Pesticide contamination of water alters the metabolism of juvenile silver catfish, *Rhamdia quelen*

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**Abstract**

We investigated how pesticide contamination of water affects the metabolism of the silver catfish, *Rhamdia quelen*, by studying fish maintained at two sites with low and high anthropic activity (Lino Creek, southern Brazil). Several pesticides were found at both stream sites. After 30 days plasma glucose levels were higher in fish exposed to water in the low anthropic activity site than those exposed to water in the high anthropic activity site. Plasma K\(^+\) levels, however, were lower after exposure to low anthropic water than after exposure to high anthropic water. Moreover, values of hepatic glycogen, muscle lactate and protein were higher, but glycogen and protein of the kidney were lower in fish exposed to water at the high anthropic activity site. Our results show that these fish can be used as pesticide toxicity indicators in streams near agricultural fields.

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1. Introduction

The aquatic environment is continuously being contaminated with toxic chemicals from industrial, agricultural and domestic activity (Begum, 2004). In the central region of the State of Rio Grande do Sul, southern Brazil, many watersheds are near agricultural areas, particularly tobacco cultures (Bortoluzzi et al., 2006). Moreover, in this region, pesticides are in common use, and Barriuso et al. (1996) reported that about 20% of pesticides, used as prophylactic treatment for the plants, could drain into the rivers. Aquatic contamination by these products may occur in and around agricultural areas and may adversely affect aquatic fauna (Jonsson et al., 1999). Fingerprinting techniques have shown that 68.3% of the suspended sediment in the Lino Creek in the agricultural year of 2003/2004 originated from agricultural fields (Minella et al., 2007). Caged fish can be used in the field to study the impact of ongoing use or of accidental spills of pesticides or related chemicals. Thereby, we can study the impact of exposure while having a precise knowledge of its place and duration, both of which are inaccurate in population or community surveys (Oikari, 2006).

Lino Creek and its tributaries constitute the watersheds of Agudo, a municipality in Rio Grande do Sul state, southern Brazil. This stream is located in a basaltic mountainside, between the Central Depression and Mid Plateau, with a surface of 480 ha. This region is characterized by the presence of the native forest and also by tobacco culture, which uses pesticides without proper control. Pellegrini (2005) characterized the watershed as follows: a low anthropic activity site has steep slopes, stream borders protected with permanent vegetation (riparian zone) and few agricultural fields. A high anthropic activity site also has steep slopes, but there are agricultural fields close to the stream and less riparian vegetation. Anthropic pressure on the watershed causes high sediment discharge. Phosphate ions are released to solution, on average, twice as rapidly as sediments collected from subwatersheds with low anthropic activity than those from subwatersheds with high anthropic activity. Several pesticides commonly used in tobacco crops, such as chlorpyriphos (O,O-diethyl O,3,5,6-trichloro-2-pyridyl), imidacloprid (N-[1-[(6-chloro-pyridyl)methyl]-4,5-dihydroimidazol-2-yl]nitramide), flumetralin (2-chloro-N-[2,6-dinitro-4-(trifluoromethyl)phenyl]-N-ethyl-6-fluorobenzemethanamine) and clomazone (2-{[2-chlorophenyl]methyl}-4,4-dimethyl-3-isoxazolinone) (GAO, 2003), were also applied in southern Brazil, as well as non-recommended pesticides for tobacco crops as iprodione (3-(3,5-dichlorophenyl)-N-isopropyl-2,4-dioxo-1-imidazolidinecarboxamide), atrazine (2-chloro-4-ethylamino-6-isopropylamino-S-triazine) and simazine (6-chloro-N,N',diethyl-1,3,5-triazine-2,4-diamine) (Bortoluzzi et al., 2006). The physico-chemical characteristics of pesticides found in Lino River creek happen to contaminate the water course.
Imidacloprid is a systemic insecticide that presents a high residual effect and mobility in the soil and has a half-life in the soil from 48 to 190 days (Gonzáles-Pradas et al., 2002). Atrazine is a highly persistent herbicide in the soil, and has a potential for groundwater contamination despite its moderate solubility in water and has a half-life from 60 to more than 100 days (Wauchop et al., 1992; Scholz and Spiteller, 1992). Clofazimine is a highly effective herbicide but causes groundwater contamination due to its water solubility (1100 mg L\(^{-1}\)) and long half-life dissipation that averages from 28 to 84 days (Colby et al., 1989; Zanella et al., 2002). Chlorpyrifos is an organophosphate insecticide that is classified as moderately hazardous. In soil, chlorpyrifos is degraded at a moderate rate; due to the low solubility (1.4 mg L\(^{-1}\)) and hydrophobic nature (log \(K_{ow}\) 3.31–5.27), chlorpyrifos rapidly partitions from the water and adsors to sediment particles (Racke et al., 1994; Khan and Kour, 2007). Simazine is a persistent herbicide and does not adsorb strongly to soil particles. As it has a lengthy soil half-life (36–234 days) and low solubility in water (6.2 mg L\(^{-1}\)), it is likely to contaminate groundwater (Arufe et al., 2004).

The silver catfish, *Rhamdia quelen* (Quoy & Gaimard, 1824; Heptapteridae), is a native freshwater fish from southern Brazil and of great economic importance. Previous studies have documented the physiological and biochemical responses of this species to exposure to herbicides (Miron et al., 2005; Crestani et al., 2006, 2007; Glusczak et al., 2007); these studies showed that several biochemical parameters are altered, such as glycogen, lactate and glucose levels in tissues and brain acetylcholinesterase (AChE) activity. In this work, we sought to study how the contamination of water by pesticides used in tobacco culture affects the metabolic parameters of silver catfish juveniles that are maintained in either low or high anthropic activity sites of Lino Creek.

## 2. Materials and methods

### 2.1. Fish

Silver catfish (100.6 ± 0.2 g, 25.2 ± 0.3 cm) juveniles obtained from a local fish farm were maintained in laboratory condition with continuously aerated 250L tanks for at least 1 week prior to experiments. They were kept in continuously aerated water with a static system and with a natural photoperiod (12 h light/12 h dark). During the acclimation period, the average of water parameters was as follows: temperature 21.5 ± 2.0 °C, pH 6.0 ± 0.2 units, dissolved oxygen 6.17 ± 2.0 mg L\(^{-1}\), non-ironized ammonia 0.7 ± 0.01 µg L\(^{-1}\), nitrite 0.05 ± 0.01 µg L\(^{-1}\), alkalinity 40 ± 1.3 mg L\(^{-1}\) \(\text{CaCO}_3\) and hardness 36 ± 1.5 mg L\(^{-1}\) \(\text{CaCO}_3\). During acclimation, fish were transported for 2 h in 20L plastic bags with aeration to the experimental sites. During the acclimation period the fish were fed twice a day with commercial feed for juveniles at 5% of biomass (*Supra* 42% CP, Alisul Alimentos S.A., Carazinho, Brazil). After acclimation, fish were stored at \(-20^\circ\text{C}\) and frozen in liquid nitrogen and then kept at \(-20^\circ\text{C}\) for 1 week until analysis. The methodology of this experiment was approved by the Ethical and Animal Welfare Committee of Universidade Federal de Santa Maria. Plasma glucose was determined by Labtest kit, and Na\(^+\) and K\(^+\) levels were measured with a 8262 flame spectrophotometer (Micronal, São Paulo, Brazil). Plasma without dilution was used to measure Na\(^+\) and K\(^+\).

### 2.2. Experimental procedure

At the end of the acclimation period (March 2005), fish were placed simultaneously for 30 days in one of two sites (two replicates each site, 6 per replicate): low or high anthropic activity sites of Lino Creek. During the experiment the fish were maintained in cage nets (1 m \(^3\)) and fed twice a day (5% total biomass). The cage nets were fixed to the bottom and there was a net also on the bottom of the cage.

### 2.3. Water analysis

Water samples were collected with semiautomatic collectors installed at different sites of the stream in 12 instances: three samplings in 2001, two in 2002, four in 2003, one in 2004, two in 2005 and one in 2006. In 2005, the samplings were done in time coinciding with the beginning and completion (30 days) of the experiment. After collection, these samples were packed separately in a thermal box with ice, according to Clesceri et al. (1998), and transported to the laboratory for immediate analysis of pesticide residues. The active ingredients were quantified according to Zanella et al. (2003). The pesticides standards were obtained from Dr. Ehrenstorfer (Augsburg, Germany). The water was purified with a Milli-Q water purification system (Millipore Bedford, MA, USA). Methanol of chromatographic grade was from Mallinckrodt (Phillipenburg, NJ, USA). Phosphoric acid of analytical grade was from Merck (Darmstadt, Germany). The solid phase extraction (SPE) cartridges were Bakerbond C18 (size 3 mL, 500 mg). A high-performance liquid chromatography with an ultraviolet detector (HPLC-UV) was used to quantify imidacloprid, atrazine, simazine and clomazone. The HPLC-UV system consisted of a Varian (Harbor City, CA, USA) Model Star 9100 pump associated with a 7125 Rhodine (Cotati, CA, USA) six-port valve with a 20 µL loop, and a Varian Star 9105 UV-vis absorbance detector. The analytical column was aBondesil C18 (250 × 4.6 mm i.d.; 5 µm) from Varian. Gas chromatography with electron capture detection (GC-ECD) was used to quantify chlorpyrifos, flutemalin and iprodione. The GC-ECD system was a Varian Model 3800 equipped with an electron capture detector and a DB-5 (30 m × 0.25 mm i.d., 0.25 µm film thickness) fused-silica capillary column. The software Star 4.5 from Varian was used for data acquisition of both systems.

Before sample application, the SPE cartridges were conditioned by passing consecutively 3 mL of the solvent used for the elution step, Milli-Q water and Milli-Q water at pH 3.0. The water samples, after adjusting the pH to 3.0 by addition of phosphoric acid, were mixed well and a volume of 100 mL was passed through the SPE column at 10 mL min\(^{-1}\). After that, the column was eluted with 1.5 mL (three aliquots of 500 µL) of methanol for HPLC-UV analysis or with ethyl acetate for GC-ECD analysis. The methanol was evaporated to dryness under a gentle steam of nitrogen, and the residue redissolved in 0.5 mL of methanol. For ethyl acetate this step was not necessary.

For HPLC-UV analysis the mobile phase was methanol–water (55:45, v/v) adjusted to pH 3.0 with phosphoric acid, and the pesticides were detected at 220 nm. The GC-ECD used the 1079 injector with splitless injection of 1 mL at 270 °C. The ECD detector was maintained at 300 °C, with the make-up gas nitrogen flow rates at 30.0 mL min\(^{-1}\). The oven temperature program was 80 °C for 2 min, ramped to 290 °C at 15 °C min\(^{-1}\), maintained for 1 min. The carrier gas was helium at a head pressure of 18 psi. The obtained limits of detection in surface water were <0.05 µg L\(^{-1}\) for chlorpyrifos, flutemalin and imidacloprid; <10 µg L\(^{-1}\) for iprodione; <0.1 µg L\(^{-1}\) for atrazine and simazine and, <0.2 µg L\(^{-1}\) for clomazone.

### 2.4. Tissue sampling and analysis

At the end of the exposure period (30 days), all fish were sampled. Blood samples were quickly collected from the caudal vein of serially netted and manually immobilized silver catfish without anesthesia. Blood was collected with heparinized syringes. Plasma was obtained after centrifugation at 5,000 rpm for 10 min and then stored during 1 week at −20 °C for subsequent analysis. After blood collection, fish were sacrificed by sectioning the spinal cord. The liver, kidney and muscle were removed, placed on ice, frozen in liquid nitrogen and then kept at −20 °C for 1 week until analysis. The methodology of this experiment was approved by the Ethical and Animal Welfare Committee of Universidade Federal de Santa Maria. Plasma glucose was determined by Labtest kit, and Na\(^+\) and K\(^+\) levels were measured with a 8262 flame spectrophotometer (Micronal, São Paulo, Brazil). Plasma without dilution was used to measure Na\(^+\) and K\(^+\).

For protein determination, the tissues (muscle, liver and kidney) were heated with KOH at 100 °C and centrifuged at 10,000 g for 10 min. Protein determination (10–50 µL) was used for the determination of lactate (Harrower and Brown, 1972) and glucose (50 µL) (sugar soluble), according to Park and Johnson (1949). Liver, muscle and kidney glycogen were estimated according to Bidinotto et al. (1998), after KOH and ethanol addition for hydrolysis and precipitation of glycogen. Glycogen content (µmol (g dry wt)−1) was determined according to Park and Johnson (1949). Total ammonium was determined according to the Nesslerization method, following Boyd and Tucker (1992). All biochemical analyses were measured spectrophotometrically and in duplicate (N = 12).

### 2.5. Statistical analysis

All data are expressed as mean ± S.E.M. Homogeneity of variances between sites was tested with the Levene test. Comparisons among the different sites were
made by one-way analysis of variance and Tukey's test. When homogeneity of variances among the sites was not obtained, data were submitted to Kruskall–Wallis ANOVA and the Mann–Whitney test. Analysis was performed using the software Statistica 5.1 (StatSoft, Tulsa, OK), and the minimum significance level was set at $P < 0.05$.

3. Results

The pesticide content was measured at several sites of the Lino stream watershed, including the sites where the cage nets were placed. The pesticides contents measured in the two sites of the Lino stream, namely low anthropic activity and high anthropic activity, are shown in Table 1. The active ingredients imidacloprid and clomazone were found in significantly higher levels in the high anthropic activity site, whereas simazine was significantly higher in the low anthropic activity site. The levels of chlorpyrifos and atrazine were not significantly different in the two sites, and flumetralin and iprodione levels were below detection limits (Table 1). Dissolved oxygen was higher than 6 mg L$^{-1}$ in all sites; temperature was in the 21–28 °C range, and pH was around 7.0. Total suspended solids and electrical conductivity were higher at the high anthropic activity site, and total and dissolved phosphorous were significantly lower than at the low anthropic activity site (Table 2).

No fish died throughout the experiment. Total protein, lactate and Na$^+$ levels in plasma were not significantly different between sites where the fish were maintained. Plasma glucose levels were significantly higher in fish from the low anthropic activity site than in those from the other site. Moreover, significantly higher plasma K$^+$ levels were observed in fish exposed to the high anthropic activity (Table 3).

Table 1
Pesticides contents found in the sites where silver catfish were maintained for 30 days.

<table>
<thead>
<tr>
<th>Pesticides contents ($\mu$g L$^{-1}$)</th>
<th>Sites</th>
<th>High anthropic activity</th>
<th>Low anthropic activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imidacloprid</td>
<td>3.65 ± 0.81</td>
<td>0.67 ± 0.11*</td>
<td></td>
</tr>
<tr>
<td>Atrazine</td>
<td>0.21 ± 0.04</td>
<td>0.22 ± 0.05</td>
<td></td>
</tr>
<tr>
<td>Chlorpyrifos</td>
<td>0.11 ± 0.20</td>
<td>0.12 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>Simazine</td>
<td>0.10 ± 0.05</td>
<td>0.81 ± 0.11*</td>
<td></td>
</tr>
<tr>
<td>Clomazone</td>
<td>1.72 ± 0.15</td>
<td>0.20 ± 0.05*</td>
<td></td>
</tr>
<tr>
<td>Flumetralin</td>
<td>0.05 ± 0.01</td>
<td>0.05 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>Iprodione</td>
<td>10.00 ± 0.05</td>
<td>10.00 ± 0.05</td>
<td></td>
</tr>
</tbody>
</table>

Mean ± S.E.M. ($N = 15$). * Indicate significant difference from high anthropic activity site by one-way ANOVA and Tukey test ($P < 0.05$).

Table 2
Physico-chemical parameters of water in the sites where silver catfish were maintained for 30 days.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Sites</th>
<th>High anthropic activity</th>
<th>Low anthropic activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS (mg L$^{-1}$)</td>
<td>413.21 ± 88.81</td>
<td>215.22 ± 75.03*</td>
<td></td>
</tr>
<tr>
<td>EC ($\mu$S cm$^{-1}$)</td>
<td>99.41 ± 9.11</td>
<td>79.81 ± 8.31*</td>
<td></td>
</tr>
<tr>
<td>Hardness (mg CaCO$_3$L$^{-1}$)</td>
<td>18.24 ± 5.46</td>
<td>14.48 ± 3.86*</td>
<td></td>
</tr>
<tr>
<td>Dissolved oxygen (mg L$^{-1}$)</td>
<td>0.20 ± 0.13</td>
<td>0.71 ± 1.21</td>
<td></td>
</tr>
<tr>
<td>T (°C)</td>
<td>28.13 ± 1.22</td>
<td>21.22 ± 1.51*</td>
<td></td>
</tr>
<tr>
<td>Turbidity (UNT)</td>
<td>15.31 ± 8.80</td>
<td>17.01 ± 7.20</td>
<td></td>
</tr>
<tr>
<td>pH (units)</td>
<td>7.31 ± 0.11</td>
<td>7.21 ± 0.10</td>
<td></td>
</tr>
<tr>
<td>K (mg L$^{-1}$)</td>
<td>3.04 ± 0.60</td>
<td>2.77 ± 0.42</td>
<td></td>
</tr>
<tr>
<td>NH$_4$ (mg L$^{-1}$)</td>
<td>0.61 ± 0.19</td>
<td>0.58 ± 0.26</td>
<td></td>
</tr>
<tr>
<td>NO$_3$ (mg L$^{-1}$)</td>
<td>1.16 ± 0.41</td>
<td>0.84 ± 0.35</td>
<td></td>
</tr>
<tr>
<td>TP (mg L$^{-1}$)</td>
<td>0.12 ± 0.04</td>
<td>0.25 ± 0.05*</td>
<td></td>
</tr>
<tr>
<td>DP (mg L$^{-1}$)</td>
<td>0.05 ± 0.02</td>
<td>0.12 ± 0.02*</td>
<td></td>
</tr>
</tbody>
</table>

TSS: total suspended solids, EC: electrical conductivity, TP: total phosphorous, DP: dissolved phosphorous, Mean ± S.E.M. ($N = 15$). * Indicate significant difference from high anthropic activity site by one-way ANOVA and Tukey test ($P < 0.05$).

Fig. 1. Glycogen, glucose and lactate levels in the liver (A), kidney (B) and muscle (C) of silver catfish maintained at different sites. Data represent mean ± S.E.M. ($N = 12$). * Indicate significant difference from high anthropic activity site by one-way ANOVA and Tukey test ($P < 0.05$).
The fish maintained at the high anthropic activity site had the highest liver glycogen levels and lowest liver glucose content when compared to the other site (Fig. 1A), but the liver lactate levels were similar between the sites. The kidney glycogen content in fish maintained at the low anthropic activity site was significantly higher than those from the other site (Fig. 1B), but their kidney glucose content and lactate levels were similar. In the muscle of fish maintained in the high anthropic activity site, the lactate levels were significantly higher than in those from the other site (Fig. 1C); glycogen and glucose contents were not significantly different between fish from different sites. Fish from the high anthropic activity site had lower total protein values in the kidney and significantly higher values in the liver and muscle when compared to the other site (Fig. 2A). Total ammonia levels in the liver were significantly higher in the high anthropic activity site compared to the other site, but total ammonia levels in the kidney and muscle were similar between sites (Fig. 2B).

4. Discussion

The physico-chemical water quality parameters analyzed in this study (see Table 1) were within the range recommended for this species (Baldisserotto, 2004). In the Lino Creek the anthropic pressure on the watershed causes high sediment discharge. Phosphate ions are released to solution, on average, twice as rapidly in sediments collected from subwatersheds with low anthropic activity than in those from subwatersheds with high anthropic activity. Many pesticides, however, are used in tobacco culture in southern Brazil. In this study, water samples from the Lino stream showed pesticides levels above 0.1 μg L⁻¹, the established limit for surface waters by European Community (CEE, 1980). In watersheds with high anthropic activity, the total suspended solids and electrical conductivity are high because of intensive use of agricultural areas associated with the lack of riparian vegetation (Toledo and Nicoll, 2002). In the Lino Creek watershed, 80% total sediment loss was from the subwatershed with high anthropic activity, due to the intense agricultural use, higher slope steepness and length (LS factor of the Universal Soil Loss Equation), presence of unpaved roads and ravines, and less riparian vegetation (Sequinatto, 2007). In fact, in the agricultural year of 2003/2004, 68.3% of the suspended sediment in the Lino Creek originated from agricultural areas, 28.1% from unpaved roads and only 3.6% from stream borders (Minella et al., 2007). Thus, high runoff and erosion carry sediments and agrochemicals to streams and other water bodies, perhaps affecting aquatic flora and fauna. The possible contamination due to pesticides found in water can affect aquatic organisms like fish.

Plasma glucose content was higher in fish from the low anthropic activity site than in those maintained at the high anthropic activity site. Thus, in the environment, fish may be exposed to stressful stimuli; as primary stress responses, corticosteroids and catecholamine levels increase in the blood within one or a few minutes (Donaldson, 1981; Randall and Perry, 1992). Upon release of these hormones, there is a significant increase in blood lactate concentration within minutes and glucose concentration within hours (Soivio and Oikari, 1976; Mazzaud et al., 1977). If stress stimuli are removed or persist at a tolerable constant level, homeostatic regulation returns the system to a pre-stress status or to a new steady state that is compensated physiologically. Both recovery and long-term physiological resistance can be considered bioenergetically demanding situations, and they may mimic the effects of chronic pollution (Wedemeyer and McLeay, 1981; Schenk, 1984).

The glycogen levels in the kidney were lower in fish from the high anthropic activity site than in those kept at the other site. This result may indicate that stress in the new environment is accompanied by rapid degradation of glycogen, probably to help maintain energy in the metabolic process. Since fish from the high anthropic activity site had higher lactate levels in the muscle, they may have had a disruption in the normal metabolism in response to energy depletion. The lactate levels in the kidney of fish from the low anthropic activity site were similar to those from the high anthropic activity site. In the present study no reduction in muscle glycogen was observed, but the most common pesticide effect is glycogen depletion due to stress situation. Several authors describe glycogen reduction in muscle after a physiological stress (Sancho et al., 1998; Begum and Vijayaraghavan, 1999; Aguilar et al., 2004; Gluszczak et al., 2006, 2007). The patterns of glycogen response seem to be specific according to pesticide and tissue considered. Muscular glycogen reduced in R. quelen exposed to clomazone (Crestani et al., 2006) and in muscle of Leporinus obtusidens exposed to herbicide glyphosate (Gluszczak et al., 2006), but no changes are observed in muscle and liver glycogen storage of Anguilla anguilla exposed to fenitrothion (Sancho et al., 1997).

In this study, total protein level was lower in the liver and muscle of silver catfish maintained in the low anthropic activity site than in those of the fish at the other site. This result is contrary to what was expected. High anthropic site is the most...
polluted site and showed high muscle and liver protein content. This result suggests that fish exposed to pesticides in high anthropic site may have a compensatory mechanism to deal with possible tissue protein loss by increasing protein synthesis. Liver protein increase was also observed in Cyprinus carpio exposed during 15 days to 2,4-D herbicide (Oruç and Üner, 1999). Gill et al. (1991) found an increase in liver protein following endosulfan intoxication. Muscle protein increase was also observed by Fonseca et al. (2008) where L. obtusidens were exposed to 2,4-D. However, in the kidney of fish from the low anthropic activity site, protein reduction was not observed; on the contrary, higher total protein level was observed. The result concerning muscle and liver protein of low anthropic site may indicate a compensatory response; the fish may also be using protein as an energy source. Sancho et al. (1998) reported that high-energy demands might lead to the increase of protein catabolism. Several authors have also reported a reduction of protein in fish tissues upon exposure to toxicants (Sancho et al., 1998, 2000; Glusczak et al., 2006, 2007). In agreement with protein reduction in the liver of silver catfish from the low anthropic activity site, ammonia levels were lower than those in fish at the high anthropic activity site; levels in the kidney and muscle were similar between the two groups. In fact, ammonia increase could represent the major excretion rate of this metabolite and also the lower ammonia concentrations in the liver could have been caused by a decrease in ammoniagenesis in this tissue. Urea production, however, could be induced in silver catfish to help detoxify the ammonia that is produced in tissues such as the liver and muscle. Additional work on this subject will be needed to clarify this discrepancy.

The lower glucose concentration in the plasma of silver catfish from the high anthropic activity site could indicate metabolic disorders induced by pesticides or also a high glucose consumption by the metabolic process. Silver catfish exposed to the high anthropic activity site exhibited higher glycogen levels in the liver and lower in the kidney than those at the low anthropic activity site. Our results are in agreement with those obtained by Crestani et al. (2006) with the same species and Glusczak et al. (2006) with piau exposed to Roundup®*, which exhibited higher levels of glycogen in the liver.

The present study shows that the pesticide concentrations used in tobacco agriculture might cause changes in the metabolic parameters of silver catfish juveniles and confirms that this species can be used as bioindicator in polluted areas.

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