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 C₃ 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 C₃ aquatic macrophytes, C₄ aquatic macrophytes, periphyton, and phytoplankton) by *P. lineatus* was determined by analysis of stable carbon isotopes (δ¹³C). The area of vegetal cover was estimated at 1,017 km² in the Ivinheima river, 669 km² in the Paraná river, and 268 km² 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 macrofitas aquáticas C₃ 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 macrofitas aquática C₃, macrofitas aquática C₄, perifiton e fitoplâncton) por *P. lineatus* foi determinada por análises de isótopos estáveis de carbono (δ¹³C). A área de cobertura vegetal foi estimada em, 1017 km² no rio Ivinheima, 669 km² no rio Paraná e 268 km² no rio Baia. A assimilação por *P. lineatus*, do carbono proveniente da vegetação ripária e das macrofitas 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; AYAGUI; 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 C₃ 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 C₃ 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°50'S; 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 Baía (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 Baía (1), Ivinheima (2) and Paraná (3) rivers.](image-url)

**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 Baía, 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 m² 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 reflectance. A new interface was generated with the classified image from the supervised classification by reflectance (SABINS-JUNIOR, 1996). 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 $p < 0.05$.

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. = Riparian vegetation, C$_3$ Mac = C$_3$ Macrophytes, C$_4$ Mac = C$_4$ Macrophytes, Phytopl. = Phytoplankton, Periphy= periphyton.

<table>
<thead>
<tr>
<th>Source/Local</th>
<th>BaiR</th>
<th>IvR</th>
<th>ParR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rip. Veg. + C$_3$ Mac</td>
<td>-28.78 ± 0.78</td>
<td>-28.92 ± 0.98</td>
<td>-29.61 ± 1.66</td>
</tr>
<tr>
<td>C$_4$ Mac</td>
<td>-12.54 ± 0.76</td>
<td>-12.84 ± 1.42</td>
<td>-13.50 ± 0.21</td>
</tr>
<tr>
<td>Phytopl.</td>
<td>-35.92 ± 0.13</td>
<td>-34.14 ± 0.83</td>
<td>-32.32 ± 2.26</td>
</tr>
<tr>
<td>Periphy</td>
<td>-29.72 ± 3.06</td>
<td>-24.37 ± 3.98</td>
<td>-27.19 ± 3.37</td>
</tr>
</tbody>
</table>

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).
A significant spatial variation was detected in the δ¹³C values of *P. lineatus* muscle, with higher values for the Paraná river (ANOVA, F², 25 = 12.7166; p = 0.00016; Tukey p = 0.000446) (Figure 2).

![Figure 2](image)

**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 C₃ 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](image)

**Figure 3.** Mean contribution (in percentage) of the carbon sources (riparian vegetation and C₃ aquatic macrophyte (Veg.rip + C₃Mac), C₄ aquatic macrophyte (C₄Mac), phytoplankton (Phytopl) and periphyton (Periphy)) in the rivers Baia (BaiR), Ivinheima (IvR) and Paraná (ParR).
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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