“The darkening waters: particulate organic carbon sedimentation rates along a water color gradient”

BIOS 569: Practicum in Field Biology

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2013

Abstract

Recently, our current understanding of the global carbon budget has been transformed by the explicit account of the inland waters into the carbon budget. Within this global carbon context, lakes have been recently recognized as disproportionately important components to carbon cycling. Even though lakes are less than 2% of the ocean’s area, they store more organic carbon (OC) than the oceans sediments. Given the increasing trend observed in dissolved organic carbon (DOC) in Northern Hemisphere lakes, the consequences of OC sedimentation rates and carbon storage on temperate lakes are still unknown. This study aims to improve our understanding of the OC burial rates among a DOC gradient in the NHLD. To test this question, we quantified sedimentation rates of OC in 5 temperate lakes, which ranged in water color (used as a proxy for DOC) from 0.048 to 0.713 (a440). We did not observed any significant relationship between particulate organic carbon (POC) and increasing concentrations of water color. This result may be explained by an artifact of our weighting techniques, rather than by physical or biological reasons. In order to elucidate if our results are representative of a relationship of OC sedimentation rates and growing DOC concentrations, a strict protocol for processing the sediments will be develop for another data set that will be examined. Also, a whole carbon budget will be assessed with the purpose to further enlighten the possible effects that increase DOC may have on Northern Hemisphere lakes carbon cycling.

Introduction

In the last decade, our current understanding of the global carbon budget has been transformed by the explicit account of the inland waters into the carbon budget (Cole et al. 2007 and Tranvik et al. 2009). The inclusion of these aquatic ecosystems adds valuable information to elucidate the dynamic interactions that occurs between the atmosphere, lithosphere, hydrosphere and biosphere. The simplified scheme of aquatic systems as passive connections from the terrestrial ecosystems to the oceans has been debated (Cole et al. 2007). Instead of being a passive connection, this inland to ocean water flow is an active and dynamic drainage network that contributes to the carbon cycle through carbon exchange with the atmosphere, storage in sediments and transport to the oceans (Cole et al. 2007).

Within this global carbon context, lakes have been recently recognized as disproportionately important components to carbon cycling (Tranvik et al. 2009; Battin et a. 2008; Cole et al. 2007; Einsele et al. 2001 and Dean and Gorham 1998), even though they occupy only 2-3% of the terrestrial landscape (Downing et al. 2006 and Einsele et al. 2001). This is because they are dynamic sites of carbon transport, transformation, and storage of considerable amounts of carbon from the terrestrial environments (Tranvik et al. 2009 and Cole et al. 2007). Moreover, lakes store much more organic carbon (OC) per unit area than all the oceans sediments (Cole et al. 2007). This argument has been proposed as a possible consequence of greater productivity of freshwater systems, and the interacting rapid lacustrine (lake related) sediment accumulation (Cole et al. 2007).

Sediment accretion may be also an interactive response of the OC inputs on the lakes. This may be supplied not only from within the lake (autochthonous), but also from airborne deposits from outside and inside ta lake's watershed and external sediments carried by water in their catchment (allochthonous inputs). This allochthonous imports are harder to degrade (recalcitrant), and more prone to sedimentation (Tranvik et al. 2009; Wachenfeldt and Tranvik 2008; Downing et al. 2008). In addition, it is important to consider the intrinsic relationship that exists between lake productivity and carbon storage, which commonly increases with lake productivity (Cole et al. 2007). This is likely due to the low oxygen concentration found in productive lake sediments (Tranvik et al. 2009). At a global scale, estimates for average carbon burial rates in lakes ranges between 4.5 and 14 g C m^2 yr^{-1} (Tranvik et al. 2009; Cole et al. 2007; Dean and Gorham 1998; Stallard 1998). If extrapolated the range of global annual carbon storage rates is estimated to be 0.03 to 0.07 Pg C yr^{-1} (Tranvik et al. 2009; Cole et al. 2007; Einsele et al. 2001; Dean and Gorham 1998).

Given the important role of lakes in carbon storage, and the increasing trend observed in dissolved organic carbon (DOC) in Northern Hemisphere lakes (SanClements et al. 2012; Tranvik et al. 2009; Monteith et al. 2007; Evans etal. 2006; Tranvik and Jansson 2002), the consequences of OC sedimentation rates, and carbon storage on temperate lakes are still unknown (Wachenfeldt and Tranvik 2008). DOC is the main source of OC, generally >90% of the total OC, (Wachenfeldt and Tranvik 2008 and Wetzel 2001). Also, high DOC constrains the reach of light on lakes (euphotic zone). This may amplify the anoxic zone, limit OC degradation mineralization, and favor sedimentation of OC.

With more than 7500 lakes (Peterson et al. 2003 and Cardille et al. 2007) ranging in DOC gradients, the Northern Highland Lake District (NHLD) of northern Wisconsin and the Upper Peninsula of Michigan is an ideal study site to quantify OC sedimentation rates. Given the necessity to elucidate the OC sedimentation on increasing DOC concentrations, this study aims to improve our understanding of the OC burial rates among a DOC gradient in NHLD. We expect to observe higher OC sedimentation rates in lakes with higher DOC concentrations.

Methods

This study was conducted at the University of Notre Dame Environmental Research Center (UNDERC) located on the border of Northern Wisconsin and the Upper Peninsula of Michigan, in the NHLD.

Organic carbon sedimentation rates were measured in 5 lakes with various levels of dissolved organic carbon (DOC). For this purpose, 3 simple and effective sediment traps (Teodoru et al. 2012) were set in each lake for 21-23 days to collect particulate organic carbon (POC) falling through the water column. All the traps were set at least 5 meters apart from each other at the deepest part close to the center of each lake, and were positioned 1.5m above the sediment surface to minimize the resuspension of sediments (Teodoru et al. 2012; Wachenfeldt and Tranvik 2008; Hâkanson and Jansson 2002).

The POC was quantified because it is the size that settles in the sediments. The POC was assumed to be half of the total sediments, and a high-temperature catalytic combustion method will be used to determine the total POC to corroborate this assumption (Teodoru et al. 2012). To calculate the dry mass of the POC, precombusted (4 h at 450°C) Whatman GF/F glass fiber filters were weighed. Then the sediments were filtered under low vacuum pressure (less than 10 cm of Hg), and were dried at 60 °C for 48 hours to remove any water. Equation 1 was used to calculate the POC.

Equation 1: $\text{Particulate Organic carbon (POC)} = \frac{\text{dry weight} - \text{ashed weight}}{\text{dry weight}}$

The DOC concentration of each lake was determined using the color analysis as a proxy, which is known to be correlated to DOC concentrations in NHLD (J. Zwart, personal communication and Pace and Cole 2002). Each lake water sample was filtered through GF/F and stored in a 60mL nalgene at 1.6 °C until analysis. The water was run in 100mm pathlength quartz cuvettes on a Spectronic Genesys II spectrophotometer. The absorbance was measured at 440nm on room temperature samples to prevent condensation on the cuvette. Equation 2 was used for calculating the G440 from absorbance (Danilov and Ekelund 2001).

Equation 2: $\text{G440}\ (m^{-1}) = \frac{\text{abs440} \times 2.303}{\text{pathlength(m)}}$

Finally, to test the relationship of POC sedimentation rates on increasing DOC concentrations, a linear regression was conducted in order to improve our knowledge OC burial rates among a DOC gradient in temperate lakes in Systat 13.

Results

After the exposure period of 21-23, the total dry-weight mass of the particulate organic carbon (POC) collected in the sediment traps of the 5 lakes ranged from 5.80-55.15mg (dry weight). The gradient of dissolved organic carbon (DOC) was determined by lake water color analysis and ranged from 0.048-0.713 (a440). The linear regression between POC carbon storage and the a440 gradient was not significant (r^2= 0.152; p-value= 0.151) (Figure 1).

Discussion

Even though lakes occupy a small fraction of the terrestrial landscape (Downing et al. 2006 and Einsele et al. 2001), they are currently being recognized as important dynamic sites in the global carbon cycling (Tranvik et al. 2009; Battin et a. 2008; Cole et al. 2007; Einsele et al. 2001 and Dean and Gorham 1998). One reason is their substantial role in storing carbon in their sediments, surpasing the carbon burial on ocean's sediments by a factor of three is reservoirs are also accounted (Tranvik et al. 2009 and Dean and Gorham 1998). Within that global context, the effects that rising concentrations of dissolved organic carbon (DOC) may have on temperate Northern Hemisphere lakes still remains unclear.

In contrast to our expectations, we did not observed any significant relationship between particulate organic carbon (POC) and increasing concentrations of water color. Our results are similar to those observed in Teodoru et al. (2012). Nonetheless, they attributed the lack of relationship to a constrained gradient of water color. In a more representative DOC gradient, Wachenfeldt and Tranvik (2008) found a significant positive correlation between DOC concentration of lakes and sedimentation of organic carbon (OC) for boreal lakes in Sweden.

This difference in our results may be explained by an artifact of our weighting techniques, rather than by physical or biological reasons. A whole data set was excluded from this analysis as a result of negative sedimentation rates, probably as a consequence of an unstandardized timing for pre-weighing the filters and the sediments. This is because we observed an increasing trend in the mass as waiting time increased. Thus, negative sediment rates may be explained by prolonged pre-weighing time of the filters in comparison with the weighing of the sediments. In order to elucidate if our results are representative of a relationship of OC sedimentation rates and growing DOC concentrations, a strict protocol for processing the sediments will be develop for another data set that will be examined in the fall.

With the aim to further enlighten the possible effects that increase DOC may have on Northern Hemisphere lakes carbon cycling, a whole carbon budget will be assessed. This will integrate active interactions of carbon through transport, transformation and storage (Tranvik et al. 2009 and Cole et al. 2007). Furthermore, another future goal may be take into account in the global carbon budget the 277 million small lakes which have an area of less than 1 km^2 (0.001–0.01 km^2) (Tranvik et al. 2009, Cole et al. 2007 and Downing et al. 2006).This will enable scientist to accurately represent the importance of lakes, and in a broad context the aquatic ecosystems, in the global carbon budget.

Acknowledgements

I would like to thank Ph.D. James Ackerman for sending me the information of UNDERC's program. Also, I am grateful for the guidance and support of Jake Zwart that assisted on the project since its conception. Finally, I am grateful for the economic support provided by the Bernard J. Hank Family Endowment.

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Figures

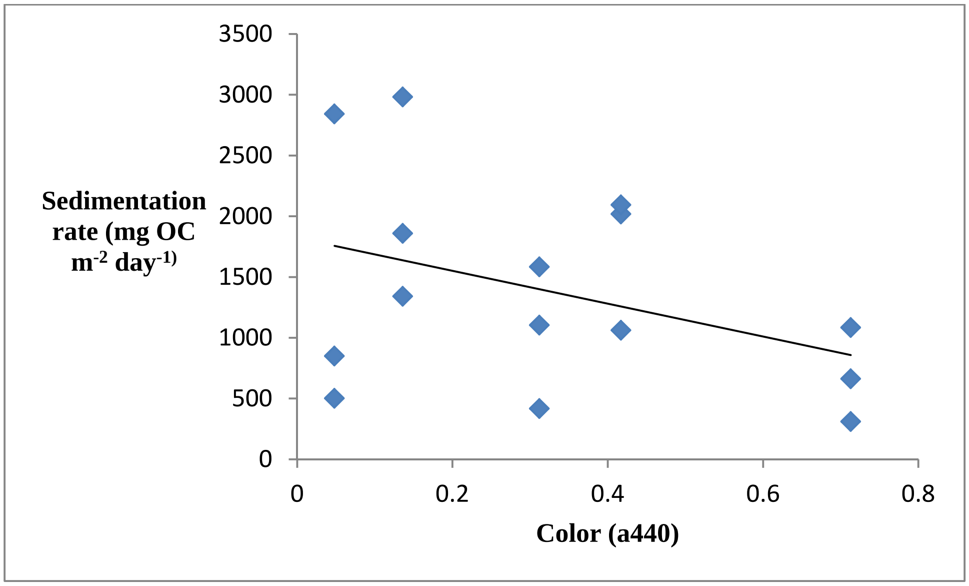

Figure 1. Relationship between sedimentation rate of particulate organic carbon (POC) and water color for 5 temperate lakes on the Northern Highland Lake District (NHLD) (r^2= 0.152; p-value= 0.151). Water color was used as a proxy for DOC because it is known to be correlated to DOC (J. Zwart, personal communication and Pace and Cole 2002).