Measuring the Components of Ecosystem Respiration in the Headwaters of the White River

Student paper by Courtney Brown

Abstract

Sediment oxygen demand (SOD) is the rate that dissolved oxygen leaves the water column in a body of water due to the build-up and decomposition of organic carbons in the sediment. The introduction of organic materials changes the chemistry of streams, and many chemical reactions occurring in bodies of water, with the exception of photosynthesis, require oxygen. Also, when the organic carbons are in the sediment of streambeds, bacteria and other microorganisms go to these organic materials to feed on them and decompose them. The combination of these two events results in an increased oxygen demand and, therefore, a decrease in streams' dissolved oxygen (DO). This increase in the oxygen demand does not only have the potential to be harmful to the aquatic life in these streams, but can also lead to a build-up of total organic carbons (TOCs) where they pour into Beaver Lake, thereby polluting the lake. This pollution can lead to dangerous effects with the potential to be hazardous to one's health, such as disinfection bi-products (DBPs).

An experiment was done to measure oxygen dynamics in the sediment and water column of the White River.

Introduction

Sediment oxygen demand (SOD) is the rate that dissolved oxygen leaves the water column in a body of water due to the build-up and decomposition of organic carbons in the sediment (Doyle & Lynch, 2006). This organic matter can come from many sources. The two different types of sources that introduce organic material into bodies of water are point and nonpoint sources. Point sources are anything, such as a wastewater treatment plant or a drain from an industry or factory, that is large and exclusive. Smaller and more spread out sources are called nonpoint sources. This category can include farms, feedlots, runoff from streets, construction sites, and runoff from septic tanks (Terry, 1997).

In northwest Arkansas, two major point sources are agriculture and runoff from urban growth. There are many farms all around the streams that lead into Beaver Lake. Organic materials, such as plants and animal feces, have the potential to go into these streams and increase the SOD rate. Furthermore, northwest Arkansas is becoming one of the fastest growing urban populations in the United States. Due to this population increase, the amount of organic wastes from the urban areas also increases, creating yet another source of an increased SOD rate. One major point source is the wastewater treatment plant, located upstream from the West Fork on the White River, one of the rivers that flows into Beaver Lake.

The Water Pollution Control Act of 1972 calls for the regulation of runoff into natural waters from both point and nonpoint sources. It requires states to put more importance on the permit system and for stricter punishments of infractions. It also forces states to increase funding for construction grants. The objectives of the Act include making water better for recreational activities, such as fishing and swimming, and eliminating pollution discharges (Terry, 1997).

The introduction of organic materials changes the chemistry of streams. Many of the chemical reactions occurring in streams, with the exception of photosynthesis, require oxygen. Also, the organic carbons in the sediment of streambeds are fed upon by bacteria and other microorganisms, resulting in a decrease in the amount of oxygen in these areas.

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With this knowledge, the water column and sediment of a stream or river can be used to determine whether or not the ecosystem is carbon-limited. A water ecosystem lacking carbons is considered carbon-limited; whereas, an ecosystem that has a large plethora of carbon is not carbon-limited. In systems that are not carbon-limited, there is an increased oxygen demand and, therefore, a decrease in streams' dissolved oxygen (DO). This increase in the oxygen demand does not only have the potential to be harmful to the aquatic life in these streams, but can also lead to a build-up of total organic carbon (TOC) where they pour into bodies of water, thereby polluting the water.

One potential threat brought about by an increased number of carbons in the lake is the formation of disinfection by-products (DBPs). These possibly toxic chemicals can be either organic or inorganic and are formed from reactions between organic compounds and oxidants, such as chlorine, which are used in the wastewater treatment plants to treat the water (Kilduff & Karanfil, n.d.). Studies have shown that human intake of DBPs can be linked to such health problems as cancer and reproductive and developmental defects (Richardson, 2006).

In order to determine whether bodies of water are carbon-limited systems, different tests can be run. The first of these was a five day biochemical oxygen demand (BOD) test. This measures the levels of DO in mg/L found in the water column of the stream. The results show how much of an oxygen demand there is just in the water of the stream, regardless of the sediment or surroundings.

A second test is the specific oxygen uptake rate (SOUR) test, which measures the rate at which dissolved oxygen leaves the sediment. This test can be followed by a potential oxygen uptake rate (POUR) test, which finds what the oxygen uptake rate of the system would be if the system had an unlimited source of carbons. Since the higher the carbon levels in the water, the lower the amounts of dissolved oxygen, if one puts an unlimited source of carbons in the water, this will give the sediment its highest potential uptake rate. The SOUR can then be compared to the POUR to see if the system is carbon-limited. If the POUR is much higher than the SOUR, then there is a shortage of carbons in the water, and the system is carbon-limited; if the SOUR is close to the POUR, then the system has plenty of carbons, meaning the system is not carbon-limited. To the best of this experimenter's knowledge, no prior research or experimentation was done to date in order to find the potential oxygen uptake rate by adding carbons to the sediment and finding the oxygen uptake rate.

The Beaver Lake Watershed is in Northwest Arkansas spread across Washington, Madison, Benton, Carroll, and Franklin counties. The water basin includes a drainage area of 1,186 square miles. 300,000 acre-feet of this region is used for flood control, and approximately 920,000 acre-feet is employed for the production of electricity and water supply. Beaver Lake is the main source of drinking water for Beaver and Carroll counties, a region that includes more than 300,000 people (Arkansas Water Resources Research Center, 1990, p. 1).

Most of the water quality problems, such as low dissolved oxygen and high levels of fecal coliform, algae, iron, manganese, and turbidity, occur in the upper regions of the lake. These issues have been linked to an increased level of nitrogen, phosphorus, and carbon runoff from urban point and nonpoint sources and rural nonpoint sources, due to the large number of confined animals in the region. Additionally, eighty-five percent of the water that flows into Beaver Lake enters the lake upstream of Highway 12 bridge; however, less than twenty percent of the actual lake is in this area. Therefore, there is a larger concentration of pollutants in the upper region of the lake (Arkansas Water Resources Research Center, 1990, p. 1).

The objective of this project was to measure oxygen dynamics in the sediment and water column of the White River. In order to meet this objective, two hypotheses were tested. The first of these was that two stream sites in the Ozark Highlands exhibit different oxygen dynamics, measured as biochemical oxygen demand and specific oxygen uptake rate (SOUR). The second hypothesis was that respiration rates of sediment from two Ozark Highland streams are limited by carbon energy sources, as measured as SOUR.

Materials and Methods

Five-day biochemical oxygen demand (BOD) tests were performed on the water samples from each of the three streams to measure the rate of the decrease of DO in the water column (APHA, 1998). The unfiltered stream water was placed into a 300-milliliter BOD bottle. An YSI 5010 BOD Probe and an YSI 5100 DO Meter were used to perform the BOD tests. The probe was cleaned and calibrated with reverse osmosis (RO) water for fifteen minutes. The DO in milligrams per liter at calibration was recorded. The probe was then placed in the BOD bottle holding the stream water. When the meter reading stabilized, the measurement for DO in milligrams per liter was recorded. Then the probe was removed, and a lid was put on the bottle. Some deionized (DI) water was put around the base of the lid to completely seal the bottle. This process was done three times with water from the same stream. It was repeated with the sampled water from all three streams, performing the BOD5 experiment a total of fifteen times. The fifteen BOD bottles containing stream water were labeled and stored in an incubator (Sheldon Manufacturing, Inc.) at twenty degrees Celsius for five days. After that, the bottles were taken out, and the same process was repeated with the water from each of the three streams.

Experimentation for this project included sampling two different sites from streams that flow into Beaver Lake. The sub-watersheds sampled included the Middle Fork of the White River (MWR) and the West Fork of the White River (WWR). Labeling of the sites was done by taking the abbreviation of the site name and adding the number of the country road or highway on which it was located (i.e. MWR 57 is located on the middle fork of the White River on Country Road 57). Sites were chosen based on the deposition of their environments. Desirable sites had fine sediment with few large rocks, little or no canopy, and low flow velocity. Also, since a range from low to high in the SOD rate was needed for this experiment, sites were chosen based on of their SOD rate. One site was sampled from the middle fork of the White River, and one site was sampled from the west fork: MWR 57 and WWR 16, respectively.

Samples of the water and sediment from the same streambed were collected from each site. The water was collected in opaque, 1-liter bottles. The samples of sediment were put in plastic containers. Samples were placed in ice chests with ice packs and transported to the lab. All water samples were analyzed within six hours of being collected, and sediment was stored in a refrigerator when not being tested. Sediment samples were analyzed within one or two days of being collected.

Oxygen uptake rate (OUR) tests were conducted to find the oxygen consumption rate of the sediment collected from the streams. Two samples from the same site, one without sugar and one with sugar, were tested simultaneously. Two YSI 5010 BOD Probes and the YSI 5100 DO Meters were used to perform this test. The probes were calibrated for fifteen minutes in RO water, and the DO levels in mg/L at calibration were recorded. Two 300-milliliter BOD bottles were filled with RO water. A lab spatula was used to fill two stainless steel weighing boats with fifteen grams apiece of sediment from the same streambed, the exact weight in grams being recorded.

Approximately one gram of sugar was put into a third weighing boat, the exact weight in grams being recorded. An OHAUS Scout scale was used to weigh the sediment and sugar. The sediment from one weighing boat was poured into one of the BOD bottles, and the sediment from the other weighing boat was poured into the other bottle. The sugar was poured into one of the bottles along with the sediment, and the bottle with the sugar was labeled. A VWR 200 Mini Stirrer was put into each of the bottles. The bottles were put on top of 220 Mini Hot Plate/Stirrers, and the power was turned on to a high enough setting to stir the sediment adequately. A probe was placed in the top of each bottle, and the stirring mechanism was activated. The initial DO levels were recorded, and every minute, the DO levels were recorded. When the DO levels changed no more than 0.05 mg/L in a minute for three consecutive minutes, readings were recorded every five minutes. This continued until the DO levels did not change more than 0.1 mg/L in five minutes or more than 0.02 mg/L in a minute for three consecutive minutes.

Specific oxygen uptake rate (SOUR) were calculated by determining the OUR per gram dry weight of sediment. A lab spatula was used to put wet sediment from the same streambed into three different stainless steel weighing boats, and each was measured on the OHAUS Scout scale to approximately fifteen grams of sediment, the exact weights being recorded. The sediment from each weighing boat was put into a different crucible. De-ionized (DI) water was used to ensure that all the sediment went from the weighing boats into the crucibles. All three crucibles were put into a Thermolyne Furnatrol 133 oven at 110 degrees Celsius for at least twenty-four hours. The next day, the crucibles were removed from the oven, and each of the three samples of dry sediment was weighed on the scale. To find the reduction in the weight of the sample after removing the moisture content, the weight of the wet sediment had the weight of the dry sediment of the same sample subtracted from it; the difference was then divided by the weight of the wet sediment. The SOUR test was performed for both sites.

Discussion and Results

From the five day BOD test, the DO levels from the first day of the three samples of water from the same stream were averaged. Five days later, the new DO levels of the three samples from each site were averaged. For MWR 57, the average DO on the first day was 6.72 mg/L, and the average DO on the fifth day was 4.76 mg/L. For WWR 16, the average DO on the first day was 8.04 mg/L, and the average DO on the fifth day was 6.81 mg/L.

To analyze the OUR results, the amount of DO in mg/L for each of the three samples from the streambed were averaged at each minute. The average of the three samples of sediment from the same streambed when sugar was added was also found at each minute. Then, the actual DO and potential DO at each site were compared in a graph, the actual DO being the samples without sugar and the potential DO being the samples with sugar (see Figures 1 and 2).

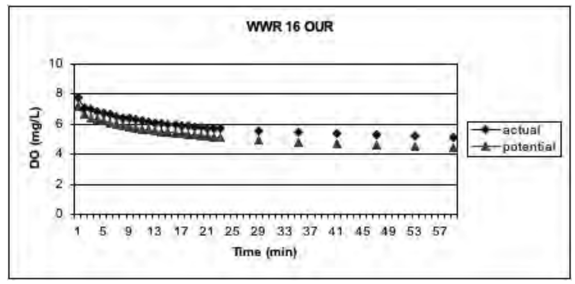

Figure 1. WWR 16 OUR Graph, University of Arkansas, 1 Aug. 2006.

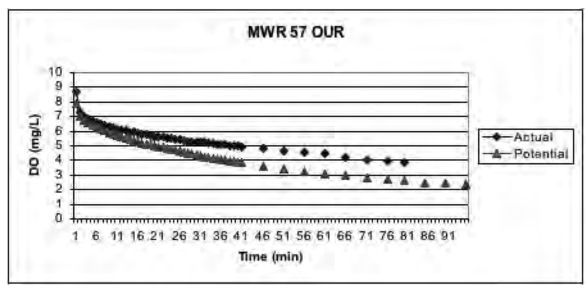

Figure 2. MWR 57 OUR Graph, University of Arkansas, 1 Aug. 2006.

For the SOUR and POUR tests, the weights of the wet sediment were compared to the weights in grams of the dry sediment to find the moisture content. The average for MWR 57 was 0.20 grams dry weight sediment (g DW sed) and the average reduction in WWR 16 was 0.23 g DW sed.

The average reduction was used to find the specific oxygen uptake rate for the sediment without sugar from each site. For each site, the final average DO from the three samples without sugar was subtracted from the initial average DO of the three samples without sugar. The difference was divided by the average reduction in grams of dry weight sediment for that site. The quotient was then divided by the number of minutes the OUR test lasted.

The objective of this project was to measure oxygen dynamics in the sediment and water column of the middle and west forks of the White River. When carbons were added to the sediment, it was found that there was only a minimal difference between the specific oxygen uptake rate of the sediment and its potential oxygen uptake rate. Overall, increasing carbon sources did not increase SOUR a great deal, considering the difference in rates ranged from 0.01 to 0.04 mg/L*g DW sed.*min.

However, even at these low numbers, the difference in response between sites suggests the systems have different carbon budgets. WWR 16 had the lower response and is located in a lower stream reach with a high contrast in the sediment. It also receives runoff from the wastewater treatment plant located upstream of this fork, and thus the SOUR as that site was not organic compound limited. MWR 57, however, is in a headwater stream with little organic carbon load. It responded to being enriched by consuming more oxygen. Therefore, the first hypothesis that the oxygen dynamics in both sites along the White River would be different failed to be rejected due to the different response to the addition of sugar between the site located on the middle fork and the site located on the west fork. The second hypothesis that the respiration rates of sediment in the two different sites are limited by carbon energy sources was rejected due to the very minimal change between the specific oxygen uptake rate and the potential oxygen uptake rate found by enriching the sediment with carbons.

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