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The influence of vegetal cover on carbon assimilation by *Prochilodus lineatus* (Characiformes: Prochilodontidae) in the upper Paraná river floodplain

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ABSTRACT. The present study examined the influence of the availability of riparian vegetation and C_3 emergent aquatic macrophytes on carbon assimilation by *Prochilodus lineatus.* The vegetal cover of these producers, available at 30 m of the bank, for the terrestrial ecosystem of the rivers Baia, Ivinheima and Paraná, was quantified with the image processing Landsat 5 TM, of the year 2000, period of sampling of the biological material at each river. The assimilation of the energy sources (riparian vegetation and C_3 aquatic macrophytes, C_4 aquatic macrophytes, periphyton, and phytoplankton) by *P. lineatus* was determined by analysis of stable carbon isotopes ($\delta^{13}C$). The area of vegetal cover was estimated at 1,017 km^2 in the Ivinheima river, 669 km^2 in the Paraná river, and 268 km^2 in the Baia river. The assimilation of the carbon from riparian vegetation and aquatic macrophytes was proportional to the availability in the environment, but these producers were not the main source of carbon for *P. lineatus*. Thus, in the rivers with greater vegetation cover, consequently, these items had higher availability in the water body becoming an important carbon source for the species maintenance.

Keywords: primary producer, remote sensing, stable isotopes, fish.

A influência da cobertura vegetal na assimilação do carbono pelo *Prochilodus lineatus* (Characiformes: Prochilodontidae) na planície de inundação do alto rio Paraná

RESUMO. No presente estudo investigou-se a influência da disponibilidade da vegetação ripária e macrófitas aquáticas C_3 emergentes sobre a assimilação de carbono por *Prochilodus lineatus.* A cobertura vegetal destes produtores, disponível a 30 m da margem para o ecossistema terrestre dos rios Baia, Ivinheima e Paraná, foi quantificada com o processamento de imagens Landsat 5 TM, do ano de 2000, período de amostragem do material biológico em cada rio. A assimilação das fontes de energia (vegetação ripária e macrófita aquática C_3, macrófita aquática C_4, perifiton e fitoplâncton) por *P. lineatus* foi determinada por análises de isótopos estáveis de carbono ($\delta^{13}C$). A área de cobertura vegetal foi estimada em, 1017 km^2 no rio Ivinheima, 669 km^2 no rio Paraná e 268 km^2 no rio Baia. A assimilação por *P. lineatus*, do carbono proveniente da vegetação ripária e das macrófitas aquáticas foi proporcional a sua disponibilidade no ambiente, porém estes produtores não foram a principal fonte de carbono para a espécie. Sendo assim, os rios que apresentaram maior cobertura vegetal, consequentemente, tiveram maior disponibilidade no corpo aquático tornando-se importante fonte de carbono para a manutenção da espécie.

Palavras-chave: produtor primário, sensoriamento remoto, isótopos estáveis, peixe.

Introduction

Detritivorous fish can dominate Neotropical aquatic ecosystems, with high presence of the family Prochilodontidae in South American rivers (BOWEN, 1983). The genus *Prochilodus* is responsible for up to 10% of dominant fauna in 77 Brazilian reservoirs (AGOSTINHO et al., 2007) and at Itaipu Reservoir, the fish landings of *Prochilodus lineatus* (Valenciennes, 1836), commonly known as curimba, represented the sixth most important species in 2004, the seventh in 2005, and increased 330% in 2008, yielding 101.3 tons (OKADA et al., 2008).

Due to this high yield, *P. lineatus* is an important commercial species and source of protein to human population (AGOSTINHO; GOMES, 2005). This species profitability influences all the fishing production, mainly of the carnivorous fish that feed on it (OKADA et al., 2008). The conservation of natural stocks of *P. lineatus* is essential to preserve biodiversity and human food supply.

The productivity of *P. lineatus* at Itaipu Reservoir is depending on changes occurring in the Upper Paraná river floodplain (OKADA et al., 2008). This ecosystem is essential for growth and reproduction of this and other migratory fish species (AGOSTINHO et al., 1993; GOMES; AGOSTINHO, 1997; AGOSTINHO et al., 2004), principally due to its high habitat heterogeneity, elevated biological diversity and complex ecological relationships (AGOSTINHO; ZALEWSKI, 1995; AOYAGUI; BONECKER, 2004; WARD; TOCKNER, 2001).

In the upper Paraná river floodplain, plant debris and litter rise the organic detritus, which is the item most consumed by *P. lineatus*, reaching 53% of the diet (FUGI et al., 1996). Beyond plant organic matter, organic detritus is composed of fine particulate material from animal, algae, protozoans, zoobenthic invertebrates, and organisms that participate in the microbial loop (FUGI et al*.,* 1996). Studies in this floodplain addressing isotopic analyses of *P. lineatus* muscles have revealed the predominance of C_3 plants (phytoplankton, periphytic algae and riparian vegetation) as the greatest sources of energy in most of the analyzed rivers and seasons (LOPES et al., 2007).

The human pressure affects the riparian forests of this area since the 1960´s (CAMPOS; SOUZA, 1997). This vegetation was transformed into a narrow mosaic confined to the river banks, surrounded by a matrix composed of pastures and agriculture, motivated chiefly by agriculture and cattle frontiers (AGUIAR et al., 2007). The organic matter provided to the aquatic environment by riparian zones has important consequences for stream fish, maintaining food-web structure and affecting biodiversity. The attention to this linkage is essential to prevent deterioration in freshwater fish populations (PUSEY; ARTHINGTON, 2003).

In this study, we assessed the influence from the availability of riparian vegetation and C_3 aquatic macrophytes on the assimilation of carbon sources by *P. lineatus.*

Material and methods

Study area

The study area is included in the Upper Paraná river floodplain (22°40' to 22°50S; 53°10' to 53°40'W) (Figure 1), located in the last dam-free stretch of the Paraná river in Brazilian territory (ROCHA et al., 2009). The biological material was collected in the rivers Baia (22°43'23.16"S; 53°17' 25.5"W), Ivinheima (22°47'59.64"S; 53°32' 21.3"W) and Paraná (22°45'39.96"S; 53°15' 7.44"W) (SOUZA-FILHO et al., 2000). The quantification of riparian vegetation and emergent aquatic macrophytes on the rivers banks was accomplished using Landsat 5 TM images, considering the maximum area of 20 km away from the sampling stations of biological material (Figure 1). This is the maximum daily distance traveled in the migration of *P. lineatus* (GODOY, 1975). The study period encompassed the year 2000, due to the availability of biological material collected and of remote sensing images of the region. *Prochilodus lineatus* presents the maximum accumulation of reserves (RESENDE, 1992), in consequence of the higher availability of silt (MAIA et al., 1999).

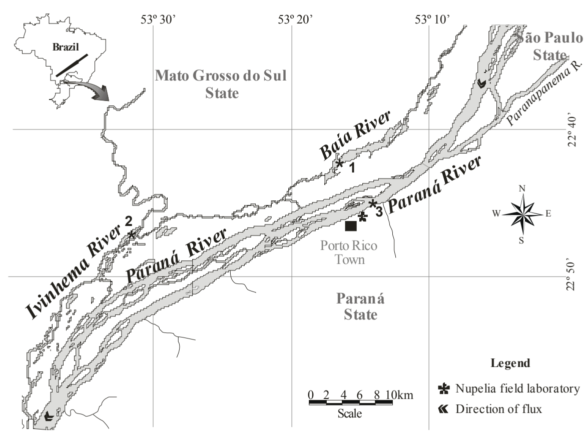

Figure 1. Study area and location of the sampling stations in Baia (1), Ivinheima (2) and Paraná (3) rivers.

Remote sensing data

For the quantification of the cover of riparian vegetation and emergent aquatic macrophytes, disposed at 30 m of the bank to terrestrial ecosystem of Baia, Ivinheima and Parana rivers, were used Landsat 5 TM images from the study area (scenes 223/76 and 224/76 - point/orbit), generated in April 2000. This material is free-available at the site of Instituto Nacional de Pesquisas Espaciais (http://www.inpe.br/). The distance of the vegetation cover was chosen considering the potential input of organic matter to the river. The spatial resolution from Landsat imageries available for the period of study was 30 m, thus, one pixel in the image corresponds to 900 m^2 of terrestrial surface (30 x 30 m). Due to this characteristic of the remote sensor, riparian vegetation and emergent aquatic macrophytes was indistinguishable in the images and have been accounted together.

To process the images, were used the software ENVI 4.3 (RSI, 2006) and the freeware SPRING 5.1.5 (CÂMARA et al., 2008). The last one was acquired from the site of Instituto Nacional de Pesquisas Espaciais (http://www.inpe.br/). The images were georeferenced in ENVI 4.3 (MP-GO, 2009) with Geocover Circa images from 2004 (NASA, 2009). This last product is available for download (NASA, 2009) and all the pixels have one location inside a coordinate system, regarding to *datum* WGS-84. Afterwards, the images passed through atmospheric corrections by the method of dark substrate in ENVI 4.3, to correct scattering, absorption and refraction interferences (SABINS-JUNIOR, 1978). These effects influence the amount of electromagnetic energy sensed by the images system (CHAVEZ-JUNIOR, 1996). Forthwith, the images processed were imported to SPRING 5.1.5 and then joined using the Mosaic function, to work with all the study area at the same time. Next, a group of variable numbers of pixels were sampled and identified as water or vegetation, according to the color on a RGB composition, formed by the overlap of the bands 3, 4, and 5 in the colors blue, red and green, respectively. Later, the program used the selected grey lengths of the groups to classify all the pixels of the image that were similar to water or vegetation, according to their reflectance. A new interface was generated with the classified image from the supervised classification by the maximum likelihood method (99% reliability), only with pixels corresponding to water and vegetation.

In the classified image, were created lines on the limit of the pixels representing water and vegetation, separated to each river: Baia, Ivinheima and Paraná, in the vectorial edition. These lines passed through a growth of 30 m, from the bank to the land, using the Distance Maps method (fixed step, initial: 0, final: 30, step: 30, number of points on the curve: 180). The results were polygons, which delimited the area of 30m from bank to land, used as masks to cut and isolate the pixels that represented riparian vegetation and emergent aquatic macrophytes at the classified image. Eventually, using the tool Classes Measures, the vegetation cover was detected in km^2.

The vegetation in the islands and backwaters of the Paraná river were not quantified because it was not possible to carry out the growth of 30 m in opposite direction, i.e., from the left to the right, since the program does not accept the initial step with a negative value.

Catch Per Unit Effort (CPUE)

CPUE data were calculated based on the relationship between the values of biomass (kg) of *Prochilodus lineatus* divided by the values of net areas (km^2) exposed for 24 hours in each river, in 2000. This information was provided by the records from the Long-Term Ecological Research (LTER) - program of CNPq, accomplished by the Núcleo de Pesquisas em Limnologia, Ictiologia e Aquicultura of the Departamento de Biologia from the Universidade Estadual de Maringá.

Stable isotope analysis

The $\delta^{13}C$ values of the primary producers (riparian vegetation, C_3 and C_4 aquatic macrophytes, periphyton and phytoplankton) (Table 1) and of 28 adult exemplars of *Prochilodus lineatus* were quantified in February and March of 2000 (LOPES et al., 2007). The variations in the possible contributions of energy sources for the isotopic signature of studied organisms were analyzed using the IsoSource 1.3.1 (PHILLIPS; GREGG, 2001), software (EPA, 2007), with increase of 1% and tolerance of 0.05, which is suitable in investigations using few isotopes and energy sources (HORNUNG; FOOTE, 2008). Carbon isotopic values of the riparian vegetation and C_3 aquatic macrophytes were pooled owing to the inability of remote sensing to distinguish the two vascular plants from the vegetal cover.

Table 1. Mean values (‰) and standard deviation of $\delta^{13}C$ from the autotrophic sources in the different rivers. BaiR = Baia river, IvR = Ivinheima river, ParR = Paraná river. Rip. Veg. + C_3 Mac = Riparian vegetation and C_3 Macrophytes, C_4 Mac = C_4 Macrophytes, Phytopl. = Phytoplankton, Periphy= periphyton.

Source/Local	BaiR	IvR	ParR
Rip. Veg. + C_3 Mac	-28.78 ± 0.78	-28.92 ± 0.98	-29.61 ± 1.66
C_4 Mac	-12.54 ± 0.76	-12.84 ± 1.42	-13.50 ± 0.21
Phytopl.	-35.92 ± 0.13	-34.14 ± 0.83	-32.32 ± 2.26
Periphy	-29.72 ± 3.06	-24.37 ± 3.98	-27.19 ± 3.37

Statistical analysis

The assumptions of normality (Shapiro-Wilk test) and homoscedasticity (Levene test) were previously tested to perform the ANOVA, using Statistica 7.1 software (STATSOFT, 2005). The Tukey's test was applied for the mean values with significant differences. The significance level adopted in all tests was $p < 0.05$.

Results

The largest area of riparian vegetation and emergent aquatic macrophytes (52%) was registered in the Ivinheima river as well as the highest biomass (49%) of *P. lineatus*; the smallest vegetation cover was verified at Baia river (14%); the lowest fish biomass was found in Paraná river (14%) (Table 2).

Table 2. Values and frequency of vegetation cover area (riparian vegetation and C_3 aquatic macrophytes), and CPUE values of *P. lineatus*, in the rivers Baia, Ivinheima and Paraná.

Local	Vegetal cover (km^2)	Frequency (%)	CPUE (Kg Km^{-2} 1000^{-1})	Frequency (%)
Baia	268	14	525	37
Ivinheima	1,017	52	693	49
Paraná	669	34	195	14
TOTAL	1,954		1,413	

A significant spatial variation was detected in the $\delta^{13}C$ values of *P. lineatus* muscle, with higher values for the Paraná river (ANOVA, $F_{2,\ 25}$ = 12.7166; p = 0.00016; Tukey p = 0. 000446) (Figure 2).

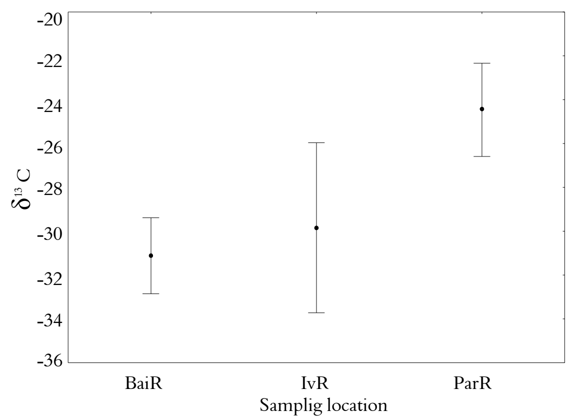

Figure 2. Mean ± SE carbon isotopic values of *P. lineatus*, in the rivers Baia, Ivinheima and Paraná. BaiR = Baia river, IvR = Ivinheima river, ParR = Paraná river.

Considering the assimilation of energy sources by *P. lineatus*, the riparian vegetation and C_3 aquatic macrophytes was higher in the rivers with greater vegetation cover, Ivinheima (29%) followed by Paraná (28%). In the Baia river, a lower vegetation cover (3%), the phytoplankton was the most assimilated (77%) (Figure 3).

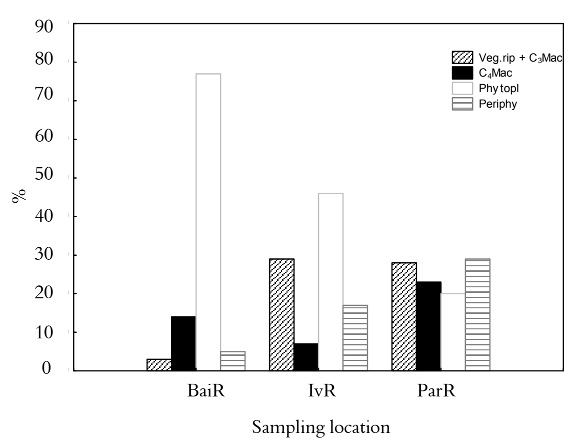

Figure 3. Mean contribution (in percentage) of the carbon sources (riparian vegetation and C_3 aquatic macrophyte (Veg.rip + C_3Mac), C_4 aquatic macrophyte (C_4Mac), phytoplankton (Phytopl) and periphyton (Periphy)) in the rivers Baia (BaiR), Ivinheima (IvR) and Paraná (ParR).

Discussion

The highest catch of *P. lineatus* occurred in the Ivinheima river, with the highest frequency of riparian vegetation and C_3 aquatic macrophytes. The second greatest capture of the species was found in Baia river, with the lowest vegetation cover. The efforts to understand the effects of deforestation should be strengthened, as well as reforestation projects need to be urgently started, especially to protect riparian habitats, considered crucial for many fish species (RODRÍGUEZ et al., 2006.).

Phytoplankton, periphyton, riparian vegetation and aquatic macrophytes are the most important carbon sources for the maintenance of the natural stocks of *P. lineatus* in the upper Paraná river floodplain, according to the mean values of contribution of these producers for the fish biomass. The significant difference in $\delta^{13}C$ of *P. lineatus* muscles between Baia, Ivinheima and Paraná rivers pointed out a nutritional variation on the assimilation of the energy sources. Oliveira et al. (2006) confirmed the importance of C_3 vascular plants to sustain fish biomass in floodplains.

The spatial variation in the assimilation of energy sources by *Prochilodus lineatus* showed a relationship with the spatial variation of estimated vegetation cover of riparian vegetation and C_3 aquatic macrophytes in Baia, Ivinheima and Paraná rivers. The contribution percentage of these carbon sources increased proportionally with the frequency of vegetation cover of the rivers Ivinheima, Paraná and Baía, respectively. Medeiros and Arthington (2011) indicated a stronger dependence of consumers on the autochthonous sources and on the locally produced organic matter from the riparian zone, than on other resources.

The phytoplankton was the most assimilated item in the rivers Baia and Ivinhema, the phytoplankton abundance was high in these environments in 2000 There are some probable factors involved on the selective assimilation of phytoplankton by detritivorous organisms. The easy assimilation of this producer makes its protein content highly nutritional (WASLIEN, 1975) and species present high degree of selectivity for diets richer in protein, although other resources are seemingly limitless in the environment (BOWEN, 1987). Vaz et al. (1999) argued that the selection of phytoplankton by detritivorous fish is related to the digestion process and occurs in the intestine and not before ingestion. Araújo-Lima et al. (1986) reject the selective feeding of this trophic group. The mechanism involved in this process is not clear and there are no recent studies with this focus, regardless the relevancy of this information for fish stock management. The relationship between phytoplankton and *P. lineatus* abundance requires further examinations, to clarify whether the availability of the producers is an attraction factor for the fish.

The highest capture of the species was coincident with the greater abundance of vegetation cover. The relationship between these variables was not clear, as well as the mechanism involved in the preferential assimilation of phytoplankton. The efforts to comprehend these relationships must be intensified, considering the importance for *P. lineatus* management strategies and the ecological and commercial importance of this species for the upper Parana river and other floodplains. The preservation of riparian vegetation is another essential action to ensure the species conservation, since it is one of the important carbon sources for *P. lineatus* in this ecosystem, along with aquatic macrophytes.

Conclusion

In the present study, we verified the influence of the availability of riparian vegetation and aquatic macrophytes in the environment, as sources of carbon for detritivorous species. These producers increase the availability of detritus due to the input of allochthonous material and the decaying of aquatic macrophytes.

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