The role of boreal lakes in the carbon cycle

The problematic of greenhouse gas emissions of global jurisdiction is quite well known from the public today. We know that several gases contribute to global warming such as carbon dioxide (CO_2) and methane (CH_4). Of course, these gases are not only caused by human activity. They are part of the normal dynamics of natural ecosystems. The development of a global budget aimed at detailing the natural contribution versus the contributions coming from human activities requires multidisciplinary work at the international scale. Therefore, it is important to better define the role of lakes and river in this substantial budget.

Boreal lakes

The definition of carbon cycle in freshwater water-resource systems is the fruit of numerous scientific studies. But, the identification of each steps of the carbon cycle and the quantification of the different components of this natural budget still remains a big challenge. In Quebec, the study of lakes in boreal regions represents an even more serious contract considering the far distances of the sites and the absence of roads to get to the sampling sites. The Eastmain-1 Project, initiated in 2003 by Hydro-Quebec in the James Bay region, will not only aims at showing the impact of an hydroelectric reservoir on the net emission of greenhouse gases but will also contribute to enlighten us on the role of boreal lakes in the carbon cycle, a role which has been disregarded until now.

The boreal forest covers close to 70% of the Quebec territory, thus representing more than 550 000 km2. Moreover, freshwater bodies and wetland environments are omnipresent and cover close to one third of the region. The number of lakes that criss-cross the Canadian Shield in Quebec is estimated at 600 000. An overview of the region allows us to truly see the importance of the water-resource system as well at the dominance of numerous small lakes compared to large surface lakes (Figures 1 and 2).

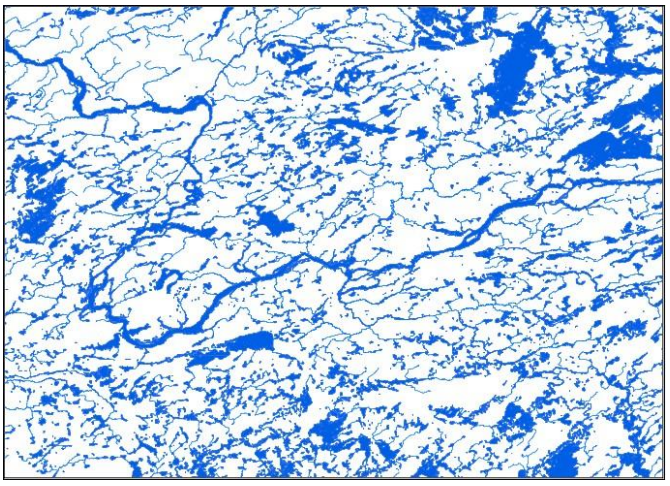


Figure 1 : *Water-resource system of the Eastmain-1 reservoir area*

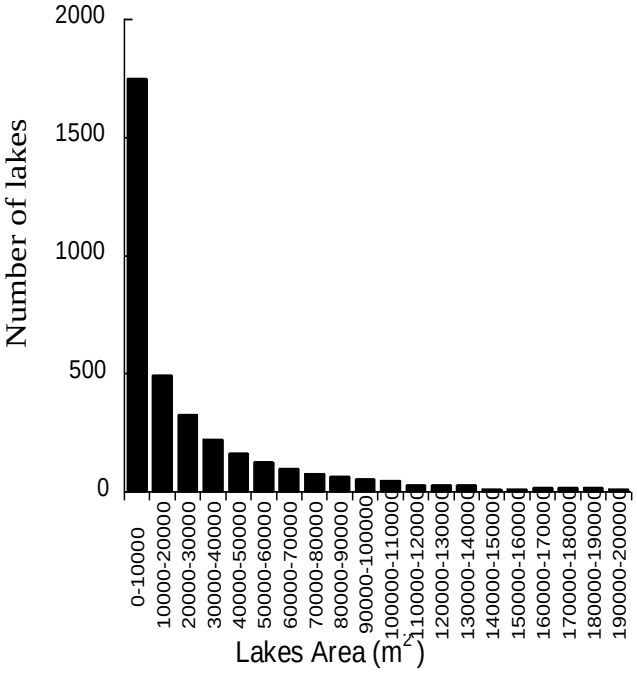


Figure 2 : *Number of lakes based on their areas*

The natural dynamics of carbon in a lake

Despite the static beauty of a lake there is a perpetual movement of carbon that circulates towards the system (lake) from several sources, or that recycles itself within the system and is released in the atmosphere or towards other lakes through rivers or other ground waters (Figure 3). Carbon will enter and exit a lake under an organic form; the particulate organic carbon or dissolved organic carbon (DOC) or under an inorganic form; dissolved inorganic carbon (DIC). The POC can be, for example, made of decomposed debris coming from vegetal plants or animals, small pieces of insect exoskeletons, debris from leaves residues originating from the forest litter, or in short, of all organic substances. It goes from a terrestrial

system to an aquatic system through leaching, can either be reduced in dissolved carbon due to bacterial activity in the lake, be stocked in the sediments or directly evacuated from the lake by an output such as a river.

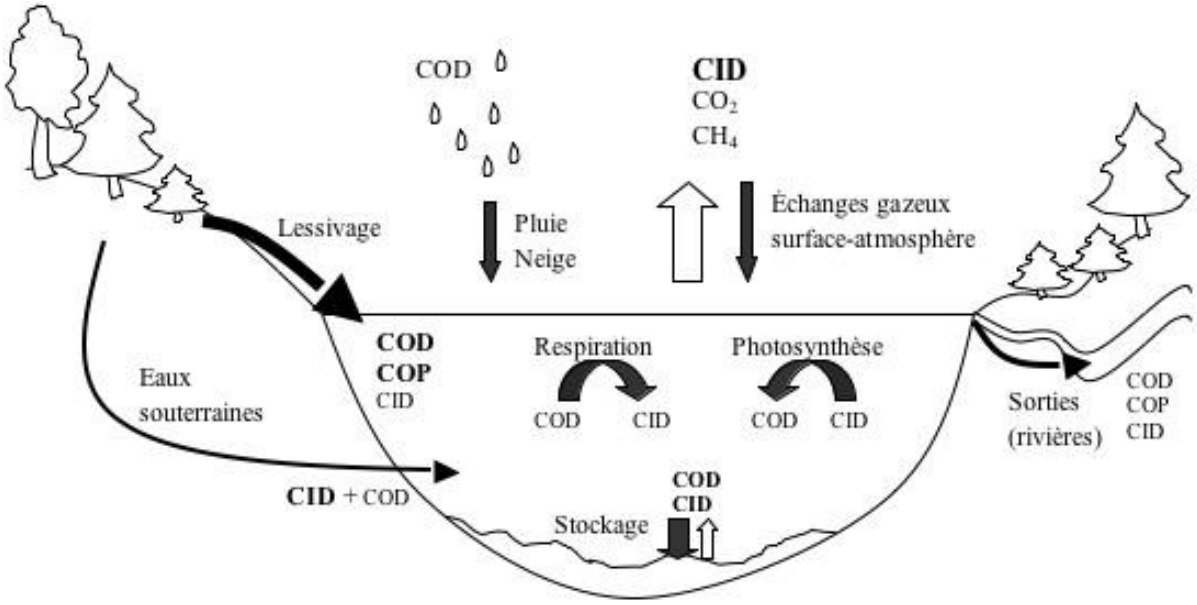


Figure 3 : *Diagram of the exchanges of carbon in lakes (DOC; dissolved organic carbon, POC; particulate organic carbon, DIC; dissolved inorganic carbon)*

The DOC is the result of bacterial decomposition of more complex organic matter such as POC. In addition to originating from water run-offs and ground-waters, its simpler configuration will enable its transport through precipitations under the form of rain or snow. The micro-organisms present in lake waters or in sediments largely participate in the recycling of DOC in a system, either by using it to breath or to multiply themselves, or by producing it during photosynthesis. The DOC unused during these metabolic activities is deposited at the bottom of the lake or evacuated towards other systems through water currents coming out of the lake. The DIC is the product of a respiration under a CO_2 form and the product of fermentation under a CH_4 form. This gaseous and volatile form of carbon is consequently easily transferable from one compartment to another in the cycle. Contrary to the DOC, the DIC recycles itself inside the lake but there is still a significant quantity of these greenhouse gases that are being released in the atmosphere from most lakes.

What do we know on the role of boreal lakes?

Certain researchers have estimated that for the totality of terrestrial carbon that reaches lakes, approximately 42% is released in the atmosphere under the form of greenhouse gases, 11% sediments towards the bottom of the lakes while 47% is transferred to oceans through the water-resource system. This is however a rough estimation, in the sense that all lakes of all biomes do not necessarily behave in the same way.

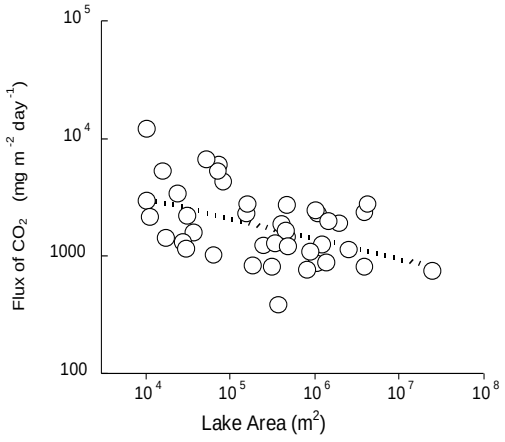


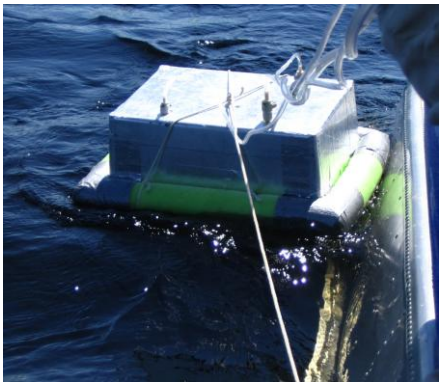
Figure 4 : *Concentration of CO_2 in the water (pCO_2) based on the lake area*

The Eastmain Project largely contributed to the quantitative estimation of a dozen boreal lakes of all sizes. Scientists have measured on-site fluxes of CO_2 towards the atmosphere, ranging from 4.33 to 273.13 mmol/m^2/day (an average of 45.83 mmol/m^2/day) and fluxes of CH_4 ranging from 0.02 to 1.93 mmol/m^2/day (an average of 0.46 mmol/m^2/day). These results show inputs that vary considerably from one lake to another but that all undeniably contributed to the natural emission of greenhouse gases. Furthermore, this study showed that smaller lakes are associated to more CO_2 at the surface and to larger fluxes of this gas towards the atmosphere (Figure 4). We have mentioned earlier that the boreal region being studied presented smaller lakes, for the most part, as opposed to larger lakes. Consequently, we must consider the fact that lakes from the Quebec boreal region play a non-negligible role in the natural dynamics of greenhouse gases.

Boreal lakes are also wells where carbon has been stocked in sediments for thousands of years. One study on 9 lakes of the Eastmain region has contributed to estimate that Quebec boreal lakes stocked in average 9.44 kg C m^{-2} (between 2.9 and 21.0 kg C m^{-2}) in their sediments. The watershed area, the lake area and the maximum water depth tend to predict rather well this stocked quantity. Quebec boreal lakes come within the scope of stocking patterns of boreal lakes world-wide and are particularly similar to the stocking in lakes of Finland. These results show once again the existing variability from one lake to another for the same region.

How to measure greenhouse gases?

Measuring the concentration of a gas in the water or of a gas being released from the water can be a serious challenge. Fortunately, we can find instruments on the scientific market with which we can obtain a precise concentration of CO_2 or CH_4 as much in the water as in the air. To obtain concentrations of CH_4 and of CO_2, the Eastmain Project uses a chromatograph. The intense mixing of a sample of water is sufficient enough to enable the gases to come out and to record their concentrations afterwards. However, an installation made of a floating chamber connected to an EGM-4 reader is needed in order to estimate a flux of gas released from a body of water. These experiences are repeated over many years over the same thaw period and at the deepest point of numerous lakes of the Eastmain-1 reservoir region (see index cards on the measure methods).



Our knowledge on the role of boreal lakes in the carbon cycle was rather minimal until now. Scientific communities of Finland and of Sweden are actively contributing to the advancement of knowledge in this field. The Eastmain Project insures the collaboration of Quebec towards a better comprehension of the involvement of lakes in the natural dynamics of greenhouse gases.

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