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Reviews in Fisheries Science & Aquaculture

ISSN: 2330-8249 (Print) 2330-8257 (Online) Journal homepage: http://www.tandfonline.com/loi/brfs21

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**To cite this article:** Tamara Fonseca, Barry A. Costa-Pierce & Wagner C. Valenti (2017) Lambari Aquaculture as a Means for the Sustainable Development of Rural Communities in Brazil, Reviews in Fisheries Science & Aquaculture, 25:4, 316-330, DOI: 10.1080/23308249.2017.1320647

**To link to this article:** http://dx.doi.org/10.1080/23308249.2017.1320647

REVIEWS IN FISHERIES SCIENCE & AQUACULTURE
2017, VOL. 25, NO. 4, 316–330
https://doi.org/10.1080/23308249.2017.1320647

# Lambari Aquaculture as a Means for the Sustainable Development of Rural Communities in Brazil

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**ABSTRACT**

The challenge of developing rural communities is to combine socioeconomic enhancement and environmental conservation. Sustainable aquaculture using low-trophic level native small fish could be an important tool to aid in the challenge. Lambari are a fish group widely distributed on neotropical and subtropical watersheds, which can be a good model for studies on the performance of small fish sustainable aquaculture to develop rural communities. A review of the available information on the status and potential economic and socio-ecological impacts of this innovative initiative is described in this article. A case study of lambari aquaculture in a rural community located in a protected coastal rainforest in southeastern Brazil was also reported. The review showed large diversification in the culture systems and management, and consequently, in the productivity. Poor management practices exist and current science-based information is still insufficient to provide technology to match rural farmer realities or needs. Simple, alternative strategies are needed to improve systems' efficiencies. Nevertheless, with participatory applied science, the aquaculture of indigenous, low-trophic level small fish, such as the lambari, can be an important tool for sustainable food production and development of rural populations, and an alternative income source for poor communities remaining in nature reserves.

**KEYWORDS**

Ecological aquaculture; native species; alternative livelihoods; socio-ecological assessment

## Introduction

Rural community development is a central topic in international and local polices worldwide (UNGA, 2015; FAO, 2017). The current global challenge for development of rural communities is to reconcile social-economic development and environment conservation (Goswami et al., 2017; Jung et al., 2017). Sustainable aquaculture using small and low-trophic level native fish could be an important tool for that. Small fish can be consumed with bones, head and viscera, which are rich in minerals and vitamins and other nutrients (Hansen et al., 1998; Fiedler et al., 2016) Thus, small fish may be an important source of nutrients for vulnerable populations, improving food security (Thilsted, 2012; Bogard et al., 2015a, b). Low-trophic level fish requires cheaper food based on primary production and thus, save natural resources and money (Naylor et al., 2000). Culture of native species reduces potential environmental negative-impacts resulting from escapes and pathogens dissemination (Naylor et al., 2001; Ross et al., 2008). Therefore, aquaculture of small indigenous species, which occupy low-trophic level, may play an essential role in programs to alleviate the poverty and promote development in several countries.

Lambari, tetra, or freshwater sardine, is a paraphyletic group of small fresh water fish from the family Characidae (Mirande, 2010). This group of fish represents a large diversity and is widely distributed on Neotropical and Subtropical watersheds from the south of United States to northern Argentina (Lima et al., 2003). Lambari species belong to the genera *Astyanax* and *Deuterodon*. They inhabit pelagic freshwater environments, have omnivorous opportunistic feeding habits, and play an important role in freshwater ecosystems as the main prey of carnivorous fish (Garutti, 2003). In addition, they are widely consumed by human population and highly valued in many different regions.

Lambari aquaculture has been developed during the past two decades as an alternative financial source for small rural producers in Brazil. As an indigenous low-trophic level fish, lambari have a large potential to be produced in a sustainable way, promoting

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socio-economic development, improving food security and conserving natural resources in Brazil. Thus, lambari can be a good model for studies on the culture performance of low-trophic level small-fish to develop local communities. Substantial literature on lambari biology and culture is obscure, including articles, books and dissertations published in local language, which hides the available information from the international audience.

This study reviews the existing information on the status and potential economic and socio-ecological impacts of lambari aquaculture in the rural communities. It also reports a case study of lambari (*Deuterodon iguape*) aquaculture in a rural poor community in the Sea Mountains State Park, a coastal rainforest protected area in Southeast Brazil, as a more sustainable alternative livelihood enterprise. “Gray literature” was avoided every time equivalent, more accessible publications exist.

## Farmed lambari species

The species *Astyanax lacustris, Astyanax scarbripinnis* complex (sensu Bertaco and Lucena, 2006) and *Deuterodon iguape* are currently farmed. They are common in natural waters of the Southeast Brazil, where they are widely consumed and high-priced. During the past years, these species have gained attention because of their potential to be commercialized as live bait for the sport fishing and as appetizer for human consumption (Valladão et al., 2016). Then, aquaculture has been started by small holder families, wherein its production technology remains in development.

### *The yellow tail lambari* (Astyanax lacustris*)*

The species *A. lacustris* (Figure 1A) was previously described as *Astyanax bimaculatus*, and *Astyanax altiparanae* (Garutti and Britsky, 2000). Recently, the species was reviewed as being *A. lacustris* (Lucena and Soares, 2016). This species is found on the upper Parana, Paraguay, Tocantins, São Francisco, and Rio Doce watersheds (Lima et al., 2003; Lucena & Soares, 2016). It has a horizontally oval, black humeral spot and two brown vertical bars situated in the humeral region (Lucena & Soares, 2016). Adults can reach 15 cm length, and sexual maturity begins at 8 cm (Rodrigues et al., 1992; Sato et al., 2006).

Reproduction occurs year-round, but at higher rates in spring and summer, suggesting that increases in temperature and rainfall increases reproductive performances (Rodrigues et al., 1992; Sato et al., 2006). Lambari eggs are spherical, opaque, and sticky (Sato et al., 2006). Eggs hatch in less than two days. Larvae have a sticky appendage on their heads, which allow them to attach themselves to the roots of macrophytes or filamentous algae (Stevanato, 2016). After three days, the digestive tract of the larvae is complete and they are able to ingest external foods (Stevanato, 2016). The digestive tract includes a terminal protractile mouth and pentacusp teeth that allows the fish to obtain food throughout the water column (Peretti and Andrian, 2008). The yellow tail lambari is broad, omnivorous opportunists, eating algae, aquatic and terrestrial insects, microcrustaceans, particles of macrophytes and leaves, fruits, seeds, and scales (Esteves, 1996; Cassemiro et al., 2002; Gomiero and Braga, 2003; Andrian et al., 2006).

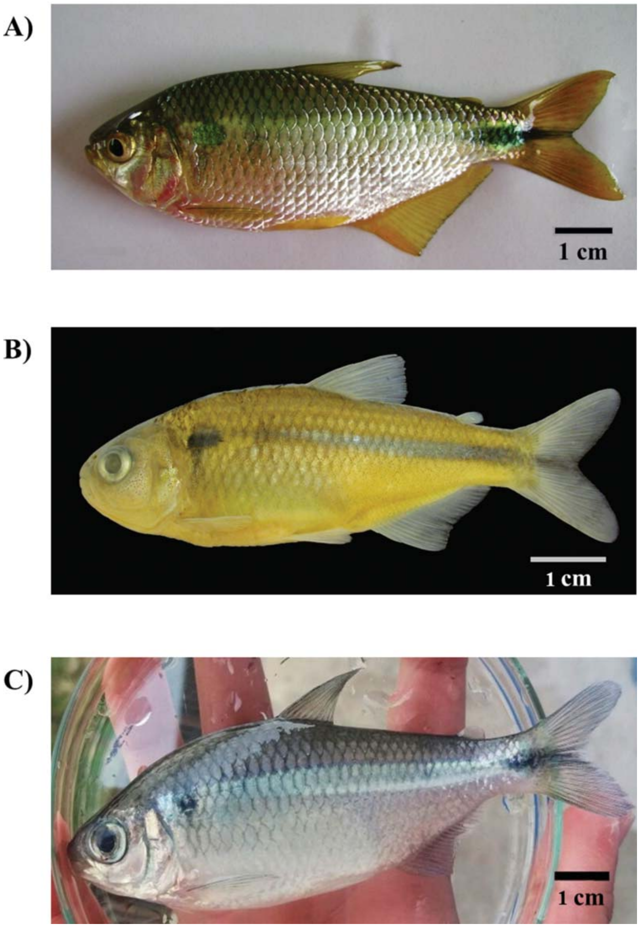

**Figure 1.** Lambari species currently farmed. (A) Yellow tail lambari (*Astyanax lacustris*); Photographed by Dr. Fabio Sussel. (B) Silver lambari (*Astyanax laticepes*); from Bertaco & Lucena (2010). (C) Atlantic forest lambari (*Deuterodon iguape*); Photographed by Thais C. P. Araujo.

### *The silver lambari* (Astyanax scarbiprinnis *complex)*

The complex *A. scarbripinnis* includes numerous morphotypes (Bertaco and Lucena, 2006, 2010; Castro et al., 2015). Their phylogeny and taxonomy remain uncertain; nevertheless, this group can be identified by a dark, lateral stripe extending to the tip of the middle of the caudal fin rays (Bertaco and Lucena, 2010). These species inhabit river headwaters of southern Brazil, Uruguay, and Argentina. They are found in cooler waters (13–21°C) with higher levels of dissolved oxygen (5.5–9.0 mg/L) (Abilhoa, 2007). Adults can reach 9.5 cm length, and males are smaller than females. First maturation occurs at 5.5 cm length (Veregue and Orsi, 2003; Abilhoa, 2007). Spawning occurs throughout the year but lower reproductive success occurs in winter. Feeding are based on terrestrial sources and includes insects and detrital particles of higher plants (Veregue and Orsi, 2003; Abilhoa, 2007). Nevertheless, their diets are variable and can change according with food availabilities (Abilhoa, 2007). The species *Astyanax laticeps* (Figure 1B) is a valid species of *A. scarbiprinnis* complex (Bertaco and Lucena, 2010) that have been exploited commercially in southern of Brazil (Dr. F. Sussel, personal communication). Taxonomic issues and difficulties in identifying each species of this complex are serious constraints to develop science-based knowledge to culture these lambari.

### *The Atlantic Forest lambari (*Deuterodon iguape*)*

The genus *Deuterodon* is widely distributed in coastal rivers of the Atlantic Forest Ecosystem (Lima et al., 2003; Virtule et al., 2008). This environment has several small watersheds, which lead to a large endemism (Pereira, 2010). The species *Deuterodon iguape* (Figure 1C) is endemic of the Ribeira de Iguape River, located on southeast coast of Brazil (Lima et al, 2003). This species is known as omnivorous tending to herbivorous (Virtule and Aranha, 2002; Mazzoni and Rezende, 2003); diet includes algae, seeds, leaves, zoobenthos, and zooplankton (Virtule and Aranha, 2002; Mazzoni and Rezende, 2003). Sexual maturity begins at 8 cm length and spawning occurs in spring and summer (Vitule et al., 2008).

## Status of lambari aquaculture

All literature on lambari fishery and culture comes from Brazil, although potential for commercial exploitation exists in many other Latin America countries and the USA. Lambari are one of the most common freshwater fish in Brazil (Garutti, 2003; Porto-Foresti et al., 2005; Silva et al., 2011a; Salaro et al., 2015; Valladão et al., 2016). The commercial exploitation of this fish was based on small scale fishery and started intended for nutritional human consumption some decades ago. Today, most of lambari production for this market is still wild caught. They are fished mainly in the rivers of Paraná watershed, where production has been about 1,068 t/yr (ICMbio–Instituto Chico Mendes, 2011), and sold in small stores and restaurants.

Lambari aquaculture has developed over the past two decades as an alternative income for smallholder rural farmers in Brazil. Production began to supply market demands for live bait for freshwater sport fishing, which remains the main market (Garutti, 2003; Porto-Foresti et al., 2005; Silva et al., 2011a, b; Salaro et al., 2015; Valladão et al., 2016). Studies on the salinity tolerances of *Deuterodon iguape* suggest it could also be used as live bait for marine recreational fishing, and even as a replacement of sardines for commercial tuna fishing (Gonçalves et al., 2015b). The species are also consumed largely as appetizer in bars, restaurants and even at home. In addition, lambari have potential in canned fish markets (Porto-Foresti et al., 2005). Recently, the aquaculture of the yellow tail lambari (*A. lacustris*) has expanded in inland areas of São Paulo State, Brazil, and some large farms (> 20 ha) have been set up.

Lambari are usually consumed whole, with bones and head, and sometimes with the viscera. Market studies show a high demand for them, which could double; nevertheless, market expansion has been limited by the irregular and seasonal fishery (Garutti, 2003; Silva et al., 2011a). If lambari aquaculture could be developed, it is likely that a large market for human consumption could be found in Brazil. Also, lambari consumed by poor people should increase substantially. Small indigenous fish consumed whole have a large potential to contribute to micronutrient intake (Hansen et al., 1998; Thilsted, 2012; Bogard et al., 2015a, b, Fiedler et al., 2016). Fishermen and farmers are unlikely to compete as they aim for different niche markets.

Lambari aquaculture is in early developing stages. There are no standard production practices. The main species produced is *A. lacustris*, but *A. laticeps* and *Deuterodon iguape* are also grown. A review of management strategies demonstrated that aquaculture production systems and practices are quite variable between producers (Table 1). Water use, liming, fertilization, feeding frequencies, and stocking densities largely differ between farms. To date, each producer has developed their own production strategies and management based on empirical practices or the adoption of previous experiences with other fish, such as tilapia and pacu (*Piaractus mesopotamicus*) (Silva et al., 2011b). In addition, the biology of lambari has only recently been described in the scientific literature. Farming aspects and bait markets have been described since the past decade (Garutti, 2003; Porto-Foresti et al, 2005; Silva et al., 2011a, b; Salaro et al., 2015; Valladão et al., 2016). Therefore, a full review

**Table 1.** Management practices adopted by lambari farmers in São Paulo State, Brazil. (Information on farm groups A to G was adapted from Silva et al., 2011).

| | Farm groups | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Management practice | Guanhanhã City Hall Aquac. Farm (present study) | A | B | C | D | E | F | G |
| Reproduction/ Hatchery | Hormone-induced spawning | Hormone-induced spawning | Hormone-induced spawning | Obtain seeds sharing fry to adults with other producers | Obtain seeds sharing fry to adults with other producers | Natural reproduction | Natural reproduction | Natural reproduction |
| Nursery | None | 40 days inside brood ponds | 30 days inside earthen ponds, 250 fry/m$^2$ | Earthen ponds, 44 fry/m$^2$ | None | None | None | 15 days inside brood ponds |
| Grow out system | Monoculture in earthen ponds | Monoculture in earthen ponds | Monoculture in earthen ponds | Polyculture with Patinga[a] | Monoculture in earthen ponds | Monoculture in earthen ponds | Polyculture with Curimbatá[b] | Monoculture in earthen ponds |
| Production period (months) | 7[c] | N/A | N/A | 4 | N/A | N/A | 4 | 2–4 |
| Fertilization regimes | Poultry manure (50 g/m$^2$) plus Chemical fertilizer (20 g/m$^2$) | Urea (3 g/m$^2$) plus rice bran (10 g/m$^2$) | No fertilization | No fertilization | No fertilization | No fertilization | No fertilization | No fertilization |
| Feed protein content (%) | 32 | 28 | 56–40 | 36 | 55–40 ground[d] | 40 | 38 ground[d] | 32 |
| Feeding frequency | 2/day | N/A | N/A | N/A | N/A | 3/day | N/A | N/A |
| Fish stocking density | 150 fry/m$^2$ | 10–30 juveniles/m$^2$ | 50 juveniles/m$^2$ | 17 juveniles/m$^2$ | 66–88 fry/m$^2$ | No control | 13 fry/m$^2$ | 20 juveniles/m$^2$ |
| Initial length (cm) | N/A | 3 | 2 | N/A | N/A | N/A | N/A | 1 |
| Final length (cm) | 8 | 9–10 | 7 | 8 | 6–8 | 6 | N/A | 5–12 |
| Sale price (US$)[e] | 5.50/kg | 3.70 – 4.60/kg | 0.02/unity (2 cm) 0.03–0.05/unity (7 cm) | 0.17/unity | 0.04/unity US$ 4.30/kg | 0.04/unity | 0.04/unity | 0.04 – 0.06/unity? |
| Market | Human consume and live bait | Live-bait | Live-bait | Live-bait | Human consume and live bait | Live bait | Live bait | Live bait |

[a] Patinga is a hybrid of *Piractus mesopotamicus* x *Piractus brachypomus* stocked at 0.7/m$^2$ and fed with 28% protein diet. The production period is 12 months, during which Lambari are harvested selectively.

[b] Curimbatá (*Prochidolus lineatus*) is a native freshwater omnivorous fish. It was stocked at 0.3/m$^2$ and was not fed.

[c] These data correspond to lambari production during the winter. Different results can be obtained in summer.

[d] Manually or mechanically grounded to obtain powder consistency.

[e] US$ 1.00 = R$ 3.15.

N/A = information not available.

of the available information on the social-ecological system and management is needed to set a baseline of current knowledge and define future research to develop scientifically based management strategies for improving lambari aquaculture.

A review of studies on pond management is summarized in Table 2. Garutti (2003) and Porto-Foresti et al. (2005) described a management strategy for lambari grow-out in semi-intensive earthen ponds. The practices described are similar to those developed by commercial producers (Sabbag et al., 2011; Silva et al., 2011). Nevertheless, fish productivities were higher on-station than on-farm; moreover, the experimental evidence was weak and unreplicated. Basic studies on stocking densities are preliminary (Vilela and Hayashi, 2001; Gonçalves et al., 2015a). Feeding amounts and frequencies have only been investigated in cage systems at low stocking densities (Hayashi et al., 2004; Meurer et al., 2005). Recommendations to perform sex reversal by hormone induction to improve production have been made without science assessments of production advantages (Bem et al., 2012).

Lambari breed throughout the year, although best results occur in spring and summer (Porto-Foresti et al., 2005; Salaro et al., 2015). Thus, breeding is not a constraint to the culture expansion. Natural breeding is used to seed ponds mainly in rural settlements, but also in medium-sized farms (Silva et al., 2011b). In these farms, spawning, nursery, and grow out are performed in the same pond, which lead to a wide size-heterogenic crop, no productivity control, and genetic issues (Silva et al., 2011b; Salaro et al., 2015). Nevertheless, natural reproduction makes small farmers independent from seed suppliers, which provide autonomy and allows the culture of lambari by communities with low incomes. The lack of seed and dependency on hatchery production are factors of failure for many poor, rural fish farmers throughout the world (Little et al., 2012). Therefore, the easy reproduction and obtaining seeds on-farm are important strengths for lambari production in rural communities.

A protocol for natural breeding was suggested by Garutti (2003) and Porto-Foresti et al. (2005). The broodstock earthen ponds should be stocked at a density of 10 fish/$m^2$, 3 males per female (Porto-Foresti et al., 2005). Garutti (2003) suggests maintain the broodstock in net cages inside grow-out ponds for 2–3 weeks. Such management allows the dispersion of larvae across the mesh and the removing of broodstock after breeding, avoiding cannibalism. Also, the use of *Eichhornia crassipes* macrophyte as substrates in concrete tanks leads to higher survival of *A. lacustris* eggs, since it allows the sticky eggs to adhere to the plant roots, improving protection from predation by insect larvae (Rezende et al., 2005). Nevertheless, there is no replicable and reliable evidence for any of these management practices to date.

**Table 2.** Management strategies used for lambari aquaculture.

| Production system | Guanhanhã City Hall Aquac. Farm (present study) Semi-intensive ponds | Sabbag et al., (2011) Semi-intensive ponds | Garutti (2003) Semi-intensive ponds | Gonçalves et al. (2015) Net-cages inside tilapia ponds | Porto-Foresti et al. (2005) Semi-intensive ponds | Vilela and Hayashy (2001) Net-cages |
|---|---|---|---|---|---|---|
| Species | *Deuterodon iguape* | *Astyanax lacustris* | *Astyanax lacustris* | *Deuterodon iguape* | *Astyanax sp.* | *Astyanax lacustris* |
| Production period (months) | 7 | 4 | 3 | 4 | 3–4 | 1–2 |
| Crops/year | 2 | N/A | 4.3 | 3 | 3–4 | N/A |
| Pond area/cage volume | 100 $m^2$ | 820 $m^2$ | 150–200 $m^2$ | 1 $m^3$ | N/A | <1 $m^3$ |
| Fertilization regime | | | | | | |
| • Organic fertilizer (g/$m^2$) | 50[a] | None | None | None | None | None |
| • Inorganic fertilizer (g/$m^2$) | 20 | None | 13 | None | None | None |
| Liming | Farmers sprinkle on pond bottoms without measuring amounts | Farmers sprinkle on pond bottoms without measuring amounts | None | None | None | None |
| Stocking seed | Fry | Larva | Larva | Fingerling | Fingerling | Fingerling |
| Stocking density | 150/$m^2$ | Not controlled[b] | Not controlled[b] | 700/$m^3$ | 50/$m^2$ | 124/$m^3$ |
| Water temperature (°C) | 20–23.2 | N/A | 15–30 | N/A | 25–28 | N/A |
| Water exchange (%) | 5.2–14.5[c] | N/A | 10 | N/A | N/A | 14.4 |
| Oxygen (mg/l) | 7.2–8.2 | N/A | > 3 | N/A | 4 | N/A |
| Diet protein content (%) | 32 | 28 | 32 | 32 | 38–40 | 45 |
| Feeding frequency | 2/day | 1/day | 3/day | N/A | 3/day | 3/day |
| Feed conversion ratio | 3.9–5.3 | 7.4 | N/A | 1.4 | N/A | 1.3 |
| Survival (%) | 12–47 | N/A | N/A | 88 | 70 | 100 |
| Final fish weight (g) | 1.5–4.5 | N/A | 10–20 | 9 | 15–20 | 56 |
| Productivity (kg/$m^2$) | 0.9–1.2 | 0,08 | 2.3 | 6.3 | 1.8–2.4 | N/A |

[a] Poultry manure.
[b] Natural breeding is performed inside grow-out ponds, without stocking density control.
[c] No water flow control relies on farmer practices. No water is changed during the first fortnight.
N/A = information not available.

Hormone-induced spawning was described for *A. lacustris* (Porto-Foresti et al., 2005; Sato et al., 2006; Felizardo et al, 2012) and for *D. iguape* (Lopes et al., 2013). Sato et al. (2006) and Felizardo et al. (2012) indicate satisfactory results using carp pituitary extract (6 mg/kg) in a single application for males and females of *A. lacustris* with a reproductive output ranging from 500 to 750 oocytes per gram of female. Porto-Foresti et al. (2005) suggest two applications (0.5 and 2.5 mg/kg) over a range of 12 hr. Double application (0.6 and 6 mg/kg) produced more oocytes per gram of female than a single application in *D. iguape* (Lopes et al., 2013). The use of synthetic gonadotropin was tested by Felizardo et al. (2012) resulting in 480–640 oocytes/cm of female. Farmers with adequate infrastructure and access to technology produce seeds by hormone induction of broodstock spawning using carp pituitary extracts (Silva et al., 2011b). These farmers exchange fingerlings for breeders with smaller farmers. Therefore, hormone-induced spawning is a feasible technique to improve fingerling production. Lopes et al. (2014) demonstrated that lambari hatcheries may be profitable; the internal rate of return may reach 34% and payback period 2.8 yr in the best scenario. Nevertheless, the investment (~US$ 110,000.00–US$ 1.00 = R$ 3.15) and risk are substantially high (Lopes et al., 2014). In addition, the economic impacts of the fingerlings price on smallholder farmers should be demonstrated.

Nutritional requirements for lambari species are unknown. Abimorad and Castellani (2011) inferred that essential amino acids for *A. lacustris* are similar to those for other low trophic level fish, such as Nile tilapia and common carp. Gonçalvez et al. (2014) evaluated the tissue fatty-acid composition of wild and farmed broodstock of *A. lacustris*. These authors concluded that lambari demand a large quantity of lipids for ovarian maturation, which are not provided by the available commercial diets. The replacement of fish meal and oil by vegetable has promoted satisfactory growth (Ferreira et al, 2014; Sussel et al., 2014), suggesting that lambari have a low dependence on fish meal/oil.

Diets formulated specifically to feed lambari are not available, although all producers use commercial feeds (Silva et al., 2011b). They choose diets based on pellet sizes, which the fish are able to swallow (Garutti, 2003; Silva et al., 2011b). Some farmers also fertilize ponds to increase natural food. The amount of food supplied, feeding frequencies and protein contents in diets vary widely between farms (Table 1). Thus, at present, feeds given to lambari are incompatible with their nutritional requirements. Additionally, they are very expensive. Clearly, a new approach to lambari feeding and nutrition in culture is needed.

Transportation of live fish is a critical issue in aquaculture. Matrices, larvae, fry and fingerlings are frequently moved among farms. Lambari culture also includes the transportation of harvested live-fish traded in bait market. Thus, high survival during transport is mandatory. Even so, no protocol specific for lambari transportation was developed. Farmers generally transport these bait-fish in plastic bags filled with water and air, in Styrofoam box provided or not with aeration, in 200-L polyethylene barrels or in transfish, which is specially adapted trucks. Fish density, water quality, time of transport and general handle used are based in the previous experience of each farmer because no scientific-based information is available. A study on stress tolerance in *Astyanax aff. bimaculatus* indicates that the use of turmeric (*Curcuma longa*) supplementation in the diet supplied before transport is effective to reduce mortality (Ferreira et al., 2017), yet the economic feasibility of this procedure should be investigated. Research on live transportation of lambari is certainly an important avenue to improve the production chain of these species.

Lambari culture is still in initial stages. More applied, replicated scientific work on breeding, nutrition, transportation and general management are needed. Also, current studies are not relevant to most rural farmer demands, since they are small producers with low incomes. Nevertheless, it is evident the potential of lambari culture to promote economic development and food security for rural poor people in Brazil.

## Sustainability indicators—A case study from Brazil

Lambari culture has potential to be developed in sustainable way with low environment impact. To estimate such prospects, it was performed a preliminary assessment of environmental sustainability of lambari (*D. iguape*) aquaculture at a single semi-intensive farm placed in a coastal protected area.

### *Study area—Environmental and social aspects*

The study was conducted on Guanhanhã City Hall Aquaculture Farm (24°12’26.12” S, 47°2’48.24” W; Figure 2) in the Southern hemispheric winter. This farm is located in a rural community bounded by the Sea Mountains State Park, an Atlantic Rain Forest protected area adjacent to the ocean in the southeast of Brazil. Over the past 40 yr, this area has been the center of several conflicts between rural communities and the government (Santos, 2008). Today, about 800 poor families are allowed to live in this area as long as their livelihoods

**Figure 2.** Location of the Guanhanhã City Hall Aquaculture Farm (24°12′26.12″ S, 47°2′48.24″ W).

are in accordance with the park aims (Fundação Florestal, 2008; Santos, 2008).

Lambari (*D. iguape*) aquaculture has been introduced to promote sustainable development for a poor community living in Sea Mountains State Park. Some of the occupants have previous experiences with tilapia aquaculture, but this species was banned from the Park area as being a risk to native biodiversity (Santos, 2008). Traditionally, lambari have been caught from the local rivers for direct consumption and informal trade in the area. Therefore, the introduction of lambari aquaculture could be an alternative income source, improving community food security, and conserving local biodiversity.

It was assessed the sustainability of grow-out phase of lambari production on three earthen ponds (0.01 ha each) from April to October, 2015. Farm management, like fish stocking density, liming, fertilizing and feeding regimes, followed usual farmer procedures (Tables 1, 2). Over this period, samples of water, sediment, animals, feed, fertilizer and greenhouse gases were collected fortnightly and, subsequently, total carbon, nitrogen, phosphorous and energy were accounted. Solid samples were analyzed by using a CHNS Elementar Analyser – Vario MACRO Cube for total carbon and nitrogen quantify and by Photometric Metavanadate Methodology (Michelsen, 1957) for phosphorous determination. Water samples were analyzed by using an Elementar Analyser – Vario TOC Select for total carbon and nitrogen, and by Stannous Chloride Methodology (APHA 2005, 4500-P D) for phosphorous determination. Gas samples were analyzed by using a Shimadzu – GC-2014 Permanent Gas Analyzer for determining greenhouses gas. The energy content in animals, diet and fertilizer were determined by Calorimetric Bomb Methodology, using an isoperibol calorimeter IKA C2000 basic. Total biomass produced was evaluated at the harvest. The environmental indicators of sustainability were calculated according to Boyd et al. (2007) and Valenti et al. (2011) and include three main aspects: (1) use of natural resources, (2) efficiency of use of natural resources, and (3) release of pollutants to the environment.

## Preliminary results of environmental indicators of sustainability

The current system of lambari culture sequestered greenhouse gases from atmosphere, but performed unsatisfactorily in many measures of sustainability examined (Table 3). The system showed high consumption of natural resources, and low resource use efficiencies. The main issues were related to water and nutrient uses. Lambari aquaculture analyzed consumed about three times more water, phosphorous and nitrogen per ton of fish than other comparable semi-intensive aquaculture systems in Asia, Africa, and Brazil (Table 3). Nevertheless, the lambari culture was more efficient in

**Table 3.** Environmental indicators of sustainability: Comparison between lambari aquaculture in Guanhanhã City Hall Aquaculture Farm and other selected aquaculture systems.

| | Lambari aquaculture | Carp polyculture[a] | | Prawn-tilapia IMTA[b] | General Semi-intensive aquaculture[c] | Tilapia cage culture[d] |
|---|---|---|---|---|---|---|
| Land use (ha/t) | 1.2–1.6 | N/A | N/A | 0.22 | 0,5–1.6 | 0.01 |
| Water use ($m^3$/t) | > 150,000 | No water control | No water change | 6,814 | 1,200–100,000 | 4.69 |
| Energy use (MJ/t) | 92,000–125,000 | N/A | N/A | 66,000 | 15,600 | 98,000 |
| Nutrients use (kg/t) | | | | | | |
| • Phosphorous | 121–164 | 60 | 13 | 19 | 32 | 10 |
| • Nitrogen | 227–307 | N/A | N/A | 83 | 141 | 82 |
| • Carbon | 2,100–2,900 | 8,000 | 1.650 | 914 | N/A | N/A |
| Efficiency in energy use (%) | 19–26 | N/A | N/A | 39 | 36 | 5 |
| Efficiency in nutrients use (%) | | | | | | |
| • Phosphorous | 13–18 | N/A | N/A | 29 | 22 | 17 |
| • Nitrogen | 25–39 | 4 – 7 | 11 | 26 | 15 | 21 |
| • Carbon | 20–25 | 7–12 | 16–22 | N/A | N/A | N/A |
| Loads to water (kg/t) | | | | | | |
| • Phosphorous | 33–96 | N/A | N/A | 5 | <8 | 57 |
| • Nitrogen | 8–374 | N/A | N/A | 6 | <36 | N/A |
| Loads to sediment (kg/t) | | | | | | |
| • Phosphorous | 54–70 | N/A | N/A | 1 | 10 | <1 |
| • Nitrogen | 150–360 | N/A | N/A | 2 | 17 | N/A |
| • Carbon | >1,000 | N/A | N/A | 244 | N/A | N/A |
| Loads to/from atmosphere (kg/t)[e] | | | | | | |
| • Carbon dioxide equivalent ($CO_2e$) | −32,000 to −385,000 | N/A | N/A | −241 ± 173 | N/A | N/A |

[a] Pucher et al. (2015).
[b] Proença (2013); IMTA = Integrated Multi-Trophic Aquaculture.
[c] Modified from Boyd et al. (2007), Costa-Pierce (2010), Gross and Boyd (1998), Gross et al. (2000) and Islam (2002).
[d] Moura et al. (2016).
[e] Negative values indicate absorption.
N/A = information not available.

assimilating energy and nitrogen. Lambari productivity was also very low when compared to those systems. Nevertheless, this study was performed during autumn and winter; better productivity can be obtained in the warmer season, which will change all indicators analyzed because they take into account the biomass output. Preliminary studies showed a productivity of ~2 t/ha in a 5 months cycle (unpublished data) during spring and summer.

The reasons for the poor performance of the system were inappropriate pond management, diets and year season. Commercial feed was the main source of nutrients as found in other aquaculture systems (Boyd and Tucker, 1998; Boyd et al., 2007; David et al., 2017). Most of the nutrients in the supplied feeds were lost to the environment as pollutants. Nutrient loss is a common issue in several aquaculture systems (Boyd and Tucker, 1998; Moura et al., 2016); nevertheless, in this assessment the waste loads were higher, and there were high feed conversion ratios, and low fish productivities (Table 3). Thus, the lambari probably ate little of the feed supplied. Therefore, the feed, an expensive resource (economically and environmentally), was really working as a pond fertilizer. In conclusion, the aquaculture system used on Guanhanhã City Hall Aquaculture Farm was inefficient and need several modifications to improve production, reduce natural resources use and decrease environmental potential impact. Nevertheless, the study showed the aspects that should be improved to enhance sustainability.

Aquaculture has potential to not follow the past path of terrestrial food production, which negatively influences on the biodiversity (De Silva et al., 2009). For this, the use of exotic species is widely discouraged (Naylor et al., 2001; Ross et al., 2008; De Silva et al., 2009). Lambari aquaculture, in contrast to tilapia aquaculture in Brazil, offers no risk of impact to local biodiversity, no hormone/pesticide releases, and can be much more environmentally friend than intensive terrestrial plant and animal protein production (Costa-Pierce et al., 2012). Moreover, an adequate management regime can be devised to improve the system efficiency. For example, changes in feed quality, feed frequency, fertilization regimes, and water exchange rates reduced nutrient and water use six times in semi-intensive carp polyculture in Vietnam (Pucher et al., 2015). Also, non-fed aquaculture and integrated multi-trophic systems can be used to improve resource use efficiency and decrease the load of pollutants discharged to the environment.

## Prospects and challenges for lambari aquaculture in rural areas in Brazil

Lambari aquaculture for the social-ecological development of poor rural communities related or not with

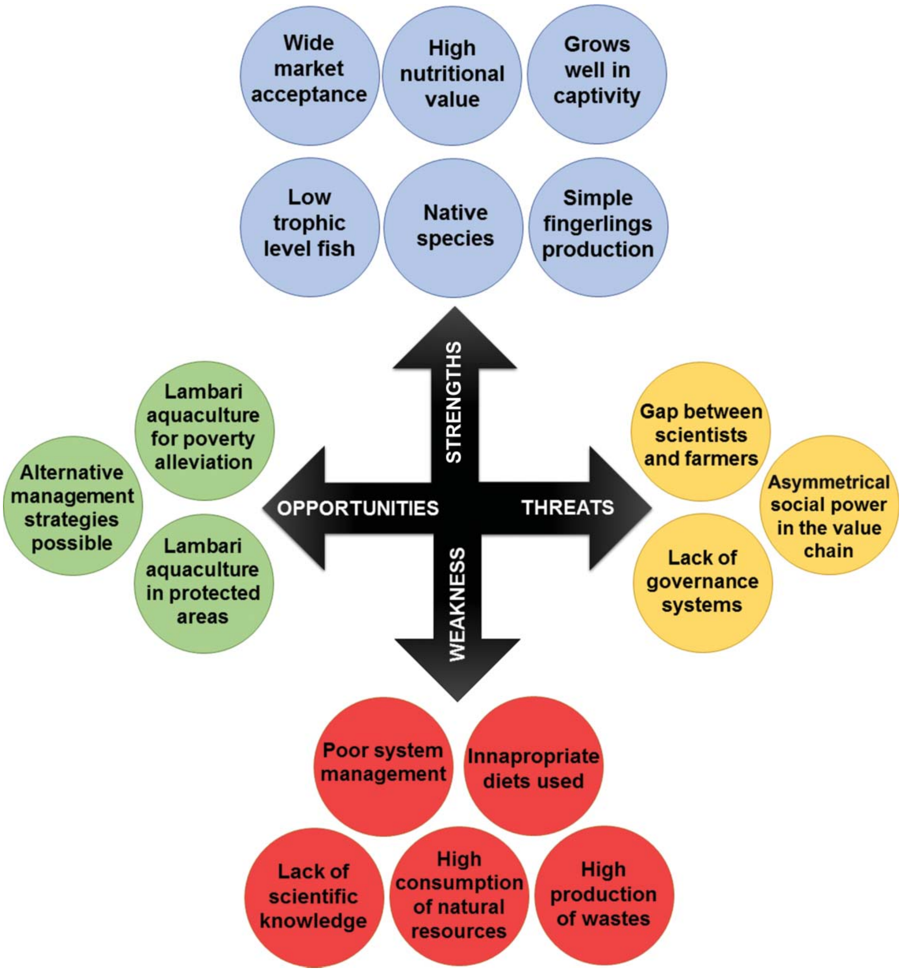

**Figure 3.** SWOT analysis of lambari aquaculture in Brazil.

conservation areas is very promising in Brazil. To make it happen in a resilient and sustainable way is necessary to identify the bottlenecks in the production chain and set goals for improving it. An analysis of Strengths, Weakness, Opportunities and Threats (SWOT) was performed (Figure 3), to assess the prospects and challenges for lambari aquaculture development. Actions for seed production, feed, management and market development were also recommended to lay out a more sustainable pathway for development (Table 4).

### *Seed*

Seed production is feasible year-round. Constant seed availability allows regularization of markets, reduction of economic risk and start the culture in the warm season, where winter is a limiting factor. Seed production is possible by simple natural breeding methods or hormone-induced spawning using carp pituitary extracts. Nevertheless, both methods have been used by farmers without scientifically derived protocols. Large scale hatcheries are feasible, but represent a high capital cost for governments and farmers. In addition, may create dependency and reinforce income inequality in the social-ecological value chain. Therefore, seed production should be improved by developing simple, replicable protocols for natural breeding on farm as they can be cheap, efficient, and simple. Natural hatcheries are recommended for all farmers, but especially for poor communities, which have little investment money and are more vulnerable to power asymmetries along the value chain. The benefits of natural breeding for poor farmers have been demonstrated for tilapia aquaculture in Bangladesh (Barman and Little, 2006; 2011). In this country, fingerlings produced are stocked in grow-out ponds and the remainders are sold for other small farms locally, saved for further culture, or even consumed in household, resulting in additional income and welfare improvement (Barman and Little, 2006). Similar results could be achieved by developing lambari aquaculture in Brazil.

Further research in lambari fingerling production should be conducted to improve genetic lines, increase productivity and reduce heterogeneity of size. Information on management and transportation of larvae, fry and fingerlings to avoid mortality are also essential. The

**Table 4.** Recommendations for the sustainable development of lambari aquaculture in Brazil.

| | Current status | Problems | Recommendations |
|---|---|---|---|
| Seed procurement | • Natural breeding in earthen ponds; natural spawning, nursery and grow out occur in the same pond.<br>• Hormone-induction of spawning using carp pituitary extracts is used in large farms. Farmers with access to this technology provide seed for small farms. There are no specialized hatcheries. | • Natural breeding can lead to no control over the production process, high predation, and genetic issues.<br>• Hormone-induced spawning requires knowledge and investment. | • Specialized hatcheries are not recommended because create a dependency in grow-out farms. Dependency on commercial hatcheries is an accountable for failures of many rural fish farmers worldwide.<br>• Encourage the use of natural reproduction; it is a simple, efficient and cheap alternative for small and medium-scale farmers.<br>• Encourage the use of hapas for maintain broodstock and/or macrophytes as substrates for larvae. |
| Feed | • Use of commercial feed. Producers choose diets based on pellet size, which the fish are able to swallow, generally of high protein content. | • Commercial diets are incompatible with fish nutritional requirements, leading to low productivity, high production cost and high wastes discharged to the environment. | • Develop a cheap commercial diet to lambari<br>• Develop fertilization procedures to increase natural foods. |
| Management | • Semi-intensive system in earthen ponds.<br>• No water flow, exchange or fertilization protocols.<br>• Each producer has developed their own production strategies based on empirical practices or previous experiences.<br>• No transportation protocol. | • The lack of a protocol for better management practices leads to low productivities, low profits, high wastes and mortality in transportation. | • Develop management protocols to improve system efficiencies.<br>• Explore polyculture and integrated-system opportunities.<br>• Develop transportation protocols for every development phase of lambari. |
| Market | • Bait for sport fishing is the largest market.<br>• Restaurants and small shops sell lambari as appetizer. | • Human consumption is underestimated. | • Introduce lambari into local markets for poverty alleviation and health benefits.<br>• Integrate lambari into existing rural farms.<br>• Develop community-based tourism markets for lambari aquaculture in the natural parks and protected areas. |

use of hapas for maintaining broodstock (Garutti, 2003), and macrophytes as substrates for eggs and larvae (Rezende et al., 2005) could be important steps.

## Feed

Currently, lambari are fed high-protein commercial feeds. There is no scientific basis established for a feeding protocol. Feeds offered do not match fish nutritional requirements and most are lost as waste to the aquatic environment. Lambari aquaculture uses feeds that are inefficient, too expensive and cause negative environmental impacts. The goals for sustainable aquaculture include reduce feed dependence in fish meal and fish oil, improve resource-use efficiency, and reduce wastes (Costa-Pierce, 2010). Thus, research to determine the basis of a cheap and efficient diet for lambari is an important avenue.

On the other hand, unfed systems may be feasible for lambari culture. Lambari have highly flexible feeding habit capable to adapt to changes in available food (Cassemiro et al., 2002). This species can eat natural foods, which may be enhanced by means of fertilization grow-out ponds (Knud-Hansen et al., 1991; Diana et al., 1994), eliminating the need for added commercial feeds. Organic and chemical fertilizers are widely available in Brazil and pond fertilization requirements can be managed by the farmers with simple and cheap technology (Knud-Hansen et al., 2003). Thus, lambari aquaculture in fertilized ponds is recommended for poor communities.

Increased productivity through techniques that increase microbial biomass inside ponds may also be an alternative. Systems based on carbon/nitrogen control associated with periphyton enhancement use resources derived from agricultural byproducts and natural food manipulation (Asaduzzaman et al., 2010). By adding carbon, microbial communities convert nitrogen wastes into detrital bioflocs, containing microorganisms and non-live organic matter that can be eaten by cultured organisms (Bosma and Verdegem, 2011). This technology improves the overall nutrient efficiency of the pond system (Asaduzzaman et al., 2010), although the input of energy is very high to replace the oxygen consumed by microorganisms. Similar systems could be tested with lambari to decrease the use of commercial diet and increase productivity.

## Farm system and management

Currently, lambari farm is based on semi-intensive earthen ponds and management has been developed by farmers based on their own empirical practices. Management is performed in diverse ways among farms in terms of liming, fertilizing, stocking densities, water exchange, feeding, and harvest. Simple and inexpensive adjustments can improve system management practices. Water quality and water flow control, accurate fertilization to increase natural food availabilities, and use of high quality inputs are crucial for semi-intensive systems successes or failures (Michielsens et al., 2002; Rahman et al., 2008; Pucher et al., 2015; Ali et al., 2016). All of these topics should be addressed and improved in lambari culture to attain good management practices, and increase profitability and resource use efficiency.

The effect of use of substrates to develop periphyton and polycultures are promising practices. The introduction of substrates for periphyton growth in semi-intensive ponds increases primary and secondary production (Azim et al., 2002). Some farmers have tested polyculture systems adding high-value species in lambari ponds. Polyculture with freshwater prawns have a good potential and has been investigated (Marques et al, 2016). Nevertheless, there is no scientific basis for using substrates or polycultures in lambari culture yet and these topics are certainly important avenues for new research.

Aquaculture wastes are a rich source of nutrients that can be used by integrating systems with other aquatic and terrestrial cultures (Lin and Yi, 2003). Integration is suitable for small farms as their production is usually more diversified than larger industrial-scale farms. Integrated Multi-Trophic Aquaculture (IMTA) improves efficiencies in natural resource use, while offering additional commercial items for sale, reducing economic risk (Chopin et al., 2001). The use of pond effluents and sediments for fertilization of greens and other vegetable crops may be a good practice to increase the environmental and economic sustainability of lambari culture. In addition, lambari can be cultured in irrigation channels, which are common in Brazilian farms. This kind of culture may represent an optimization of space and a diversification of products in terrestrial farms, increasing sustainability.

Modern intensified aquaculture techniques, such as high density cultures in large net-cages automatically fed and raceways, demand high-quality well-balanced diets, which are non-existent for lambari. In addition, these systems need high investment and technical expertise, which are unaffordable by small farmers in developing countries. Thus, these intensive systems are presently unfeasible to produce lambari.

## *Markets*

Market access and appropriate technology are necessary conditions to aquaculture provide good quality food, income, and employment for marginalized people (Belton et al., 2012; Béné et al., 2016). Lambari production has grown over the past years combined with the sport fishing and tourism markets in Brazil. Lambari have been used widely as live baits and as appetizers. Demands are growing and markets are expanding. Furthermore, studies demonstrate a new market opportunity for lambari as a more sustainable replacement of sardines for commercial tuna fishing (Gonçalves et al., 2015b). Market expansion has attracted an emergent commercial sector with investment power and larger infrastructure, which certainly will have access to market and available technology. The rural lambari farms are smallholders, who are unable to compete with larger producers for large markets. Nevertheless, small farms use cheaper technologies and are frequently placed close to niche markets, which give them an important advantage. For instance, the transportation of live fish for long distances is very expensive and can lead to losses due to transportation stress, but it is cheaper and simpler at farm gate. Therefore, presumable there is market for products from farms operating in different scales of production and both simple and sophisticated technology should be developed to attend different farm categories.

The market for human consumption of lambari as a nutrient source rather than as an appetizer has been underestimated by farmers and scientists. Studies performed in Brazil show a great acceptance of lambari as food and demand can increase with new supplies (Silva et al., 2011a). Fish consumption is a better source of protein when compared to poultry, cattle, and pork (Costa-Pierce, 2016). Small fish consumed with bones, head and viscera, are an important source of vitamins for vulnerable populations such as women and children (Thilstead et al., 2016). Thus, the consumption of lambari as high quality human food in cities, small towns and in programs to eradicate malnutrition has a large potential.

Lambari aquaculture can be introduced in existing agriculture/livestock farms or in wild protected areas as an alternative income source. In Brazil, food production for human consumption is based on small family farms, while industrial agriculture produces commodities such as soybeans for foreign markets (Brazil Gov News, 2015). The small farms usually show diversified crops and part of production is for the family subsistence. Culture of lambari into these farms adds a new product, which may share the market distribution channels previously used to output the other crops. Furthermore, lambari may be farmed in harmony with environmental protection. Thus, lambari may be reared by indigenous or poor communities living in reserves and protected areas, which is an environmentally sustainable opportunity. Protected areas offer a growing niche market for sustainable, ecologicallyoriented aquaculture to produce certified fish for human consumption or related to community-based tourism. Therefore, lambari production may increase food security and income in small farms and protected areas and ensure the permanency of traditional people in home.

## Concluding remarks

Lambari aquaculture can become an important tool for promoting sustainable development of rural populations in Brazil and other developing countries, including in zones of environmental protection. Nevertheless, its culture is in the initial stages and requires large research effort to obtain essential information. Market is diversified and includes baitfish use for sport and commercial fisheries and human consume as appetizers or food for nutrition. Exist a large diversification in culture systems and management, and consequently in the productivity. Poor management practices are frequent and science-based studies are still insufficient to provide reliable technology to match rural farmer necessities. Simple, alternative strategies are needed to improve system efficiencies. A well-designed on-station and on-farm research agenda and protocols (Costa-Pierce, 2002) would be a useful tool to improve culture performance in a short term.

Food production systems consistent with community needs and conservation of ecosystem goods and services should be developed in mega biodiverse countries like Brazil. Lambari culture may be planned to match such characteristics. If aquaculture is the solution for food production in the Anthropocene (Costa-Pierce, 2016), indigenous low-trophic level small-fish with high nutritional value, such as lambari, will play a vital role.

## Acknowledgments

The authors express the most sincere thanks to Dr. Fábio Sussel, Dr. Newton J. R. Silva and Fernando H. Gonçalves, MSc, for providing essential information on lambari aquaculture. The authors also thank the Agricultural Department of the City of Peruíbe for assistance with the collection of the data used to calculate the sustainability indicators.

## Funding

This work was supported by the São Paulo Research Foundation under Grants #FAPESP 10/52212–3, #FAPESP 2015/02143-9 and #FAPESP 2016/03085-5, as well as The National Council for Scientific and Technological Development under Grants #CNPq 562820/2010-8 and #CNPq 406069/2012-3.

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## References

Abilhoa, V. Natural history aspects of *Astyanax scabripinnis* Jenyns (Teleostei, Characidae) in an Araucaria Forest stream in southern Brazil. *Rev. Bras. Zoologia*, **24**: 997–1005 (2007).

Abimorad, E. G. and D. Castellani. Amino acid requirements of lambari-do-rabo-amarelo based on whole body and muscle composition. *Bol. Inst. Pesca*, **37**: 31–38 (2011).

Ali, H., K. Murshed-e-Jahan, B. Belton, G. C. Dhar, and H. O. Rashid. Factors determining the productivity of mola carplet (*Amblypharyngodon mola*, Hamilton, 1822) in carp polyculture systems in Barisal district of Bangladesh. *Aquaculture*, **465**: 198–208 (2016).

Andrian, I. F., D. Peretti and D. Lambrecht. Recursos alimentares explorados por *Astyanax* (Characiformes, Characidae) em diferentes bacias hidrográficas. *Arquivos Museu Dinâmico Interdisciplinar*, **10**: 21–27 (2006).

APHA (American Public Health Association). *Standard Methods for the Examination of Water and Waste Water*. Washington DC, USA: APHA (2005).

Asaduzzaman, M., M. A. Wahab, M. C. J. Verdegem, R. K. Adhikary, S. M. S. Rahman, M. E. Azim and J. A. J. Verreth. Effects of carbohydrate source for maintaining a high C:N ratio and fish driven re-suspension on pond ecology and production in periphyton based freshwater prawn culture systems. *Aquaculture*, **30**: 37–46 (2010).

Azim, M. E., M. C. J. Verdegem, H. Khatoon, M. A. Wahab, A. A. Van Dam, and M. C. M. Beveridge. A comparison of fertilization, feeding and three periphyton substrates for increasing fish production in freshwater pond aquaculture in Bangladesh. *Aquaculture*, **212**: 227–243 (2002).

Barman, B. K. and D. C. Little. Nile tilapia (*Oreochromis niloticus*) seed production in irrigated rice-fields in Northwest Bangladesh — an approach appropriate for poorer farmers? *Aquaculture*, **261**: 72–79 (2006).

Barman, B. K. and D. C. Little. Use of hapas to produce Nile tilapia (*Oreochromis niloticus* L.) seed in household foodfish ponds: A participatory trial with small-scale farming households in Northwest Bangladesh. *Aquaculture*, **317**: 214–222 (2011).

Belton, B., M. M. Haque, and D. C. Little. Does size matter? Reassessing the relationship between aquaculture and poverty in Bangladesh. *J. Dev. Stud.*, **48**: 904–922 (2012).

Bem, J. C., C. S. Fontanetti, J. A. Senhorini and P. P. Parise-Maltempi. Effectiveness of estradiol valerate on sex reversion in *Astyanax altiparanae* (Characiformes, Characidae). *Braz. Arch. Biol. Technol.*, **55**: 283–290 (2012).

Béné, C., R. Arthur, H. Norbury, E. H. Allison, M. Beveridge, S. Bush, L. Campling, W. Leschen, D. C. Little, D. Squires, S. H. Thilsted, M. Troell, and M. Williams. Contribution of fisheries and aquaculture to food security and poverty reduction: assessing the current evidence. *World Dev.*, **79**: 177–196 (2016).

Bertaco, V. A. and C. A. S. Lucena. Redescription of *Astyanax obscurus* (Hensel, 1870) and A. laticeps (Cope, 1894) (Teleostei: Characidae): two valid freshwater species originally described from rivers of Southern Brazil. *Neotrop. Ichthyol.*, **8**: 7–20 (2010).

Bogard, J. R., A. L. Hother, M. Saha, S. Bose, H. Kabir, G. C. Marks, and S. H. Thilsted. Inclusion of small indigenous fish improves nutritional quality during the first 1000 days. *Food Nutr. Bull.*, **36**: 276–289 (2015a).

Bogard, J. R., S. H. Thilsted, G. C. Marks, M. A. Wahab, M. A. R. Hossain, J. Jakobsen, and J., Stangoulis. Nutrient composition of important fish species in Bangladesh and potential contribution to recommended nutrient intakes. *J. Food Compos. Anal.*, **42**: 120–133 (2015b).

Bosma, R. H. and M. C. J. Verdegem. Sustainable aquaculture in ponds: principles, practices and limits. *Livestock Sci.*, **139**: 58–68 (2011).

Boyd, C. E. and C. S. Tucker. *Pond Aquaculture Water Quality Management*. Boston, USA: Kluwer Academic Publisher (1998).

Boyd, C. E., C. Tucker, A. McNevin, K. Bostick, and J. Clay. Indicators of resource use efficiency and environmental performance in fish and crustacean aquaculture. *Rev. Fish. Sci.*, **15**: 327–360 (2007).

Brazil Gov News – Presidency of the Republic of Brazil. Agricultura Familiar produz 70% dos alimentos consumidos por brasileiro. Available from http://www.brasil.gov.br/economia-e-emprego/2015/07/agricultura-familiar-produz-70-dos-alimentos-consumidos-por-brasileiro. Accessed in Jul/2016 (2015).

Cassemiro, F. A. S., N.S. Hahn and R. Fugi. Avaliação da dieta de *Astyanax altiparanae* Garutti and Britski, 2000 (Osteichthyes, Tetragonopterinae) antes e após a formação do reservatório de Salto Caxias, Estado do Paraná, Brasil. *Acta Sci. Biol. Sci.*, **24**: 419–425 (2002).

Castro, J. P., M. O. Moura, O. Moreira-Filho, O. A. Shibatta, M. H. Santos, V. Nogaroto, M. R. Vicari, M. C. Almeida, and R. F. Antoni. Diversity of the *Astyanax scabripinnis* species complex (Teleostei: Characidae) in the Atlantic Forest, Brazil: species limits and evolutionary inferences. *Rev. Fish Biol. Fisheries*, **25**: 231–244 (2015).

Chopin, T., A. H. Buschmann, C. Halling, M. Troell, N. Kautsky, A. Neori, G. P. Kraemer, J. A. Zertuche-González, C. Yarish, and C. Neefus. Integrating seaweeds into marine aquaculture systems: a key toward sustainability. *J. Phycol.*, **37**: 975–986 (2001).

Costa-Pierce, B. A. Farming systems research and extension methods for the development of sustainable aquaculture ecosystems, pp. 103–124. In: *Ecological Aquaculture: The Evolution of the Blue Revolution*. Blackwell Science, Oxford, UK: Blackwell Science (2002).

Costa-Pierce, B. A. Sustainable ecological aquaculture systems: the need for a new social contract for aquaculture development. *Mar. Technol. Soc. J.*, **44**: 88–112 (2010).

Costa-Pierce, B. A. Ocean foods ecosystems for planetary survival in the Anthropocene. *Keynote Speech at the World Nutrition Forum: Driving the Protein Economy*, Vancouver, B. C., Canada (2016).

Costa-Pierce, B. A., D. M. Bartley, M Hasan, F. Yusoff, S. J. Kaushik, K. Rana, D. Lemos, P. Bueno and A. Yakupitiyage. Responsible use of resources for sustainable aquaculture, pp. 113–147. **In**: *Farming the Waters for People and Food, Proceedings of the Global Conference on Aquaculture 2010* (R. P. Subasinghe, J. R. Arthur, D. M. Bartley, S. S. De Silva, M. Halwart, N. Hishamunda, C. V. Mohan, and P. Sorgeloos. Eds). Phuket, Thailand: FAO, Rome and NACA, Bangkok (2012).

David, F. S., D. C. Proença, and W. C. Valenti. Phosphorus budget in integrated multi-trophic aquaculture system with Nile Tilapia, *Oreochromis niloticus*, and Amazon River Prawn, Macrobrachium amazonicum. *J. World Aquac. Soc.* Early view (2017). doi:10.1111/jwas.12404.

De Silva, S. S., T. T. T. Nguyen, G. M. Turchini, S. Upali, U. S. Amarasinghe, and N. W. Abery. Alien species in aquaculture and biodiversity: a paradox in food production. *AMBIO: A J. Hum. Environ.*, **38**: 24–28 (2009).

Diana, J. S., C. K. Lin, and K. Jaiyen. Supplemental feeding of tilapia in fertilized ponds. *J. World Aquac. Soc.*, **25**: 497–506 (1994).

Esteves, K. E. Feeding ecology of three *Astyanax* species (Characidae, Tetragonopterinae) from a floodplain lake of Mogi-Guaçú River, Paraná River Basin, Brazil. *Environ. Biol. Fishes*, **46**: 83–101 (1996).

FAO. *Strategic Work of FAO to Reduce Rural Poverty*. Rome: FAO (2017).

Felizardo, V. O., L.D. S. Murgas, E. S. Andrade, P. A. López, R. T. F. Freitas, and M. R. Ferreira. Effect of timing of hormonal induction on reproductive activity in lambari (*Astyanax bimaculatus*). *Theriogenology*, **77**: 1570–1574 (2012).

Ferreira, P. M. F., L. S. Nascimento, D. C. Dias, D. M. V. Moreira, A. L. Salaro, M. B. D. Freitas, A. P. S. Carneiro and J. A. S. Zuanon. Essential oregano oil as a growth promoter for the yellowtail tetra, Astyanax altiparanae. *J. World Aquac. Soc.*, **45**: 28–34 (2014).

Ferreira, P. M. F., J. S. Rocha, J. R. Gomes, D. W. Caldas, M. T. S. Martins, J. M. Oliveira, A. L. Salaro and J. A. S. Zuanon. *Curcuma longa* supplementation in the diet of *Astyanax aff. bimaculatus* in preparation for transport. *Aquacult. Res., Early view* (2017). doi:10.1111/are.13277.

Fiedler, J. L., K. Lividini, E. Drummond, and S. H. Thilstead. Strengthening the contribution of aquaculture to food nutrition security: the potential of a vitamin A-rich, small fish in Bangladesh. *Aquaculture*, **452**: 291–303 (2016).

Fundação Florestal. Plano de Manejo do Parque Estadual da Serra do Mar. São Paulo. Available at: http://fflorestal.sp.gov.br/planos-de-manejo/planos-de-manejo-planos-concluidos/. Accessed 07.16. (2008).

Garutti, V. *Piscicultura Ecológica*. São Paulo: Ed. UNESP (2003).

Garutti, V. and H. A. Britski. Descrição de uma espécie nova de *Astyanax* (Teleostei: Characidae) da bacia do alto rio Paraná e considerações sobre as demais espécies do gênero na bacia. *Comunicações Museu Ciênc. Tecnol. PUCRS - Série Zoologia*, **13**: 65–88 (2000).

Gomiero, L. M. and F. M. S. Braga. O lambari Astyanax altiparanae (Characidae) pode ser um dispersor de sementes?. *Acta Sci.: Biol. Sci.*, **25**: 353–360 (2003).

Gonçalves, F. H., N. J. R. Silva, and M. B. Henriques. Economic analysis of *Deuterodon iguape* cultured in Nile tilapia ponds. *Bol. Inst. Pesca*, **41**: 579–589 (2015a).

Gonçalves, F. H., N. J. R. Silva and M. B. Henriques. Tolerance of lambari Deterodon iguape to different salinities: new perspectives of market. Conference paper in: Aquaculture 2015, Montpellier, France (2015b).

Gonçalvez, L. U., G. Parisi, A. Bonelli, F. R. Sussel and E. M. M. Viegas. The fatty acid compositions of total, neutral and polar lipids in wild and farmed lambari (*Astyanax altiparanae*) (Garutti & Britski, 2000) broodstock. *Aquacult. Res.*, **45**: 195–203 (2014).

Gonwami, R., S. Saha, and P. Dasgupta. Sustainability assessment of smallholder farms in developing countries. *Agroecol. Sustain. Food Syst.*, Early view (2017). doi:10.1080/21683565.2017.1290730.

Gross, A. and C. E. Boyd. A digestion procedure for the simultaneous determination of total nitrogen and total phosphorus in pond water. *J. World Aquac. Soc.*, **29**: 300–303 (1998).

Gross, A., C. E. Boyd, and C.W. Wood. Nitrogen transformations and balance in channel catfish ponds. *Aquacult. Eng.*, **24**: 1–14 (2000).

Hansen, M., S. H. Thilsted, B. Sandström, K. Kongsbak, T. Larsen, M. Jensen, and S. S. Sørensen. Calcium absorption from small soft-boned fish. *J. Trace Elem. Med. Biol.*, **12**: 148–154 (1998).

Hayashi, C., F. Meurer, W. R. Boscolo, C. H. F. Lacerda, and L. C. B. Kavata. Feeding frequency for yellow tail lambari (*Astyanax bimaculatus*) fingerlings. *Rev. Bras. Zootecnia*, **33**: 21–26 (2004).

ICMbio–Instituto Chico Mendes. Boletim Estatístico da Pesca e Aquicultura. Available at: www.icmbio.gov.br/cepsul/…/estatistica/est_2011_bol__bra.pdf. Accessed 07.16. (2001).

Islam, M.S. Evaluation of supplementary feeds for semi-intensive pond culture of mahseer, Tor putitora (Hamilton). *Aquaculture*, **212**: 263–276 (2002).

Jung, S., L. V. Rasmussem, C. Watkins, P. Newton, and A. Agrawal. Brazil's National Environmental Registry of Rural Properties: implications for livelihoods. *Ecological Econ.*, **136**: 53–61 (2017).

Knud-Hansen, C. F., T. R. Batterson, C. D. McNabb, I. S. Harahat, K. Sumantadinata, and M. H. Eidman. Nitrogen input, primary productivity and fish yield in fertilized freshwater ponds in Indonesia. *Aquaculture*, **94**: 49–63 (1991).

Knud-Hansen, C. F., K. D. Hopkins, and H. Guttman. A comparative analysis of the fixed-input, computer modeling, and algal bioassay approaches for identifying pond fertilization requirements for semi-intensive aquaculture. *Aquaculture*, **228**: 189–214 (2003).

Lima, F. C. T., L. R. Malabarba, P. A. Buckup, J. F. Pezzi da Silva, R. P. Vari, A. Harold, R. Benine, O. T. Oyakawa, C. S. Pavanelli, N. A. Menezes, C. A. S. Lucena, M. C. S. L. Malabarba, Z. M. S. Lucena, R. E. Reis, F. Langeani, L. Casatti, V. A. Bertaco, C. Moreira, and P. H. F. Lucinda. Genera incertae sedis in Characidae, pp. 106–169. **In**: *Check List of the Freshwater Fishes of South and Central America* (Reis, R. E., S. E. Kullander and C. J. Ferraris Jr.. Eds.), Porto Alegre, RS, Brazil: Edipucrs (2003).

Lin, C. K. and Y. Yi. Minimizing environmental impacts of freshwater aquaculture and reuse of pond effluents and mud. *Aquaculture*, **226**: 57–68 (2003).

Little, D. C., B. K. Barman, B. Belton, M. C. Beveridge, S. J. Bush, L. Dabaddie, H. Demaine, P. Edwards, M. M. Haque, G. Kibria, E. Morales, F. J. Murray, W. A. Leschen, M. C. Nandeesha, and F. Sukady. Alleviating poverty through aquaculture: progress, opportunities and improvements. **In**: *Farming the Waters for People and Food, Proceedings of the Global Conference on Aquaculture 2010* (R. P. Subasinghe, J. R. Arthur, D. M. Bartley, S. S. De Silva, M. Halwart, N. Hishamunda, C. V. Mohan and P. Sorgeloos. Eds), Phuket, Thailand: FAO, Rome and NACA, Bangkok (2012).

Lopes, M. C., N. J. R. Silva, and M. B. Henriques. Custos e viabilidade econômica da produção de alevinos de lambaris reproduzidos artificialmente. *Informações Econômicas*, **44**: 60–68 (2014).

Lopes, M. C., N. J. R. Silva, L. M. Casarini, F. H. A. S. B. Gonçalves, and M. B Henriques. Desova induzida do Lambari *Deuterodon iguape* com extrato hipofisário de carpa. *Tropical J.Fisheries Aquatic Sci.*, **13**: 9–13 (2013).

Lucena, C. A. and H. G. Soares. Review of the species of *Astyanax bimaculatus* "caudal peduncle spot" subgroup sensu Garutti & Langeani (Characiformes, Characidae) from the rio La Plata and rio São Francisco drainages and coastal systems of southern Brazil and Uruguay. *Zootaxa*, **4072**: 101–125 (2016).

Marques, H. L., M. B. New, M. V. Boock, H. P. Barros, M. Mallasen, and W. C. Valenti. Integrated freshwater prawn farming: state-of-the-art and future potential. *Rev. Fish. Sci. Aquac.*, **24**: 264–293 (2016).

Mazzoni, R. and C. F. Rezende. Seasonal diet shift in a Tetragonopterinae (Osteichthyes, Characidae) from the Ubatiba river, RJ, Brazil. *Braz. J. Biol.*, **63**: 69–74 (2003).

Meurer, F., C. Hayashi, W. R. Bolscolo, L. B. Kavata, and C. H. F. Lacerda. Nível de arraçoamento para alevinos de Lambari-do-rabo-amarelo (*Aastyanax bimaculatus*). *Rev. Bras. Zootecnia*, **34**: 1835–1840 (2005).

Michelsen, O. B. Photometric determination of phosphorus as molybdovanadophosphoric acid. *Anal. Chem.*, **29**: 60–62 (1957).

Michielsens, C. G. J., K. Lorenzen, M. J. Phillips, and R. Gauthier. Asian carp farming systems: towards a typology and increased resource use efficiency. *Aquacult. Res.*, **33**: 403–413 (2002).

Mirande, J. M. Phylogeny of the family Characidae (Teleostei: Characiformes): from characters to taxonomy. *Neotrop. Ichthyol.*, **8**: 385–568 (2010).

Moura, R. S. T., W. C. Valenti and G. G. Henry-Silva. Sustainability of Nile tilapia net-cage culture in a reservoir in a semi-arid region. *Ecol. Indic.*, **66**: 574–582 (2016).

Naylor, R. L., R. J. Goldburg, J. H. Primavera, N. Kautsky, M. C. Beveridge, J. Clay, C. Folke, J Lubchenco, H. Mooney, and M. Troell. Effect of aquaculture on world fish supplies. *Nature*, **405**: 1017–1024 (2000).

Naylor, R. L., S. L. Williams, and D. R. Strong. Aquaculture—a gateway for exotic species. *Science*, **294**: 1655–1656 (2001).

Pereira, T. N. A. *Filogenia das espécies de Deuterodon Eigenmann, 1907 (Characiformes: Characidae), um gênero de lambaris da Mata Atlântica* (Master thesis). Botucatu, SP, Brazil: Biosciences Institute – São Paulo State University (2010).

Peretti, D. and I. F. Andrian. Feeding and morphological analysis of the digestive tract of four species of fish (*Astyanax altiparanae, Parauchenipterus galeatus, Serrasalmus marginatus and Hoplias aff. malabaricus*) from the upper Paraná River floodplain, Brazil. *Braz. J. Biol.*, **68**: 671–679 (2008).

Porto-Foresti, F., R.B. Castilho-Almeida and F. Foresti. Biologia e criação do lambari-do-rabo-amarelo (*Astyanax altiparanae*), pp. 101–116. **In**: *Espécies Nativas para Piscicultura no Brasil* (Baldisseroto, B. & Gomes, L. C.. Eds.), Santa Maria, RS, Brazil: Editora UFMS (2005).

Proença, D. C. *Aplicação de indicadores e índices para avaliar a sustentabilidade ambiental em um sistema de aquicultura integrado e multitrófico, com diferentes substratos* (Masther thesis). Jaboticabal, SP, Brazil: Aquaculture Center – São Paulo State University (2013).

Pucher, J., R. Mayrhofer, M. El-Matbouli, and U. Focken. Pond management strategies for small-scale aquaculture in northern Vietnam: fish production and economic performance. *Aquacult. Int.*, **23**: 297–314 (2015).

Rahman, M. M., M. Verdegem, L. Nagelkerke, M. A. Wahab, A. Milstein, and J. Verreth. Effects of common carp *Cyprinus carpio* (L.) and feed addition in rohu Labeo rohita (Hamilton) ponds on nutrient partitioning among fish, plankton and benthos. *Aquacult. Res.*, **39**: 85–95 (2008).

Rezende, F. P., O. P. R. Filho, M. M. Pereira, E. Y. Takabatake, R. D. Navarro, L. C. Santos, R. F. Silva, and C. B. C. Filho. Eficiência de diferentes substratos na desova de tambiú (*Astyanax altiparanae*). *Rev. Ceres*, **52**: 527–533 (2005).

Rodrigues, A. M., E. C. Campos, R. A. Santos, J. M. Junior, and J. J. C. Camara. Tipo de desova e fecundidade do tambiú (*Astyanax bimaculatus* Linnaeus 1758 (Pisces, Characiforme, Characidae), na represa de Ibitinga, estado de São Paulo, Brasil. *Braz. J. Vet. Res. Anim. Sci.*, **29**: 309–315 (1992).

Ross, L. G., C. A. M. Palacios, and E. J. Morales. Developing native fish species for aquaculture: the interacting demands of biodiversity, sustainable aquaculture and livelihoods. *Aquacult. Res.*, **39**: 675–683 (2008).

Sabbag, O. J., L. S. Takahashi, A. N. Silveira, and A. S. Aranha. Custos e viabilidade econômica da produção de lambaris-do-rabo-amarelo em Monte Castelo/SP: um estudo de caso. *Bol. Inst. Pesca*, **37**: 307–315 (2011).

Salaro, A. L., D. A. V. Campelo, M. D. Pontes, J. A. S. Zuanon, V. R. B. Furuya and W. M. Furuya. Avanços na nutrição e produção de lambaris, pp. 491–501. **In**: *Aquicultura no Brasil: novas perspectivas* (Brito, P. A. M. and J. R. M. Brito Eds.), São Carlos, SP, Brazil: Editora Pedro & João (2015).

Santos, M. M. *Políticas públicas e gestão: o caso dos bairros rurais de Peruíbe localizados no Parque Estadual da Serra do Mar (Undergraduate Monography)*. São Vicente, SP, Brazil: Coastal Campus - São Paulo State University (2008).

Sato, Y., E. V. Sampaio, N. Fenerich-Verani, and J. R. Verani. Biologia reprodutiva e reprodução induzida de duas espécies de Characidae (Osteichtyes, Characiformes) da bacia do São Francisco, Minas Gerais, Brasil. *Rev. Bras. Zool.*, **23**: 267–273 (2006).

Silva, N. J. R., M. C. Lopes, F. H. A. S. Gonçalves, G. Z. Gonsales, and M. B. Henriques. Avaliação do potencial do mercado consumidor de lambari da baixada santista. *Inform. Econ.*, **41**: 5–17 (2011a).

Silva, N. J. R., M. C. Lopes, J B K. Fernandes, and M. B. Henriques. Caracterização dos sistemas de criação e da cadeia produtiva do lambari no estado de São Paulo, Brasil. *Inform. Econ.*, **41**: 17–28 (2011b).

Stevanato, J. D. *Ontongenia larval e pós-larval de Astyanax altiparanae (Garutti & Britsky, 2000) em laboratório* (Master thesis). Curitiba, PR, Brazil: Federal University of Paraná (2016).

Sussel, F. R., E. M. M. Viegas, M. M. Evangelista, G. S. Gonçalves, F. A. Salles, and L. U. Gonçalves. Replacement of animal protein with vegetable protein in the diets of *Astyanax altiparanae*. *Acta Sci. Animal Sci.*, **36**: 343–348 (2014).

Thilsted, S. H. The potential of nutrient-rich small fish species in aquaculture to improve human nutrition and health. **In**: *Farming the Waters for People and Food, Proceedings of the Global Conference on Aquaculture 2010* (R. P. Subasinghe, J. R. Arthur, D. M. Bartley, S. S. De Silva, M. Halwart, N. Hishamunda, C. V. Mohan and P. Sorgeloos. Eds), Phuket, Thailand: FAO, Rome and NACA, Bangkok (2012).

Thilsted, S. H., A. Thorne-Lyman, P. Webb, J. R. Bogard, R. Subasinghe, M. J. Phillips, and E. H. Allison. Sustaining healthy diets: The role of capture fisheries and aquaculture for improving nutrition in the post-2015 era. *Food Policy*, **61**: 126–131 (2016).

UNGA - United Nations General Assembly. Transforming our world: the 2030 Agenda for Sustainable development. New York, NY, USA: United Nations (2015).

Valenti, W. C., J. M. Kimpara, and B. L. Preto. Measuring aquaculture sustainability. *World Aquacult.*, **42**: 26–30 (2011).

Valladão, G. M. R., S. U. Gallani, and F. Pilarski. South America fish for continental aquaculture. *Rev. Aquacult.*, Early view (2016). doi: 10.1111/raq.12164.

Veregue, A. M. L. and M. L. Orsi. Reproductive biology of *Astyanax scabiprinnis paranae* (Eigenman) (Ostheichtyes, Caracidae), from Marrecas creek of the Tibagi basin, Paraná. *Rev. Bras. Zool.*, **20**: 97–105 (2003).

Vilela, C. and C. Hayashi. Desenvolvimento de juvenis de lambari *Astyanax bimaculatus* (Linnaeus, 1758), sob diferentes densidades de estocagem em tanques-rede. *Acta Sci. Biol. Sci.*, **23**: 491–496 (2001).

Virtule, J. R. S. and J. M. R. Aranha. Ecologia alimentar do lambari *Deuterodon langei* Travassos, 1957 (Characidae, Tetragonopterinae), de diferentes tamanhos em um riacho da Floresta Atlântica, Paraná (Brasil). *Acta Biol. Paranaense*, **31**: 137–150 (2002).

Virtule, J. R. S., M. R. Braga, and J. M. R. Aranha. 2008. Population structure and reproduction of *Deuterodon langei* Travassos, 1957 (Teleostei, Characidae) in a neotropical stream basin from the Atlantic Forest, Southern Brazil. *Braz. Arch. Biol. Technol.*, **51**: 1187–1198 (2008).