

# Carbon cycling in the epilimnion of Lake Kivu (East Africa): surface net autotrophy and emission of CO<sub>2</sub> to the atmosphere sustained by geogenic inputs

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We report organic and inorganic carbon distributions and fluxes in Lake Kivu acquired during four cruises that capture the seasonal variations (March 2007 - mid rainy season, September 2007 - late dry season, June 2008 - early dry season, and April 2009 - late rainy season). The partial pressure of CO<sub>2</sub> (pCO<sub>2</sub>) in surface waters of the main basin of Lake Kivu showed modest spatial variations (coefficient of variation between 3% and 6%), and modest seasonal variations with an amplitude of 163 ppm (between 579±23 ppm on average in March 2007 and 742±28 ppm on average in September 2007). The most prominent spatial feature of the pCO<sub>2</sub> distribution was the very high pCO<sub>2</sub> values in Kabuno Bay (a small sub-basin of Lake Kivu) ranging between 13158 ppm and 14213 ppm (between 18 and 26 times higher than in the main basin). Surface waters of the main basin of Lake Kivu were a net source of CO<sub>2</sub> to the atmosphere at an average rate of 5.9 mmol m<sup>-2</sup> d<sup>-1</sup> which is lower than the global average reported for freshwater (16.0 mmol m<sup>-2</sup> d<sup>-1</sup>), saline (81 to 105 mmol m<sup>-2</sup> d<sup>-1</sup>) and volcanic lakes (458 to 51,183 mmol m<sup>-2</sup> d<sup>-1</sup>). In Kabuno Bay, the CO<sub>2</sub> emission to the atmosphere was on average 274.8 mmol m<sup>-2</sup> d<sup>-1</sup> (~46 times higher than in main basin). The deepening of the mixed layer and entrainment of deeper waters to the surface mixed layer was main driver of the seasonal variations of CH<sub>4</sub> as shown by the positive correlation of pCO<sub>2</sub> and CH<sub>4</sub>, of pCO<sub>2</sub> and the mixed layer depth, and of pCO<sub>2</sub> and δ<sup>13</sup>C<sub>DIC</sub>. Indeed, deeper waters have higher pCO<sub>2</sub> and CH<sub>4</sub>, and dissolved inorganic carbon (DIC) is more <sup>13</sup>C-depleted than that in surface waters.

In order to test if vertical mixing was the only driver of seasonal variations of pCO<sub>2</sub>, we computed DIC whole-lake mass balance of bulk concentrations (black numbers) and of stable isotopes (red numbers). The budgets show that the input of DIC from depth and export by the Ruzizi (the only outflow of the lake) were the main players in the DIC budget. Export of CaCO<sub>3</sub> was significant. There was a net loss of carbon from surface waters that can only ascribed to export of POC to depth, hence, we show that the epilimnion of Lake Kivu was net autotrophic. This is due to the modest river inputs of organic carbon owing to the small ratio of catchment area to lake surface area (2.15), and implies that the CO<sub>2</sub> emission to the atmosphere must be sustained by DIC inputs from depth of geogenic origin from deep geothermal springs.

Based on metabolic rate measurements and mass balance considerations, we show that bacterial respiration is not solely sustained by particulate primary production, and is substantially sustained by dissolved primary production. This leads to moderate to high levels of Percent of extracellular release (PER).

**Table :** Photic depth (Z<sub>e</sub>), chlorophyll-a concentration (Chl-a), particulate net primary production (PNPP), bacterial production integrated over Z<sub>e</sub> (BP), bacterial respiration (BR), and percent of extracellular release (PER, %), at two stations in the main basin of Lake Kivu [Kibuye, Ishungu], in March 2007, September 2007, June 2008, and April 2009

	Z <sub>e</sub> (m)	Chl-a (mg m <sup>-3</sup> )	PNPP (mmol m <sup>-2</sup> d <sup>-1</sup> )	BP (mmol m <sup>-2</sup> d <sup>-1</sup> )	BR (mmol m <sup>-2</sup> d <sup>-1</sup> )	PNPP-BR (mmol m <sup>-2</sup> d <sup>-1</sup> )	PER (%)
March 2007							
15/03/2007 Kibuye	18	38.3	27.0	23.2	35.7	-8.7	54
17/03/2007 Kibuye	20	48.4	42.5	25.8	39.9	2.6	33
23/03/2007 Ishungu	17	36.1	49.7	40.5	49.6	0.1	32
September 2007							
09/09/2007 Kibuye	19	56.4	42.9	35.9	47.9	-5.0	42
12/09/2007 Kibuye	18	55.1	45.9	34.0	45.9	0.1	36
04/09/2007 Ishungu	20	48.2	<i>n.d.</i>	16.0	29.9	<i>n.d.</i>	<i>n.d.</i>
June 2008							
23/06/2008 Kibuye	24	42.8	46.0	7.7	21.6	24.4	3
11/07/2008 Kibuye	20	37.8	42.0	11.1	24.3	17.7	17
03/07/2008 Ishungu	19	28.1	40.7	3.9	13.6	27.1	-4
April 2009							
04/05/2009 Kibuye	21	22.9	14.2	49.8	61.2	-47.0	82
21/04/2009 Ishungu	24	39.3	24.5	43.5	58.9	-34.4	68

