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Dissolved oxygen and its response to eutrophication in a tropical black water river

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ABSTRACT

The Siak is a typical, nutrient-poor, well-mixed, black water river in central Sumatra, Indonesia, which owes its brown color to dissolved organic matter (DOM) leached from surrounding, heavily disturbed peat soils. We measured dissolved organic carbon (DOC) and oxygen concentrations along the river, carried out a 36-h experiment in the province capital Pekanbaru and quantified organic matter and nutrient inputs from urban wastewater channels into the Siak. In order to consider the complex dynamic of oxygen in rivers, a box-diffusion model was used to interpret the measured data. The results suggest that the decomposition of soil derived DOM was the main factor influencing the oxygen concentration in the Siak which varied between ~100 and 140 μmol l^{-1}. Additional DOM input caused by wastewater discharges appeared to reduce the oxygen concentrations by ~20 μmol l^{-1} during the peak-time in household water use in the early morning and in the early evening. Associated enhanced nutrient inputs appear to reduce the impact of the anthropogenic DOM by favoring the photosynthetic production of oxygen in the morning. A reduction of 20 μmol l^{-1}, which although perhaps not of great significance in Pekanbaru, has strong implications for wastewater management in the fast developing areas downstream Pekanbaru where oxygen concentrations rarely exceed 20 μmol l^{-1}.

1. Introduction

The exponential worldwide population growth and the associated rising food production results in increased demand for nitrogen, which is a limiting nutrient for plants in many terrestrial and marine systems (e.g., McElroy, 1983; Matson et al., 1999). In order to make nitrogen available to plants, dinitrogen gas, which constitutes 78% of our atmosphere, has to be converted into fixed or reactive nitrogen. According to recent estimates 18.8 TgN yr^{-1} (10% of the total anthropogenic fixed nitrogen) is carried as dissolved inorganic nitrogen into the coastal ocean, where eutrophication is considered to be the main reason for the spreading of "dead zones" (Seitzinger et al., 2005; Diaz and Rosenberg, 2008; Duce et al., 2008; Galloway et al., 2008). Dead zones are, of course, not dead but reveal oxygen levels which are too low to sustain plant and animal life. Benthic fauna, for example, often starts to respond to decreasing availability of oxygen when oxygen levels drop below 80 μmol l^{-1} and mass mortality can occur when the oxygen concentration falls below 22.4 μmol l^{-1} (Diaz and Rosenberg, 2008 and references therein). If the oxygen concentration falls below 5 μmol l^{-1} the microbial world also responds and denitrifying bacteria, which use nitrate instead of dissolved oxygen for the oxidation of organic matter, become active (Codispoti et al., 2001).

Besides eutrophication there are also natural processes such as black water events that lead to anoxic and hypoxic conditions in rivers and estuaries (Hamilton et al., 1997; Howitt et al., 2007). Black water events are flood events during which an enhanced leaching of DOM from leaf litter colors the water dark brown; the subsequent decay thereof reduces the oxygen concentration in the water. The leaching of carbon from organic-rich peat soils and its subsequent decay is a further process that leads to oxygen poor conditions in the black water rivers draining peat soils such as the Siak river in eastern Sumatra, Indonesia (Baum et al., 2007; Rixen et al., 2008). Due to the nutrient-poor peat soils dissolved inorganic nitrogen concentrations were, at 5.8–65.1 μmol l^{-1} much lower in the Siak than in other non-black water rivers revealing a mean nitrate concentration of 142 μmol l^{-1} in South Asia (Baum, 2008; Subramanian, 2008). In order to study the response of an oxygen-poor black water river to eutrophication we measured oxygen and DOC concentrations along the Siak, established a 36-h time-series station at the Siak during an expedition in November 2008 and quantified organic matter and nutrient inputs from urban wastewater channels into the Siak (Fig. 1). Furthermore we used a box-diffusion model allowing us to consider the complex oxygen dynamic in the river (Rixen et al., 2008) during the interpretation of the measured data.

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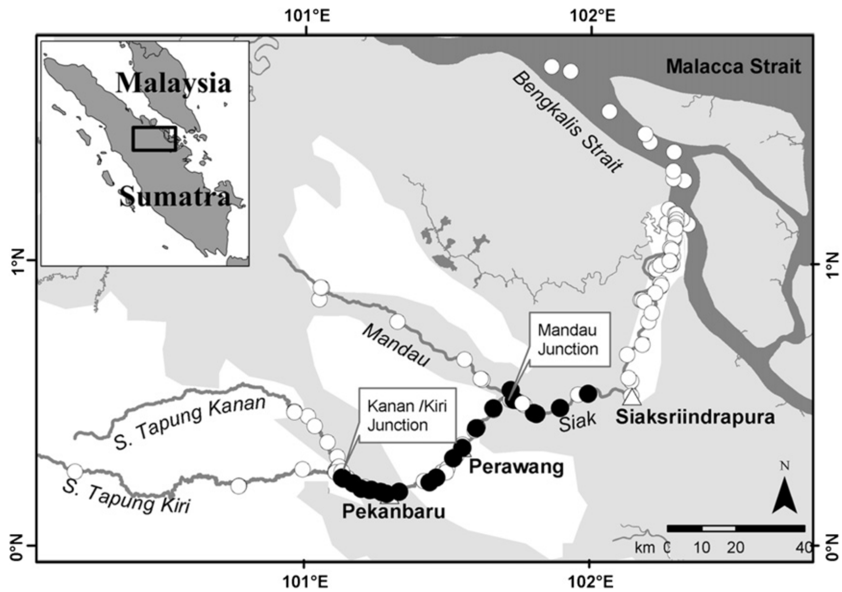

Fig. 1. Study area: the Siak with its headstreams S. Tapung Kiri and S. Tapung Kanan, and its tributary Mandau. The locations of the main cities (Pekanbaru, Perawang, and Siaksriindrapura) are indicated by triangles. Peat soil distribution (marked in grey) is obtained from FAO (2003). Samples collected during our former expeditions are indicated by open circles and sampling sites during the expedition in November 2008 are represented by black circles.

2. Study area and methods

Central Sumatra experiences high rainfall and a weakly pronounced seasonality with a dry season (May–September) and a rainy season (October–April) due to the meridional variation of the inter-tropical convergence zone (Fig. 2). On inter-annual time scales the precipitation rates are influenced by the climate anomaly El Niño/Southern Oscillation (ENSO, Ropelewski and Halpert, 1987) which in its positive mode was referred to as La Niña in 2008.

The Siak is one of the main peat-draining rivers in central Sumatra and originates at the confluence of its two headstreams, S. Tapung Kanan and S. Tapung Kiri (Fig. 1). The Siak passes through the eastern Sumatran lowlands and discharges into the Malacca Strait at river-km 370 km. The S. Tapung Kanan and the Mandau, the main tributary of the Siak, originate in the peat swamps. Due to high DOM input from these two peat-draining lowland rivers the DOC concentrations in the Siak increased from approximately 500 to 1300 and from 1300 to 1900 $\mu mol\ l^{-1}$ around the Kanan/Kiri and Mandau junctions (Fig. 3a, Baum et al., 2007; Rixen et al., 2008). DOM decomposition and the resulting oxygen consumption were considered to be a main factor influencing the oxygen concentrations which were inversely related to DOC concentrations along the Siak and dropped to 12 $\mu mol\ l^{-1}$ at the onset of the estuary (Fig. 3b).

Today the peatlands are heavily disturbed by drainage, deforestation and conversion into palm oil and rubber estates as well as shrub lands (Laumonier, 1997; Hooijer et al., 2006). The population of Pekanbaru has increased dramatically since the 1960s and local authorities estimate a further increase from 671,777 (in 2006) to 1,284,849 inhabitants by 2031. In the last 4 years we have noticed a growing number of highways and two new bridges which were built downstream Pekanbaru near Siaksriindrapura, the second largest city along the Siak. Due to these developments the Siak is slowly losing its role as a major transport pathway in the region.

2.1. Field methods

In November 2008, an expedition to the Siak was carried out in the course of which water samples were taken to determine DOC and dissolved oxygen concentrations using a Niskin bottle at a water-depth of 1 m along the river (Figs. 1 and 3). A time-series station was set up for 36-h in Pekanbaru at a ferry boat jetty named "Pelita Pantai" which is hardly in use anymore. A submergible pump was deployed at the jetty (Fig. 4) which continuously pumped water through a plexi-glass box which was equipped with electrodes to measure oxygen concentration and water temperature (WTW Tetra Con 325_3) every minute. We also took hourly water samples to determine ammonia, oxygen, and DOC concentrations (Fig. 5, Table 1).

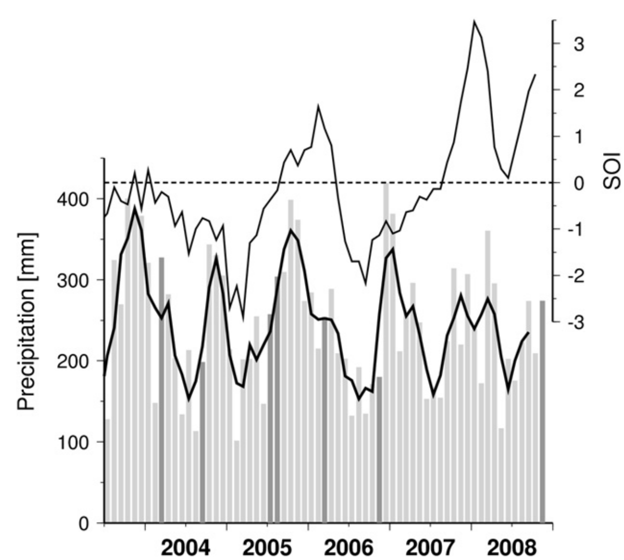

Fig. 2. Precipitation rates obtained from DWD (2006) and averaged for the area 1°S–1°N and 100–102°E are indicated by the grey bars. The dark grey bars show the months during which the expeditions were carried out. The black bold line shows the precipitation rates smoothed with a three-month moving average. The Southern Oscillation Index (SOI) was obtained from http://www.cpc.ncep.noaa.gov/data/indices/soi and also smoothed with a three-month moving average.