Acta Scientiarum

http://www.uem.br/acta
ISSN printed: 1679-9283
ISSN on-line: 1807-863X
Doi: 10.4025/actascibiolsci.v36i4.20336

Effects of the flood pulse on the isotopic composition ($\delta^{13}C$ and $\delta^{15}N$) of the particulate organic carbon (POC) in the upper Paraná floodplain

Leandro Fabrício Fiori*, Patricia Almeida Sacramento, Daiany de Fátima Corbetta, Lucas Milani Pereira and Evanilde Benedito

*Núcleo de Pesquisas em Limnologia e Aquicultura, Universidade Estadual de Maringá, Avenida Colombo, 5790, 87020-900, Maringá, Paraná, Brazil. *Author for correspondence. E-mail: leandrofiori_8@hotmail.com*

ABSTRACT. The particulate organic carbon (POC) is an important energy source present in the food chain of detritivorous fish. Considering its importance, this study aimed to investigate the effect of the flood pulse on the composition of the POC in a neotropical floodplain. For this, we analyzed the seasonal variations of the carbon isotopic composition ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) in two different hydrological periods in the years 2000 and 2009. Sampling of potential sources of primary producers, as well as the POC, was held in different subsystems of the floodplain of the upper Paraná river (subsystems of the rivers Parana, Baía and Ivinheima). In 2000, there were significant differences on isotopic signature ($\delta^{13}C$) of the POC, unlike what was seen in 2009, where the values of $\delta^{13}C$ were depleted us three subsystems, and showed significant differences both in the Paraná and Baia rivers. As this isotopic variation was attributed to the presence of flooding in 2009, that may be incorporated into new sources of the ecosystem. This is contrary to what was observed in 2000, when they were filled with recorded values below 3.5 m fluviometric. Thus, it can be concluded that the flood event has an effect on the composition of POC and therefore can directly influence the structure of fish food chains scavengers of the basin.

Keywords: potamophase, limnophase, rivers, water level, wetlands.

Efeitos do pulso de inundação sobre a composição isotópica ($\delta^{13}C$ e $\delta^{15}N$) do carbono orgânico particulado (COP), na planície de inundação do alto rio Paraná

RESUMO. O carbono orgânico particulado (COP) é uma fonte de energia importante presente na cadeia alimentar de peixes detritívoros. Considerando sua importância, esse estudo teve como objetivo investigar o efeito do pulso de inundação sobre a composição do COP em uma planície de inundação neotropical. Para isso, foi analisado as variações sazonais da composição isotópica de carbono ($\delta^{13}C$) e nitrogênio ($\delta^{15}N$) em dois períodos hidrológicos distintos, verificados para os anos de 2000 e 2009. As amostragens das potenciais fontes de produtores primários, bem como o COP, foram realizadas em diferentes subsistemas da planície de inundação do alto rio Paraná (subsistemas dos rios Paraná, Baía e Ivinheima). Constatou-se que em 2000 não foram registradas diferenças significativas na composição isotópica de carbono ($\delta^{13}C$) do COP, diferentemente do verificado em 2009, em que os valores de $\delta^{13}C$ foram deplecionados nos três subsistemas, apresentando diferenças significativas tanto no rio Paraná como Baia. A essa variação isotópica atribuiu-se a presença de cheias em 2009, que pode ter incorporado novas fontes ao ecossistema, ao contrário do que foi verificado em 2000, quando foram registradas cheias com valores fluviométricos inferiores a 3,5 m. Assim, pode-se concluir que o evento de inundação apresenta efeito sobre a composição do COP e que, por conseguinte, pode influenciar a estrutura das cadeias alimentares de peixes detritívoros da bacia.

Palavras-chave: potamofase, limnofase, rios, nível hidrométrico, áreas alagáveis.

Introduction

Most medium-to-large rivers have adjacent floodable areas, which along with the main channel, are called river-floodplain systems (JUNK et al., 1989; NEIFF, 1990). In these systems, one prevailing ecological model is the *Flood-pulse Concept* (FPC), which states that the hydrologic pulse is the major driver of biotic and abiotic variations (JUNK et al., 1989). The upper Paraná river floodplain is the last dam-free stretch in Brazilian territory, which is under the influence of upstream impoundments by means of the control in the water level, interfering thus with natural processes, such as the flood pulses (AGOSTINHO et al., 2008). However, even with the indirect influence of the reservoirs, the floodplains have a high habitat heterogeneity and maintain a considerable biodiversity of aquatic and terrestrial organisms (AGOSTINHO et al., 2004). According to these authors, the flood pulse in this area is still the main force regulating community structure and functions of this ecosystem. The overflow of the river in a floodplain should increase habitat area, availability of allochthonous resources, and should supply water enrichment thanks to nutrients transported from adjacent areas or the organic and inorganic material flooded (AGOSTINHO et al., 2004).

The particulate organic carbon (POC), a component of organic carbon, occurs both as living matter and as dead matter (detritus) (LAMPERT; SOMMER, 2007). According to these authors, detritus may have an autochthonous or allochthonous origin and its distinctions can be evaluated by using the stable carbon isotope analysis ($\delta^{13}C$) and nitrogen ($\delta^{15}N$), allowing the identification of the origin of detritus particles. Stable isotopes are present in ecosystems and their natural distribution reflects in an integrated way the history of physical and metabolic processes of the environment (LOPES; BENEDITO, 2002), providing evidence about the origins and transformations of the organic matter (FRY; SHERR, 1989).

Thus, carbon and nitrogen isotopes are used to elucidate photosynthetic pathways, physiological processes in plants or, as is the case of POC analysis, the determination of the change in food sources for consumers in food webs, representing an useful tool for researchers studying the cycles of matter and energy in the environment (BARROS et al., 2010; HUNSINGER et al., 2012; MAZZOLA; SARA, 2001; PEREIRA; BENEDITO, 2007). In this way, this study aimed to evaluate the effects of the flood pulse in a neotropical floodplain on POC isotopic composition in years with distinct hydrological cycles (2000 and 2009), mostly aiming to understand the structure and functions of the food webs.

Material and methods

Study area

The study area was carried out in the upper Paraná river floodplain (22º 40' to 22º 50' S; 53º 10' a 53º 40' W). This floodplain has the Paraná river as the main channel and secondary channels as the Baía, Ivinheima, and Amambai (AGOSTINHO et al., 2001) (Figure 1).

The upper Paraná river floodplain is the last stretch of this river that is free of dams, featuring different types of riparian vegetation formations, such as Floresta Estacional Semidecidual Submontana, and Floresta EstacionaI Semidecidual Aluvial (CAMPOS; SOUZA, 1997). The climate is humid subtropical in the summer and the average temperature is above 22°C (IAPAR, 1994). The average annual rainfall is between 1,200 and 1,300 mm. The rain is distributed during all months of the year, with the largest volume in the period from September to December and the lowest averages in the months from June to August, but always greater than 30mm monthly (IAPAR, 1994).

Daily water levels were obtained in the Fluviometric Station of Porto São José, Paraná State. Hydrological periods were classified into potamophase and limnophase (NEIFF, 1990) according to the water level, being considered flood period (potamophase) when it had exceeded 3.5 m in the Paraná river (THOMAZ et al., 1997). Thus, the floodplain in 2000 was characterized by not presenting well-defined limnophase and potamophase, but as short periods of oscillations with a single pulse of short duration (approximately 15 days) in March-April. In 2009, one pulse of short duration was registered in February-March, which was different from 2000. In 2009, there was a pronounced potamophase period from October (Figure 2).

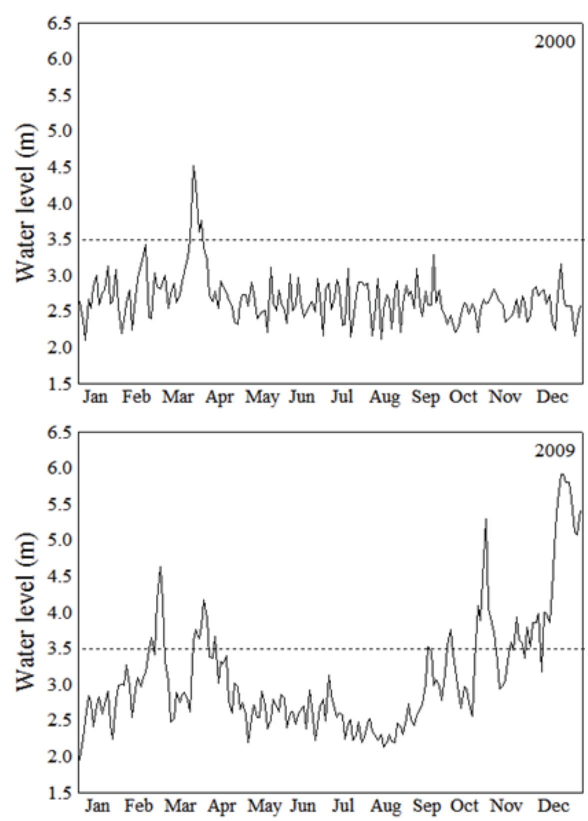

Figure 2. Mean water level of the upper Paraná river basin, obtained at Porto São José, in 2000 and 2009.

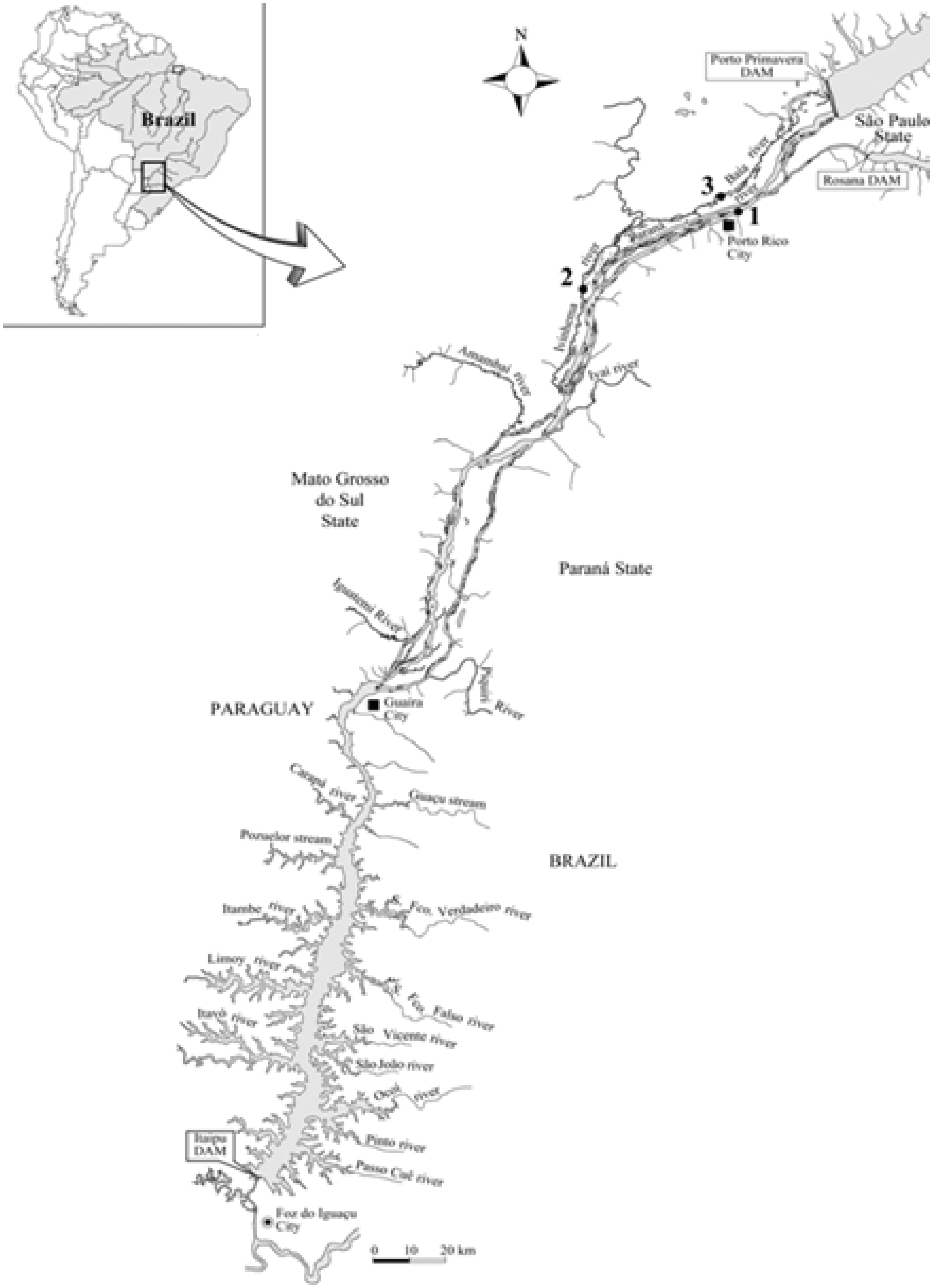

Figure 1. Study area in the upper Paraná river floodplain. 1: Paraná river; 2: Baia river; 3: Ivinheima river.

Samplings

Particulate Organic Carbon samples were collected in February 2000, August 2000, and June 2009, corresponding to limnophase, and December 2009, corresponding to potamophase (Figure 2). The samples were taken with 500 mL-plastic vials, and retained on glass fiber filters (GF/C 47 mm Whatman), previously combusted at 550ºC for 4 hours.

In this study, we investigate the isotopic signal of periphyton, phytoplankton, sediment, riparian vegetation, aquatic macrophytes, and grasses, because those sources can be constituents of POC mixture. Samplings of sources and of POC were comprised of four samples per sampled river. Vascular plant species corresponded to those most abundant at each sampling site (CAMPOS; SOUZA, 1997). The periphyton was obtained by scraping the stems of aquatic plants, and putting them on previously combusted glass fiber filters (GF/C 47 mm Whatman). The phytoplankton was collected with a plankton net (15 μm mesh size), with the purpose of concentrating the material, also kept on glass fiber filters. The sediment was collected using a modified Petersen grab. Samples of riparian vegetation, aquatic macrophyte, grasses, and sediment were dried in an oven at 60°C and macerated a fine and homogenous powder was obtained. Samples were sent to the UC Davis Stable Isotope Facility - Davis, California, USA, for isotopic determination ($\delta^{13}C$ and $\delta^{15}N$) in mass spectrometer. Values of isotopic ratios were expressed in delta notation (δ) and in parts per thousand (‰); $\delta^{13}C$ or $\delta^{15}N$ = $([R_{sample}/R_{standard}] - 1) \times 1000$, where R= $^{13}C/^{12}C$ or $^{15}N/^{14}N$.

Primary producers and sediment were collected in order to identify their isotopic contribution to POC. However, it was not possible to run isotopic mixing models with these sources due to overlapping carbon and nitrogen isotopic values, which makes it impossible to evaluate the contribution of each isotope signal in the POC composition. Thus, the isotopic signal of the $\delta^{15}N$ it was only used for a graphic inspection to visualize the isotopic variation of the primary producers and POC in the upper Paraná river floodplain. These graphics were run in the software R.2.11.1®.

Data analysis

It was not possible to do parametric tests (ANOVA) because the assumptions of normality and homoscedasticity were not met. Thus, a non-parametric analysis of variance (Kruskal-Wallis) was employed to check differences in isotopic signal ($\delta^{13}C$) of POC at each period sampled (2000 and 2009) in the three subsystems (Baia, Ivinhema, and Paraná). These analyses were run in the software Statistica 7.1® (STATSOFT, 2005) with a level of significance of 5%.

Results

The highest value of isotopic composition was recorded in June 2009 on the Paraná and Ivinheima rivers. For the Baía river, more depletion values were recorded in 2000 (Table 1).

A significant difference was found between periods in 2009 (limnophase x potamophase), for the Paraná ($H_{1,8}$ = 5.33; p = 0.02) and Baía ($H_{1.8}$ = 5.33; p = 0.02) rivers. In 2000, there was no significant difference between the periods studied (Figure 3).

Table 1. Minimum and maximum values of carbon and nitrogen isotopic composition ($\delta^{13}C$ and $\delta^{15}N$, respectively) in Paraná, Baia and Ivinheima rivers in 2000 and 2009.

river/period	$\delta^{13}C$ (‰)		$\delta^{15}N$ (‰)	
	min	max	min	max
Paraná - Feb/2000	-26.4	-25.0	0.3	4.2
Paraná - Aug/2000	-27.4	-25.2	7.2	9.3
Baia - Feb/2000	-33.2	-25.4	3.8	8.0
Baia - Aug/2000	-34.4	-30.4	0.8	3.0
Ivinheima - Feb/2000	-28.6	-25.3	2.1	4.1
Ivinheima - Aug/2000	-25.6	-25.0	4.8	8.2
Paraná - June/2009	-22.2	-22.0	0.7	2.3
Paraná - Dec/2009	-28.6	-25.3	0.8	3.2
Baia - June/2009	-26.0	-25.3	0.7	1.7
Baia - Dec/2009	-28.8	-28.3	1.4	5.9
Ivinheima - June/2009	-24.5	-22.0	0.4	3.9
Ivinheima - Dec/2009	-25.1	-24.1	1.7	3.1

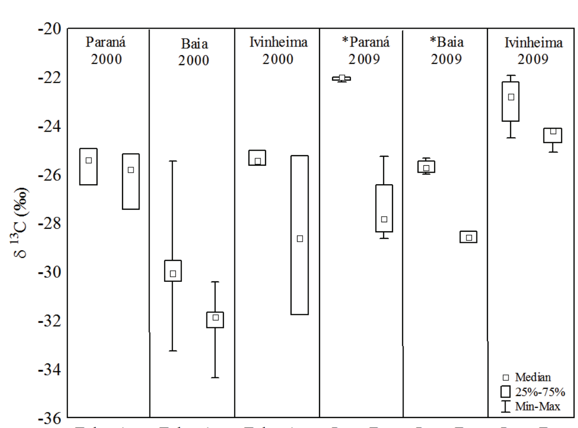

Figure 3. Isotopic value of $\delta^{13}C$ for Poc in Paraná, Baia and Ivinheima rivers, in 2000 and 2009. (Feb: February; Aug: August; Jun: June; Dec: December). *significant differences.

The isotopic composition of primary producers and sediment, analyzed in 2000, showed in general, a relatively high standard deviation for both carbon and for nitrogen. We could note the overlapping isotopic signature of POC with numerous sources, except sediment and grasses in both periods (Figure 4).

In 2009, the average carbon composition of primary producers and sediment changed in the three rivers. It is noteworthy that the isotopic signal of the POC was positioned outside the polygon, which is drawn from the values of the sources, except only for the Baia river. In the Paraná river, not all sources were investigated because of the absence of grasses and macrophytes in the river channel. In the Ivinheima river, the isotopic signal of POC was more enriched in relation to the investigated sources (Figure 5).

Discussion

POC isotopic composition in 2000 had no seasonal variation but presented a high amplitude for the three rivers investigated, ranging from -25‰ to -34‰. In contrast, in 2009, there was a seasonal variation for the rivers, and small amplitude for the isotopic composition of the POC. Studies performed with the POC in four of the largest river systems in the USA (Mississippi, Colorado, Rio Grande, and Columbia), also registered high values of $\delta^{13}C$ for the POC, varying between -37‰ and -18‰ (KENDALL et al., 2001). Others who researched in the Bekanbeushi river basin, Japan, pointed out little variation in the values, from -29.1‰ to -28.7‰, without seasonal variation in the POC values (NAGAO et al., 2010).

The occurrence of a single peak in the water level, lower than 4.6 m, was verified in 2000. In 2009, there were at least two peaks above 4.6 m in the Paraná river, in both hydrological periods. When the water level of the Paraná river reaches 4.6 m, the flooding of the Baía and Ivinheima rivers is observed, with the inflow of water into less connected lakes, which are separated from lotic systems by low banks (SOUZA FILHO, 2009). Thus, the isolated areas can be connected through flood pulses and can contribute to the input of new sources to the water column, modifying the isotopic composition of the POC, as observed in the $\delta^{13}C$ values of POC, and the lower amplitude in 2009. Riera and Richard (1997) showed that the reduction in the $\delta^{13}C$ values of POC coincides with the period of high discharge of the river. According to these authors, this implies that the flood pulse can lead to depletion of the isotopic signal of POC, due to the contribution of new terrestrial sources. Similar result was found in our study in 2009, when we observed a depletion of $\delta^{13}C$ in the potamophase compared with the limnophase.

Particulate organic carbon and dissolved organic carbon have the main source from biogenic carbon, consisting live biomass, litter and soil organic carbon (ZHANG et al., 2009). In our study was not possible identify the sources of POC contribution due overlap of primary producers isotopic signature. This result is similar to that investigated by Gimenes et al. (2012), which considered POC as a source and there was an overlap between it and other sources. Considering that the study above was conducted in the same area of ours, it is possible that the overlap of primary producers isotopic signature is a characteristic of this floodplain.

Numerous studies have identified the potential sources for POC in important watersheds worldwide. In the Amazon river, the POC is formed by approximately 60% phytoplankton, which makes depleted the $\delta^{13}C$ (ARAÚJO-LIMA et al., 1986). In the Godavari river (India), during the potamophase, the major contribution comes from the organic matter from the soil, while in other periods the phytoplankton is the main source (BALAKRISHNA; PROBST, 2005). In the Zengjiang river (China), the C/N ratio showed that the aquatic biomass is the major contributor, and the participation of autochthonous organic carbon in the POC is greater in low turbidity rivers (GAO et al., 2007). POC isotopic analysis in the Tokachi river (Japan) presented a high contribution from the particulate organic matter in the river bed, loaded onto the continental margins (NAGAO et al., 2005).

These results demonstrated the flood pulses influence on the POC dynamics. The flood events probably modified the isotopic composition of POC by transporting new sources to the aquatic system, highlighting the importance of these events in the organic carbon pool dynamics in river systems like the floodplains.

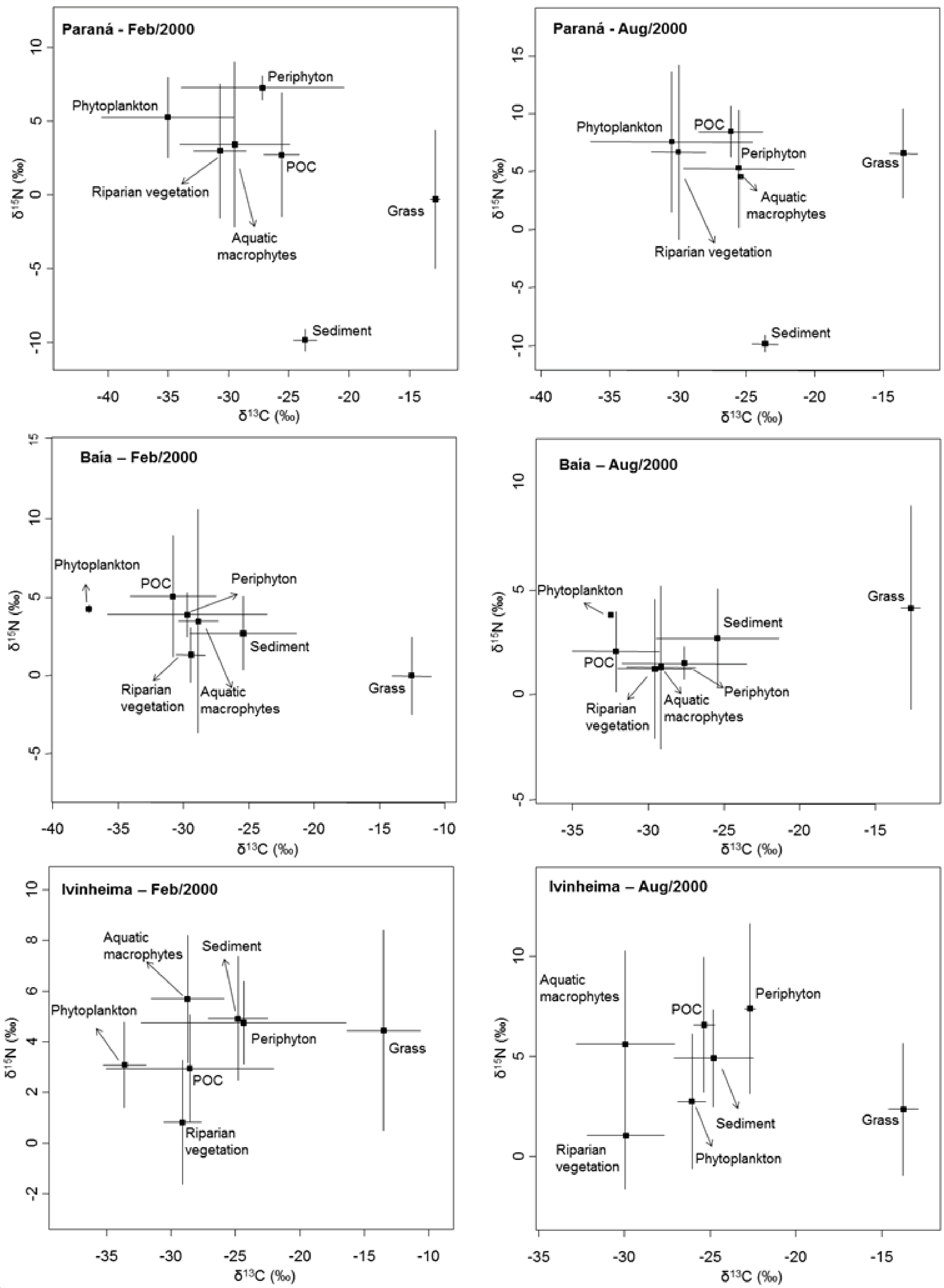

Figure 4. Biplot of mean (±SD) stable isotopic composition of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) for POC and primary producers in 2000 (Feb: February; Aug: August).

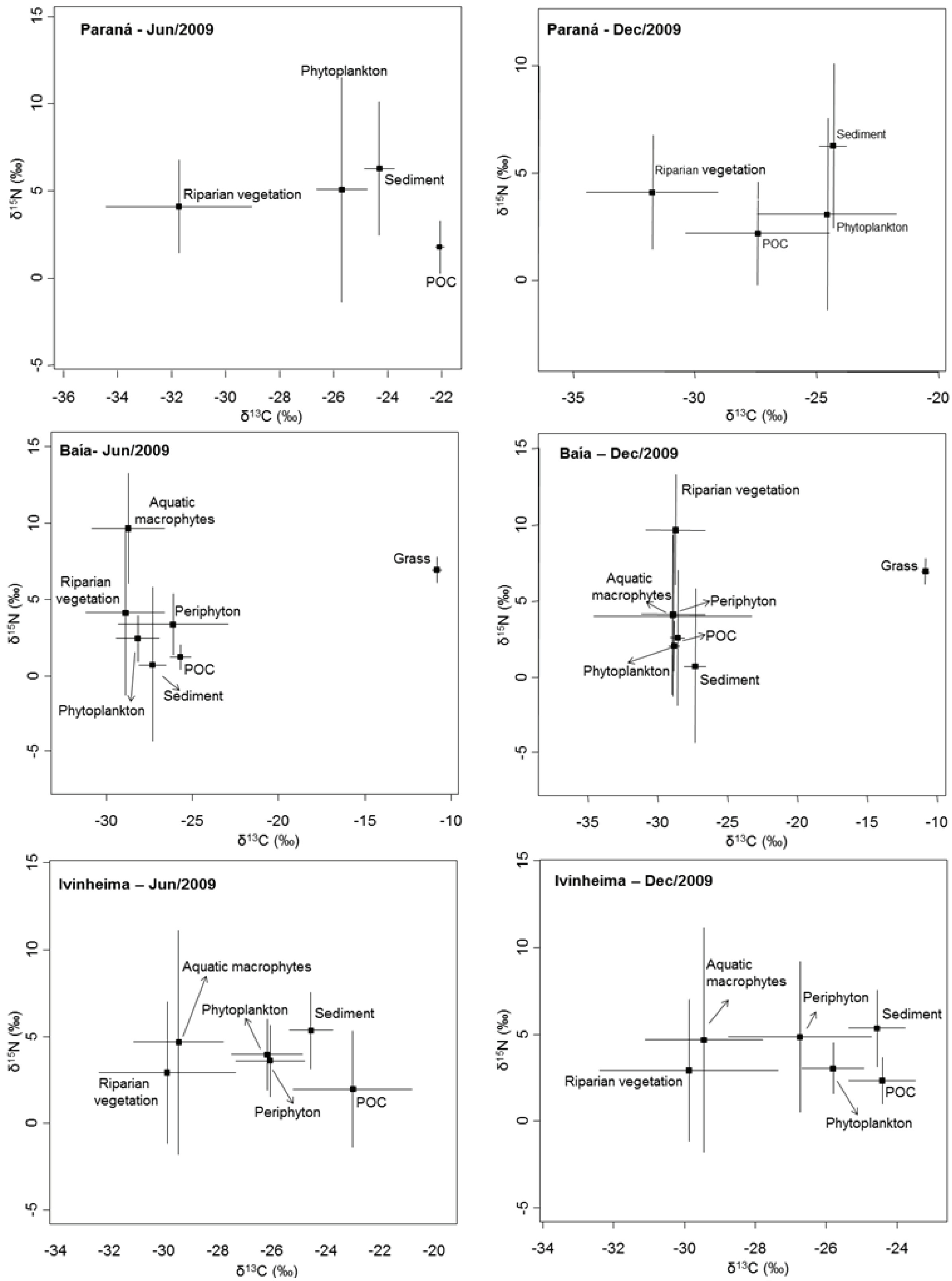

Figure 5. Biplot of mean (±SD) stable composition of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) for POC and primary producers in 2009 (Jun: June; Dec: December).

Conclusion

In this study, the input of POC constituent materials depends on the flood pulse, which was determined by its isotopic composition. In these systems, the biomass of detritivorous is high in the species that are benefited by the settled POC. The composition of the bodies of these organisms exhibits spatial variations in isotopic composition (LOPES et al., 2009), which is important to precisely identify the sources, because they allow identifying processes in the environment and thus perform more effective management actions.

Acknowledgements

To the Núcleo de Pesquisas em Limnologia, Ictiologia e Aquicultura (NUPELIA) for logistic support, to PIBIC/CNPq-UEM and Araucária Foundation for financial support and scholarships; to the staff of the laboratory of energetic ecology.

References

AGOSTINHO, A. A.; GOMES, L. C.; ZALEWSKI, M. The importance of floodplains for the dynamics of fish communities of the upper river Paraná. **Ecohydrology and Hydrology**, v. 1, n. 1-2, p. 209-217, 2001.

AGOSTINHO, A. A.; THOMAZ, S. M.; GOMES, L. C. Threats for biodiversity in the floodplain of the upper Paraná river: effects of hydrological regulation by dams. **Ecohydrology and Hydrology**, v. 4, n. 3, p. 255-268, 2004.

AGOSTINHO, A. A.; PELICICE, F. M.; GOMES, L. C. Dams and the fish fauna of the Neotropical region: impacts and management related to diversity and fisheries. **Brazilian Journal of Biology**, v. 68, n. 4, p. 1119-1132, 2008.

ARAÚJO-LIMA, C. A. R. M.; FORSBERG, B. R.; VICTÓRIA, R. L.; MARTINELLI, L. A. Energy sources for detritivorous fishes in the Amazon. **Science**, v. 234, n. 4781, p. 1256-1258, 1986.

BALAKRISHNA, K.; PROBST, J. L. Organic carbon transport and C/N ratio variations in a large tropical river: Godavari as a case study, India. **Biogeochemistry**, v. 73, n. 3, p. 457-473, 2005.

BARROS, G. V.; MARTINELLI, L. A.; NOVAIS, T. M. O.; OMETTO, J. P. H. B.; ZUPPI, G. M. Stable isotopes of bulk organic matter to trace carbon and nitrogen dynamics in an estuarine ecosystem in Babitonga Bay (Santa Catarina, Brazil). **Science of the Total Environment**, v. 408, n. 10, p. 2226-2232, 2010.

CAMPOS, J. B.; SOUZA, M. C. Vegetação. In: VAZZOLER, A. E. A. M.; AGOSTINHO, A. A.; HAHN, N. S. (Ed.). **A planície de inundação do alto rio Paraná**: aspectos físicos, biológicos e socioeconômicos. Maringá: Eduem, 1997. p. 331-342.

FRY, B.; SHERR, E. B. $\delta^{13}C$ Measurements as indicators of carbon flow in marine and freshwater ecosystems. In: RUNDEL, P. W.; EHLERINGER, J. R.; NAGY, K. A. (Ed.). **Stable isotopes in ecological research.** Ecological Studies, v. 68, 1989. p. 196-229.

GAO, Q.; TAO, Z.; YAO, G.; DING, J.; LIU, Z.; LIU K. Elemental and isotopic signatures of particulate organic carbon in the Zengjiang river, southern China, **Hydrological Processes**, v. 21, n. 10, p. 1318-1327, 2007.

GIMENES, M. F.; TAKEDA, A. M.; BENEDITO, E. The role of sediment on the energy availability for fishes in the upper Paraná river floodplain. **Acta Scientiarum. Biological Sciences**, v. 34, n. 4, p. 391-398, 2012.

HUNSINGER, G. B.; MITRA, S.; FINDLAY, S. E. G.; FISCHER D. T. Littoral-zone influences on particulate organic matter composition along the freshwatertidal Hudson river, New York. **Limnology and Oceanography**, v. 57, n 5, p. 1303-1316, 2012.

IAPAR-Instituto Agronômico do Paraná. **Cartas climáticas do Estado do Paraná**. Londrina: Iapar, 1994.

JUNK, W. J.; BAYLEY, P. B.; SPARKS, R. E. The flood pulse concept in river-floodplain systems. In: DODGE, D. P. (Ed.). **Proceedings of the International Large river Symposium**. Ontario: Canadian Special Publication of Fisheries and Aquatic Sciences, 1989. p. 110-127.

KENDALL, C.; SILVA, S. R.; KELLY, V. J. Carbon and nitrogen isotopic compositions of particulate organic matter in four large river systems across the United States. **Hydrological Processes**, v. 15, n. 7, p. 1301-1346, 2001.

LAMPERT, W.; SOMMER, U. **Limnoecology**: The Ecology of Lakes and Streams. 2nd ed. Oxford: Oxford University Press, 2007. p. 72-79.

LOPES, C. A.; BENEDITO, E. Variabilidade isotópica ($\delta^{13}C$ e $\delta^{15}N$) em produtores primários de ambientes terrestres e de água doce. **Acta Scientiarum. Biological Sciences**, v. 24, n. 2, p. 303-312, 2002.

LOPES, C. A.; BENEDITO, E.; MARTINELLI, L. A. Trophic position of bottom-feeding fish in the upper Paraná river floodplain. **Brazilian Journal of Biology**, v. 69, n. 2, p. 573-581, 2009.

MAZZOLA, A.; SARA, G. The effect of fish farming organic waste on food availability for bivalve molluscs (Gaeta Gulf, Central Tyrrhenian, MED): stable carbon isotopic analysis. **Aquaculture**, v. 192, n. 2-4, p. 361-379, 2001.

NAGAO, S.; ARAMAKI, T.; SEKI, O.; UCHIDA, M.; SHIBATA, Y. Carbon isotopes and lignin composition of POC in a small river in Bekanbeushi Moor, northern Japan. **Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms**, v. 268, n. 7-8, p. 1098-110, 2010.

NAGAO, S.; USU, T.; YAMAMOTO, M.; MINAGAWA, M.; IWATSUKI, T.; NODA, A. Combined use of $\delta^{14}C$ and $\delta^{13}C$ values to trace transportation and deposition processes of terrestrial particulate organic matter in coastal marine environments. **Chemical Geology**, v. 218, n. 1-2, p. 63-72, 2005.

NEIFF, J. J. Ideas para la interpretación ecológica del Paraná. **Interciencia**, v. 15, n. 6, p. 424-441, 1990.

PEREIRA, A. L.; BENEDITO, E. Isótopos estáveis em estudos ecológicos: métodos, aplicações e perspectivas. **Revista Biociências**, v. 13, n. 1-2, p. 16-27, 2007.

RIERA, P.; RICHARD, P. Temporal variation of δ13C in particulate organic matter and oyster Crassostrea gigas in Marennes-Oleron Bay (France): effect of freshwater inflow. **Marine Ecology Progress Series**, v. 147, p. 105-115, 1997.

SOUZA FILHO, E. E. Evaluation of the upper Paraná river discharge controlled by reservoirs. **Brazilian Journal of Biology**, v. 69, n. 2, p. 707-716, 2009.

STATSOFT, Inc. **Statistica (data analysis software system)**. Version 7.1 for Windows. Tulsa: Statsoft. Inc., 2005.

THOMAZ, S. M.; ROBERTO, M. C.; BINI, L. M. Caracterização limnológica dos ambientes aquáticos e influência dos níveis fluviométricos. In: VAZZOLER, A. E. A. M.; AGOSTINHO, A. A.; HAHN, N. S. (Ed.). **A Planície de inundação do alto rio Paraná**. Maringá: UEM-Nupelia, 1997. p. 73-102.

ZHANG, S.; LU, X. X.; SUN, H.; HAN, J.; HIGGITT, D. L. Geochemical characteristics and fluxes or organic carbon in a human-disturbed mountainous river (the Luodingjiang river) of the Zhujiang (Pearl river), China. **Science of the Total Environment**, v. 407, n. 2, p. 815-825, 2009.

Received on April 2, 2013.
Accepted on October 10, 2013.