a profile taken on 13 December 2006 in Lago Guajataca (E. Otero) revealed that the maximum depth of chlorophyll-a had moved deeper to between 10 and 12 m. In both lakes, turbidity increased with depth with maximum values at about 12 m being 2x surface values (2 NTUs). 10% of the maximum photosynthetically active radiation did not exceed seven meters in both lakes.

In general, water pH increased from the surface to near the metalimnion and then decreased with depth, with values being slightly greater in Guajataca (Figure 3 and Figure 4). This trend is consistent with water quality profile data gathered during November 2006 which showed that Lago Guajataca had greater water hardness (mean of 36.1 vs. 124.1 meq/L for Lago Cerrillos and Guajataca, respectively), Ca, Mg, K, Na, and Si concentrations than Lago Guajataca. Only total Fe and Mn appeared to consistently increase with depth in Lago Guajataca, and did not occur in Lago Cerrillos. Electrical conductivity values generally increased slightly with depth and were generally higher in Lago Guajataca (Figures 3 and 4).

Lago Guajataca was strongly stratified between 6 and 7 months of the year, from April to November. There was a weak stratification for the months of December, February and March (Figure 5). The bottom of the metalimnion ranged from 4.8 to 7.1 from August to December, which in the latter time period evidences the initiation of mixing within the water column (Table 4). Evidence for the formation of the thermocline was again observed on 30 April 2007. The stratification in Lago Cerrillos was not as strong as that in Lago Guajataca, with delta temperature values less than 1$_o$C (Figure 6). Stratification was stronger for the months of April to September (approximately 5 months) and weak during October and November. We estimate that there was no stratification from December to March, and were taken as the months of holomixis or meromixis.

The rate of mixing in Lago Guajataca was apparently much slower because by December complete mixing had occurred in Lago Cerrillos, yet in Lago Guajataca it was still on-going (probably due to the fact that Guajataca experienced much higher epilimnion temp and that temperature gradients (epilimnion vs. hypolimnion) were much higher at Guajataca than at Cerrillos).

Dissolved oxygen concentrations generally decreased with depth, at both sites but were always at or above saturation values throughout the epilimnion and the top part of the metalimnion. DO concentrations sharply decreased to less than 10% saturation values in the hypolimnion and in most instances thereafter were effectively zero (< 1 mg/L) (Figures 7 and 8). A similar pattern was observed in Lago Cerrillos except once complete overturn occurred (15 December 2006), concentrations ranged from 87 to 45% throughout the water column to 22 m depth. The oxidation-reduction potential patterned DO patterns during the epilimnion and metalimnion with the redox-cline occurring well below DO minimum (Figures 7 and 8). This is reflective of the presence of alternate redox couples in the absence of oxygen, and further exhaustion of these with increasing depth (Figure 3b and 3d). Volume weighted DO concentrations in Lago Guajataca ranged from 1.3 to 3.8 mg/L, which indicates that the lake does not meet PREQB water quality standards of 5 mg/L. Volume weighted DO concentrations in Cerrillos ranged from 2.6 to 5.9, and was in violation of PREQB standards on selected dates.

Hypolimnetic oxygen content and dynamics: Burns (1995) has shown that estimated hypolimnetic oxygen consumption rates are unrealistically low when DO concentrations fall below 2 mg/L because the DO depletion rates are first order with respect to oxygen concentrations. In Guajataca, 90% of all of the volume-weighted hypolimnetic concentrations measured were below 2 mg/L, so that the computed data may not adequately serve to compare to other lakes, nor to quantitatively show the relationship between oxygen depletion and trophic state of the two lakes evaluated. The hypolimnetic DO concentrations in Guajataca were always less than 1 mg/L. The profile taken on January reveled that DO concentrations persisted to between 1 and 4 mg/L well below the expected thermocline, but concentrations were exhaused by the next sampling date increased in the hypolimnion.

In Cerrillos, a strong oxycline occurred for the months of September to November and in May. At all other times, there were variable hypolimnetic DO concentrations. Hypolimnetic concentrations generally were less than 2 mg/L until November. An increased in hypolimnetic DO concentrations was observed on December and persisted until February after which concentrations were exhaused by the May sampling. Further refinements in DO volumetric contents will be made by obtaining detailed bathymetry data, such that the water volumes corresponding to each of the hypolimnetic depths can be estimated more accurately. Work is also underway to estimate the degree of stratification by quantification of lake water column stability.