PRIMARY RESEARCH PAPER

The role of *Campsurus notatus* (Ephemeroptera: Polymitarcytidae) bioturbation and sediment quality on potential gas fluxes in a tropical lake

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Abstract About 30% of the total area of Lake Batata (Amazon) was impacted by the disposal of bauxite tailings originated from the process of washing bauxite. This effluent, composed by fine particles of clay and water, settled on top of the natural sediment, originating a new substratum with a different physical and chemical composition. This phenomenon created a new distinct habitat (impacted sediment) influencing the benthic community. The aim of this study was to evaluate the impact of bioturbation by *Campsurus notatus* (Ephemeroptera: Polymitarcytidae) on potential gas fluxes in the sediment of natural and impacted areas of the lake. The natural sediment had a significantly higher methane concentration when compared to the impacted one. In incubated sediment cores, the presence of *C. notatus* nymphs resulted in a significant increase in oxygen consumption and methane and carbon dioxide release to the water column. The effect of the presence of nymphs on methane was ambiguous. The *C. notatus* nymphs strongly decreased methane concentration in natural sediment samples, probably because of the enhancement of the oxic sediment area. However, this effect was not observed in impacted samples. Finally, the new substratum of Lake Batata decreased methane concentration in sediment and water column. *C. notatus* nymphs demonstrated to have a significant role on gas flux (methane and CO_2) from sediment to water column as well as on oxygen consumption in Lake Batata, consequently influencing the carbon cycle in this lake.

Keywords Amazonian lake · Bioturbation · *Campsurus notatus* · Methane · Sediment

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Introduction

In the mid 70s the mining company Mineração Rio do Norte S.A. began its activity of bauxite ore

extraction at Porto Trombetas (Pará, Brazil). As part of the process, bauxite ore must be washed to remove clay particles. Until the end of 1989, bauxite tailings (water + clay) originated from the washing process was dumped directly into Lake Batata, impacting nearly 30% of the total area of the lake. This effluent is composed of solid particles (clay) and is deposited on the bottom of Lake Batata over its natural sediment formed by layers of up to 5 m. The new substratum is poor in organic matter, nutrients, and has extremely fine granulometry (<0.49 μm).

By the end of the 80s several studies were carried out in this aquatic ecosystem searching for solutions that could mitigate and understand the impact of this disturbance (eg. Bozelli et al., 2000). The deposition of clay particles in Lake Batata altered the physical and chemical aspects of the sediment (Roland & Esteves, 1993; Callisto & Esteves, 1996), leading to a decrease in the richness and abundance of many benthic species (Leal & Esteves, 1999).

Nymphs of *Campsurus notatus* (Needham and Murphey 1924 Ephemeroptera: Polymitarcyidae) have colonized the new habitat at the impacted area. The occurrence of this organism in higher densities and biomass in the impacted area, as compared to the natural one, indicates that this species has benefited from the conditions imposed by the presence of bauxite tailings (Leal & Esteves, 1999; 2000).

The nymphs build long U-type tunnels in sediment where a continuous water flow is established, revealing a high bioturbation capacity in Amazonian floodplain lakes, as well as at other tropical aquatic ecosystems (Cressa, 1986; Nolte, 1987; Melo et al., 1993). The importance of *C. notatus* to bacterioplankton production was recently demonstrated because of its effect on the mineralization and liberation of nitrogen stocked in the sediment to the water column (Leal et al., 2003). Nevertheless, until now, the effect of these organisms on carbon cycling and organic matter decomposition is unclear.

The aim of this research was to experimentally evaluate the effect of *C. notatus* nymph colonization on aerobic and anaerobic organic matter decomposition (methanogenesis) in both natural and impacted sediment. This will provide more

direct and conclusive information about nutrient cycling and the role of benthic fauna (post disturbance) on Lake Batata sediment.

Study area

Located in the Amazonian plain, on the right margin of Trombetas River, Lake Batata is situated between 1°25′ and 1°35′ S and 56°15′ and 56°25′ W in Porto Trombetas, District of Oriximiná (State of Pará, Brazil). Lake Batata is classified as a clear water ecosystem (Sioli, 1984), with high transparency, low electric conductivity, low nutrient concentration, predominantly slightly acid or acid pH (Bozelli et al., 2000). Some limnological and morphological data were described by Ferrão-Filho & Esteves (1994) and Panosso et al. (1995), respectively. Biological features were investigated by Bozelli (1992, 1994) who researched the zooplankton community. Anésio et al. (1997) and Huszar & Reynolds (1997) studied the bacterioplankton and phytoplankton communities, respectively.

This ecosystem shows high water level fluctuation associated to the Trombetas River flood pulse, causing a high variation in its depth (around 9.0 m) and surface area (from 18 Km² to 30 Km² approximately), representing low and high water periods (Panosso et al., 1995).

During 11 years (1979–1989), about 50,000 m³ d⁻¹ of the resulting effluent originated from the bauxite washing process were dumped into Lake Batata. The liquid effluent is composed of solid particles (7%), predominantly clay, rich in silicate (47%), iron oxide and aluminum (21%), which was deposited on top of the natural sediment of the lake, covering approximately 3 km² of its total area. Tables 1 and 2 show a summarized description of the sediment granulometry and porosity, as well as nutrients and water content on natural and impacted areas.

Methods

Sediment sampling and acclimatization

During the low water period (December 2001), 0.03 m³ of sediment from the 0–20 cm fraction

Table 1 Comparative sediment granulometric composition and porosity of the superficial sediment (0–10 cm; $n = 5$) from impacted and natural areas of Lake Batata

Sediment	Grain size (μm)	Impacted Sediment (%)	Natural
Fine sand	62–125	0.93	1.35
Large silt	31–62	0.0	0.35
Medium silt	16–31	6.65	0.35
Fine silt	8–16	7.67	7.9
Very fine silt	4–8	8.85	4.5
Large clay	2–4	5.45	18.55
Medium clay	1–2	8.9	35.6
Fine clay	0.5–1	61.55	31.4
Porosity (%)		70.51	89.94

Table 2 Organic matter, total nitrogen, total carbon, and pore water concentration in the sediment of Lake Batata (Pará, Brazil)*

	Organic matter (%DW)	Total nitrogen (%DW)	Total carbon (%DW)	Pore water (%)
Natural area	20.80	0.46	5.10	73.86
Impacted area	14.80	0.18	1.72	62.03

* modified from Leal et al. (2003)

was sampled in both natural and impacted areas with a core sampler (Ø = 8 cm; area = 50 cm²) modified from Ambühl & Bührer (1975).

In the laboratory, natural and impacted sediment were washed in a 0.5 mm mesh size sieve to remove macroinvertebrates which were stored in glass flasks. Filtered lake water (GF/C Whatman) was added to the sediment, which was kept in the dark for 10 days at a mean temperature of 29.8°C (±0.5).

The experiment consisted of 3 steps: acclimatization, pre-incubation and incubation. After acclimatization subsamples were taken to determinate methane concentration and pore water content in sediment from natural and impacted areas (Fig. 1).

Sediment pre-incubation

Pre-incubation consisted of storing 20 cores from the acclimatized natural sediment and 20 from the acclimatized impacted sediment in thermal boxes. Each core (L = 20 cm; Ø = 4 cm) was filled with

8–10 cm of water and 10–12 cm of sediment and sealed in the bottom. All 40 samples were kept in filtered water from each sampling site. Aeration pumps were used to keep O_2 saturation near 100% (99.6 ± 0.5) both for inner and outer water. Water column was homogenized according to the model proposed by Svensson & Leonardson (1996) (Fig. 2).

During pre incubation (24 h) the cores were kept in the dark. After this period, 5 cores of each area were taken to determine dissolved oxygen concentration, CO_2 and CH_4 in water (initial concentration, see flux/consumption equation) and CH_4 in the sediment (0–2; 2–4; 4–6; 6–8 and 8–10 cm), and the pore water content.

Sediment incubation with *C. notatus* nymphs

The other 30 cores were divided into 2 groups (15 with natural sediment; 15 with impacted sediment), and were later divided into 3 subgroups of 5 cores each. Sub group 1 represented the control (without *C. notatus* nymphs). One or two nymphs were added in cores of subgroups 2 and 3 respectively, representing the density registered at Lake Batata (793 and 1587 ind. m^{-2}). After the introduction of the nymphs, the top of the cores were kept open for 3 h, and then, sealed for 6 h (incubation period). The CH_4, CO_2, and O_2 concentrations in the water and the CH_4 vertical distribution in the sediment were estimated at the end of the incubation period.

CH_4 and CO_2 sediment-water flux and O_2 consumption in the water were evaluated by the equation described by Dalsgaard et al. (2000).

$$\text{Sediment} - \text{water flux/consumption}$$
$$= ([Fc - Ic]) * V/a * t$$

where Fc = Final concentration; Ic = Initial concentration; V = Water volume (L); a = Core area (m²) and t = incubation time (h).

Analyses

Dissolved oxygen concentration was estimated following the method proposed by Roland et al. (1999). CO_2 concentration was determined by the pH-alkalinity method (Carmouze, 1994).
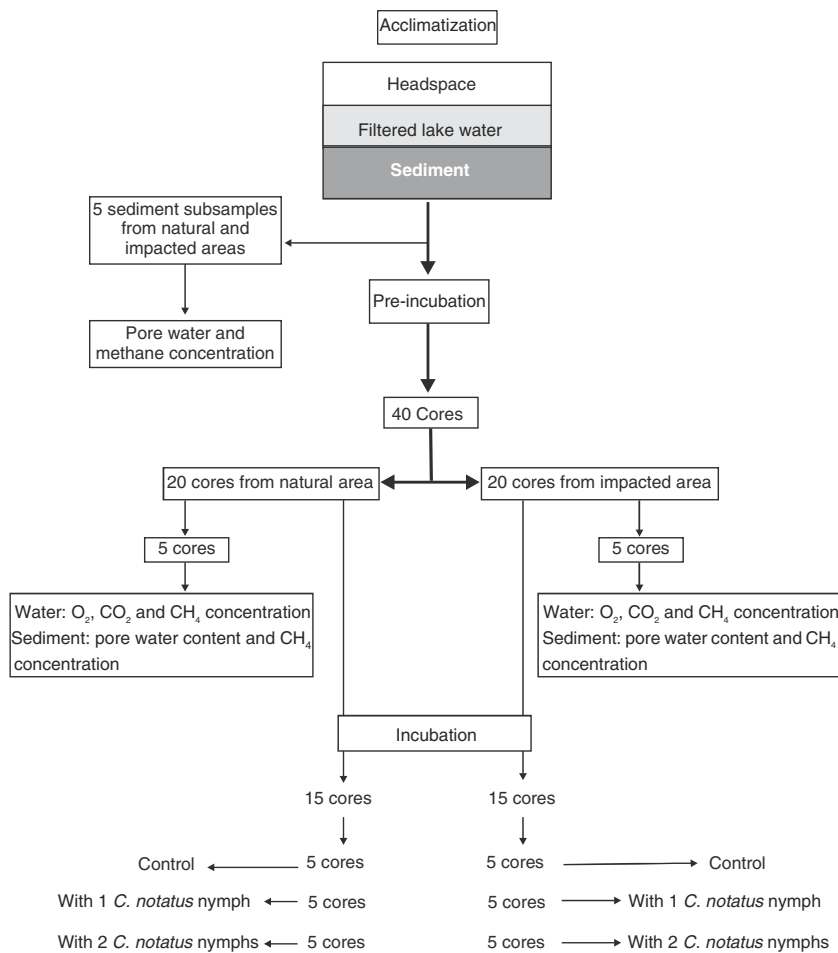
Fig. 1 Diagram of the experiment represents pre-incubation phase and incubation phase. During pre-incubation the sediment samples from natural and impacted areas were saturated with O_2 for 6 h and incubated for 24 h in the dark at 30°C. After pre-incubation the cores were kept open for 3 h. Incubation was stopped 6 h after atmosphere isolation and introduction of *Campsurus notatus*

To determine methane concentration in the pore water, 5 ml ($n = 5$) of each sediment fraction was taken and put in 12 ml flasks with 2 ml of NaOH (4%) and immediately sealed with rubber covers. Headspace subsamples were used to determinate methane concentration, which were kept in dark and low temperature conditions (<10°C) until injection. Methane was determined by gas chromatography using a Varian Star 3400 chromatograph equipped with a POROPAK-Q column (1 m, 60/100 mesh) at 85°C, FID detector at 220°C and injection at 120°C, N_2 was the carrier gas. The samples were injected using a Valvo C6W6 port loop valve (250 µl). For data recording and peak registration a Star Chroma-

tography workstation 5.51 (Varian, USA) was used.

For the determination of water content and porosity, subsamples of fresh sediment were weighed in ceramic vessels and their weight loss recorded after heating for 4 days at 60°C (Dalsgaard et al., 2000).

A two-way ANOVA Statistical analysis was performed on the acclimatized and pre-incubated sediment samples in order to assess the influence of depth and sediment type on methane concentration and to test the influence of *C. notatus* density (control, 1-nymph and 2-nymphs) on methane concentration. Differences between the sediment-water flux on controls and treatments
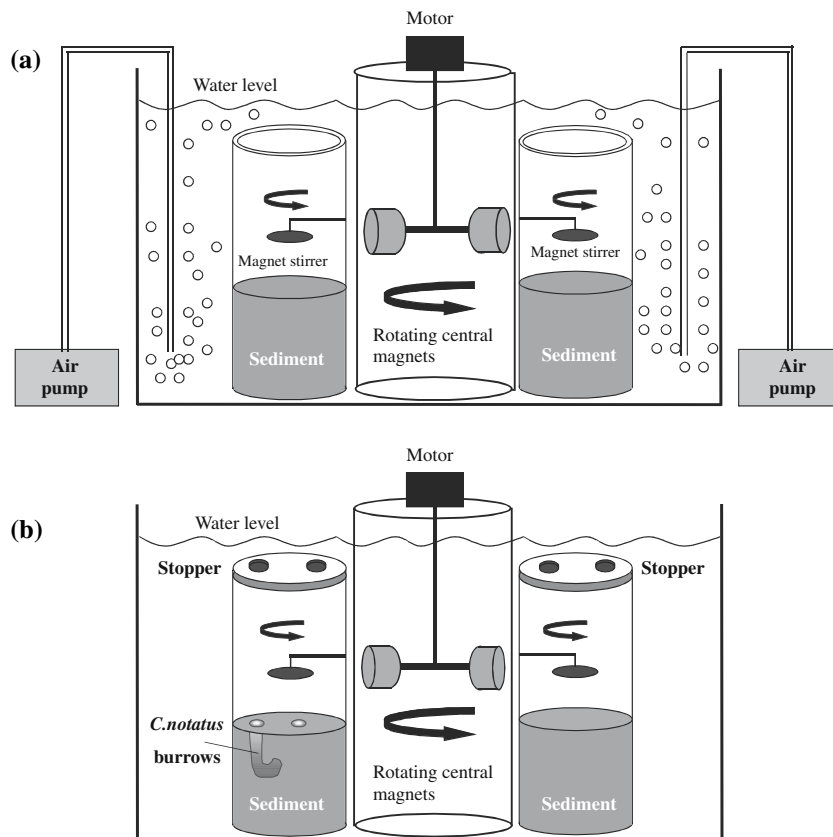
Fig. 2 Schematic representation of (**a**) pre-incubation phase (without *Campsurus notatus* and (**b**) incubation phase (with *Campsurus notatus*)

(1-nymph or 2-nymphs) were tested with the Kruskal-Wallis test with a Dunn's pos test.

Results

Acclimatization, pre-incubation and incubation

Methane concentration profiles estimated from sediment after acclimatization and pre-incubation are shown in Fig. 3. We found a similar pattern on both natural and impacted sampling areas, i.e., the concentration increased significantly with depth (Two-way ANOVA, $F = 36.2$, $p < 0.05$). The effect of sediment type was strongly pronounced in the upper layers (0–2 cm) of natural and impacted sediment. The methane concentration in the natural top layer was 7–8 times higher than in the impacted one, contrasting with the other layers, in which we observed a relatively lower difference (approximately 3 times less), but statistically significant (Two-way ANOVA, $F = 146.01$, $p < 0.05$).

Methane concentration of impacted sediment varied from 14.0 μmol l^{-1} to 110.8 μmol l^{-1} and from 10.0 μmol l^{-1} to 112.0 μmol l^{-1} after acclimatization and pre-incubation, respectively (Fig. 3a). The two-way ANOVA indicated no significant differences in methane concentration between the two treatments (Two-way ANOVA, $F = 0.25$, $p < 0.05$). On the other hand, we observed a statistically significant difference in the natural sediment (Two-way ANOVA, $F = 7.89$, $p < 0.05$), demonstrating that the artificial water oxygenation column between acclimatization and pre-incubation promoted a decrease of the methane concentration in the sediment (Fig. 3b). Nonetheless, the concentrations measured during acclimatization and pre-incubation
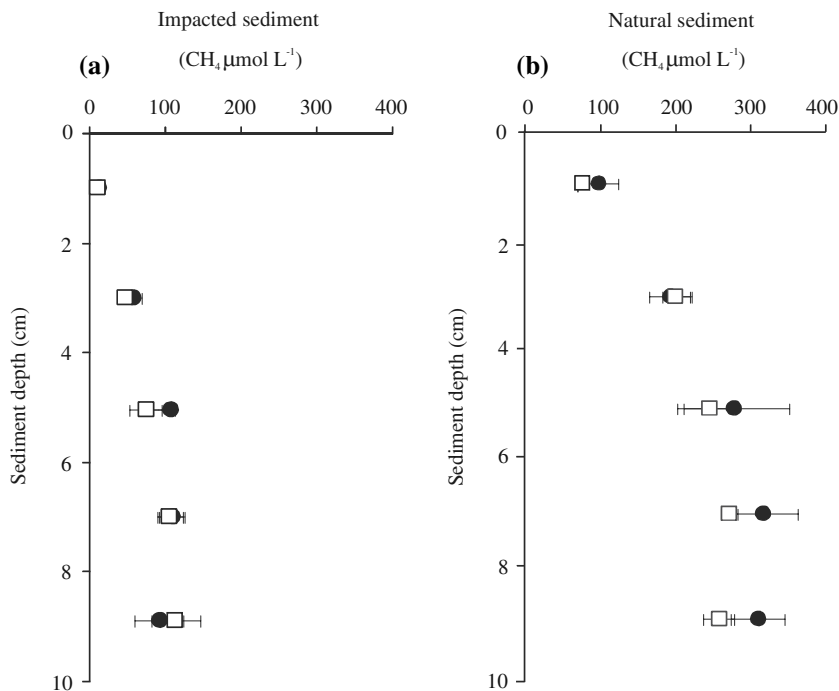
Fig. 3 Methane profile in sediment samples without nymphs of *Campsurus notatus*. Impacted sediment (**a**) and natural sediment (**b**). ● Acclimatization; □ Pre-incubation. Bars represent standard deviations ($n = 5$)

were in the range of amplitude usually observed in situ, both in natural and impacted sediments (50–300 $\mu mol\ l^{-1}$).

In the experiment with impacted sediment, the presence of *C. notatus* nymphs did not have significant effect on methane concentration (Two-way ANOVA, $F = 3.55$, $p < 0.05$; Fig. 4a), but methane concentration increased with depth. We recorded methane concentrations varying from 13.3 $\mu mol\ l^{-1}$ to 119.9 $\mu mol\ l^{-1}$ in controls; from 10.2 $\mu mol\ l^{-1}$ to 116.7 $\mu mol\ l^{-1}$ in cores incubated with 1 nymph; and from 16.0 $\mu mol\ l^{-1}$ to 139.3 $\mu mol\ l^{-1}$ in cores incubated with 2 nymphs.

Moreover, the results revealed a significant decrease in methane concentration in the natural cores with the addition of *C. notatus* nymphs (Two-way ANOVA, $F = 27.4$, $p < 0.05$; Fig. 4b). Methane concentration in control cores was significantly higher than those in the treatments with 1 or 2 nymphs. However, the statistical analysis showed no significant difference on methane concentration in natural sediment colonized by 1 or 2 nymphs (Two-way ANOVA, $F = 1.22$, $p < 0.05$)

Methane and carbon dioxide flux and oxygen consumption.

A significant increase in methane sediment-water flux was observed for both types of sediment (natural and impacted), independently of the density of nymphs, when compared to controls (Kruskal-Wallis test, $KW = 28.1$, $p < 0.05$; Table 3). For instance, in control samples of natural sediment the estimated flux was low (0.52 $\mu mol\ m^{-2}\ h^{-1}$), while in the core with 1 nymph the flux was 307 times higher, and in the cores with 2 nymphs it was 457 times higher. Methane flux in the 2-nymphs sample only was 1.5 times higher than in the 1-nymph sample.

CO_2 sediment-water flux was significantly enhanced in samples submitted to bioturbation when compared to controls for both types of sediment (Kruskal-Wallis test, $KW = 25.32$, $p < 0.05$; Table 3). CO_2 flux with 1 nymph, in treatments with either natural or impacted sediments, was 8 times higher than measured in the controls. In treatments with 2 nymphs, a significant increase in CO_2 flux was also observed. In
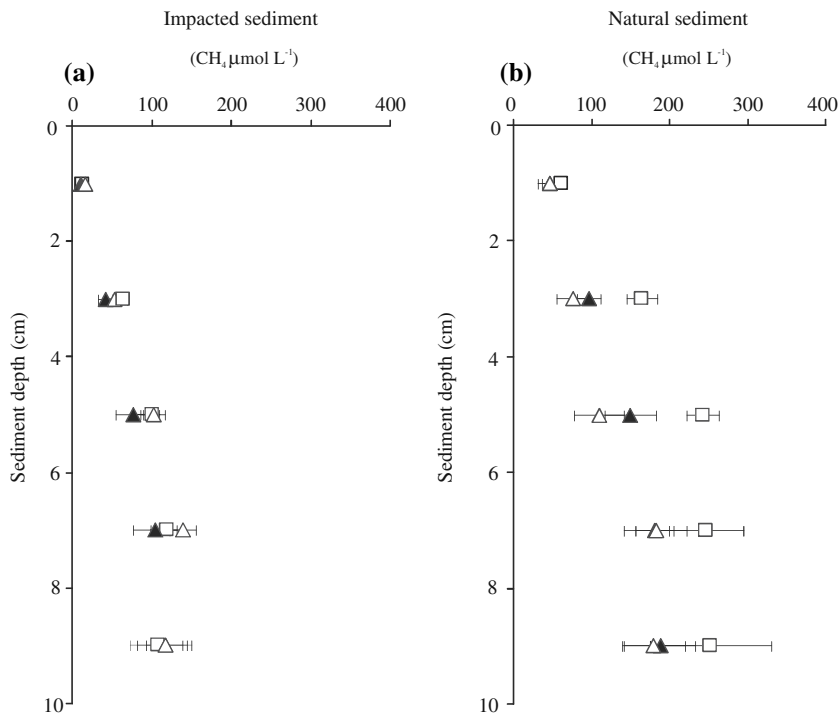
Impacted sediment   Natural sediment

$(CH_4 \mu mol \ L^{-1})$ $(CH_4 \mu mol \ L^{-1})$

Fig. 4 Methane profile in sediment samples during the incubation with nymphs of *Campsurus notatus*. (**a**) Impacted sediment and (**b**) natural sediment. Nymphs were kept in the cores for 6 h in the dark at 30°C. □ Control; ▲ 1 individual; △ 2 individuals. Bars represent standard deviations ($n = 5$)

contrast with the methane flux, the CO_2 sediment-water flux was not significantly different when comparing impacted and natural samples (Kruskal-Wallis test, $KW = 25,32$, $p < 0.05$). In natural sediment samples the flux varied from 0.11 (control) to 1.12 mmol $m^{-2} \ h^{-1}$ (2-nymphs sample), while in impacted sediment samples the flux fluctuated from 0.09 (control) to 1.06 mmol $m^{-2} \ h^{-1}$ (2-nymphs sample), indicating a proportional increase in CO_2.

Oxygen consumption displayed a similar pattern to the one observed for CO_2 flux, being significantly lower in the controls (absolute values) than in samples with one or two nymphs, independently of the type of sediment (Kruskal-Wallis test, $KW = 24.01$, $p < 0.05$; Table 3). Otherwise, in both natural and impacted sediments we did not observe a significant difference between treatments with one or two nymphs (Kruskal-Wallis test, $KW = 24.01$, $p < 0.05$). Oxygen consumption and carbon dioxide flux were less affected by the presence of nymphs than methane flux, as demonstrated by flux ratio and

sample ratio. Nymphs induced a raise in oxygen consumption and CO_2 flux, on average 3 and 12 times greater, respectively, whereas sample ratio measured for methane was higher.

Discussion

The development of research in Lake Batata was only made possible because of the unusual anthropogenic impact that occurred in this lake—the effluent of bauxite washing, which impacted a large area of the lake (nearly 30%). As a result of the dumping of the effluent, which ceased in 1989, part of the "igapó" (flooded forest) became "terra-firme" (nonflooded forest), causing death of the natural vegetation. On the other hand, some areas of the littoral zone, which in the past were inundated only at high water periods, are nowadays permanent flooded areas (Esteves, 2000).

Because of the colloidal and unconsolidated features of the clay, there are still bauxite tailings

Table 3 Methane and carbon dioxide flux, oxygen consumption in the water column and flux ratio (natural/impacted) and sample ratio (sample/control) in samples incubated with sediment from impacted and natural areas of Lake Batata (Pará, Brazil). Control represents samples without the presence of *C. notatus*. Samples were incubated in the dark at 30°C for 6 h (mean ± standard deviation are shown; $n = 5$)

	Area	Control	Flux ratio	1 Nymph	Flux ratio	2 Nymphs	Flux ratio	Sample ratio
CH_4 (µmol m² h)	Impacted[1]	0.31 (0.16)	1.7	67.88 (30.75)	2.4	129.20 (48.21)	1.8	219–417
	Natural	0.52 (0.58)		159.60 (3.92)		237.84 (36.39)		307–457
CO_2 (mmol m² h)	Impacted	0.09 (0.01)	1.2	0.69 (0.11)	1.3	1.06 (0.23)	1.1	8–12
	Natural	0.11 (0.03)		0.87 (0.11)		1.12 (0.09)		8–10
O_2 (mmol m² h)	Impacted	0.46 (0.12)	1.3	1.46 (0.18)	1.5	1.50 (0.21)	1.6	3–3
	Natural	0.60 (0.15)		2.17 (0.30)		2.43 (0.36)		4–4

suspended in the water column, with huge consequences for plankton (Bozelli, 1994; Anésio et al., 1997; Huszar & Reynolds, 1997) and fish communities (Lin & Caramaschi, 2005). However, the sediment was the most affected compartment since the disturbance destroyed some ecological niches and created others. In this new situation, *Campsurus notatus* nymphs have shown to be more capable of colonizing the sediment than other species of the benthic local fauna.

Data related to the effects of bauxite tailings on microorganisms are scarce and are basically restricted to bacterioplankton (Anésio, 2000; Farjalla et al., 2002) and nitrogen fixation and denitrification in sediment (Esteves et al., 2001). Furthermore, the scientific information concerning the genus *Campsurus* is restricted to seasonal dynamics and biomass (Takeda & Grzybkowska, 1997; Leal & Esteves, 2000) and due to the nature of the disturburance on Lake Batata there is no comparative data.

The lower methane concentrations in sediment with bauxite tailings indicate the influence of the sediment constitution on CH_4 production. The anthropogenic impact caused a decrease in nutrient availability such as C, N, and P (Roland et al., 2000), as well as changes in the physical structure of the sediment (Callisto, 2000) and water content. In general, the concentration of carbon in the impacted area is at least 7 times lower than that observed in the natural area.

Methane concentration depends on substratum availability of low molecular weight molecules such as acetate, methanol, formate, propanol and hydrogen (Angenent et al., 2002; Tonouchi, 2002; Weijma et al., 2003; Bodegom et al., 2004; Vető et al., 2004), methane oxidation (Segers, 1998), and oxygen diffusion since this gas has a inhibitory capacity on methanogens (Fetzer et al., 1993; Frenzel et al., 1999) and it is also important as a substrate for aerobic oxidation. At Lake Batata, despite the fact that both areas present similar oxygen concentrations (about 0.25 mmol l^{-1}) in their superficial sediment layers (0–0.4 mm), the impact caused huge differences on the oxygen vertical profile. At the impacted area, oxygen penetrates twice as much as in the natural area, reaching 6 mm in depth, reflecting the fast oxygen consumption in the surface of natural sediment as

compared to the non organic impacted sediment (Leal et al., 2005). This fact might explain why methane concentration in the upper natural sediment layers was 7–8 times higher than in the impacted area. However, in the anoxic layers of the sediment, the natural/impacted concentration ratio was 3:4. Besides, methane vertical profile concentrations for both sediments were similar, i.e., the concentration gradually increases from the surface to the deepest layers of the sediment, which is an outcome usually found in continental aquatic environments (Mathias, 2000; Casper et al., 2003; Koizumi et al., 2003).

Benthic invertebrates, which build galleries or tubes, interfere in microbiological processes, feed bacteria and create structures with different properties from those observed in adjacent sediments, since they pump the water-sediment layer rich in oxygen through these tubes (Aller, 2001). The oxygen-rich water pumped by macrofauna, from top to bottom sediment layers, influences metabolic processes dynamics because it changes the oxi-reduction sites (Altmann et al., 2004) and stimulates the colonization of these galleries by aerobic bacteria and meiofauna (Wang et al., 2001). Kajan & Frenzel (1999) reported that Chironomidae larvae created microhabitats by constructing U-type or J-type tubes and increasing the bacterial activity in rice cultivation in Italy. Similarly, C. notatus nymphs built long galleries (more than 10 cm long), where oxygen concentration varied from 0.2 mmol l^{-1} to 0.3 mmol l^{-1}, the same oxygen concentration which was measured in the superficial sediment layer (Leal et al., 2005). This pattern had a strong effect on methane oxidation in the natural sediment of Lake Batata (Fig. 4b). Furthermore, our results indicate the importance of C. notatus nymphs in decreasing the methane concentration in sediments, probably both through induction of oxidation and release of methane into the water column. Nevertheless, the absence of perceptible methane bubbles in the sediment suggests that oxidation is the principal process involved. Recently, Kiyashko et al. (2004) demonstrated that Stictochironomus pictulus (Diptera: Chironomidae) larvae feed preferentially on methane-oxidizing bacteria, yet why this species has this selective feeding remains unclear.

In contrast, nymphs had no effect on methane concentration in impacted sediment (Fig. 4a). Part of this result might be explained by sediment granulometry. Clay deposition has changed mainly the physical structure, increasing the percentage of fine clay in the impacted sediment and changing its porosity, which might represent an impediment for gas diffusion (Table 1). Indeed, there is evidence that methane oxidation is positively related with soil particle size, likely complicating the diffusion of gas in soils with small granules (Min et al., 2002).

The influence of bioturbation observed only in the sediment from the natural area (Fig. 4b) contrasts with the flux results (Table 3), since we measured a raise of gas flux and gas consumption in both natural and impacted sediments. Bioturbation caused an increase of methane concentrations in the water column, which must have been due to the pumping of pore water with high CH$_4$ concentration. Svensson (1997) showed that the presence of Chironomus plumosus larvae stimulated the ammonium flux from the sediment to the overlying water, in part due to the pumping process. In addition, some authors reported that benthic fauna stimulated microbial activity in marine (Hansen & Kristensen, 1997; Heilskov & Holmer, 2001) and freshwater sediments (Svensson, 1997). Thus, it seems acceptable to infer that in Lake Batata C. notatus furthers methane production in sediment and increases methane concentration in the water column as a consequence of this pumping.

Oxygen consumption and carbon dioxide flux were less affected by the presence of nymphs than methane flux, as demonstrated by flux ratio and sample ratio, indicating that the activity of C. notatus nymphs stimulated a more effective anaerobic decomposition of organic carbon, even though it increases the oxygenation of the sediment during pumping. The sample ratio for methane varied from 219 to 457, while for the other gases the variation was lower (from 3 to 12). It is still unclear why methane flux was more affected by this benthic organism than carbon dioxide flux or oxygen consumption.

We assume that our results demonstrate the actual conditions in Lake Batata because both in situ and in the experimental study the

estimated methane concentration in situ were similar (data not shown) and *C. notatus* displayed the same behavior.

Even though our study describes a local phenomenon, it provides important information for other ecosystems because bauxite tailings are essentially composed by clay and clay is an important component of Amazonian and other tropical soils. Many other types of anthropogenic impacts may have similar effects by increasing sediment inflow. In a smaller scale but in the long term, farming and deforestation can have a similar outcome.

Finally, this study reveals that the new substratum (impacted sediment) of Lake Batata, which resulted from the deposition of bauxite tailings on top of the natural sediment layer, affected methane dynamics, leading to a lower methane concentration in the sediment and water column, and had a stronger effect on anaerobic organic matter mineralization.

Bauxite tailing influenced carbon cycle in two distinct ways: on one hand *C. notatus* nymphs contributed to a significant increase of CH_4 flux from the sediment to the water column and, on the other, stimulated methane oxidation in the sediment. In contrast, its influence on the organic matter aerobic mineralization was less clear. The results reveal a significant effect of *C. notatus* density on the fluxes of CH_4 and CO_2 as well as on O_2 consumption in both areas.

The bioirrigated zone produced by *C. notatus* raises microbiological activity in both types of sediment. This is proved by the high flux of CO_2 from the sediment to the water column. The results indicate that bioturbation promotes the colonization of the bioirrigated area of the impacted sediment by aerobic bacteria and intensifies the microbiological activity in this area. This implies that this species plays a role as a direct and indirect source of carbon incorporation into the sediment of lake thus improving ecological conditions in the impacted area of Lake Batata.

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