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Contribution of floodplain lakes to the global carbon cycle

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Abstract Inland waters are an important source of carbon. We measured concentration of carbon dioxide (CO₂) and oxygen (O₂), and some ancillary parameters in lakes of the Ob floodplain during several seasons. We received good correlations between carbon dioxide and oxygen concentrations, and studied dependence of CO₂ concentrations on the time of day and the season.

1. Introduction

Rivers, streams, lakes, and other inland waters are sources of carbon. They play an important role in the carbon cycle [1-3]. Carbon emissions have a great impact on climate [4, 5]; it is known that methane is a more potent greenhouse gas than carbon dioxide, and its global warming potential is significantly higher [1, 6].

The spring flood is a period, when the river demonstrates its power and strength. Every year for several weeks the Ob covers huge adjacent areas by water. During the periods of ice-cover and the following spring flood, the chemical composition and content of dissolved gases in water change. Accumulated heavy metals, organic compounds, macro- and trace elements are transported from shallow channels and flooded lakes into the Ob main watercourse and then to the ocean [7]. The importance of the Ob floodplain is significant: first of all, it is one of the largest floodplains in the world; it is 10 km wide, and can reach 60 km. Because of its size the floodplain is the main carbon contributor from land to the Arctic Ocean. Since the Ob's watershed lies in the boreal zone, the floodplain has high productivity [8]. Moreover, carbon inputs from Arctic rivers have enormous influence on biogeochemical cycling [9]. But the role of floodplain lakes and streams in the biogeochemical cycles is still largely unstudied.

2. Materials and Methods

2.1 Study site

The Ob River is one of the major rivers in the world. It is formed in the Altai Mountains by the confluence of the Biya and Katun rivers and debouches into the Gulf of Ob (Ob Bay). Its length is 3,650 km; the drainage area is 2,990,000 km². The Ob passes through different landscape zones: semi-desert, steppe, forest-steppe, taiga, forest-tundra and tundra. The Ob is the largest river discharging into the Arctic Ocean in terms of watershed area (average annual discharge is 12,475 m³ s⁻¹). The Gulf of Ob is the world's longest estuary (the length is more than 800 km, the width is 30-80 km, and the depth is about 25 m). It remains frozen from October till July [10].

Depending on the riverine net, feeding conditions and water regime formation, the Ob is divided into three parts: the upper Ob, middle Ob and lower Ob. The middle course of the Ob goes from the



Tom mouth to the Irtysh mouth, and is about 1,500 km long. It remains frozen from November till April; the average thickness of ice at the beginning of April is 90 cm [11].

Our research station, Kaibasovo, is located in the Krivosheinsky District in the Tomsk Region. The sampling points are typical lakes of the central part of the floodplain. They lie in inter-ridge deep depression and have an elongated shape. The lakes are surrounded by high ridges with developed meadow and shrub vegetation (Figure 1).



Figure 1. A typical floodplain oxbow lake (photographer S N Kirpotin)

A slight slope to the lake in the middle of the ridge is occupied by hillock herb-turfy-sedge phytocenoses. The community is flooded. The turf sedge (*Carex spitosa* L.) dominates, its tussocks have a height from 25 to 50 cm and 25-35 cm in diameter; they occupy about 60% of the area. *Fillipendula ulmaria* L. Maxim., *Thalictrum flavum* L. and *Veronica longifolia* L. are codominants (projective coverage 6-7%). In a small abundance (1-3%) there are *Calamagrostis purpurea* Trin., *Sanguisorba officinalis* L., *Lathyrus pratensis* L., *Galium boreale* L., etc. In total there are 17 species. Sedge and sedge-wood-reed phytocenoses abut to the lake shore in the plain low part of the ridge. Tussock microrelief with water between hummocks is developed here. The total projective cover of grass stand is 70%, its height is 120-170 cm. Tussocks form the dominant communities *Carex acuta* L. (20%) and *Calamagrostis purpurea* Trin. (60%). On the tussocks we observed *Phalaroides arundinacea* Rausch., *Lycopus exaltatus* L., *Scutellaria galericulata* L. in groups (1-3%). *Veronica longifolia*, *Carex atherodes* Spreng., *Comarum palustre* L. (in the water between tussocks) are quite abundant (3-5%). *Rumex aquaticus* L., *Lytrum salicaria* L., *Lathyrus palustris* L., *Thalictrum flavum* are not abundant (1% and less) on the tussocks, *Naumburgia thyrsoiflora* Reichenb., *Stachys palustris* L. were observed between the tussocks in the water.

In the lake water the groupments of *Cicuta virosa* L., *Equisetum fluviatile* L., *Hydrocharis morsuranae* L., *Stratiotes aloides* L. are developed. Two last-mentioned species form a continuous cover in the shallows.

2.2 Data sampling

At first we chose several typical floodplain lakes. One of them was studied using transects and with twenty-four-hour measurements. This lake is about 730 m long and 50 m wide. We measured dissolved carbon dioxide, dissolved oxygen, conductivity, pH, temperature in water lengthwise the lake in the middle every 80 meters and by three cross transects. Our equipment also allowed us to take the same measurements every five minutes during the twenty-four-hour period. All measurements were taken every season: in autumn, at the end of winter, during the spring flood and in summer.

Another part of our work was studying different floodplain lakes. We made measurements of the same parameters (dissolved carbon dioxide, dissolved oxygen, conductivity, pH, temperature) in five lakes in different seasons during the years 2016-2017.

We measured dissolved carbon dioxide in water using a data-logger with an underwater sensor (GM70 Hand-Held Carbon Dioxide Meter, Vaisala®). We waited for the reach of the curve's saturation before noticing the measured value. Dissolved oxygen, pH, conductivity and temperature were measured by WTW Multi 3320 with data-loggers: Cell Ox 325, pH-Electrode Sen Tix® 41 and WTW Tetra Con 325. In order to evaluate the interdependencies between water reservoir characteristics and seasons, we did a one-way ANOVA test using the "Statistica 6.0" software.

3. Results and Discussion

We made the measurements in water not only in ice-free seasons, but also in winter, boring holes in ice. Ice cover is very important in the floodplain carbon cycle. Ice covers the river and floodplain lakes for five months per year, which prevents the gas exchange between the water and the atmosphere. According to our measurements in 2016, the complete ice coverage at the Ob middle course started in the second decade of November and the river ice breakup took place March, 2017. The floodplain lakes remained ice-covered until the middle of April.

The interdependencies between dissolved CO₂ and O₂ are shown on Figure 2. Other authors showed the inverse relation between oxygen and carbon dioxide [12, 13]. Our study confirms this fact. The correlation between CO₂ and O₂ is negative. Also we noticed the higher means of CO₂ near the aquatic vegetation, which is likely related to plant respiration. Especially low oxygen and high carbon dioxide concentrations we observed nearby *Stratiotes aloides* L.

With the twenty-four hours measurements we established daily dynamics of CO₂ in the water. In the ice-free seasons the concentration of CO₂ increases during the night and reaches its peak from 6 to 8 a.m., and then it starts to decrease. But in winter, when the lake is ice-covered, we did not observe the difference between day and night meanings; the CO₂ concentration is stable or has slow and steady increase. According to Hutchinson, the reason of higher oxygen in day time is the process of photosynthesis.

One of the floodplain's characteristics is the lack of dissolved oxygen in water. Oxygen easily enters water in summer, but in winter its inflow from the atmosphere into water stops because of ice cover. River water goes downstream and is replenished by wetland and groundwater deprived of oxygen. Processes connected with organic matter oxidation (organisms' breathing, fermentation, organic residue decay) influence the CO₂ and O₂ concentration during the summer low-water period [13-15]. With a one-way ANOVA test (Figure 3) we reliably ascertained the decrease in dissolved CO₂ in lake water during the floodplain period and increase during the summer and especially winter low-water seasons ($F=40.5785$, $p<0.000001$). The content of dissolved oxygen reaches its maximum in the period of spring flood ($F=49.5892$, $p<0.000001$). It is important to mention that the contents of dissolved CO₂ and O₂ are interconnected ($r=-0.732297$, $p<0.05000$, $N=57$).

4. Conclusion

The floodplain is a major part of any catchment basin. Different processes, connected with the content of gases in water and atmosphere, happen there. The most important period is the spring flood, when the water is saturated by oxygen.

Life is not impossible without oxygen and carbon dioxide. Oxygen comes into water from the atmosphere and photosynthesis, and is consumed by organisms' breathing and dead organic matter oxidation. The increase in oxygen concentration provokes the decrease in carbon dioxide, and vice versa. But in winter streams and lakes are ice-covered, so there is no oxygen input, only expenditure. The concentration of carbon dioxide increases in winter. In spring floodplain lakes release great amount of carbon dioxide emission to the atmosphere. In the ice-free period there is difference between day and night carbon dioxide concentrations: at night without the process of photosynthesis the amount of carbon dioxide grows up.

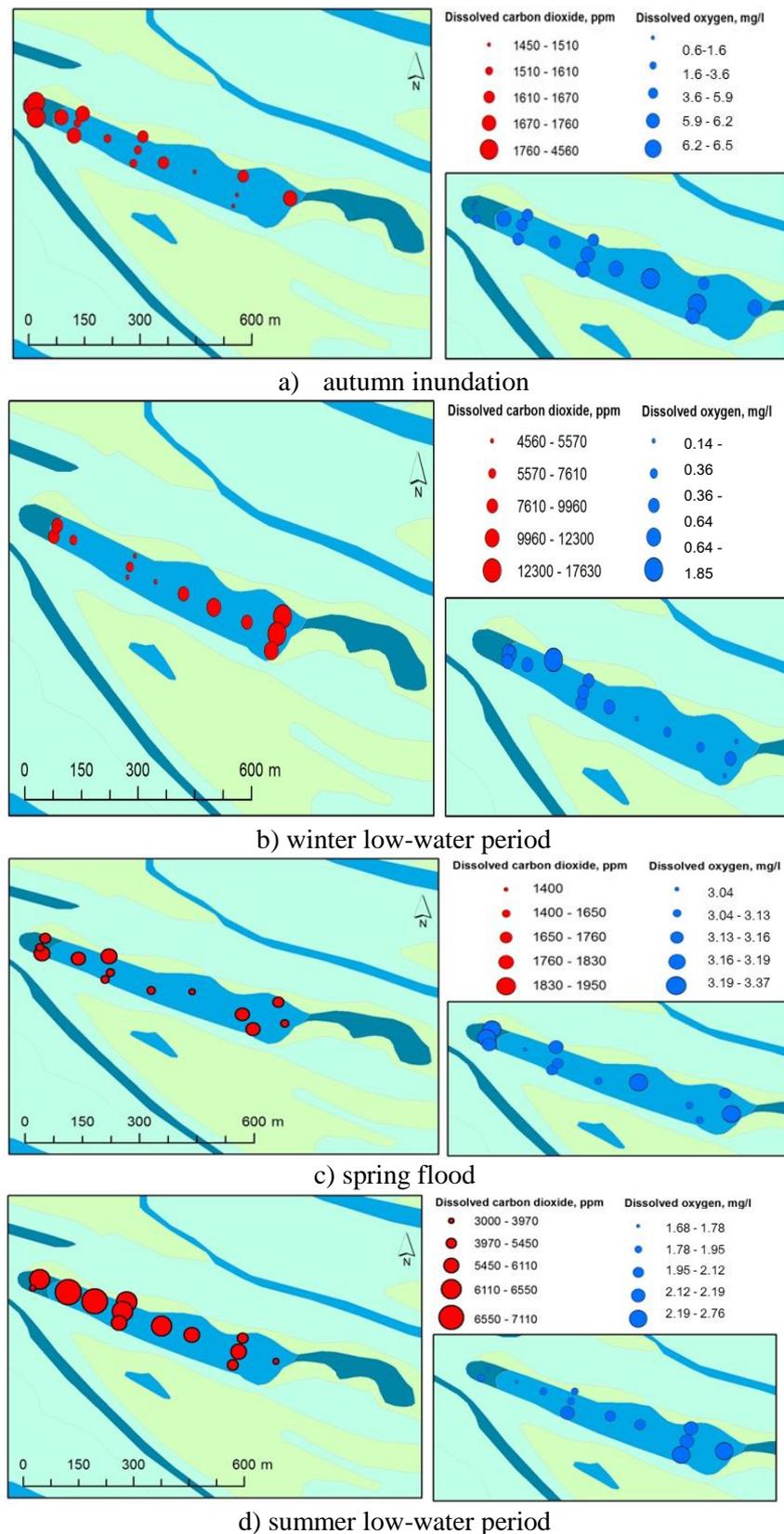


Figure 2 (a-d).Concentration of CO₂ and O₂ in different seasons

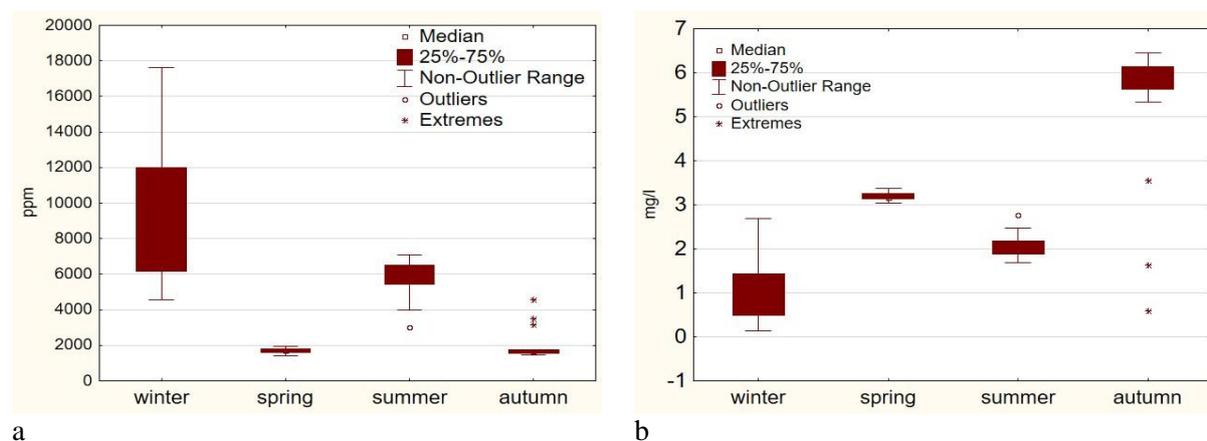


Figure 3. Concentration of dissolved CO₂ (a) and O₂ (b) in different seasons

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