Research, Society and Development, v. 10, n. 15, e227101522737, 2021
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v10i15.22737

Can turbid water and refuges with aquatic macrophytes increase the survival and growth of *Brycon amazonicus* larvae?

Água turva e refúgios com macrófitas aquáticas podem aumentar a sobrevivência e o crescimento de larvas de *Brycon amazonicus*?

¿Pueden el agua turbia y los refugios con macrófitos acuáticos aumentar la sobrevivencia y el crecimiento de larvas de *Brycon amazonicus*?

Received: 11/03/2021 | Reviewed: 11/10/2021 | Accept: 11/16/2021| Published: 11/17/2021

Joana Paula de Souza Cornélio
ORCID: https://orcid.org/0000-0002-7865-2354
Universidade Estadual de Santa Cruz, Brazil
E-mail: joanapaula_aqui@hotmail.com
Luís Gustavo Tavares Braga
ORCID: https://orcid.org/0000-0002-8989-5845
Universidade Estadual de Santa Cruz, Brazil
E-mail: gbraga@uesc.br
Marle Angélica Villacorta-Correa
ORCID: https://orcid.org/0000-0001-7056-1194
Universidade Federal do Amazonas, Brazil
E-mail: marleangelica@hotmail.com

Abstract
The productivity of aquatic organisms and higher concentration of suspended solids that occur in areas flooded by Whitewater Rivers and the presence of aquatic macrophytes are conducive to the initial development of matrinxã (*Brycon amazonicus*). The objective of this study was to evaluate whether turbid waters and refuges with aquatic macrophytes improve the survival and growth of the larvae of *Brycon amazonicus*, a species of great interest in Amazonian fish farming. For this, two experiments were conducted using a completely randomized design and with four replicas per treatment up to 120 hours after hatching (HAH), In experiment I: *Brycon amazonicus* larvae at 24 HAH were subjected to three treatments with different types of water: clear water (CW); clayey water (AW) and green water (GW). Experiment II: larvae with 24 HAH were maintained in clear water (CW); clear water with refuge (CWR); green water (GW); green water with refuge (GWR); clayey water (AW) and clayey water with refuge (AWR). Experiment I showed that clayey water, followed by green water, increased the survival of larvae (73.92 and 54.32%). Growth was best in larvae maintained in green water. In experiment II, the use of aquatic macrophytes did not influence the survival and growth of the larvae. Thus, we suggest the use of turbid (clayey and green) waters without refuge to increase the survival and growth of *Brycon amazonicus* larvae.
Keywords: Clayey water; Green water; Larviculture; Matrinxã; Performance.

Resumo
A produtividade dos organismos aquáticos e a maior concentração de sólidos em suspensão que ocorrem em áreas inundadas por rios de águas brancas e a presença de macrófitas aquáticas favorecem o desenvolvimento inicial do matrinxã (*Brycon amazonicus*). O objetivo deste estudo foi avaliar se águas turvas e refúgios com macrófitas aquáticas melhoram a sobrevivência e o crescimento das larvas de *Brycon amazonicus*, espécie de grande interesse na piscicultura amazônica. Para isso, foram realizados dois experimentos em delineamento inteiramente casualizado e com quatro réplicas por tratamento até 120 horas após a eclosão (HAE). No experimento I: larvas de *Brycon amazonicus* a 24 HAE foram submetidas a três tratamentos com diferentes tipos de água: água clara (AC); água argilosa (AA) e água verde (AV). Experimento II: larvas com 24 HAE foram mantidas em água clara (AC); água clara com refúgio (ACR); água verde (AV); água verde com refúgio (AVR); água argilosa (AA) e água argilosa com refúgio (AAR). O experimento I mostrou que a água argilosa, seguida da água verde, aumentou a sobrevivência das larvas (73,92 e 54,32%). O crescimento foi melhor em larvas mantidas em água verde. No experimento II, o uso de macrófitas aquáticas não influenciou a sobrevivência e o crescimento das larvas. Assim, sugere-se o uso de águas turvas (argilosas e verdes) sem refúgio para aumentar a sobrevivência e o crescimento das larvas de *Brycon amazonicus*.
Palavras-chave: Água argilosa; Água verde; Larvicultura; Matrinxã; Desempenho.

Resumen
La productividad de los organismos acuáticos y la mayor concentración de sólidos en suspensión, que tienen lugar en áreas inundadas por ríos de aguas blancas, y la presencia de macrófitos acuáticos favorecen el desarrollo inicial del yamú (*Brycon amazonicus*). Este estudio tuvo como propósito evaluar si las aguas turbias y los refugios con macrófitos acuáticos mejoran la sobrevivencia y el crecimiento de las larvas de *Brycon amazonicus*, especie de gran interés en la piscicultura amazónica. Para ello, se realizaron dos experimentos en diseño completamente aleatorio y con cuatro corridas por tratamiento hasta 120 horas después de la eclosión (HAE). En el experimento I, se sometieron larvas de *Brycon amazonicus* a 24 HAE a tres tratamientos con diferentes tipos de agua: agua clara (AC); agua arcillosa (AA) y agua verde (AV). En el experimento II, se mantuvieron larvas con 24 HAE en agua clara (AC); agua clara con refugio (ACR); agua verde (AV); agua verde con refugio (AVR); agua arcillosa (AA) y agua arcillosa con refugio (AAR). El experimento I demostró que el agua arcillosa, seguida del agua verde, aumentó la sobrevivencia de las larvas (73,92 y 54,32 %). El crecimiento fue mejor en las larvas que se mantuvieron en agua verde. En el experimento II, el uso de macrófitos acuáticos no influyó la sobrevivencia ni el crecimiento de las larvas. Por lo tanto, se sugiere el uso de aguas turbias (arcillosas y verdes) sin refugio para aumentar la sobrevivencia y el crecimiento de las larvas de *Brycon amazonicus*.
Palabras clave: Agua arcillosa; Agua verde; Larvicultura; Yamú; Desempeño.

1. Introduction

Brycon amazonicus is noted for being a fish of economic importance and has potential in aquaculture in Brazil and other South American countries (Muller, Villacorta-Correa & Carvalho, 2019) due to it being well accepted in the consumer market, and for having good growth performance (Zaniboni-Filho, Reynalte-Tataje & Weingartner, 2006; Gomes & Urbinati, 2010). However, one of the main difficulties for large-scale production is the low survival rate due to its aggressive behavior and cannibalism (Carvalho *et al*., 2018), which can result in more than 90% mortality during larviculture (Bernardino *et al*., 1993; Romagosa *et al*., 2001).

As such, a number of studies have been developed in an attempt to mitigate the effect of cannibalism, increase survival and improve the zootechnical performance of *Brycon amazonicus* in breeding systems, which included darkening of incubators (Lopes; Senhorini & Soares, 1995); supply of planktonic organisms (Atencio-García *et al*., 2003); different levels of luminous intensity (Lopes, Villacorta-Correa & Carvalho, 2018), stocking densities and water temperature (Barros, Villacorta-Correa & Carvalho, 2019), as well as the use of common salt as a modulator of aggressiveness (Oliveira, Duncan & Carvalho, 2020). These studies are mostly based on the manipulation of environmental factors in order to reduce cannibalism and potentiate the production of species of commercial interest, as highlighted by Howell *et al*. (1998) and Franke *et al*. (2013).

Turbidity and the use of refuges are environmental conditions that are of fundamental importance for the survival of some species of fish in the larval phase. Improvement in the survival and growth of larvae reared in turbid environments, which can be induced by the addition of microalgae or clay (Shaw, Pankhurst & Battaglene, 2006), have been used as part of the protocols for some species such as *Seriola lalandi* (Stuart & Drawbridge, 2011), *Esox lucius* (Salonen & Engstrom-Ost, 2013) and *Sander lucioperca* (Ljubobratović *et al*., 2019).

Some studies have shown a positive relationship between the use of shelters and survival and growth in the larviculture of certain fish species, for example, *Monopterus Cuchia* and *Clarias batrachus* grow well with water hyacinths (Narejo, Rahmatullah & Rashid, 2003; Sahiduzzaman, Tauhiduzzaman & Rahman, 2018). Mitellbach (1984) and Gotceitas (1990) used macrophytes as shelters for *Lepomis gibbosus* and *Lepomis macrochirus* larvae, respectively, and demonstrated increased survival and reduced predation, both interspecific and intraspecific.

For the larvae of *B. amazonicus*, turbidity and the presence of aquatic macrophytes are of paramount importance in their natural habitat, since during this phase of development, their assemblages colonize areas flooded by whitewater rivers that have high loads of suspended clay and silt, which is of Andean origin (Junk, 1983), and results in muddy waters with high turbidity (33 to 94 NTUs) and the presence of macrophyte banks due to the contribution of these nutrients (Sioli, 1968, Araújo-Lima & Oliveira, 1998; Azevedo, 2006; Bittencourt *et al*., 2020). These characteristics of the environment provide refuge, food availability, visual ability to detect predators and ease of escape, which increase the chances of survival and better growth of the larvae (Sanchez-Botero *et al*., 2003; Sanchez-Botero *et al*., 2007; Cajado *et al*., 2018).

The manipulation of these characteristics of the natural habitat of *Brycon amazonicus* larvae can potentiate their production in captivity; however, studies using turbid waters and natural refuges with Neotropical freshwater species are still incipient. Thus, this study evaluated whether the use of turbid waters and natural refuges improve the survival and growth of *Brycon amazonicus* larvae, a species with great potential in Amazonian fish farming and one which has been gaining prominence at the national level.

2. Methodology

2.1 Breeding conditions

The research was carried out in the Aquaculture Laboratory at the Experimental Farm of the Federal University of Amazonas (UFAM), Manaus, Brazil. The larvae were produced using the pituitary technique with raw pituitary extract of carp, according to the adjusted protocol of Romagosa, Narahara & Fenerich-Verani (2018). After extrusion, the oocytes were fertilized and stored in 60 L incubators with constant water renewal at a temperature of 26.76 ± 0.9 °C and at a density of 1 g of eggs per liter of water.

2.2 Experimental design and type of research

The study was divided into two experiments. In experiment I, the effect of three types of water on the survival and zootechnical performance of *B. amazonicus* larvae from 24 to 120 HAH was evaluated. In experiment II, we tested the effect of the use of natural refuges on the survival and zootechnical performance of *B. amazonicus* larvae from 24 to 120 HAH

This research is of a quantitative nature that, according to Botelho and Cruz (2013), presents as its reference the analysis of statistical data, which transforms information into numbers in order to analyze and interpret events that occurred or that may occur through statistical analysis, i.e., the data are quantified and measured (Fachin, 2006).

2.2.1 Experiment I

To evaluate the effect of the different types of water, three experimental treatments were compared: CW (clear water), AW (clayey water) and GW (green water), with four replicates each and in an entirely randomized experimental design. The clear and clayey waters came from nurseries with few suspended solids and clay, respectively, while the green water was obtained via culture of the microalgae *Chlorella* sp., which was produced in the laboratory.

The larvae were previously acclimated from 20 HAH in 4 L trays for 4 hours and then stored at a standardized density of 45 larvae/L, which is a value close to that used by Barros *et al*. (2019). Larvae with a length of 5.247 ± 0.363 mm and weight of 1.211 ± 0.225 mg were transferred to plastic trays (40 x 30 x 8 cm) and a useful volume of 4 L with a constant aeration system. Cleaning and renewal of 10% of the water volume of the experimental units were carried out on a daily basis. The feeding of the larvae consisted of cladocera (*Moina micrura* and *Diaphanosoma* sp.) from controlled production, in the proportions proposed by Jomori *et al*. (2013) of 1250 organisms/larva, divided into eight daily meals. Water quality variables, such as temperature (°C), dissolved oxygen (mg L^{-1}) and pH, were measured using a digital system (Minipa, MV-363), a digital oximeter (HI 9146) and a digital pH meter (pH-221) respectively (Table 1).

In all, 60 larvae were collected at the beginning, and 8 larvae/experimental unit at the end of the experiment for analysis of zootechnical indices. These individuals were euthanized with the use of the anesthetic eugenol (5 µl L^{-1}) and fixed in formaldehyde that was buffered at 4% with $CaCO_3$, as described by Souza *et al*. (2014). Body weight was measured using an analytical balance (Adventurer – OHAUS, model AR2140), and total length was measured by analyzing images captured using a stereomicroscope (LEICA, MC170 HD) and subsequently processed with BEL View software, version 6.2.3. The survival rate (s%) and the following zootechnical parameters were calculated: mean final weight (MFW); mean final length (MFL); specific growth rate (SGR) and apparent condition factor (Kn) (Wt/aLpb), as described by Kesmont and Stalmans (1992), Jobling (1994); Senhorini, Mantelatto & Casanova (1998), Dias *et al*. (2011), and Le Creen (1951).

Table 1. Physical-chemical water variables (mean ± standard deviation) for each type of water CW: clear water / AW: clayey water / GW: green water

Variable	Types of water		
	CW	AW	GW
Temperature (°C)	25.56 ± 1.40	25.96 ± 1.60	25.81± 1.49
Dissolved oxygen (mg L^{-1})	5.78 ± 0.52	5.62 ± 0.38	5.64 ± 0.55
pH	8.05 ± 0.12	8.05 ± 0.06	7.81 ± 0.07

Source: Authors, 2021.

2.2.2 Experiment II

In order to evaluate the effect of the use of the aquatic macrophyte *Cabomba furcata* as a refuge, the larvae of B. amazonicus were subjected to six treatments: CW (clear water); CWR (clear water with refuge); GW (green water); GWR (green water with refuge); AW (clayey water); AWR (clayey water with refuge), each with four replicates, in an entirely randomized experimental design. A total of 25 *Cabomba furcata* leaves with an average leaf area of 6.90 cm^2 were inserted in each tray in the treatments with clear water with refuge, green water with refuge and clayey water with refuge. The inserted leaves occupied 14.94 % of the total tray area, which is equivalent to 179.33 cm^2 of 1200 cm^2. The waters used in this experiment follow the same pattern as experiment I, except for the clayey water, which was collected from the Solimões River, near where it meets the Negro River, which is a spawning area of this species.

At 20 hours after hatching, the larvae were acclimated for four hours and stored at a length of 5.583 ± 0.275 mm and a weight of 1.535 ± 0.288 mg under the same conditions as experiment I. Cleaning, water volume renewal, larvae feeding were performed, as well as monitoring of survival rate and zootechnical indices as described in experiment I. The variables of water quality, temperature (°C), dissolved oxygen (mg L^{-1}) and pH were measured using a digital system (Minipa, MV-363), a digital oximeter (HI 9146), and a digital pH meter (pH-221) respectively. The mean values of the physicochemical variables of the water from experiment II are shown in Table 2.

Table 2. Physicochemical water variables (mean ± standard deviation) for larviculture with presence and absence of natural refuge

Variable	Larviculture with the presence and absence of a natural refuge					
	CW	CWR	GW	GWR	AW	AWR
Temperature (°C)	24.57 ± 0.39	24.25 ± 0.40	24.44 ± 0.33	24.33 ± 0.65	24.58 ± 0.38	24.40 ± 0.55
Dissolved oxygen (mg L^{-1})	7.18 ± 0.36	7.30 ± 0.29	7.21 ± 0.33	7.21± 0.28	7.00 ± 0.32	7.20 ± 0.26
pH	7.50 ± 0.11	7.61 ± 0.18	7.53 ± 0.26	7.55 ± 0.28	7.43 ± 0.14	7.51 ± 0.15

Note: Code of treatments: CW: clear water; CWR: clear water with refuge; GW: green water; GWR: green water with refuge; AW: clayey water; AWR: clayey water with refuge. Source: Authors, 2021.

2.3. Data analysis

The data were analyzed for discrepant values and then tested for normality using the Shapiro-Wilk test. In experiment I, the survival rate (S %) was compared between the experimental treatments using one-way analysis of variance (ANOVA), followed by the Tukey post-hoc test. Zootechnical parameters (with the exception of the specific growth rate) were compared using the Kruskal-Wallis test, followed by the Dunn's test for multiple comparisons. The specific growth rate (SGR) was compared using one-way ANOVA. In experiment II, the survival rate (S %) and the specific growth rate (SGR) were compared between treatments using one-way ANOVA, which was followed by the Fisher LSD post-hoc test. The relative condition factor (Kn) and final weight (MFW) were compared between the treatments using the Kruskal-Wallis test, with the MFW being followed by the Tukey test, for multiple comparisons. The MFL was compared using the Holm-Sidak test followed by the Tukey test, for multiple comparisons.

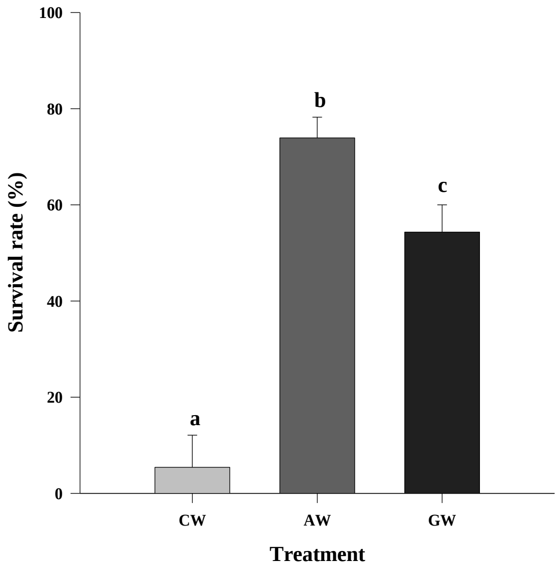
3. Results

3.1. Experiment I

The survival rate of the *B. amazonicus* larvae was significantly influenced by the different types of water (Figure 1). Clayey and green waters increased the survival rate during the experimental period, while larvae kept in clear water presented the lowest survival rates (one-way ANOVA; F=56.91; P=< 0.001).

There was no significant difference in specific growth rate (SGR) and relative condition factor (Kn) between treatments. The final weight and length were not significantly different in clear or in clayey water, though these indices were significantly higher in larvae kept in green water when compared to those kept in clayey water (Kruskal-Wallis, P=0.004; P=0.036), as can be seen in Table 3.

Figure 1. Mean (± standard deviation) for survival rate of matrinxã larvae



Note: Treatment code: CW: clear water/ AW: clayey water/ GW: green water. Source: Authors, 2021.

Table 3. Zootechnical parameters (mean ± standard error) for matrinxã larvae reared in different types of water (CW: clear water / AW: clayey water / GW: green water

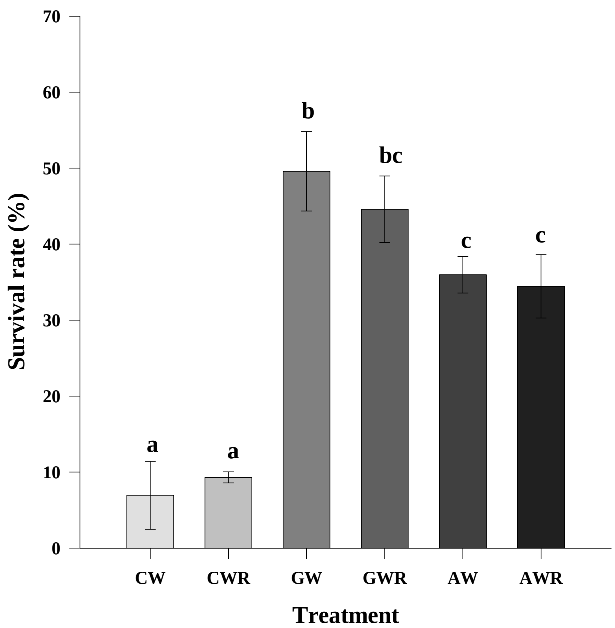
	Types of water		
Parameter	CW	AW	GW
MFW (mg)	2.85 ± 0.59^{c}	2.52 ± 0.60^{ac}	3.15 ± 1.03^{bc}
MFL (mm)	7.26 ± 0.33^{c}	6.98 ± 0.43^{ac}	7.42 ± 0.49^{bc}
SGR (%)	21.78 ± 5.67^{a}	18.13 ± 4.34^{a}	23.84 ± 3.96^{a}
Kn	0.99 ± 0.08^{a}	1.00 ± 0.07^{a}	1.01 ± 0.13^{a}

Note: Different lowercase letters in the lines indicate a significant difference between the types of water (Dunn's, p < 0.001). Code of zootechnical parameters MFW: mean final weight; MFL: mean final length; SGR: specific growth rate; Kn: relative condition factor. Source: Authors, 2021.

3.2 Experiment II

The survival rates of the larvae in the treatments with clear water, in the presence and absence of a refuge, were significantly lower than the treatments with green and clayey water with and without a refuge. There was greater survival of the larvae kept in green water without shelter when compared to the larvae kept in clayey water. The presence of a refuge did not influence survival in either green or clayey water (one-way ANOVA; F=20.71; P=<0.001). The differences between experimental treatments are shown in Figure 2.

Figure 2. Mean (± standard deviation) for survival rate of matrinxã larvae reared in the presence and absence of natural refuge.



Note: Code of treatments: CW: clear water; CWR: clear water with refuge; GW: green water; GWR: green water with refuge; AW: clayey water; AWR: clayey water with refuge. Different lowercase letters indicate a significant difference between treatments (Fisher LSD, p<0.001). Source: Authors, 2021.

No difference was observed between treatments for the values of the condition factor (Kn) during the experimental period (Kruskal-Wallis; P=0.987). TGE was lower in larvae kept in clear water, with or without a refuge. Those kept in green water had a higher TGE than those kept in clayey water without a refuge. The TGE of those who were maintained in the green water with a refuge and those in clayey water without a refuge did not differ significantly (one-way ANOVA; F=20.20; P=<0.001).

The mean final weight values (Table 4) were higher for larvae raised in green water with or without a refuge, and there was a significant difference in relation to those raised in clear water with or without a refuge and clayey water without a refuge (Tukey; P=0.001). The mean final length had lower values for larvae kept in clear water with or without a refuge and the greatest lengths were achieved in green water with or without a refuge and in clayey water without a refuge, as shown in Table 4 (one-way ANOVA; F=157,343; P=<0.001).

4. Discussion

The results of experiment I demonstrated that the survival of *B. amazonicus* larvae was low when they were maintained in clear water and high when raised in turbid (clayey and green) waters. This response can be attributed to the decrease in the visibility of the larvae in the water column caused by the presence of clay and microalgae (Eiane *et al*., 1999), which reduces the chances of encounters between them and facilitates escape.

In their natural environment, Silva (2009) found greater abundance of *Brycon amazonicus* larvae and juveniles in floodplain areas of the Solimões River, which have typically white or "muddy" waters and lower water transparency. Lima & Araújo-Lima (2004) state that in rivers of clear and black waters the potential predation rates may be higher due to greater visibility of eggs and larvae by predators because of the few suspended solids in the water.

According to Hecht and Pienaar (1993), turbid waters simulate conditions of low light and greater availability of refuge, which ends up increasing the survival of the larvae. Studies that employed the manipulation of light intensity in the larviculture of *B. amazonicus* showed that at low intensity, larvae with 24, 48, 72, 120 and 240 HAH, showed an increase in their survival rate due to the reduction in the display of aggressive interactions in these periods (Lopes, Villacorta-Correa & Carvalho, 2018; Muller, Villacorta-Correa & Carvalho, 2019). In addition, the turbid waters provide an effective shelter due to the suspended solids, which facilitate hiding by the larvae (Maes *et al*., 1998; Snickars, Sandstrom & Mattila, 2004; Engström-Öst, Karjalainen & Viitasalo, 2006). This was observed during the cleaning of the experimental units in the treatment using clayey water (AW), which resulted in the highest survival rate, since the larvae did not swim to the surface and took shelter in the decanted clay at the bottom of the experimental units.

Another factor is that less swimming activity occurs in turbid waters due to a lower detection of threat by the larvae (Abrahams & Kattenfeld, 1997) and thus a reduced need to seek shelter (Gregory, 1993). Therefore, a reduced swimming activity decreases the likelihood of counterattacks between members of the group (Souza, Villacorta-Correa & Carvalho, 2014), as observed in *Esox lucius* (Lehtiniem, Engström-Öst & Viitasalo, 2005) and *B. amazonicus* (Lopes *et al*., 2019). However, the effects of turbid water use are different for each species of aquatic animal (He *et al*., 2020). For aquatic animal species that rely on vision to catch prey, turbid water can affect the predator's vision and thus reduce aggressiveness and cannibalism. However, for those looking for prey without the aid of vision, water turbidity has little effect on cannibalistic behavior (Liao & Chang, 2010).

The larvae of *B. amazonicus* bred in green water had better growth when compared to clayey or clear water. This indicates that during *B. amazonicus* larviculture the microalgae acted as a food source for the cladocera (zooplankton) that remained in the experimental units after the feeding (Reitan, Rainuzzo, Oie & Olsen, 1997), which played an indirect role in improving the growth rate of the larvae (Reitan, Rainuzzo, Oie & Olsen, 1993; Tamaru, Murashinge & Lee, 1994). As such, there was an increase in the population density of cladocera, which caused greater prey availability, and was a preponderant factor for higher values of weight, length and specific growth rate. However, some studies have shown that the growth of larvae of some fish species slows down over time in green water because the increased turbidity induced by algae negatively influences the ability of the larvae to capture prey (Salonen & Engstro¨mO¨st, 2010), as observed in the larvae of *Rhombosolea tapirina* (Shaw *et al*., 2006) and *Esox lucius* (Salonen & Engstro¨mO¨st, 2013).

Some species show increased feeding when kept in green water, but decreased feeding in clayey water (Shaw *et al*., 2006). This corroborates our results in which the larvae of *B. amazonicus* bred in clayey water showed significantly lower growth rates compared to those bred in green water. The same occurred with Clupea harengus pallasi (Boehlert & Morgan, 1985), *Lepomis macrochirus* (Rafinesque) (Miner & Stein, 1993) and *Gobiusculus flavescens* (Fabricius) (Utne, 2005).

In experiment II, the use of a natural refuge did not significantly influence the survival rates of *B. amazonicus* larvae. These results may be due to the concomitant use with more turbid waters, which, regardless of the presence of the aquatic macrophyte *Cabomba furcata*, caused the reduction of water transparency, hindered the passage of light (Tomazoni *et al*., 2005) and provided shelter (Gregory & Northcote, 1993; Maes *et al*., 1998), which decreased the visibility among the larvae in the experimental units. Therefore, turbid waters reduce the use of vegetative shelter (Utne-Palm, 2002; Snickars, Sandstrom & Mattila, 2004; Maes *et al*., 1998; Engström-Öst, Karjalainen & Viitasalo, 2006), as observed with *Steindachneridion* sp. larvae (Feiden *et al*., 2006) and *Clarias gariepinuss* (Alsaqufi *et al*., 2020).

The best zootechnical performance values in green water, regardless of the presence of the aquatic macrophytes, can be attributed to the improvement in vision in moderately turbid waters (Naas, Naess & Harboe, 1992; Utne-Palm, 2002) and the fact that green water functions as a parallel production of live food (Reitan *et al*., 1993; Tamaru *et al*., 1994) during *B. amazonicus* larviculture, which increased the number of zooplankton in the experimental units. On the other hand, the clayey waters decreased the visibility of the larvae due to the higher level of turbidity and consequently less probability of finding the prey (Eiane *et al*., 1999).

The use of only one species of aquatic macrophyte and food (Cladocera) may have influenced the results, since, because they have a structural complexity of species-specific leaves and roots in lowland areas, the aquatic macrophytes harbor a great diversity of aquatic invertebrates and fish larvae, which are part of the diet of *B. amazonicus*, which in its early stages of development feeds on zooplankton (Leite & Araújo-Lima, 2002; Leite, 2004).

5. Final Considerations

It was observed that green and clayey waters, with and without refuges, were efficient for larviculture of *Brycon amazonicus* since the larvae presented higher survival rates and zootechnical index values, such as mean final weight, mean final length and specific growth rate, when compared to whitewaters. Turbid waters (green and clayey) can thus be employed to replace whitewaters in fish farms where they are commonly used during the larviculture of *Brycon amazonicus*.

Given the above, we suggest new studies on this topic that test different concentrations of clay and microalgae, i.e., determine different turbidity ranges (NTU) in the larviculture of *Brycon amazonicus* in order to verify the optimal level for survival and productive performance. In addition, the realization of larviculture in experimental units of larger volumes, such as incubators, would be interesting since it would reflect the reality of fish farms and indicate possible adaptations in this type of system. Another interesting future study would be to test the use of turbid waters during a longer period of larval development, and exceed the 120 HAE period of this study.

Acknowledgments

The authors would like to thank FAPESB for granting the internship (4201/2014) to the first author during her PhD. To Mr. Geraldo Bernardino (*In memoriam*) for financial support via the DARPA project (Development of Aquaculture and Fisheries Resources in the Amazon). To the Federal University of Amazonas for making the facilities of the Experimental

Farm (FAEXP) available for our research. To Mr. Paulo Sérgio de Oliveira (*In memoriam*) and André B. de Souza for their technical support.

References

Abrahams, M., & Kattenfeld, M. (1997). The role of turbidity as a constraint on predator-prey interactions in aquatic environments. *Behavioral Ecology and Sociobiology*, 40,169–174. https://doi.org/10.1007/s002650050330.

Alsaqufi, A., Mathew, R., Alkhamis, Y., Rahman, M.M., & Pathiri, M. (2020). Influence of Photoperiod and Shelter on Some Phenotypic Traits in African Catfish (*Clarias gariepinus* Burchell, 1822) larvae. *Pakistan journal of zoology*. https://dx.doi.org/10.17582/journal.pjz/20200507220534.

Araújo-Lima, C. A. R. M., & Oliveira, E.C. (1998). Transport of larval fish in the Amazon. *Journal of Fish Biology*, 53, 297–306. doi.org/10.1111/j.1095-8649.1998.tb01033.x.

Atencio-García, V., Zaniboni-Filho, E., Pardo-Carrasco, S., & Arias-Castellanos, A. **(**2003). Influência da primeira alimentação na larvicultura e alevinagem de yamú *Brycon siebenthalae* (Characidae). *Acta Scientiarum: Animal Science*, 25, 61-72. https://doi.org/10.4025/actascianimsci.v25i1.2092.

Azevedo, R.P. (2006). Uso de água subterrânea em sistema de abastecimento público de comunidades na várzea da Amazônia central. *Acta amazônica*, 36, 313 – 320. https://doi.org/10.1590/S0044-59672006000300004.

Bernardino, G., Senhorini, J. A., Fontes, N. A., Bock, C. L., & Mendonça, J. O. J. (1993). Propagação artificial da matrinxã, *Brycon cephalus*. *Boletim Técnico do CEPTA*, 6, 1–9.

Bittencourt, S.C. S., Zacardi, D.M., Monteiro, T., Nakayama., & Queiroz, H.L. (2020). Juvenis de peixes associados à macrófitas aquáticas em ambientes de várzea na Amazônia Central, Brasil. Biota Amazônia, 10, 38-45. http://dx.doi.org/10. 18561/2179-5746/biotaamazonia.

Boehlert, GW., & Morgan, JB. (1985). Turbidity aprimora as habilidades de alimentação do arenque larval do Pacífico, *Clupea harengus pallasi*. *Hydrobiologia*, 123**,** 161-170. https://doi.org/10.1007/BF00018978.

Botelho, J. M. & Cruz. V. A. G. (2013). *Metodologia científica*. São Paulo: Pearson Education do Brasil.

Cajado, R. A., Oliveira, L. S., Oliveira, C. C., Ponte, S. C. S., Bittencourt, S. C. S., Queiroz, H. L., & Zacardi, D. M. (2018). Distribuição de larvas de *Brycon amazonicus* (Pisces: Bryconidae) no entorno da Reserva de Desenvolvimento Sustentável Mamirauá: base ecológica para manejo. *Revista Ibero Americana de Ciências Ambientais*, 9, 78-87. http://doi.org/10. 6008/CBPC2179- 6858.2018.006.0010.

Carvalho, T. B., Souza, E. C. M., Silva, J. P., & Villacorta - Correa, M. A. (2018). Effect of body size heterogeneity on the aggressive behavior of larvae of matrinxã, *Brycon amazonicus* (Characiformes, Bryconidae). *Acta Amazonica*, 48, 304-310. https://doi.org/10.1590/1809-4392201800541.

Dias, D. C., Corrêa, C. F., Leonardo, A. F. G., Tachibana, L., Romagosa, E., & Ranzani-Paiva, M. J. T. (2011). Probiótico na larvicultura de matrinxã, *Brycon amazonicus*. *Acta Scientiarum*, 33, 365–368. https://doi. org/10.4025/actascianimsci.v33i4.11764.

Eiane, K., Aksnes, DL., Bagøien, E., & Kaartvedt, S. (1999). Fish or jellies - a question of visibility? *Limnology and Oceanography*, 44, 1352 - 1357. https://doi.org/10.4319/lo.1999.44.5.1352.

Engstrom-Ost, J., Karjalainen, M., & Viitasalo, M. (2006). Feeding and Refuge Use by Small Fish in the Presence of Cyanobacteria Blooms. *Environmental Biology of Fishes***,** 76**,** 109-117. https://doi.org/10.1007/s10641-006-9013-8.

Fachin, O. (2006). Fundamentos de metodologia. (5a ed.), Saraiva.

Feiden, A., Hayashi, C., Boscolo, W.R., & Reidel, A. (2006). Desenvolvimento de larvas de *Steindachneridion* sp. em diferentes condições de refúgio e luminosidade. *Pesquisa Agropecuária*, 41, 133-137. https://doi.org/10.1590/ S0100-204X2006000100018.

Franke, S., Brüning, A., Hölker, F., & Kloas, W. (2013). Study of biological action of light on fish. *Journal of Light and Visual Environment*, 37, 194–203. https://doi.org/10.2150/jlve.IEIJ130000518.

Gomes, L.C., Baldisserotto, B, B., & Senhorini, J.A. (2000). Effect of stocking densityon water quality, survival, and growth of larvae of the matrinxã, *Brycon cephalus* Characidae, in ponds. *Aquaculture***,** 183, 73-81.

Gotceitas, V. (1990). Variation in plant stem density and its effects on foraging success of juvenile bluegill sunfish. *Environmental Biology of Fishes*, 27**,** 63 - 70. https://doi.org/10.1007/BF00004905.

Gregory, R.S., & Northcote, TC. (1993). Surface, planktonic, and benthic foraging by juvenile chinook salmon (*Oncorhynchus tshawytscha*) in turbid laboratory conditions. *Canadian Journal of Fisheries and Aquatic Sciences***,** 50, 233–240. https://doi.org/10.1139/f93-026.

He, J., Shi, H., Xu, W., & Su, Z. (2020). Research progress on the cannibalistic behavior of Aquatic Animals and The Screening of Cannibalism-Preventing Shelters (Review). *Israeli Journal of Aquaculture - Bamidgeh*, 72, 1-9. https://doi.org/10.46989/001c.21014.

Hecht, T., & Pienaar, A.G. (1993). A review of cannibalism and its implications in fish larviculture. *Journal of the World Aquaculture Society*, 24, 246-261. https://doi.org/10.1111/j.1749-7345.1993.tb00014.x.

Howell, B.R., Day, O.J., Ellis, T., & Baynes, S.M. (1998). Early life stages of farmed fish. In: Black, K., & Pickering, A (Ed.), *Biology of farmed fish. Sheffield* (pp.27-66). England: Sheffield Academic Press.

Jobling, M. (1994), Fish bionergetics. London: Chapman e Hall.

Jomori, R. K., Luz, R. K., Takata, R., Fabregat, T. E. H. P., & Portella, M. (2013). Água levemente salinizada aumenta a eficiência da larvicultura de peixes neotropicais. *Pesquisa Agropecuária Brasileira*, 48, 809–815. https://doi.org/10.1590/S0100-204X201300080000.

Junk, W. J. (1983). As águas da região Amazônica. In: SALATI, *Eneas et al. Amazônia: desenvolvimento, integração e ecologia* (pp.54-55). São Paulo: Brasiliense.

Le Cren, E. D. (1951). The length-weight relationship and seasonal cycle in gonadal weight condition in the perch *Perca fluviatilis. J. An. Ecol*., 20(2): 201-19.

Leite, R.G.; Araújo-Lima, C.A.R.M. (2002) Feeding of the *Brycon cephalus*, *Triportheus elongatus* and *Semaprochilodus insignis* (Osteichthyes, Characiformes) larvae in Solimões/Amazonas River and floodplain areas. *Acta Amazonica*. 32, 129-147. https://doi.org/10.1590/1809-43922002323515.

Leite, R.G.A. (2004). A alimentação de juvenis de matrinxã, *Brycon amazonicus* (Pisces, Characidae), em áreas inundadas da Ilha de Marchantaria, Amazonas, Brasil. *Acta Amazônica*, 4, 661-664. https://doi.org/10.1590/S0044-59672004000400018.

Leite, R., Silva, J., & Freitas, C. (2006). Abundância e distribuição das larvas de peixes no Lago Catalão e no encontro dos rios Solimões e Negro, Amazonas, Brasil. *Acta Amazonica*. 36 (4), 557-562. https://doi.org/10.1590/S0044-59672006000400018.

Leonardo, A. F. G., Hoshiba, M. A., Urbinati, E. C., & Senhorini, J. A. (2013). Improvement of matrinxã, *Brycon amazonicus*, larviculture by exposing eggs to triiodothyronine. *Journal of the World Aquaculture Society*, 44, 141–147. https://doi.org/10.1111/jwas.12007.

Liao I. C., & Chang, E. (2010). Role of sensory mechanisms in predatory feeding behavior of juvenile red drum *Sciaenops ocellatus*. *Fisheries Science*, 69, 317-322. https://doi.org/10.1046/j.1444-2906.2003.00623.x.

Lima, A.C., & Araújo-Lima, C.A.R.M. (2004). The distributions of larval and juvenile fishes in Amazonian Rivers of different nutrient status. *Fresh Water Biology*, 49, 787-800. https://doi.org/10.1111/j.1365-2427.2004.01228.x.

Ljubobratovic, U., Kucska, B., Feledi, T., Poleksic, V., Marković, Z., Lenhardt, M., Peteri, A., Kumar, S., & Rónyai, András. (2015). Effect of Weaning Strategies on Growth and Survival of Pikeperch, *Sander lucioperca*, Larvae. *Turkish Journal of Fisheries and Aquatic Sciences*, 15(2), 325-331. 10.4194 / 1303-2712-v15_2_15.

Lopes, R.N.M., Senhorini, J.A., & Soares, M.C.F. (1995). Desenvolvimento larval e embrionário do matrinchã *Brycon cephalus* Günther, 1869, (Pisces, Characidae). *Boletim Técnico do CEPTA*, 8, 41-48.

Lopes, A. C. C., Villacorta-Correa, M. A., & Carvalho, T. B. (2018). Lower light intensity reduces larval aggression in matrinxã, *Brycon amazonicus*. *Behavioural Processes*, 151, 62–66. https: //doi.org/10.1016/j. beproc.2018.01.017.

Maes, J., Taillieu, A., Van Damme, PA., Cottenie, K., & Ollevier, F. (1998). Seasonal patterns in the fish and crustacean community of a turbid temperate estuary (Zeeschelde Estuary, Belgium). *Estuarine, Coastal and Shelf Science*, 47, 143–151. https://doi.org/10.1006/ecss.1998.0350.

Miner, G., & Stein, R. (1993). Interactive influence of turbidity and light on larval bluegill (*Lepomis macrochirus*) foraging. *Canadian Journal of Fisheries and Aquatic Sciences*, 50, 781–788. https://doi.org/10.1139/f93-090.

Muller, R. L., Villacorta-Correa, M. A., & Carvalho, T. B. (2019). Light intensity affects the survival and growth of matrinxã larvae, *Brycon amazonicus* (Spix & Agassiz, 1829). *Aquaculture Research*, 50, 2410– 2418. https://doi.org/10.1111/are.14194.

Naas, K.E., Naess, T., & Harboe, T. (1992). Enhanced first feeding of halibut larvae (*Hippoglossus hippoglossus L*.) in green water. *Aquaculture*, 105, 143–156. https://doi.org/10.1016/0044-8486(92)90126-6.

Narejo, N.T., Rahmatullah, S.M., & Rashid, M.M. (2003). Effect of different shelters on growth, survival and production of freshwater mud eel, *Monopterus cuchia* (Hamilton) reared in concreted cisterns of BAU Mymensingh, Bangladesh. Pak. *Pakistan Journal of Biological Sciences*, 6, 1753-1757. https://doi.org/10.3923/ pjbs.2003.1753.1757.

Oliveira, E.N., Ducan, W.P., & Carvalho, T.B. (2020). Use of common salt affects aggressiveness in matrinxã larvae (*Brycon amazonicus*). *Aquaculture Research*, 00:1–7. https://doi.org/10.1111/are.14730.

Reitan, K.I., Rainuzzo, J.R., Oie, G., & Olsen, Y. (1993). Nutritional effects of algal addition in first-feeding of turbot (*Scophthalmus maximus* L.) larvae. *Aquaculture*, 118, 257–275. DOI: https://doi.org/10.1016/0044-8486(93)90461-7.

Reitan, K.I., Rainuzzo, J.R., Oie, G., & Olsen, Y. (1997). A review of the nutritional effects on algae in marine fish larvae. *Aquaculture*, 155, 207–221. https://doi.org/10.1016/S0044-8486(97)00118-X.

Rieger, P., & Summerfelt, R.C. (1997). The influence of turbidity on larval walleye, *Stizostedion vitreum*, behavior and development in tank culture. *Aquaculture*, 159, 19-32. https://doi.org/10.1016/S0044-8486(97)00187-7.

Romagosa, E., Narahara, M. Y., & Fenerich-Verani, N. (2018). Stages of embryonic development of the “matrinxã”, *Brycon cephalus* (Pisces, Characidae). *Boletim Instituto de Pesca*, 27, 27–32. http://orcid.org/0000-0002-4879-479X.

Romagosa, E., Narahara, M.Y., Borella, M.I., & Fenerich-Verani, N. (2001) Seleção e caracterização de fêmeas de matrinxã, *Brycon cephalus*, induzidas a reprodução. *Boletim do Instituto de Pesca*, São Paulo, 27, 113-121. Retrieved from https://www.pesca.agricultura.sp.gov.br/27%5B2%5D-art_03.pdf.

Sahiduzzaman, S., Tauhiduzzaman& Rahman, S.M..(2018). Effects of shelter on growth and survival of Asian catfish (*Clarias batrachus*). *International Journal of Fisheries and Aquatic Research*, 3, 60-63. Retrieved from http://www.fishjournals.com/archives/2018/vol3/issue1/3-1-24.

Salonen, M., & Engström-Öst, J. (2010). Prey capture of pike *Esox lucius* larvae in turbid water. *Journal of Fish Biology*, 76, 2591–2596. https://doi.org/10.1111/j.1095-8649.2010.02647.x.

Salonen, M., & Engström-Öst, J. (2013). Growth of pike larvae: effects of prey, turbidity and food quality. *Hydrobiologia*, 717, 169–175. https://doi.org/10.1007/s10750-013-1575-9.

Sanchez-Botero, J. I., Leitão, R. P., Caramaschi, E. P., & Garcez, D. S. (2007). The aquatic macrophytes as refuge, nursery and feeding habitats for freshwater fish Cabiúnas Lagoon, Restinga de Jurubatiba National Park, Rio de Janeiro, Brazil. *Acta Limnologica Brasiliensia*, 19,143-153. Retrieved from https://www.ablimno.org.br/acta/pdf/acta19_vol2_03.pdf.

Senhorini, J. A., Mantelatto, F. L. M., & Casanova, S. M. C. (1998). Larvae of Amazon species matrinxã, *Brycon cephalus* (Pisces, Characidae) in larviculture ponds. *Boletim Técnico do CEPTA*, 11, 13–28.

Senhorini, J.A., Gaspar, L.A., & Fransozo, A. (2002). Crescimento, sobrevivência e preferência alimentar de larvas de matrinxã *(Brycon cephalus)* e de piracanjuba *(Brycon orbignyanus)* em viveiros. *Boletim Técnico do Cepta*, 15, 9-21.

Shaw, G.W., Pankhurst, P.M., & Battaglene, S.C. (2006). Effect of turbidity, prey density and culture history on prey consumption of greenback flounder *Rhombosolea tapirina* larvae. *Aquaculture*, 253, 447–460. https://doi.org/10.1016/j.aquaculture.2005.09.025.

Silva, C.M. (2009). Abundância de juvenis do ovo de Characiformes migradores em área de várzeas do Rio Solimões (Amazonas, Brasil). Dissertação de mestrado INPA-FUA 54p. Retrieved from https://bdtd.inpa.gov.br/handle/tede/1425.

Sioli, H. (1968). Hydrochemistry and geology in the Brazilian Amazon region. *Amazoniana*, 1, 267–277. Retrieved from https://pure.mpg.de/rest/items/item_3148443_1/component/file_3148444/content.

Skov, C., & Koed, A. (2004). Habitat use of pike in experimental ponds in relation to cannibalism, zooplankton, water transparency and habitat complexity. *Journal of Fish Biology*, 64, 448–459. https://doi.org/10.1111/j.0022-1112.2004.00310.x.

Snickars, M., Sandstrom, A., & J. Mattila. (2004). Antipredator behaviour of 0-year *Perca fluviatilis*: effect of vegetation density and turbidity. *Journal of Fish Biology*, 65, 1604–1613. https://doi.org/10.1111/j.0022-1112.2004.00570.x.

Souza, E. C. M., Silva, J. P., Villacorta-Correa, M. A., & Carvalho, T. B. (2014). Aggressiveness and locomotion activity related to hatching time in matrinxã, *Brycon amazonicus* (Spix and Agassiz, 1829). *Applied Animal Behaviour Science*, 157, 146–151. https: //doi.org/10.1016/j.applanim.2014.05.009.

Stuart, Kevin., & Drawbridge, Mark. (2011). The effect of light intensity and green water on survival and growth of cultured larval California yellowtail (*Seriola lalandi*). *Aquaculture*, 321, 152-156. https://doi.org/10.1016/j.aquaculture.2011.08.023.

Tamaru, C.S., Murashinge, R., & Lee, C.S. (1994). The paradox of using phytoplankton during the larval culture of striped mullet, *Mugil cephalus* L. *Aquaculture*, 119, 167–174. https://doi.org/10.1016/0044-8486(94)90173-2.

Tomazoni, J.C., Mantovani, L.E., Bittencourt, A.V. L., & Rosa Filho, E. F. (2005). Utilização de medidas de turbidez na quantificação da movimentação de sólidos por veiculação hídrica nas bacias dos rios Anta Gorda, Brinco, Coxilha Rica e Jirau – Sudoeste do Estado do Paraná. *Boletim Paranaense de Geociências*, 57, 49-56. http://dx.doi.org/10. 5380/geo.v57i0.6044.

Utne-Palm, A.C. (2002). Visual feeding of fish in a turbid environment: Physical and behavioural aspects, Marine and Freshwater Behaviour and Physiology, 35, 111-128. https://doi.org/10.1080/10236240290025644.

Utne, ACW. (2005). The effect of turbidity and illumination on the reaction distance and search time of the marine planktivore *Gobiusculus flavescens*. *Journal of Fish Biology*, 50, 926–938. https://doi.org/10.1111/j.1095-8649.1997.tb01619.x.

Zaniboni Filho, E., Reynalte-Tataje, D., & Weingartner, M. (2006). Potencialidad del género *Brycon* em la piscicultura brasileña. *Revista Colombiana de Ciências Pecuárias*, 19, 233-240. Retrieved from http://www.scielo.org.co/pdf/rccp/v19n2/v19n2a17.pdf.