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COMPARISON OF SEASONAL AND DIURNAL VERTICAL OXYGEN DISTRIBUTIONS IN CENTRAL AMAZONIAN WHITE AND BLACK WATER LAKES

Ulrich Saint-Paul

Zentrum für Marine Tropenökologie, Fahrenheitstr. 1, D-28359 Bremen, Germany

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INTRODUCTION

Floodplain lakes in Amazonia, formed by recent deposition of alluvium, are typical along white water rivers, which are rich in suspended minerals throughout the year. The limnological conditions in such lakes change periodically with natural seasonal water level fluctuations of as much as 11 m. During rising and high water vast areas (várzea) are covered by extensive aquatic and marsh vegetation. This material is decomposed very rapidly due to high temperatures during falling and low water levels, thus producing a considerable amount of organic matter. As a consequence, changes in oxygen concentration are particularly pronounced. Some extreme seasonal changes, including long periods of oxygen depletion, have been reported (Marlier 1967, Sioli 1968, Schmidt 1973, Junk 1970, Kramer *et al.* 1978, Junk *et al.* 1983, Melack & Fisher 1983, MacIntyre & Melack 1988, Saint-Paul & Soares 1988).

Central Amazonian black water rivers, which have very acid dark water, are known to be poor in minerals. Inundated areas are mostly covered by igapó, which is the main source of organic material. Primary production is low or even absent and floating meadows develop only rarely. Decomposition in black waters is very slow and is carried out mainly during the dry phase by terrestrial soil fauna (Junk 1983). Despite the fact that the amount of organic material is low, oxygen depletion on the bottom of lakes and flooded forest are reported by Gessner (1961) and Rai & Hill (1981), which they explain by the amount of humic substances. These results are not confirmed by Geisler (1969) thus demonstrating that our understanding of the oxygen regime is still unclear.

As simultaneous oxygen measurements in a white and a black water lake have been carried out for the first time, differences in stratification can be discussed with regard to water chemistry and lake topography.

STUDY SITES AND METHODS

Lago do Inácio is located close to the city of Manacapurú in the floodplain on the north side of the Rio Solimões 80 km upriver from its confluence with the Rio Negro. Since it is connected to the Rio Solimões the lake's surface area varies from 5 to 9 km^2 and its maximum depth from 4 to 10 m in concert with the yearly water level fluctuations. While the greater part of the lake is open water, some areas are covered by aquatic macrophytes, and the southeastern shore is fringed by flooded forest. It is connected to the river system by a channel. Only during high water, when the whole várzea becomes flooded, does white water flow into the system from all sides.

Lago Prato, the black water sample site, is located about 75 km upstream on the Rio Negro within the Anavilhanas Archipelago. Its surface area is similar to that of Lago do Inácio. Lago Prato is deeper because of minimal sediment load in black compared to white water. Most of the shores are fringed by flooded forest. It is a lake-like waterbody that has an inlet and outlet through which it fills and drains with the river channel fluctuations.

During one complete hydrological cycle, diel variations of both temperature and dissolved oxygen measurements were taken at both sample sites. Dissolved oxygen was measured with a Clark probe (WTW) and temperature by using a thermistor. Lake level was read from an echo sounder (Lowrence). Vertical oxygen-concentration profiles were measured at three-hour intervals, starting at 9 am, during rising, high, falling and low water level. Both sampling sites were located in the middle of the lake in the open water.

RESULTS AND DISCUSSION

Diel oxygen cycles are caused by physical as well as biological and chemical processes. The actual oxygen concentration reflects the net balance of all these three processes.

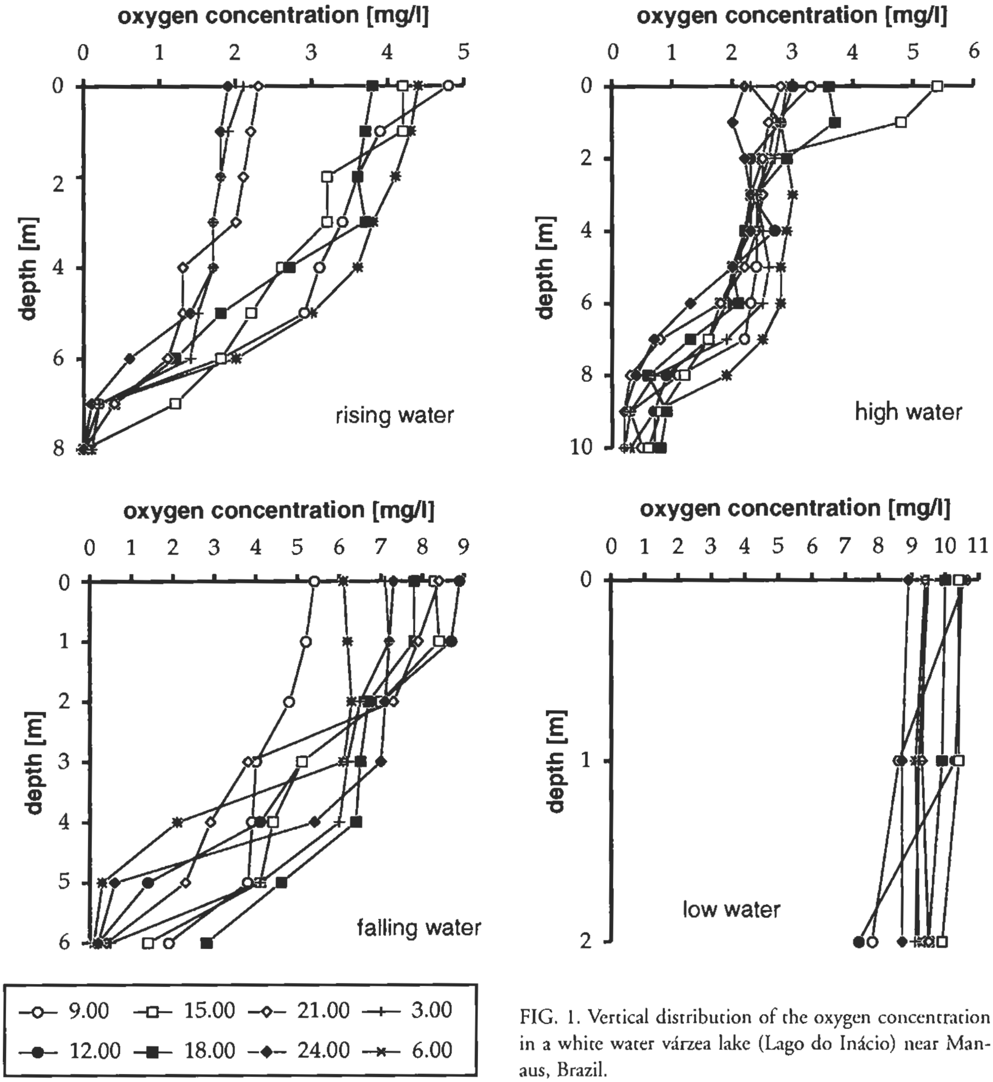
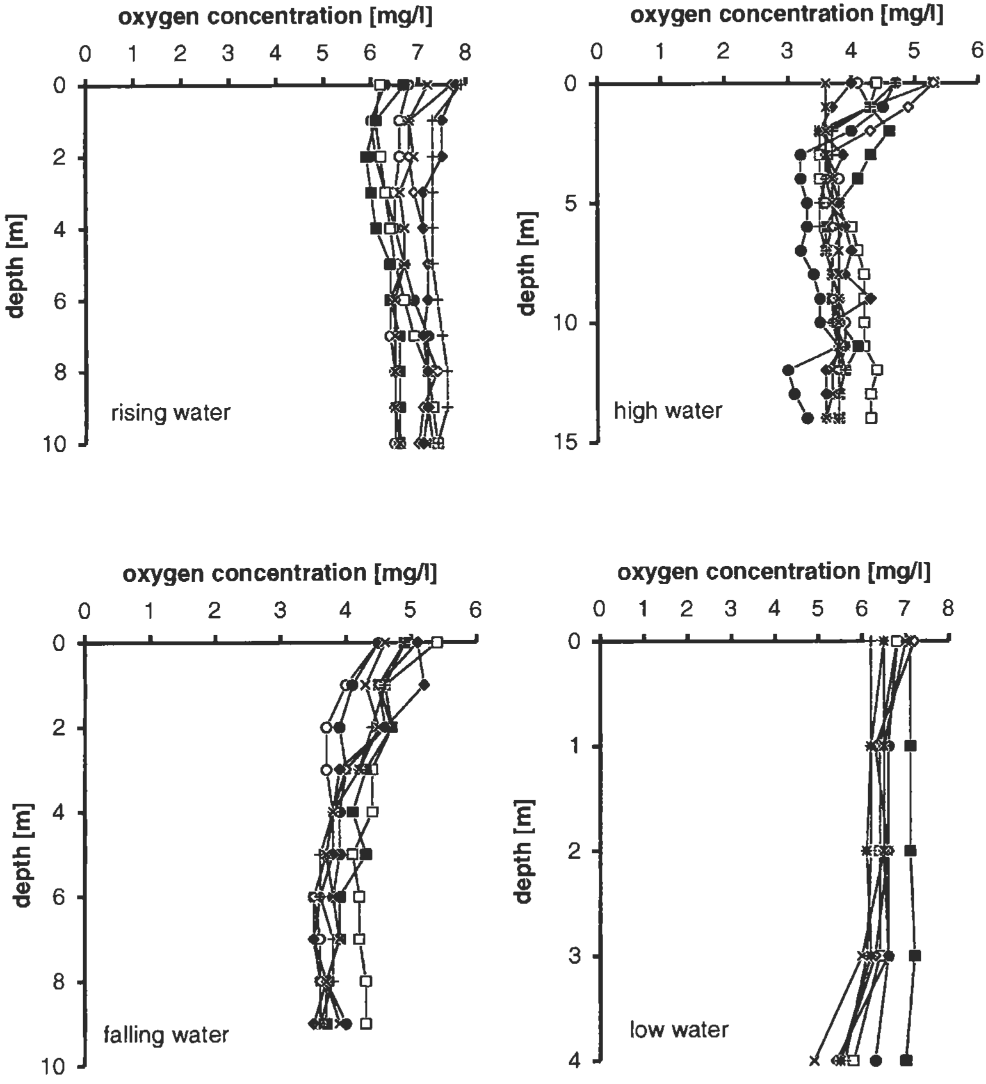


FIG. 1. Vertical distribution of the oxygen concentration in a white water várzea lake (Lago do Inácio) near Manaus, Brazil.



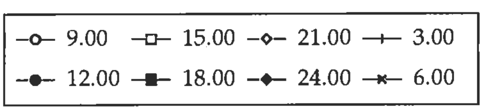


FIG. 2. Vertical distribution of the oxygen concentration in a black water várzea lake (Lago Prato, Anavilhanas) near Manaus, Brazil.

Oxygen conditions in the white water várzea lake showed a clear clinograde stratification throughout most of the year, though with some alterations depending on water level fluctuations (Fig. 1). Surface oxygen values fluctuated between 2 and 11 mg/l while temperature varied between 27° and 30° C. Bottom water was normally one degree colder. During rising water, oxygen levels showed pronounced epilimnic deficiencies at night between 21:00 h and 03:00 h probably because large areas of igapó forest become inundated, increasing the amount of organic material. Supersaturation was observed especially at low water because of phytoplankron bloom and wind induced turbulences. During the period of investigation water circulation extended to the lake bottom only at low water, whereas when the lakes were deeper circulation did not reach the bottom and consequently an anoxic hypolimnion developed.

Oxygen stratification in the black water was typically orthograde during the whole year (Fig. 2). Surface water oxygen concentrations varied between 3.5 to nearly 8 mg/l. Bottom concentrations never fell below 50 % saturation.

The results demonstrate clearly the fundamental differences between white and black water lakes. Oxygen deficiency, common in Lago Inácio for long periods of the year, is a consequence of decomposition processes of submersal and floating aquatic and semiaquatic macrophytes. This has been shown by various other investigations in várzea lakes as mentioned above. As great parts of the surface area remain uncovered by macrophytes, oxygen input by phytoplankton growth and diffusion from the air is facilitated. The investigations by Junk *et al.* (1983) and Saint-Paul & Soares (1988) on Lago Camaleão, which is mostly covered by macrophytes, showed that under such conditions oxygen can reach daytime maximum values of only 0.5 mg/l at a temperature of 28° C. Such hypoxic conditions may also be observed beneath the broad belt of macrophyte vegetation that spreads over the várzea lakes from the shore. However, the level of hypoxia depends on frequency and extent of turbulence, phytoplankton growth, and the amount of organic material available for decomposition. As already mentioned by Melack & Fisher (1983), the combination of moderate to high winds and undersaturation results in especially rapid diffusion influx. The much larger Lago Inácio was never covered to such a high extent by macrophytes and as a consequence oxygen depletion was not common in the surface water. However, because of the large amount of organic matter, with its high biological oxygen demand, hypolimnic oxygen depletion was observed during most of the year. This indicates that larger lakes are not so endangered by epilimnic oxygen depletion.

The better oxygen supply of black waters is a consequence of poor nutrition supply and unfavourable light conditions. Even with a stable temperature stratification, due to decreasing temperatures from surface to bottom, hypolimnic water never became anoxic. However Geisler (1969), working on a small tributary of the lower Rio Negro, reported considerable oxygen deficiency in deeper waters in the inundated forest along the shore due to the abundant supply of organic material from the forest, causing an oxygen depletion of 50 %, which is confirmed by Irmler (1975). The good oxygen conditions in the open water of the lake investigated indicate that the decomposition of organic material occurs mostly in the inundated forest, thus keeping the open watets free of oxygen depletions. Since in white water floodplains the greatest amount of organic material comes from macrophyte vegetation, its impact on the open waters is much higher. Only in larger water bodies can the high biological oxygen demand be compensated for by wind induced turbulences.

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