

Carbon balance and CO₂ exchange in lakes and streams integrating entire watersheds (CARBON)

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Project summary:

Our overall goal is to quantify the emission of CO₂ from lakes and streams and integrate the rates for entire hydrological networks. Our advanced automatic measurement equipment can, thereby, be put in full use. The results should also allow us to evaluate the, hitherto, neglected importance of bicarbonate for CO₂ consumption and release processes and to improve the models predicting CO₂ emissions. We will, then, use the data to evaluate for entire catchments how changes in land use and temperature influences sources and sinks of CO₂ in the hydrological network. This information is needed in the optimal management of lakes and streams and in the planning of restoration projects, e.g. reestablished flooded river valleys, under the prospects of strengthening CO₂ sinks in the future.

Background

Freshwater systems transport water, nutrients and organic matter from sources in the watershed to the recipient marine waters. Along this hydrological continuum of subsystems, organic and inorganic carbon is continuously transformed by biological and chemical processes occurring in soil water, groundwater, streams and lakes. Eventually most of the CO₂ originally captured through photosynthesis in plants is reemitted to the atmosphere. Most of the captured CO₂ from the terrestrial environment is usually held in organic matter in the water, but other important sources include supersaturated CO₂ and bicarbonate resulting from dissolution of carbonate and silicate minerals by CO₂ in the soils. In calcareous soils, the output of CO₂ locked in bicarbonate can in fact exceed the organic pools (Sand-Jensen, Staehr and Pedersen 2008).

While part of this input to the aquatic environments can accumulate as organic matter in the sediments and dissolved in the waters, most of the originally captured atmospheric CO₂ is eventually released back to the atmosphere by decomposition processes and re-precipitation of carbonate and silicate compounds. As some of the few, we have quantified the emission of CO₂ from a number of different-sized lakes (Sand-Jensen and Staehr 2007) and two Danish streams (Sand-Jensen, Staehr and Pedersen 2008). Also, we have established how much atmospheric CO₂ is sequestered in the soils to the formation of bicarbonate and how much of this is eventually released by mineral precipitation in a downstream lake. These studies show a significant net release of CO₂ from ponds and small lakes to the atmosphere, but the CO₂ evasion is (on an area basis) several magnitudes higher from the streams, supporting the notion that streams are important windows for degassing of CO₂. The dissolution of carbonates in soils and precipitation in eutrophic lakes are quantitatively important processes in the transport and

transformation of CO₂ that have been grossly neglected in the literature (Sand-Jensen, Staehr and Pedersen 2008), although it will strongly influence the molar balances in the exchange of oxygen and CO₂ exchange with the atmosphere from both aquatic and terrestrial ecosystems. *The overall goal of this project is to quantify the net release of CO₂ from freshwater systems and to understand the processes and conditions that regulate this emission.*

Although freshwater systems tend to be net heterotrophic and take up atmospheric oxygen, most systems are very productive. In fact, large lakes with little shading and input of organic material from the land can be net autotrophic, i.e. produce more organic matter than they degrade, and thus release oxygen to the atmosphere. Because of input of CO₂ with the incoming water and precipitation of carbonates and silicates that release CO₂ and subsidise primary production, CO₂ may either be taken up or emitted to the atmosphere depending on the exact magnitude of the processes. *We wish to clarify the balance between organic production and degradation, by determining the exchange of oxygen, and evaluate the balance between organic and inorganic transformation processes determining the direction and quantity of CO₂ exchange with the atmosphere in a number of freshwater systems.* This will be accomplished through a network of our newly developed automatic equipment, allowing simultaneous on-line monitoring of light-, wind-, oxygen- and CO₂ conditions in the lakes (Fig. 1). In the streams we will determine transport of organic and inorganic carbon and apply direct flow-through gas chambers (Sand-Jensen, Staehr and Pedersen 2008) in combination with free-water measurements to determine fluxes and piston velocities of CO₂ between water and air. We are confident that accurate prediction of piston velocity should be possible based on key parameters such as flow velocity, turbulence and depth allowing calculations of CO₂ fluxes from a wide range of streams. Although measurements have been conducted in specific lakes, there is a pressing need to integrate our knowledge through simultaneous measurements by direct methods in all freshwater systems of the entire watershed. Combining continuous recordings of oxygen and CO₂ with measurements of irradiance, temperature, wind and stream flow, furthermore makes it possible to determine the sensitivity and predictable power of these parameters. Also, we have very limited knowledge on CO₂ fluxes across the air-water interface in small lakes, because they have usually been calculated as a simple function of wind speed which appears to overestimate the actual fluxes (Sand-Jensen and Staehr 2008). Considering CO₂ exchange rates from streams only one paper has hitherto offered direct measurements (Sand-Jensen, Staehr and Pedersen 2008).

The rate and extent of biological degradation of organic material in aquatic systems are regulated by the source of organic material, temperature, oxygen and the retention time. We have published several papers on the importance of temperature and time for the degradation of organic material in lakes and streams (e.g. Pedersen and Sand-Jensen 2004, Staehr and Sand-Jensen 2006, Sand-Jensen et al. 2007, Staehr and Sand-Jensen 2007). Considerably less is known about the amount and degradability of terrestrial material of different origin (agricultural land, waste water, surface and groundwater in forests) in different aquatic systems. The current fragmented understanding makes it difficult to predict how major changes in land use (e.g. re-establishment of flooded river valleys) and global climate (i.e. altered hydrology and temperature) influence the balance between production and degradation of organic matter

and CO₂ exchange for entire catchments. Concerning flooded river valleys we expect net deposition of organic material in the soils and a shift of the major CO₂ emission to more downstream systems because decomposition of organic matter to CO₂ is delayed while it can to a lesser extent take place in the newly established wet soils than in the former drained fields. Concerning global warming, we expect increasing temperatures to enhance respiration in all aquatic systems, but in particular in the upper parts which receive high amounts of terrestrial matter. This should decrease respiration rates and, thus, oxygen demand and CO₂ release further downstream and lead to input of more fully degraded organic matter to the recipient marine waters. In order to comprehensively understand and model the flow of carbon from source to the marine recipient, we need to perform catchments integrated study of the flow and degradation of carbon at relevant time and spatial scale. *We propose to make a comparative catchment study of the balance between production and respiration (P/R, an index of energy balance).* This will be accomplished through a mass-balance analysis of long-term data-series of oxygen, CO₂, temperature and water flow obtained through the Danish environmental monitoring program and direct measurements of pools and temperature-dependent decomposition of organic matter along the route. Catchments will be selected to represent differences in land use (forest, urban, agricultural land), geology (alkaline clay soils vs. low-alkaline sand soils) and hydrology (dredged channels in drained fields vs. natural meandering streams in un-drained meadows). Land use affects both the type and amount of organic matter entering the aquatic systems; catchments geology defines the relative role of bicarbonate in the transfer of carbon; while hydrology determines the surface areas and retention times for degradation in the different freshwater systems. An analysis of the extent to which these master variables regulate long-term oxygen conditions and carbon dynamics is not only of academic interest but also of great importance for the optimal management of lakes and streams and the planning of restoration projects under the prospects of strengthening CO₂ sinks in the future.

Goals and hypothesis

Our main goals are:

- *To quantify the emission of CO₂ from lakes and streams and integrate the rates for entire hydrological networks and, furthermore, improve the empirical models predicting the emissions.*
- *To determine the coupling between oxygen and CO₂ in the exchange with the atmosphere and, thereby, in combination with mass balances of organic and inorganic carbon evaluate the importance of bicarbonate formation and loss for CO₂ consumption and release.*
- *To determine how differences in land use and changes in temperature and hydrology will influence the distribution along the hydrological network of CO₂ sinks and sources and P/R- balances through production (P) and decomposition (R) of organic matter.*

Experimental plan

We will select one catchments in North Zealand (Pøleå) located in calcareous moraine soils and one in Mid Jutland (tributaries to Gudenå) located on well-leached sandy soils

for detailed analysis and construction of empirical models. We have already studied several of the relevant sites in the Pøleå-catchment and will supplement these data and include the Jutland-catchment to attain the necessary data background. Streams in North Zealand have great seasonal variation in discharge, while those in Mid-Jutland display little variation due to a large, stabilizing input of groundwater. The two stream types also represent a contrast in alkalinity and, thus, in the role of bicarbonate in carbon budgets and transformations. In both catchments it is possible to sample in sub-catchments of different land use and drainage pattern. We will experimentally define the degradation rates and time patterns for different sources of organic matter, while we are confident that temperature dependence are already described accurately by our recent published studies (e.g. Sand-Jensen et al. 2007).

In the two selected systems, we will use already established permanent stations for measurements of water discharge and we will include our own frequent measurements of inorganic and organic carbon species to construct mass balances. We will deploy automatic sensor systems and gas flux chambers (Staeher and Sand-Jensen 2007, Sand-Jensen, Staeher and Pedersen 2008) for measurements of oxygen and CO₂ exchange rates, production-respiration rates and the parameters that regulate them (e.g. light, wind, turbulence, mixing, flow velocity, etc) and are used for construction of empirical models.

We will, then, expand the data background by including additional catchments examined as part of the comprehensive Danish environmental program. Specifically, this will provide us with catchments of different hydrology and land use. To supplement this data set, we will include campaign-measurements of oxygen, CO₂, bicarbonate and organic carbon compounds. Empirical gas exchange models derived from direct measurements will then be implemented and used to construct balances for entire catchments.

References

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