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Discussions

Interactive comment on "Biogeochemistry of a large and deep tropical lake (Lake Kivu, East Africa): insights from a stable isotope study covering an annual cycle" *by* C. Morana et al.

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First of all, we would like to thank the referee 1 for his review of the initial version of our manuscript.

Q1 : The authors derive conclusions about lake Kivu being autotrophic from the seasonal pattern in 13C-DIC and other limnological concentration data. I am concerned with their definition of and proof for autotrophy in lake Kivu. Autotrophy means the ratio of primary production (PP)/respiration (R) > 1. Because PP + I = O + B + R, this means that in autotrophic lakes PP-R = O + B - I > 0 , which means O + B > I, with O = organic carbon out through outflow, B = sediment burial of organic carbon, I = organic carbon

inputs from catchment (allochthonous carbon). Please note that from the equations it follows that autotrophy means that the ratio of PP / I (= autochthonous / allochthonous carbon inputs) > R /(O + B). Therefore, true autotrophy cannot be demonstrated (or refuted) by the results shown in this paper. At best you can say from the results, it seems likely the lake is autotrophic.

REPLY : The seasonal pattern in δ13C-DIC we reported in this study is an additional evidence that adds to other arguments (gathered from DIC mass balance calculation, see Borges et al. 2014 ; or phytoplankton and bacterial processes measurements, see Morana et al. 2014). Together, these multiple lines of evidences strongly support the conclusion that the mixolimnion of Lake Kivu is net autotrophic.

According to the reviewer's equation, the lake would be autotrophic (PP-R > 0) if O + B > I. The organic carbon inputs from the catchment (I) in Lake Kivu have been estimated at different periods of the year (rainy or dry season). These data were recently published in Borges et al. (2014). We cited this paper and provided an estimation of I (0.7-3.3 mmol m-2 d-1) line 25 of page 17237 in the initial version of our manuscript. Sediment trap mooring (with traps at 50, 90, 130, and 172 m ; i.e. at the bottom and below the mixolimnion) have been deployed in Lake Kivu (see Pasche et al. 2010) to measure the rate of organic carbon burial (B). In their study, Pasche et al. (2010) reported an averaged B of 9.4 mmol m-2 d-1 for the period 2006-2008, that would be much higher than I (0.7-3.3 mmol m-2 d-1). Preliminary data gathered in 2012-2013 in parallel to this study appear to support the estimate of Pasche et al. (2010). The only outflow of Lake Kivu is the Ruzizi river. Based on the long term discharge average of Ruzizi (83.2 m3 s-1), the average POC and DOC in surface waters of (0.04 and 0.2 mmol/L) and lake's surface area (2322 km2), O can be evaluated at 0.7 mmol m-2 d-1. Hence, O + B = 0.7 + 9.4 > 0.7-3.3 (mmol m-2 d-1). We tried to improve the clarity of text in the revised version of our manuscript, the discussion section dealing with the δ13C-DIC dynamic now reads : "Primary producers preferentially incorporate the lighter isotope (12C) into the biomass with the consequence that the heavier isotope

(13C) accumulates into the DIC pool, whereas mineralization releases 13C-depleted CO2 from the OM being respired, into the DIC pool. Therefore, increasing primary production leads to higher δ13C-DIC but increasing respiration should tend to decrease δ13C-DIC (Bade et al. 2004). For instance, several studies conducted in temperate lakes have reported a significant increase in δ13C-DIC during summer, resulting from primary production (Herczeg 1987, Hollander & McKenzie 1991). In Lake Kivu, the δ13C-DIC increased linearly with time during the stratified rainy season, deviating gradually from the δ13C-DIC value expected if the DIC pool was at equilibrium with the atmospheric CO2 ($\sim$ 0.49 ‰. It appears unlikely that this linear isotopic enrichment of the DIC pool would be due to physical processes : the δ13C-DIC signature of the DIC input from the inflowing rivers (Borges et al. 2014) and deep waters (Fig. 3a) was indeed lower than the measured δ13C-DIC in the mixed layer. Therefore, biological processes (i.e. photosynthetic CO2 uptake) would be responsible of the isotopic enrichment of the DIC pool observed during the stratified rainy season. Nevertheless, a small decrease in δ13C-DIC was recorded at the beginning of the dry season (early in July 2012), but was concomitant with the characteristic deepening of the mixed layer observed during the dry season. As the depth profile of δ13C-DIC revealed that the DIC pool was isotopically lighter in the bottom of the mixolimnion, the measurement of lower δ13C-DIC values during the dry season could have resulted from the seasonal vertical mixing of surface waters with bottom waters containing relatively 13C-depleted DIC. Overall, the data revealed that the input of DIC originating from the monimolimnion during the dry season provided the dominant imprint on δ13C-DIC in the mixolimnion, but the seasonal variability of δ13C-DIC observed in the mixed layer hold information on biological processes. The gradual increase with time of the δ13C-DIC in the mixed layer suggests that photosynthetic CO2 fixation exceeded the respiration of OM, implying that the surface waters of Lake Kivu were net autotrophic, and hence, the microbial food web was supported by autochthonous organic C sources. In Lake Kivu, riverine inputs of allochthonous OM from the catchment (0.7 – 3.3 mmol m-2 d-1, Borges et al. 2014) are minimal compared to primary production (49 mmol m-2 d-1 ; Darchambeau

et al. 2014) and the export of organic carbon to the monimolimnion of 9.4 mmol m-2 d-1 reported by Pasche et al. (2010). The outflow of organic carbon through the Ruzizi River is also relatively low and was computed to be 0.6 mmol m-2 d-1, based on the long term discharge average of Ruzizi (83.2 m3 s-1, Borges et al. 2014), the average POC and DOC in surface waters (0.052 and 0.142 mmol L-1) and the lake surface area (2322 km2). This nevertheless implies that the outputs of OM (9.4 + 0.7 = 10.1 mmol m-2 d-1) are higher than the inputs of OM from the catchment (0.7-3.3 mmol m-2 d-1) suggesting a net autotrophic status. This conclusion is supported by the parallel study of Borges et al. (2014) who reported, based on a DIC (bulk concentration and isotopic) mass balance approach, that the mixed layer of Lake Kivu was net autotrophic while acting as a source of CO2 to atmosphere. Indeed, CO2 emissions to the atmosphere from Lake Kivu are sustained by CO2 inputs of geogenic origin from deep geothermal springs (Borges et al. 2014)".

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