The introduced snail *Melanoides Tuberculatus* (Muller, 1774) (Mollusca: Thiaridae) in aquatic ecosystems of the Brazilian Semiarid Northeast (Piranhas-Assu River basin, State of Rio Grande do Norte)

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(With 2 figures)

Abstract

Records of the gastropod *Melanoides tuberculatus* (Müller, 1774), family Thiaridae, in the Piranhas-Assu River basin in Rio Grande do Norte reveal the dispersal of this native Southeast Asian and East African species into aquatic environments of the Brazilian semiarid region, including artificial environments (reservoirs) and lotic systems. The eutrophic conditions of the local waterbodies appear to favor the present situation, where this invasive species reaches extremely high densities, sometimes over 10,000 ind.m^{-2} as in Armando Ribeiro Gonçalves Reservoir. These observations indicate the immediate need for new studies on the spatial distribution of the species and its potential impact on the biodiversity and water quality of the waterbodies of the semiarid region of the state. Implantation of regular and systematic monitoring of the aquatic resources of the region is urgently required.

Keywords: Thiaridae, *Melanoides tuberculatus*, invasor species, Brasilian semiarid.

O gastrópode introduzido *Melanoides tuberculatus* (Muller, 1774) (Mollusca: Thiaridae) em ecossistemas aquáticos do semiárido brasileiro da região Nordeste (Bacia do Rio Piranhas-Assu, Estado de Rio Grande do Norte)

Resumo

Registros da presença do gastrópode *Melanoides tuberculatus* (Müller, 1774), família Thiaridae, na bacia do Rio Piranhas-Assú no Rio Grande do Norte, revelam a dispersão desta espécie nativa do sudeste asiático e leste africano para ambientes aquáticos do semiárido brasileiro, incluindo ambientes artificiais (reservatórios) e sistemas lóticos. As condições eutróficas dos corpos d'água potiguares parecem favorecer a presente situação, em que a espécie invasora atingiu densidades extremamente elevadas, com valores acima de 10.000 ind.m^{-2}, como no reservatório Armando Ribeiro Gonçalves. Estas observações indicam a necessidade imediata de novos estudos sobre a distribuição espacial da espécie e seu potencial de impacto sobre a biodiversidade e qualidade da água dos corpos d'água do semiárido potiguar. Neste contexto, torna-se urgente a implantação de um regular e sistemático monitoramento dos recursos hídricos da região.

Palavras-chave: Thiaridae, *Melanoides tuberculatus*, espécie invasora, semiárido brasileiro.

1. Introduction

Several studies have revealed the continuing expansion of the distributional area of *Melanoides tuberculatus* (Müller, 1774) (Gastropoda: Prosobranchia: Thiaridae) in Brazil. The first specimen of the species in Brazil was observed in the city of Santos, in São Paulo, in 1967 (Vaz et al., 1986). It is believed that one of the principal means of dispersion was accidental, associated with the trade and transport of fish and ornamental plants (Silva et al., 1994). Other possible modes of introduction are through stocking of fish, natural transport by material adhering to migratory birds or other animals, and transport in ballast water and/or the associated sediment.

Over the years, new records of this mollusk have revealed its dissemination into many aquatic environments, from the Brazilian Northeast to areas in the southern and southeastern parts of the country (Fernandez et al., 2003; Rocha-Miranda and Martins-Silva, 2006). In the Northeast, this snail has been recorded in the states of Paraíba, Ceará, Pernambuco and Bahia (Paz et al., 1995; Abílio, 1997; Mello and Cordeiro, 1999; Fernandez et al., 2003).

The first record of *M. tuberculatus* in the state of Rio Grande do Norte was in the Municipality of Pendências (Fernandez et al., 2003). A recent study noted its introduction as one of several environmental problems in reservoirs of the Piranhas-Assu Basin (Eskinazi-Sant'Anna et al., 2006). These reservoirs exist in a semiarid climate, are highly eutrophic, and generally have high mean water temperatures (>28 °C), which demonstrates the impressive ecological plasticity of this species. These exotic and invasive mollusks can colonise different environments and in different trophic conditions, from oligotrophic to intensely eutrophic, lotic or lentic, and even brackish systems (Roessler et al., 1977; Thiengo et al., 1998; Sinha and Das, 1993; Silva et al.,1994; Giovanelli et al., 2005; Vidigal et al., 2005).

Associations between *M. tuberculatus* and *Biomphalaria* spp. are frequent, since the former is a biological control agent for schistosomiasis and can reduce the population of gastropods of the genus *Biomphalaria*, the intermediate hosts of *Schistosoma mansoni* (Giovanelli et al., 2003; Guimarães et al., 2001; Pointier, 2001). However, studies indicate that *M. tuberculatus* also acts as a primary intermediate host of parasitic trematodes of respiratory and hepatic systems in humans (*Paragonimus westermani* and *Clonorchis sinensis*) (Souza and Lima, 1990; Vaz et al., 1986; Boaventura et al., 2002). In addition, *M. tuberculatus* can also transmit parasites of native birds and fishes (Scholz and Salgado-Maldonado, 2000; Mitchell et al., 2005), or even mammals, which represents a serious threat to public health.

The objective of the present study was to record the occurrence and determine the quantitative patterns of the exotic species *M. tuberculatus* in different aquatic ecosystems of the Piranhas-Assu Basin, Rio Grande do Norte. Furthermore, by documenting its distribution, we call attention to the urgent need for regular studies to support monitoring and management efforts for waterbodies of the semiarid region of this state.

2. Material and Methods

The largest reservoir studied, Engenheiro Armando Ribeiro Gonçalves (ARG) is broad (19,200 ha) and deep (40 m maximum depth), with a water volume of more than 2 billion cubic metres. It is surrounded by urban and agricultural areas. The reservoir is frequently occupied by blooms of cyanophyceans, including toxic species, predominantly *Microcystis aeruginosa* and *Planktothrix agardii* (Costa et al., 2006).

Four medium-sized reservoirs were also studied: Boqueirão de Parelhas (1,327 ha, 29 m maximum depth, the deepest), Itans (1,340 ha, 23 m maximum

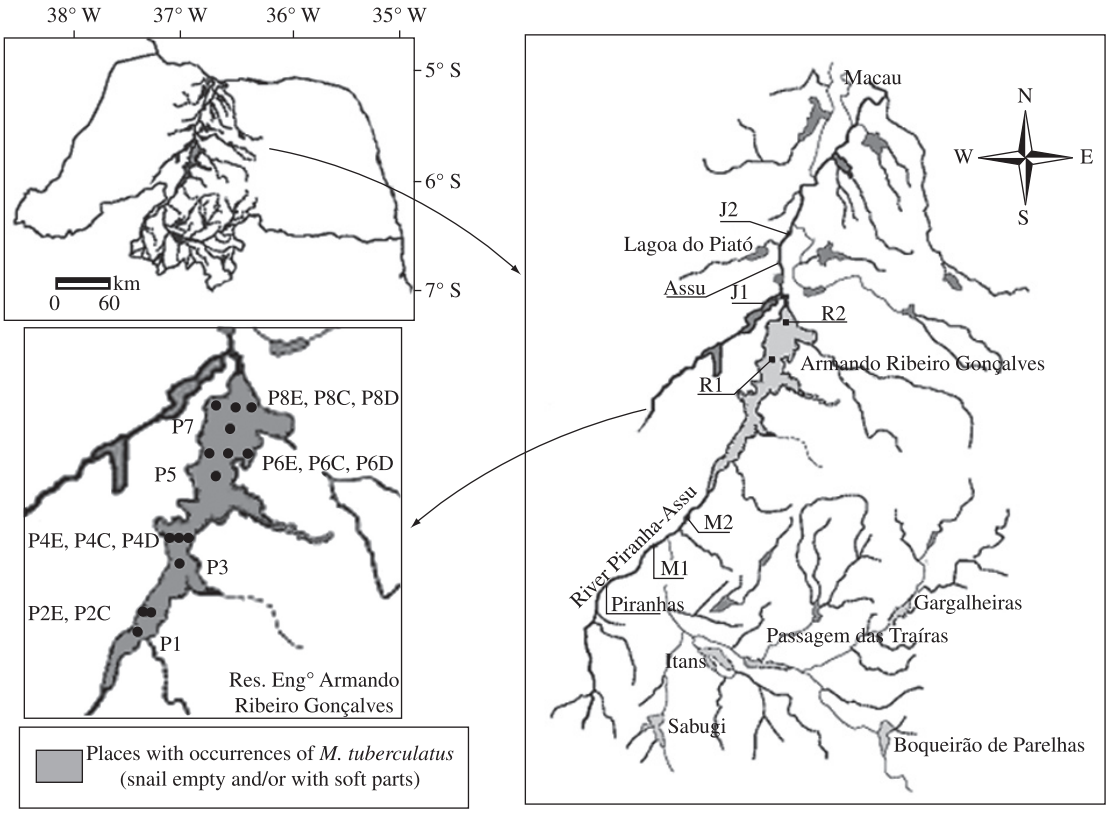

Figure 1. Map of localization of the sampling stations in the Piranhas-Assu Basin (RN), with indication of the places with occurrences of *Melanoides tuberculatus*.

depth), Passagem das Traíras (1,005 ha, 25 m maximum depth), and Sabugi (1,260 ha, 20 m maximum depth). All of these reservoirs are widely used in recreational activities and fishing, and are undergoing intense eutrophication, principally due to erosion from cultivated areas and domestic wastes. In Sabugi and Passagem das Traíras, hypertrophic conditions have been recorded at certain points, and the algal biomass (Chl *a*) can exceed 400 μg.L^{-1} (Costa el al., 2006). These authors reported on blooms of toxic cyanobacteria, principally *Microcystis* sp., in all the reservoirs. The small eutrophic reservoir Gargalheiras was also visited. It covers 780 ha and is shallow (25 m maximum depth). The phytoplankton biomass is normally high (>100 $mm^3.L^{-1}$). In this reservoir as well, Costa et al. (2006) reported sporadic blooms of toxic algae, mainly *Microcystis* spp. In the present study, samples were taken for analysis of the benthic community in two stages. First, qualitative samples were taken in the ARG, Boqueirão de Parelhas, Itans, Passagem das Traíras, Sabugi and Gargalheiras reservoirs, and stretches of the Piranhas and Assu rivers, in March 2004. All the samples were taken from a central point of the reservoirs, and in the middle of the main stream in the lotic systems.

Second, quantitative samples were taken in the ARG Reservoir in two campaigns. In the 2004 collections in July, 6 sampling points in upstream, central, and downstream points of the reservoir were visited. In collections made from October 2004 through March 2005, the sampling scheme was extended to include 15 collection points distributed over the entire area of the reservoir (see Figure 1).

Values of dissolved oxygen, pH, electrical conductivity and temperature were measured in situ with a Horiba

Table 1. Average values for the physical and chemical variable of the water of the points of sampling of the Piranhas-Assu Basin. Prof.: local depth; Sec.: Secchi Disk; T °C: temperature of the water; CE: electrical conductivity and OD: dissolved oxygen. GAR: Gargalheiras; BOQ: Boqueirão de Parelhas; ITA: Itans; PAT: Passagem das Traíras; SAB: Sabugi; ASS: Assu and PIR: Piranhas. For localization of the points to see map.

Point	Prof. (m)	Sec. (m)	T °C (°C)	pH	CE (μS.cm^{-1})	OD (mg.L^{-1})	Date
GAR	12.00	1.33	28.1	7.28	0.573	-	Mar/04
BOQ	9.50	0.68	28.5	6.85	0.533	-	Mar/04
ITA	13.25	0.20	30.3	6.90	0.265	-	Mar/04
PAT	11.50	0.58	30.8	7.49	0.422	-	Mar/04
SAB	9.50	0.95	30.5	6.35	0.132	-	Mar/04
ARG	12.10	0.76	31.8	6.72	0.274	-	Mar/04
ASSU	1.50	0.55	34.2	6.57	0.204	-	Mar/04
PIR	0.40	0.40	30.2	6.78	0.304	-	Mar/04
M1	1.10	-	30.9	8.40	0.425	9.43	Jul/04
M2	0.50	-	30.0	8.06	0.421	9.37	Jul/04
R1	9.00	0.90	29.1	8.91	0.228	10.29	Jul/04
R2	20.00	0.50	29.2	8.30	0.228	7.61	Jul/04
J1	0.50	-	33.7	8.88	0.629	10.07	Jul/04
J2	0.40	-	28.4	6.93	0.230	9.98	Jul/04
P8E	15.50	0.73	28.9	8.93	0.252	4.32	Oct/04
P8C	11.50	0.87	28.8	9.21	0.251	4.66	Oct/04
P8D	11.00	0.84	28.3	8.96	0.251	4.78	Oct/04
P7	31.00	0.88	28.0	8.42	0.255	3.80	Oct/04
P6E	9.50	0.80	28.1	7.51	0.258	4.55	Dec/04
P6C	24.00	0.75	28.5	8.08	0.261	4.18	Dec/04
P6D	7.50	0.75	28.9	8.46	0.261	5.78	Dec/04
P5	26.00	0.70	28.4	8.05	0.270	4.36	Dec/04
P4E	2.00	0.70	30.6	8.18	0.276	7.36	Mar/05
P4C	18.50	0.70	29.9	8.04	0.279	4.14	Mar/05
P4D	1.50	-	30.1	7.88	0.276	5.80	Mar/05
P3	16.50	0.80	29.9	7.64	0.279	4.15	Mar/05
P2E	2.10	0.60	31.2	8.95	0.277	8.21	Mar/05
P2C	18.00	0.60	30.1	8.45	0.283	5.03	Mar/05
P1	14.90	0.60	30.2	8.23	0.280	5.48	Mar/05

multianalyser, the average was calculated between deep and surface measures of the sampling collected in March/04, and of the profile of the column (to each 0.50 cm) in the other samples. The local depths were also recorded, and water transparency was measured with a Secchi disc.

The qualitative samples of the benthic fauna were taken with a sieve sampler (2 mm mesh), and the quantitative samples were taken with a Van Veen grab (278.18 m²), in triplicate. The material was washed on site through a net with mesh size 250 µm, and fixed with 4% formol (which was later replaced by 70% ethanol). In the laboratory, the material was sorted and the organisms identified with the aid of a stereomicroscope and the identification key suggested by Thompson (2004). When necessary, a subsample was taken to count the organisms. The value of density for the whole sample was calculated, and the final result estimated as number of individuals per square metre. Next, the maximum, minimum and mean values were calculated for each sampling point.

3. Results

The mean values of the physical and chemical variables of the water at the sampling points in the Piranhas-Assu Basin are presented in Table 1. Mean water temperatures were quite high, between 28 and 34.2 °C. The overall mean of the pH values was 7.90, slightly basic, but ranged from more acid values with a minimum of 6.35, to more basic with a maximum of 9.21. As expected for aquatic systems in semiarid regions, electrical conductivy values were high (from 0.132 to 0.629 µS.cm^{-1}, with a mean of 0.306 µS.cm^{-1}). Dissolved oxygen varied widely between points, from 3.8 to 10.29 mg.L^{-1}, with a mean of 6.35 mg.L^{-1}, but none of the reservoirs showed anoxic conditions in the hypolimnion.

Individuals of *M. tuberculatus* were observed at 7 of the 21 points sampled (quantitative analysis), with mean densities ranging between a minimum of 13 ind.m^{-2} (point R1) and a maximum of 7,323 ind.m^{-2} (point P4E), both observed in Armando Ribeiro Gonçalves Reservoir. Although live snails were found at one-third of the sampling locations, innumerable empty shells were observed at 15 points (see Table 2). This observation led us to count the shells separately (because the presence of shells gives an idea of the population density) (see Figure 2). The state of conservation of the empty shells was similar to those containing live animals; therefore, no distinctions were made in respect to the state of conservation of the shells.

The mean density at the points where empty shells were found reached 64,352 ind.m^{-2}; the maximum value was obtained in a single sample of 134,381 ind.m^{-2} (point P8E located on the left bank of the reservoir, near the dam) (see Table 2). Empty shells were concentrated in the area near the dam, both at the banks and in the central part.

Live individuals were also observed in the Sabugi and Boqueirão de Parelhas reservoirs, with populations composed of young individuals (most smaller than

Table 2. Occurrence of snail with soft parts of organism and snails without soft parts (*) in the points of sampling quantitative of Piranhas-Assu Basin (RN). Absent points (M2, P7, P6C, P5, P4C) without vestiges of organisms (0 ind.m^{-2}).

	M. tuberculata	***M. tuberculata*** **(*)**	***Biomphalaria*** **sp.**	***Biompharia*** **sp. (*)**	***Pomacea*** **sp.**	***Pomacea*** **sp. (*)**
M1	+	+	–	–	–	–
R1	+	+++	+	–	–	–
R2	–	+++	–	–	–	–
J1	+++	–	–	–	+	–
J2	+	+	+	–	–	–
P8E	–	++++	–	+++	–	+
P8C	–	++++	–	–	–	–
P8D	–	++++	–	+	–	+
P6E	+	++++	–	+	–	–
P6D	–	+++	–	–	–	–
P4E	++++	+++	+	+	–	–
P4D	+	+	+	–	–	–
P3	–	+	–	+	–	–
P2E	–	+++	–	++	–	+
P2C	–	+	–	–	–	–
P1	–	+	–	–	–	–

\+ 0-500 ind.m^{-2}
++ 501-1000 ind.m^{-2}
+++ 1001-5000 ind.m^{-2}
++++ >5000 ind.m^{-2}

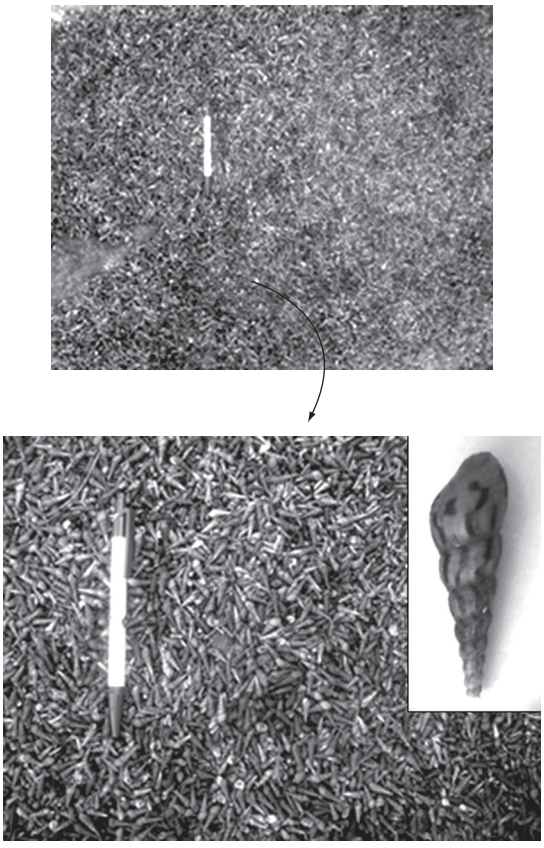

Figure 2. Dense aggregation of *Melanoides tuberculatus* in the littoral region of the Itans reservoir (RN) (march/2008). Species in plan.

1.0 cm in Sabugi, and larger than 1 cm, up to 2 cm in Boqueirão). Only in Gargalheiras Reservoir was there no sign of the presence of this gastropod. Individuals of *M. tuberculatus* were also found in streams, including the Piranhas and Assu rivers. In general, densities in lotic waters were lower than those observed in the semi-lentic systems, with values between 250 and 5,000 ind.m^{-2} (see Table 2).

We also recorded *Biomphalaria* sp and *Pomacea* sp at some sampling points (R1, J1, J2, P4E, P4D), although in much lower numbers than the dominant *M. tuberculatus* (see Table 2).

4. Discussion

The introduction of invasive species into a natural system is a matter for concern, because these can displace native biological populations, reducing the biodiversity. Consequently, food chains may become shortened, with a drastic change in the local ecological equilibrium (Park, 2004). The propagation of exotic species has been mentioned as the second-greatest cause of loss of aquatic biodiversity (Allan and Flecker, 1993). Although many factors may influence the success of an invasive species, from its arrival to its establishment and integration with its new environment (Moyle and Light, 1996), human activities greatly accelerate the invasion process, directly or indirectly, broadening its geographical area and favouring so-called global homogenization (Ricciardi, 2007).

The gastropod *M. tuberculatus* shows great adaptability to different ecological conditions, but its successful establishment is frequently associated with eutrophic environments (Martins-Silva and Barros, 2001; Callisto et al., 2005; Giovanelli et al., 2005; Vidigal et al., 2005; Rocha-Miranda and Martins-Silva, 2006). Areas located near the Rio Doce State Park in the state of Minas Gerais, which are impacted by eucalyptus plantations, were also favourable for the development of high densities of this species (Vidigal et al., 2005).

The observations made in the present study clearly illustrate the efficiency of this species in colonising the artificial aquatic systems of the semiarid region of Rio Grande do Norte. During the study period, the reservoirs showed constant vertical thermal stability, with high temperatures near the bottom. Maximum temperatures of 30.9 °C were recorded, and the minimum measured was 27.5 °C. Mitchell and Brandt (2005) observed that *M. tuberculatus* survives well in temperatures between 18 and 32 °C, and a recent study by Okumura (2006) showed that, in the laboratory, the range of tolerance of this species is between 16 and 37 °C, with an optimum range between 29 and 34 °C. This reinforces the plasticity of this species, which is capable of occupying environments in extreme situations, and is highly competitive. The high densities observed in the present study demonstrate the biological success of this snail, which even in constant high temperatures can propagate rapidly and heterogeneously.

The long residence time of water in the local reservoirs may also be a factor favoring the populations of *M. tuberculatus*. Data obtained from the Secretaria Estadual de Recursos Hídricos (SERHID) indicate that the mean water renewal time is over one year, except for the Boqueirão de Parelhas Reservoir where the mean residence time is about 95 days.

In general, we observed that the largest individuals were close to 2 cm in size, with the majority less than 1.5 cm. Rocha-Miranda and Martins-Silva (2006), in a comparative analysis of two populations in the Paraná River basin, pointed out certain differences in the structure of the populations: one being formed mostly by young individuals (belonging to the 0-0.4 cm size class) and the other composed of adult individuals (between 2.0 and 2.4 cm). However, there are records of individuals 3.3 cm (Bogéa et al., 2005) and up to 4 cm in length. *M. tuberculatus* can reproduce sexually, but reproduces mainly via parthenogenesis, which partly accounts for its success as an invasive organism; it is viviparous. According to Dudgeon (1986), individual snails as small as 0.28 cm can be reproductively mature, although Okumura (2006) observed, in the laboratory, individuals of about 1.0 cm long in their first reproduc-

tion. Therefore we assume that most of the individuals found were mature.

Nevertheless, the presence of large numbers of empty shells and the size of the individuals suggest that some event is controlling the populations. This possibility should be investigated, because it may represent an alternative for the control of this exotic species. Recurrent blooms of toxic algae have been reported for the reservoirs of the region (Costa et al., 2006). The senescent algae tend to accumulate on the sediment and can generate anoxic conditions or even release toxins into the sediment. Toxicological tests of the water and sediment may provide important information on their potential toxicity and the potential role of toxins as a control mechanism for *M. tuberculatus*. Studies might also be conducted to evaluate the potential for bioaccumulation of these toxins by this gastropod, as observed in zooplankton organisms (Ferrão-Filho et al., 2002), and also whether these gastropods might function as vectors for toxins to higher trophic levels such as fish.

The lack of historical information about the benthic fauna of the study area makes it impossible to define the changes that may have occurred since this exotic species was introduced. However, the small number of records of *Pomacea* sp and *Biomphalaria* sp, with densities less than 150 ind.m^{-2}, is notable. These low population levels may equally be a result of low competitive capacity of the native species, as of the combined action of factors such as intense eutrophication, biogeochemical factors influenced by high temperatures, and the possible presence of metals in the sediment. High concentrations of heavy metals, especially aluminum and cadmium, were found in water samples from the same waterbodies as in the present study (Eskinazi-Sant'Anna et al., 2006).

The records of *M. tuberculatus* indicate that it is now widely distributed in the Piranhas-Assu Basin. New studies will provide information on its expansion and propagation in the different systems, and indicate whether the populations are continuing to increase or may be subject to some type of limitation. In general, the benthic fauna of the systems studied reflects the eutrophic conditions of the local waterbodies, with low diversity and high dominance of individual species. The massive presence of *M. tuberculatus* may accelerate the process of homogenization of the benthic macrofauna of the aquatic ecosystems of the semiarid region of Rio Grande do Norte, profoundly impacting the biodiversity and trophic structure of the benthos.

Our observations raise alarms about the ecological status of the aquatic ecosystems in the Piranhas-Assu River basin, principally because this region naturally has few sources of freshwater and the quality of the available water is limited. The riverine communities, with little access to treated water, tend to use these waters directly for domestic purposes, for watering animals, in aquaculture or in traditional fisheries. Therefore it is imperative that greater efforts be directed toward monitoring the expansion of *M. tuberculatus* in the aquatic ecosystems of Rio Grande do Norte, and the possible effects of this bioinvasion on the biodiversity and water quality of these essential sources of supply.

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