



Growth parameters of the invasive gastropod *Melanoides tuberculata* (Müller, 1774) (Gastropoda, Thiaridae) in a semi-arid region, Northeastern Brazil

Cicero Diogo Lins de Oliveira^{1*} and Carlos Yure Barbosa de Oliveira²

¹Laboratório de Dinâmica de Populações Aquáticas, Universidade Federal Rural de Pernambuco, Rua Dom Manuel de Medeiros, s/n, 52171-900 Recife, Pernambuco, Brazil. ²Laboratório de Cultivo de Algas, Universidade Federal de Santa Catarina, Florianópolis, Santa Catarina, Brazil. *Author for correspondence. E-mail: linsdiogoc@gmail.com

ABSTRACT. *Melanoides tuberculata* has invaded several aquatic ecosystems in the Neotropical region. This species shows high adaptive capacity and plasticity, establishing itself in several basins, promoting negative impacts on environments and native species. Here, we determine the growth parameters and the population structure of this species, in a semi-arid environment, in Northeast Brazil (Pernambuco state). Monthly captures were conducted at three types of substrate: site 1: soft bottom with macrophytes, site 2: soft bottom without macrophytes, and site 3: gravel and rocks. Shells were classified as occupied or empty, and their shell length (SL) and opening width (SW) were measured. The growth parameters of the von Bertalanffy's model were estimated from the size-length frequency distribution using the ELEFAN I. Also, the maturity was verified, through the size at onset of maturity (SOM - 14.85 mm SL) proposed in the literature. A total of 1,013 individuals were collected, with shells varying from 7 to 39 mm SL and mean density of 84.42 (\pm 3.86) individuals m⁻². The substrate with the largest number of mollusks was the site 1. Largest amount of empty shells was detected at site 3. Growth of *M. tuberculata* indicates rapid increment, with $k = 0.56$, $L_{\infty} = 42$ mm and $t_0 = -0.26$ years. The mean estimated age for the species was 0.95 years. According to the SOM, 86% of individuals sampled were considered mature.

Keywords: invasive mollusk; population structure; growth curve.

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Introduction

Biological invasions are one of the most serious threats to global biodiversity, second only to the destruction of habitats, can cause substantial changes to biotic communities and abiotic (Everett, 2000; Mack, Simberloff, Mark Lonsdale, Evans, Clout, & Bazzaz, 2000; Ricciardi & Simberloff, 2009). In almost all of the environments colonized by human, there were introductions of invasive organisms, often followed by total or partial extinction of native species (Rocha, 2003). Due to this threat, the invasion of mollusks has been studied long ago because of its economic losses (Mead, 1979), their impacts on native fauna (Civeyrel & Simberloff, 1996) and its role in transmitting parasites to humans (Malek, 1980). In particular, South America is severely affected by the invasion of limnic mollusks, such as: *Corbicula fluminea* (Müller, 1774) (Cyrenidae, Bivalvia), *Limnoperna fortunei* (Dunker, 1857) (Mytilidae, Bivalvia) and *Melanoides tuberculata* (Müller, 1774) (Thiaridae, Gastropoda) (Santos et al., 2012).

Melanoides tuberculata is a native species in Eastern and Northern Africa, Southeast Asia, China and the Indo-Pacific islands, with a wide distribution in these areas (Santos et al., 2012). In Brazil, it was reported for the first time in the Santos city (São Paulo state), around 1967, and since then it has spread to all regions of the country (Vaz, Teles, Correa, & Leite, 1986; Santos, Miyahira, & Lacerda, 2007; Santos et al., 2012). This parthenogenetic species forms large population aggregates and tolerates high amplitudes of temperature, salinity, pH, and other parameters (Pointier, 2001; Duggan, 2002; Santos et al., 2007).

The reports indicate that the gastropod *M. tuberculata* had extensively invaded aquatic ecosystems in the Neotropical region, because it has a high adaptive and migratory capacity, establishing itself in diverse substrates, besides indicative of active dispersion (Pointier, Théron, & Borel, 1993; Supian & Ikhwanuddin,

2002). *Melanoides tuberculata* has common characteristics to many invasive species: high growth rate, capacity of migration and territorial expansion, and can be established on different types of substrates (Miyahira, Lacerda, & Santos 2009, Santos et al., 2012).

The variation in the growth rate of the individuals can affect the survival and reproduction chances and has been an important component to be analyzed in population dynamics studies (Paschoal, Andrade, & Darrigran, 2015). Therefore, is fundamental importance to establish patterns of growth for the species, in order to try to explain the relationship between the growth of individuals and the environment where they live (Darrigran, Damborenea, & Greco, 2007; Paschoal et al., 2015). In this sense, the growth patterns of *M. tuberculata*, as well as its population structure were determined, in a reservoir located in the semi-arid region, Northeast Brazil.

Material and methods

The collections were carried out between August and November 2016 at the Cachoeira II reservoir, located in Serra Talhada, Pernambuco state, Brazil (Figure 1). This reservoir is an important source of drinking water supply and income, for artisanal fishermen, for this region. Although it has 21,031,000 m³ of water capacity, an extreme drought season has been gradually affected the volume of water of this body (Oliveira, Oliveira, Almeida, Gálvez, & Dantas, 2019).

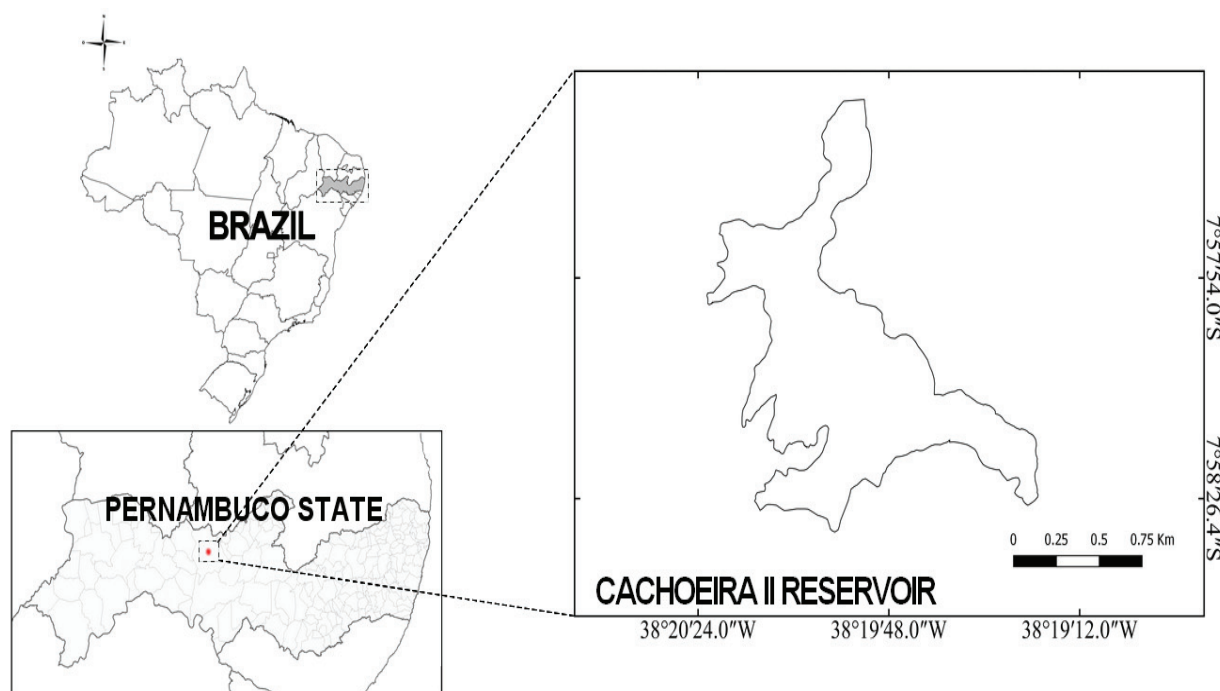


Figure 1. The study area of the Cachoeira II reservoir, located in Serra Talhada, Pernambuco state, Brazil.

In each month, three samples, with the aid of a fishing net (0.5 mm) were taken, in different sites with an area of 1 m² each and depth between 20-30 cm. The site 1 was characterized by the soft bottom substrate and the macrophytes presence, site 2, the soft bottom substrate without macrophytes, and site 3, the substrate contained gravel and rock.

To assess the distribution of organisms over the time and collection sites, normality and homoscedasticity by the Shapiro-Wilk and Barlett tests, respectively, were evaluated. One-way analysis of variance (ANOVA), followed by the Tukey's test, was applied using a significance level of 0.05 (Zar, 2009).

Each captured specimen was identified according to Fernandez, Santos, Miyahira, Gonçalves, Ximenes, and Thiengo (2012) and the shell length (SL) and opening width (SW) were measured with analog caliper (0.05 mm) (Figure 2). Then, it was then identified whether the shell was empty or occupied, through presence or absence of operculum and soft mass. The *t-student* test was performed to compare the lengths per month to verify if there was a significant difference between months (Zar,

2009). In addition, the proportion of empty and full shells sampled by site and collection months was verified.

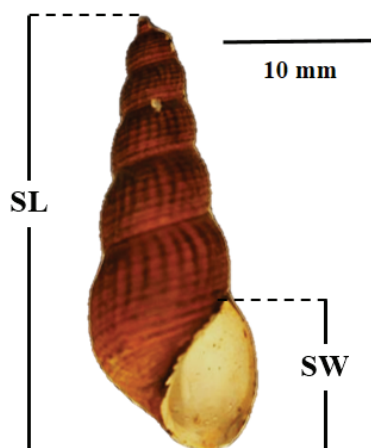


Figure 2. General scheme for shell size dimensions used in the morphometric analysis of *Melanoides tuberculata*. SL - shell length and; SW - shell opening width.

A linear regression was adjusted, relating SL and SW, in order to evaluate if these two measures grow at the same proportion. The equation was classified according to the values of the slopes (b), such as: negative allometric when $b < 1$, positive allometric when $b > 1$ and isometric when $b = 1$ (Gould, 1966).

The growth parameters of the Von Bertalanffy (1938) curve were estimated to complete (Equation 1):

$$L_t = L_{\infty} \times (1 - \exp^{-K \times (t - t_0)}) \quad (1)$$

at where:

L_t = length at age t ,

L_{∞} = asymptotic or theoretical maximum length,

K = growth coefficient, and

t_0 = theoretical age at birth.

The growth coefficient (K) and maximum asymptotic length (L_{∞}), was determined by the ELEFAN I method (Pauly & David, 1981), inserted in the computational package FISAT II (FAO ICLARM Stock Assessment Tools), which is based on the modal shift of time sequences of length distributions (Gayaniilo Jr., Sparre, & Pauly, 1997).

For the calculation of the theoretical age parameter at zero length (t_0), the equation of Pauly (1981) was used (Equation 2):

$$\log(-t_0) = -0.3922 - 0.2752 \times \log(L_{\infty}) - 1.038 \times \log(K) \quad (2)$$

The proportion of mature and immature individuals was carried out, considering the size at the onset of morphometric maturity (SOM: 13.20 mm) proposed by Work and Mills (2013). It was then tested whether there was a significant difference between the proportions by chi-square (χ^2) method, with significance level of 5% (Zar, 2009).

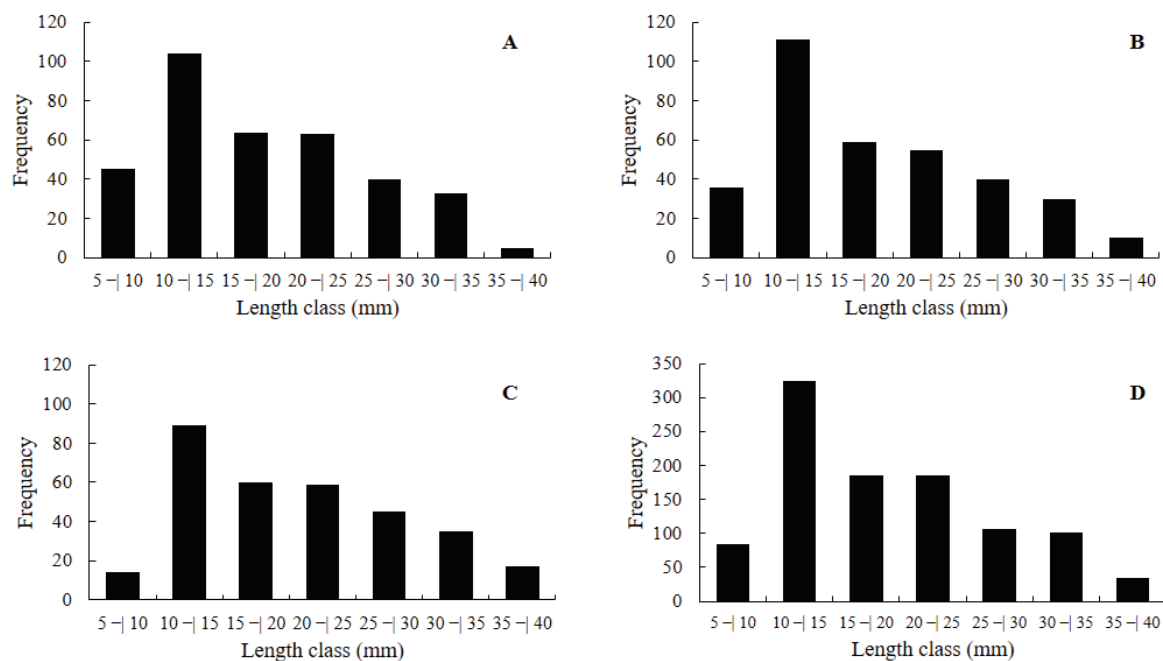
Results

A total of 1,013 snails were collected, with shells varying from 7 to 39 mm SL, the mean total density was 84.42 ± 3.86 individuals m^{-2} (Table 1). The place with the largest amount of mollusk was the soft bottom substrate with the macrophytes presence in the four months sampled, followed by the soft bottom environment. However, there was no difference between sites (p -value = 0.673). Regarding the number of empty shells, the highest account was for the rocky environment, with average 17.56%, while the lowest account was for the soft bottom with macrophytes presence with only 2.82%.

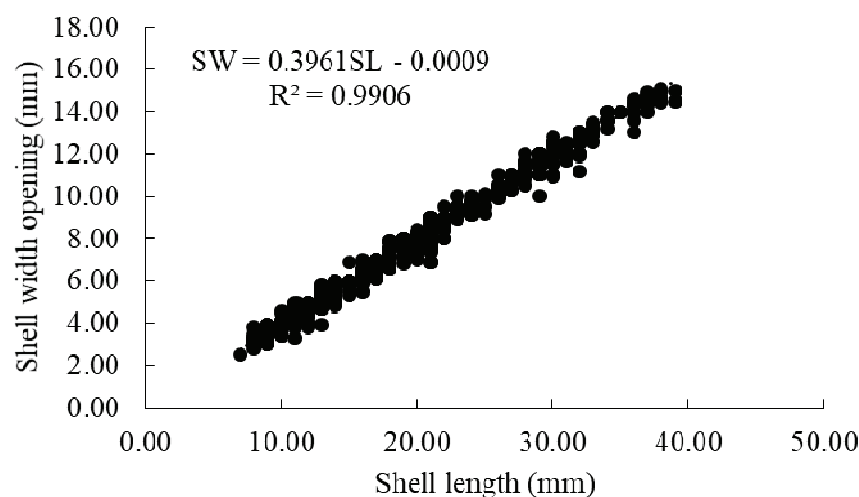
Table 1. Number of individuals of *Melanoides tuberculata* collected each month and each type of substrate during the study.

	Aug	Sep	Oct	Nov	Total	Average (mm)	Density (ind m ²)	Empty shells N (%)
Site 1	95	89	85	85	354	17.4 ± 8.9	88.5 ± 4.7	10 (2.83%)
Site 2	90	85	81	85	341	19.1 ± 7.3	85.3 ± 3.7	16 (4.69%)
Site 3	85	72	79	82	318	18.4 ± 8.1	79 ± 5.6	56 (17.61%)
Grouped sites	270	246	245	252	1013	18.3 ± 8.6	84.4 ± 5.8	82 (8.10%)

The number of empty shells registered at the three sites showed significant differences in its composition ($F = 38.03$ p-value = 0.01), with site 3 showing higher quantity of shells when compared to the others. The shell length of the mollusks ranged from 7 to 39 mm SL, with a modal peak at the class of 10- 15 mm (> 300 individuals). Small (5-10 mm SL) and large (35-40 mm SL) size snails showed low frequency of occurrence (Figure 3D). According to the SOM, 66.1% of the sampled individuals were considered mature, showing a significant difference (p-value = 0.021) between the maturation phases.

**Figure 3.** Length frequency distribution of *Melanoides tuberculata*. A: Site 1; B: Site 2; C: Site 3; and D: grouped sites.

The morphometric relationship SW vs. SL showed a high correlation ($r^2 = 0.99$), the b value showed a negative allometry ($b < 1$) (Figure 4).

**Figure 4.** Relationship between width opening and length shell of *Melanoides tuberculata*.

The cohort analyses showed six age groups for *M. tuberculata* in the Cachoeira II reservoir (Figure 5), these groups were continuous over the months occasioned to the low sampled period.

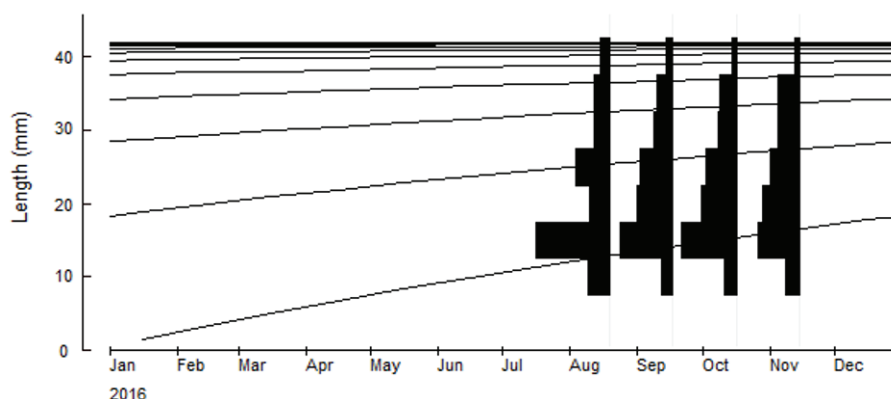


Figure 5. Cohorts of *Melanooides tuberculata* verified during the study.

Melanooides tuberculata showed a rapid growth, with $k = 0.56$, $L_{\infty} = 42$ mm e $t_0 = -0.26$ years (Figure 6). The highest growth rate was recorded in the first year of life, and the species can reach 21.31 mm. Between the first and second year, the growth rate is 8.87 mm, while in later years the species tends to grow less than 1 mm per year.



Figure 6. Von Bertalanffy (1938) growth curve for *Melanooides tuberculata*.

The mean estimated age for *M. tuberculata* in the present study was 0.95 years, with a minimum age of 0.1 and a maximum of 4.45 years (53.4 months). The maximum theoretical estimated age was 11 years, assuming that the maximum length that the species could reach is 42 mm.

Discussion

The substrate and aquatic vegetation are important conditioners for distribution and occurrence of mollusks in different biotopes (Pip, 1987). In the present study, the percentage of empty shells (17.6%) was significant higher for the substrate composed of gravel and rocks. In relation to the macrophytes presence, there were no significant differences between the three sites. However, the number of individuals caught in soft bottom substrate with macrophytes presence was higher during the four months. Abílio et al. (2007) also observed in water bodies of the Paraíba state (Northeast Brazil). That the potential of *M. tuberculata* (and other gastropods) were directly associated with the aquatic macrophytes presence, showing that the presence of vegetation may also influence the abundance of gastropod.

Melanooides tuberculata showed high density with aggregated distribution at the sampling sites. The population density registered in the present study, was higher than that reported in 2009 at the same

reservoir by Almeida, Nascimento Filho, and Viana (2018). These authors reported the highest average density of 63 individuals m^{-2} . This increase can be justified by the dominance of the species in the study area over the years. In addition, other studies also indicated high density of *M. tuberculata* in Brazil. Suriani, França and Rocha (2007) reported a maximum density of 5,503 individuals m^{-2} in the Ibitinga dam in São Paulo state (Southeast Brazil), and Santos and Eskinazi-Sant'Anna (2010) recorded a sample of 134,381 individuals m^{-2} in the Piranhas-Assu river basin in Rio Grande do Norte state (northeast Brazil).

In relation to the size class, Santos and Eskinazi-Sant'Anna (2010) also reported data like the present study, being found most of the individuals with less than 15 mm. However, Murray (1975) reported that in a lake in Texas (USA), shell lengths of *Melanoides tuberculata* with 70-80 mm SL, yet, Thompson (1983) pointed that this species typically reaches 30-36 mm SL. These differences in lengths were directly related to environmental factors, especially temperature, oxygen, pH, which may limit shell formation, and organic materials such as diatoms (Madsen, 1992; Souza, Drummond, Silva, Queiroz, Guimarães, & Rocha, 1998; Oliveira & Viana, 2019). Thus, *M. tuberculata* can present different lengths depending on where it is.

The SL vs. SW relationship was negative allometric, showing that the length of the shell increases faster with which shell opening. Other studies also find close values such as Chagas, Barros, and Bezerra (2018) that verified a negative allometric relation of $b = 0.26$. This relationship may be linked to the degree of establishment of the species in the environment, since when well established, it can reduce or even eliminate other species of the same trophic level (Ricciardi & Simberloff, 2009), thus possessing space and food without competition and growing more rapidly.

The high growth rate of *M. tuberculata* registered in the present study, corroborated the potential of invasive species. Elkarmi and Ismail (2007) also recorded rapid growth for the species in the Arabian Peninsula, with $K = 0.245$, $L_{\infty} = 28$ mm and $t_0 = 0.837$. Here, we verified that the highest growth occurs in the first year, reaching about 21 mm, similar to Supian and Ikhwanuddin (2002) that observed, maximum value of length of 25 mm in Sabah, Borneo for the first year of life. Due to this highly rapid growth, the species may have advantages over other mollusks, a striking characteristic observed in invasive species (Santos et al., 2012). This pattern of growth was also verified in some terrestrial gastropods (for this statement see Table 2). When compared to other invasive species, growth rates were similar, as *C. fluminea* (Müller, 1774) that had $K = 0.65$, $L_{\infty} = 32$ mm and $t_0 = 0.5$ (Cataldo & Boltovskoy, 1999).

Table 2. Growth parameters of the von Bertalanffy(1938) model for other mollusk species. (N.I. = Not informed).

Species	K (years)	L_{∞} (mm)	t_0	Reference
<i>Biomphalaria straminea</i>	0.21	7.75	0	Ituarte, 1989
<i>Biomphalaria glabrata</i>	0.27	19.9	N. I.	Puga, Pointier, Cong, & Lopez., 1991
<i>Simpulopsis ovate</i>	0.36	14.86	0	Gomes, Silva, Gil, & Thomé, 2004

In relation birth size, according to Dudgeon (1986) *M. tuberculata* born with 2.2-3.4 mm. In opposition, the present study showed a higher value, being the size at birth of 5.5 mm. According to Ben-Ami and Hodgson (2005), the differences in size of the newborns were related to the fact that the embryos can remain inside the reproductive pouch of the females, for three to five months before being released.

Melanoides tuberculata shows rapid growth and early maturation. As the maturation of snails was anticipated (approximately 0.41 years, 13.20 mm) the species is already able to reproduce at reduced sizes, being capable of structure itself faster in the environment than native species. Invasive species may, thus, displace native species, due to the characteristics cited above (Paschoal et al., 2015). The high proportion of adults in the study area was also observed in other reservoirs of Brazil (Suriani et al., 2007; Santos & Eskinazi-Sant'Anna, 2010), highlighting the ecological risks that this species can play in environments.

The population of *M. tuberculata* was well established at the Cachoeira II reservoir, semi-arid Pernambuco state (Northeast Brazil). This was not a good news, once this invasive species is capable of repel native species, modify aquatic habitats and alter environment scenario (Santos et al., 2012), such as other invasive species: *C. fluminea* (Paschoal et al., 2015) and *L. fortunei* (Darrigran & Damborenea, 2006; Darrigran et al, 2007). This result could be related both to the environment aspects, since the species tolerates different substrates (having more affinity to the soft bottom substrate with the macrophytes presence), as well as to the biology of the species, characterized by rapid growth, early maturation and population composed mainly by adults.

Conclusion

Therefore, it was observed that *Melanoides tuberculata* presented fast growth, had preference for environment soft bottom with macrophytes presence. In addition, it was observed that, during this study, the population was predominantly adult.

Mitigating measures should be implemented in the study area and surveys should be carried out continuously to verify the increase (or not) of the *M. tuberculata* populations and possible decreases or changes in the benthic community of the analyzed reservoir.

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