LAMBARICULTURA COMO FORMA DE DESENVOLVIMENTO SUSTENTÁVEL DE COMUNIDADES RURAIS REMANESCENTES DE ÁREAS PROTEGIDAS NO BRASIL

TAMARA FONSECA DE ALMEIDA

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ATA DA DEFESA PÚBLICA DA DISSERTAÇÃO DE MESTRADO DE TAMARA FONSECA DE ALMEIDA, DISCENTE DO PROGRAMA DE PÓS-GRADUAÇÃO EM BIODIVERSIDADE AQUÁTICA, DO INSTITUTO DE BIOCIÊNCIAS.

Aos 17 dias do mês de janeiro do ano de 2017, às 14:00 horas, no(a) Sala 03 do Instituto de Biociências - UNESP/CLP, reuniu-se a Comissão Examinadora da Defesa Pública, composta pelos seguintes membros: Prof. Dr. WAGNER COTRONI VALENTI - Orientador(a) do(a) Instituto de Biociências - Câmpus do Litoral Paulista / UNESP, Prof. Dr. RAFAEL MENDONÇA DUARTE do(a) Instituto de Biociências - Câmpus do Litoral Paulista / UNESP, Dra. FERNANDA SELES DAVID do(a) Centro de Aquicultura da Unesp / UNESP, sob a presidência do primeiro, a fim de proceder a arguição pública da DISSERTAÇÃO DE MESTRADO de TAMARA FONSECA DE ALMEIDA, intitulada **LAMBARICULTURA COMO FORMA DE DESENVOLVIMENTO SUSTENTÁVEL DE COMUNIDADES RURAIS REMANESCENTES DE ÁREAS PROTEGIDAS NO BRASIL**. Após a exposição, a discente foi arguida oralmente pelos membros da Comissão Examinadora, tendo recebido o conceito final: APROVADO. Nada mais havendo, foi lavrada a presente ata, que após lida e aprovada, foi assinada pelos membros da Comissão Examinadora.

Prof. Dr. WAGNER COTRONI VALENTI

Rafael M Duarte
Prof. Dr. RAFAEL MENDONÇA DUARTE

Fernanda Seles David
Dra. FERNANDA SELES DAVID

SUMÁRIO

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RESUMO

O desafio global para a gestão de áreas protegidas é conciliar desenvolvimento social e conservação. Nós apresentamos um estudo de caso sobre o desenvolvimento da aquicultura do lambari em uma comunidade rural localizada na área de entorno do Parque Estadual da Serra do Mar, sudeste do Brasil, com ênfase na informação disponível sobre o status e potenciais impactos sócio-ecológicos da cadeia produtiva. Práticas de manejo inadequadas e falta de ciência aplicada tem levado à baixa produtividade e um alto consumo de recursos naturais. A aquicultura do lambari praticada no parque consome três vezes mais água e nutrientes por tonelada de peixe do que outros sistemas semi-intensivos de aquicultura realizados no Brasil e no exterior. Estratégias simples e alternativas são necessárias para melhorar a eficiência dos sistemas. Com mais pesquisa aplicada, a aquicultura de peixes nativos, de baixo nível trófico, como o lambari, pode ser uma ferramenta importante para a produção de alimentos e desenvolvimento sustentável das populações rurais no Brasil. Além disso, pode representar uma alternativa para geraração de renda para populações que vivem no entorno de áreas de conservação.

ABSTRACT

The current global challenge for protected areas management is to reconcile social development and conservation. We report on a case study of the development of lambari aquaculture in a rural community located in a protected coastal rainforest in SE Brazil, with an emphasis on available information on the status and potential socio-ecological impacts of this innovative enterprise. Poor management practices and a lack of applied science has led to low productivity and a high consumption of natural resources. Lambari aquaculture performed in this protected area consumes three times more water and nutrients per ton of fish than other comparable semi-intensive aquaculture systems globally. Simple, alternative strategies are needed to improve systems' efficiencies. With participatory applied science, the aquaculture of indigenous, low trophic level 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 in Brazil.

Palavras-chave: Aquicultura Sustentável; Peixe Nativo; Alternative Livelihoods; Ecological Aquaculture.

INTRODUÇÃO GERAL

Áreas protegidas são amplamente reconhecidas pela sua capacidade de conservar a biodiversidade e os recursos naturais (Bruner, 2001). Essas áreas fornecem serviços ecossistêmicos importantes em nível local, nacional e até global. Tais serviços incluem os de provisão, suporte, regulação e serviços culturais (Millenium Ecosystem Assessment, 2005). No entanto, existe uma preocupação a respeito dos custos impostos sobre as comunidades que vivem dentro ou no entorno das áreas protegidas (Coad, 2008). Esses custos geralmente incluem deslocamento e restrição de acesso, resultando em falta de moradia, desemprego, marginalização, insegurança alimentar e desarticulação social (Coad, 2008). O impacto da designação de uma unidade de conservação sobre uma comunidade fragilizada pode influenciar negativamente sua atitude em relação à conservação (Naughton-Treves, 2005), podendo reduzir a sua eficácia.

O desafio atual para a gestão de áreas protegidas é conciliar objetivos de desenvolvimento social e conservação (Naughton-Treves, 2005). Uma estratégia de gestão alinhada à sustentabilidade poderia conservar os recursos biológicos, e ao mesmo tempo proporcionar benefícios para o desenvolvimento das comunidades vizinhas. Por definição, a sustentabilidade inclui produção lucrativa, desenvolvimento social e conservação ambiental (Valenti, 2012). A gestão baseada nos ecossistemas (Ecosystem Based Management - EBM) tem sido proposta como uma estratégia alternativa para tomadas de decisão, que incorpora questões de desenvolvimento social e conservação (Barbier, 2008). A EBM sugere a manutenção de sistemas naturais em condições saudáveis, produtivas e resilientes para que possam fornecer os serviços que a sociedade almeja e precisa (McLeod, 2005). Algumas atividades econômicas, como o ecoturismo, cultivo em agroflorestas e extrativismo sustentável, têm sido promovidas em unidades de conservação visando esse objetivo (Naughton-Treves, 2005).

A aquicultura pode ser uma ferramenta para a gestão de unidades de conservação. Em 2008, a FAO definiu uma abordagem ecológica para a aquicultura que integra a produção ao ecossistema, de forma a promover o desenvolvimento sustentável, a equidade e a resiliência dos sistemas socio-ecológicos (FAO, 2008). Como princípio, a aquicultura deve ser desenvolvida no contexto dos serviços ecosistêmicos (incluindo a biodiversidade), promover bem-estar humano e equidade e ser integrada nas políticas e metas públicas (Costa-Pierce, 2010). Ao nível das unidades produtivas, propõe-se melhores práticas de gestão, incluindo a avaliação de impacto ambiental, a utilização de espécies nativas e o conhecimento dos impactos socioeconômicos (Costa-Pierce, 2010).

Entre os peixes nativos com potencial para a aquicultura, destaca-se os lambaris. Essas espécies constituem um conjunto de peixes de pequeno porte amplamente destribuído nas bacias hidrográficas neotropicais. São peixes pequenos, pelágicos e de habito alimentar onívoro. Esse grupo possui alta importância ecológica uma vez que são a principal presa dos peixes carnívoros de água doce. As espécies *Astyanax lacustris, Astyanax scarbiprinnis e Deuterodon iguape* são comuns na região sudeste do Brasil e têm se destacado pelo seu potencial para o cultivo. A aquacultura do lambari, ou lambaricultura, se desenvolveu nas últimas três décadas como uma alternativa de renda para pequenos produtores rurais no sudeste brasileiro. A produção começou com o objetivo de suprir as demandas do mercado de isca viva para a pesca esportiva de água doce, atividade que permanece como principal mercado (Valladão et al., 2016). O lambari também é comumente consumido como aperitivo em bares e restaurantes. Recentemente, a lambaricultura expandiu-se no interior do estado de São Paulo, e algumas grandes fazendas (> 20 ha) foram criadas.

Na zona costeira, a aquacultura do lambari-da-mata-atlântica (*Deuterodon iguape*) foi introduzida como forma de promover o desenvolvimento sustentável de uma comunidade carente localizada no entorno do Parque Estadual da Serra do Mar. Alguns dos ocupantes têm experiências anteriores com tilapicultura, porém a tilápia foi banida da área do Parque como sendo um risco para a biodiversidade local (Santos, 2008). Como peixe nativo de baixo nível trófico, que possui aceitação de mercado e alto valor nutricional, o grupo de espécies chamado lambaris tem potencial para ser desenvolvido de forma sustentável na região. A introdução da aquicultura de peixes nativos pode ser uma atividade econômica lucrativa, promover segurança alimentar para a comunidade e conservar a biodiversidade local.

O presente estudo revisa as informações disponíveis a cerca do status e potenciais impactos socio-ecológicos da aquicultura do lambari em comunidades rurais do sudeste brasileiro. Nós também reportamos um estudo de caso do desenvolvimento da aquicultura do lambari-da-mata-atlântica (*Deuterodon iguape*) em uma comunidade rural de baixa renda localizada no entorno do Parque Estadual da Serra do Mar como uma atividade econômica ambientalmente mais sustentável.

Esse manuscrito foi elaborado em forma de artigo científico sob a orientação do Professor Dr. Wagner C. Valenti em parceria com o Professor Dr. Barry A. Costa-Pierce (University of New England).

Indigenous Small-Fish Aquaculture as a Means for the Sustainable Development of Rural Communities in Brazil

1. Introduction

The roles of protected areas to conserve biodiversity and natural resources, and providing important ecosystem services are well known (Bruner, 2001). However, communities who live within or in the boundaries of protected areas regularly are displaced or have restricted access to traditional resources resulting in homelessness, joblessness, marginalization, food insecurity, and social disruption (Coad, 2008). The management of resource uses in protected areas will influence attitudes toward conservation (Naughton-Treves, 2005), improving or decreasing the effectiveness of conservation.

The current challenge for protected areas management is how to implement social development and conservation aims (Naughton-Treves, 2005). A management strategy in line with sustainability could conserve biological resources while provide developmental benefits to nearby communities. Sustainability includes profitable production, social development and environmental conservation (Valenti, 2012). Alternative economic activities as ecotourism, agroforestry and sustainable harvest, has been promoted in nature reserves aiming the maintenance of the natural systems in healthy, productive and resilient conditions so that they can provide the services human wants and need (Naughton-Treves, 2005).

Aquaculture could be an important tool for the management of protected areas. In 2008, FAO defines an ecosystem approach for aquaculture (EAA) by the integration of aquaculture within the wider ecosystem such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems (FAO, 2008). Aquaculture should be developed in the context of ecosystems services (including biodiversity), improving human well-being and equity and be integrated in policies and goals (Costa-Pierce, 2010). At the farm level, EAA proposes better management practices, including the assessment of the environmental impact, the use of native species and knowledge of economic and social impacts at the farm level (Costa-Pierce, 2010).

The lambari is a group of small fresh water fish widely distributed on Neotropical watersheds. The species *Astyanax lacustris, Atyanax scarbiprinnis* and *Deuterodon iguape* are common in the Southeast Brazil and are widely consumed and highly valued. Lambari aquaculture has 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 has a large potential to be produced in a sustainable way, promoting socio-economic development, improving food security and conserving natural resources in Brazil.

This study reviews the available information on the status and potential socio-ecological impacts of lambari aquaculture in the rural communities of SE Brazil. We also report a case study of the development 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.

2. Lambari in Brazil

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 watersheds from the south of United States to northern Argentina (Lima et. al., 2003). Lambari species belongs to the genera *Astyanax* and *Deuterodon*. They inhabit pelagic aquatic environments, have omnivorous feeding habits, and play an important role in freshwater ecosystems as the main prey of carnivorous fish (Garutti, 2003). Lambari have gained attention due to their potential to be commercialized as live bait for the sport fishing and as food for human consumption (Valladão et. al., 2016). Lambari aquaculture has been started recently in Brazil and is cultured generally by small holder families, wherein its production technology remains in development.

2.1. Astyanax lacustris, the Yellow Tail Lambari

A member of the bimaculatus subgroup, the taxonomy and phylogeny of *Astyanax lacustris* (Figure 1) remains unresolved (Lucena & Soares, 2016). Previously described as *Astyanax bimaculatus* Linnaeus, and *Astyanax altiparanae* by Garutti & Britsky (2000), this species was reviewed recently as being *Astianax lacustris* (Lucena & Soares, 2016). This lambari species is found on the upper Parana, São Francisco, and Rio Doce watersheds (Lima et. al., 2003; Lucena & Soares, 2016). It has a flat and long sided body, two black humeral and caudal spots, a yellow tail and fins (Garutti & Britsky, 2000). 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 morphology includes a terminal protractile mouth and pentacusp teeth that allows the fish to obtain food throughout the water column (Peretti & Andrian, 2008). *A. lacustris* are broad, omnivorous opportunists eating insects, larvae, microcrustaceans, particles of macrophytes and scales (Andrian et. al., 2006; Esteves, 1996; Gomiero & Braga, 2003).

2.2.Astyanax scarbiprinnis Complex, the Silver Lambari

Astyanax scarbripinnis is a species complex that includes numerous morphotypes (Bertaco & Lucena, 2006, 2010; Castro et. al., 2015). Their phylogeny and taxonomy remain uncertain; however, this group of fish can be identified by a dark, lateral stripe extending to the tip of the middle of the caudal fin rays (Bertaco & Lucena, 2010). These species inhabit the headwater rivers 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 in length, and males are smaller than females. First maturation occurs at 5.5 cm length (Abilhoa, 2007; Veregue & Orsi, 2003). Spawning occurs throughout the year but lower reproductive success occurs in winter. Feeding habits are based on allochthones sources and includes insects and detrital particles of higher plants (Abilhoa, 2007; Veregue & Orsi 2003). However, their diets are variable and can change according with food availabilities (Abilhoa, 2007). *Astyanax laticeps* (Figure 2) (Bertaco & Lucena, 2010) is a member of this complex and have been exploited commercially in southern Brazil.

2.3.Deuterodon iguape, the Atlantic Forest Lambari

The genus *Deuterodon* is distributed widely in coastal rivers of the Atlantic Forest Ecosystem (Lima et. al., 2003; Virtule et. al., 2008). This environment has several small watersheds which leads to a large endemism (Pereira, 2010). *Deuterodon iguape* (Figure 3) is endemic of the Ribeira de Iguape River, located on southeast coast of Brazil (Lima et. al, 2003). Studies on this species are scarce. *Deuterodon* is known as omnivorous tending to herbivorous (Mazzoni & Rezende, 2003; Viturle & Aranha, 2002) with a diet that includes algae, seeds, leaves, zoobenthos, and zooplankton (Mazzoni & Rezende, 2003; Vitule & Aranha, 2002). Sexual maturity begins at 8 cm length and spawning occurs in spring and summer (Vitule et. al., 2008).

3. Status of Lambari Aquaculture in Brazil

Lambari are one of the most common freshwater fish in SE Brazil (Garutti, 2003; Porto-Foresti et. al., 2005; Salaro et. al., 2015; Silva et. al., 2011a; Valladão et. al., 2016). The commercial exploitation of this fish started intended for human consumption and was based on small scale fishery. Today, most of lambari production aiming this market still wild caught. They are fished in the rivers of Paraná watershed, where production is about 1,068 t/year (ICMbio, 2011), and sold in small stores and restaurants.

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

Lambari is usually consumed whole, with bones and head, and sometimes with the viscera. Market studies show a high demand for them, which could double; however, expansion is limited by the irregular seasonal production of the fishery (Garutti, 2003; Silva, 2011a). If lambari aquaculture could be developed, it is likely a large market for human consumption could be found in Brazil. Also, the use of lambari for the poor is not to be underestimated. Small indigenous fish consumed whole have a large potential to contribute to micronutrient intake (Bogard et. al., 2015a, 2015b; Fiedler et. al., 2016; Hansen et. al., 1998; Thilsted, 2012.). Fishermen and farmers are unlikely to compete as they aim for different niche markets.

Lambari aquaculture development is in its early stages. There are no standard production practices. The main species produced is *Astyanax lacustris* but *Astyanax laticeps* and *Deuterodon iguape* are also grown. A review of management strategies, in terms of water use, liming, fertilization, feeding frequencies, and stocking densities demonstrated that aquaculture production systems and practices are extremely variable between producers (Table 1). To date, each producer has developed their own production strategies based on empirical practices or the adoption of previous experiences with other fish such as tilapia and pacu (Silva et. al., 2011b). In addition, the biology of lambari has only recently been described in the scientific literature. Farming aspects of the species and bait markets for sport fish have been reviewed (Garutti, 2003; Porto-Foresti et. al, 2005; Salaro et. al., 2015; Silva et. al., 2011a, 2011b; Valladão et. al., 2016). Nevertheless, a full review of all of the available information on the social-ecological system and management is needed to set a baseline of current knowledge and define future research efforts to develop scientifically-based management strategies for the expansion of lambari aquaculture.

A review of studies on pond management are 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 (Silva, 2011; Sabbag et. al., 2011). However, fish productivities were higher on-station than on-farm, moreover, the experimental evidence was weak and unreplicated. Basic studies on stocking densities are preliminary (Gonçalves et. al., 2015a; Vilela & Hayashi, 2001). 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 basic aquaculture production science assessments (Bem et. al., 2012).

Breeding in lambari species has been described as feasible throughout the year although best results occur in spring and summer (Porto-Foresti et. al., 2005; Salaro et. al., 2015). Natural breeding is used to seed ponds (Silva et. al., 2011b) mainly in rural settlements where there is little funding for hatchery fish and feeds, but natural spawning is also used in medium-sized farms (Silva, et. al. 2011b). In these areas, wild spawning, nursery and grow out occur in the same pond, which can lead to a wide size heterogeneity of the crop, no productivity control, and genetic issues (Salaro, et. al., 2015; Silva et. al., 2011b). However, natural reproduction makes small farmers independent from seed suppliers, which provide autonomy and allows lambari aquaculture to be performed by communities with very low incomes. The lack of seed and dependency on hatchery production is a factor of failure for many poor, rural fish farmers throughout the world (Little et. al, 2012).

A protocol for natural breeding has been suggested by Garutti (2003) and Porto-Foresti et. al. (2005). The broodstock density recommended is 10 fish/m², 3 males per female in earthen ponds (Porto-Foresti et. al., 2005). Garutti (2003) suggest to insert net cages for broodstock inside ponds for a period of 2-3 weeks. Such management allows producers to remove broodstock after breeding, avoiding cannibalism (Garutti, 2003). Also, the use of macrophytes (*Eichhornia crassipes*) as substrates in concrete tanks for *Astyanax lacustris* leads to higher survival rates, since it allows the sticky eggs to adhere to the plant roots, improving survival and protection from predation by insect larvae (Rezende et. al., 2005). However, to date, there is no replicable experimental evidence for any of these management practices.

Hormone-induced spawning was described for *Astyanax lacustris* (Felizardo et al, 2012; Porto-Foresti et. al., 2005; Sato et. al., 2006) and for *Deuterodon iguape* (Lopes et. al., 2013). Felizardo et. al. (2012) and Sato et. al. (2006) indicate satisfactory results using carp pituitary extract (6 mg/kg) in single application for males and females of *A. lacustris* (500 - 750 oocytes/g). Porto-Foresti et. al. (2005) suggest a double dose application (0.5 mg/kg and 2.5 mg/kg) over a range of 12 hours. Similarly, the double dose application (0.6 mg/kg and 6 mg/kg) showed a higher productivity than a single dose for *D. iguape* (Lopes et. al., 2013). The use of synthetic gonadotropin was tested by Felizardo et. al. (2012) with satisfactory results (480-640 oocytes/cm of fish). Farmers with adequate infrastructure and access to technology produce seeds through hormone induction of broodstock spawning using carp pituitary extracts (Silva et. al., 2011b). These farmers provide fingerlings for smaller farmers in exchange for breeders. Therefore, hormone-induced spawning is a feasible technique to improve fingerling production; however, more applied research is needed on hormone dosages, frequencies, and economic feasibility.

Nutritional requirements for lambari species are unknown. Abimorad & Castellani (2011) inferred that essential amino acids for *Astyanax lacustris* is similar to those for other low trophic level fish such as Nile tilapia and common carp. Gonçalvez et. al. (2014) evaluated the fatty acid composition of wild and farmed broodstock lambari tissues and 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 oil was found to promote satisfactory growth (Ferreira et. al, 2014; Sussel et. al., 2014) suggesting that lambari has a low dependence on fish oil/meal proteins.

Even though there are no specific diets for lambari, all producers use commercial feeds (Silva, et. al. 2011b). They choose a diet based on pellet sizes which the fish are able to swallow (Garutti, 2003; Silva et. al., 2011b). The amount of food supplied, feeding frequencies and feed protein contents vary widely between farms, and some growers fertilize ponds (Table 1). Thus, at present, feeds given to lambari are incompatible with their anatomy and nutritional requirements. Additionally, they are very expensive. Clearly a new approach to lambari feeding and nutrition in culture is needed.

The potential for the aquaculture development of the indigenous lambari for the economic and nutritional development among the rural poor people in Brazil is very promising; however, its aquaculture development remains in its initial stages. More applied, replicated scientific work on breeding, nutrition and general management are needed. Also, current studies are not relevant to most rural farmers' realities or needs since they are small producers with low incomes.

4. Sustainability Indicators - a Case Study from Brazil

Globally, fish production depends heavily on small-scale fishers and farmers, many of whom are poor (FAO, 2016; Thilsted et. al., 2016). Aquaculture has been proposed as a tool for social development, human nutrition and health (Bené et. al, 2016; Costa-Pierce, 2016; Thilsted et. al., 2016). However, for aquaculture to achieve this goals and to be developed in a sustainable way, it needs to improve the quantity and quality of fish supply (Thilsted et. al., 2016), maintain ecosystems goods and services (Naylor et. al., 2009), and be concerned with its wider social context (Costa-Pierce et al., 2010; Valenti et. al., 2011).

Lambari aquaculture in Brazil has been performed by many small farmers in rural areas with little access to investment and infrastructure (Silva et. al., 2011b). As an indigenous, low-trophic level fish with high nutritional value, this species group has a good potential to be developed in sustainable way and promote community health and welfare. In order to estimate such prospects, we performed a preliminary assessment of environmental sustainability of lambari (*Deuterodon iguape*) aquaculture at a single semi-intensive farm.

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

Lambari (*Deuterodon iguape)* aquaculture has been introduced as way to promote sustainable development for a poor community 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). Lambari have been caught from the local rivers for direct consumption and informal trade historically in the area. Therefore, the introduction of native fish aquaculture could be an alternative income source, improve community food security, and conserve local biodiversity.

We assessed the grow-out phase of lambari production on three earthen ponds (0,01ha each) from April to October, 2015. Fish stocking density, liming, fertilizing and feeding regimes followed usual farmer procedures (Tables 1,2). Over this period, samples of water, sediment, animals and greenhouse gases were collected fortnightly and, subsequently, total carbon, nitrogen, phosphorous and energy were accounted. Total biomass produced was evaluated at the harvest. The environmental indicators of sustainability were measured according to Boyd et. al. (2007) and Valenti et. al. (2011) and includes three main aspects: (1) use of natural resources, (2) efficiency of use of natural resources, and (3) release of pollutants to the environment.

4.2. Preliminary Results of Environmental Indicators of Sustainability

Environmental indicators of sustainability are shown in Table 3. Farm management followed the same procedures described earlier (Tables 1, 2).

The current aquaculture system performs poorly in all measures of sustainability examined. The lambari aquaculture system has a high consumption of natural resources, and low resource use efficiencies. The main issues are related to water and nutrient uses. Lambari aquaculture consumes about three times more water, phosphorous and nitrogen per ton of fish than other comparable semi-intensive aquaculture systems in Asia, Africa and Brasil (Table 3). However, the lambari culture analyzed is more efficient in assimilating energy and nitrogen. Lambari productivity is very low when compared to those systems. Nevertheless, the present study of the culture system was performed during winter and better productivity certainly can be obtained in the warmer season.

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 & Tucker, 1998; Boyd et. al., 2007). Most of the nutrients in the applied feeds were lost to the environment as pollutants. Nutrient loss is a common issue in several aquaculture systems (Boyd & Tucker, 1998; Moura et. al., 2016); however, in this assessment the waste loads were higher, and there were very high feed conversion ratios, and low fish productivities (Table 3). It can be concluded that the lambari ate little of the feed supplied. Therefore, the feed, an expensive resource (economically and environmentally), was really a pond fertilizer.

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's 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.

5. 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 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. We performed a Strengths, Weakness, Opportunities and Threats (SWOT) analysis (Table 4) aiming to assess the prospects and challenges for lambari aquaculture development. We also recommend actions for seed production, feed, management and market development in order to lay out a more sustainable pathway for development (Table 5).

*5.1.*Seed

Seed production is feasible year-round. Constant seed availability allows a regularization of markets, reducing economic risk or 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. However, both methods have been used by farmers without scientifically derived protocols. Large scale hatcheries represent a high capital cost for governments and farmers in Brazil, create a dependency, and reinforce income inequality in the social-ecological value chain. This is a significant factor in the failure of many producers, mainly for small farmers (Little et. al., 2012).

We recommend seed production by developing simple, replicable protocols for natural breeding on farm as they can be inexpensive, 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 & Little, 2006; Barman & Little 2011). Fingerlings produced were sold for other small farms locally and/or stocked for further culture in their own grow-out system; also, some were used directly for household consumption, resulting in additional income and welfare improvement (Barman & Little, 2006). Similar results could be achieved by developing lambari aquaculture in Brazil. Further research in lambari fingerling production should be conducted in order to improve productivity and reduce insect predation, heterogeneity of size classes, and improve genetic lines. The use of hapas for broodstock and seed production (Garutti, 2003) and macrophytes as substrates (Rezende et. al., 2005) could be the next steps.

*5.2.*Feed

Currently, lambari are fed high protein commercial feeds. There's 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 and too expensive. Also, there's a concern about negative environmental impacts. The goals for sustainable aquaculture include to 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 diet for lambari is an important avenue.

On the other hand, unfed systems may be feasible for lambari culture. Lambari species have broad spectrum, omnivorous feeding habits consuming insects, crustaceans, larvae and plants where prey items change according to their availabilities. The aquaculture of lower trophic level species as lambari are encouraged as it uses natural resources in an efficient way (Naylor et. al., 2000). This species can eat natural foods produced by fertilized ponds, eliminating the need for added commercial feeds (Diana et. al., 1994; Knud-Hansen et. al., 1991). Organic and chemical fertilizers are widely available in Brazil and pond fertilization requirements can be managed by the farmer 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 is also an alternative. Usually aquaculture intensification demands high investment and technical expertise, which are not affordable by small farmers in developing countries (Asaduzzaman et. al., 2010). Carbon/nitrogen controlled, periphyton-based systems intensify aquaculture by using resources derived from agricultural byproducts and natural food manipulation to maximize nutrient retention (Asaduzzaman et. al., 2010). By adding carbon, microbial communities convert nitrogen wastes into detrital bioflocs that can be eaten by cultured organisms (Bosma & 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. Many aquatic species obtain nutritional benefits from microbial biomasses, enhancing system efficiency (Bosma & Verdegem, 2011). Similar systems could be tested with lambari.

5.3. System Management

Current aquaculture system management for lambari is based on semi-intensive earthen ponds and has been developed by farmers based on their own empirical practices. It is performed in diverse ways among farms in terms of liming, fertilizing, stocking densities, water exchange, feeding, and harvest. Some lambari producers have tested polyculture systems adding higher value native species as alternative income sources. Polyculture with freshwater prawns have a good potential and has been investigated (Marques et al, 2016). However, there is no current scientific basis for these polycultures at present.

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 (Ali et. al., 2016; Michielsens, Lorenzen, Phillips & Gauthier, 2002; Pucher et. al., 2014; Rahman et. al., 2008). Good management practices can also increase profitability and resource use efficiency (Michielsens et. al., 2002; Pucher et. al., 2014). Furthermore, aquaculture wastes are a rich source of nutrients that can be used by integrating systems and through alternative management strategies.

The introduction of substrates for periphyton growth in semi-intensive ponds increases primary and secondary production (Azim et. al., 2002). Integrated Multi-Trophic Aquaculture (IMTA) improves efficiencies in natural resource use while offering additional commercial items for sale by farmers, reducing economic risk (Chopin et. al., 2001). Integration can occur between aquaculture-aquaculture systems or aquaculture-agriculture systems (Lin & Yi, 2003), and is applicable for small farms as their production is usually more diversified than larger commercial farms. 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.

5.4. Markets

Lambari production has grown over the past years combined with the sport fishing and tourist markets in Brazil. Lambari has 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. The rural lambari farms are smallholders, who are unable to compete with larger producers for large markets. Nevertheless, the transportation of live fish is expensive and small farms are frequently placed very close to several niche markets, which give them an important advantage.

Aquaculture production can improve the livelihoods of poor and marginalized people by providing good quality food, income, and employment (Béné et. al., 2016), but market access and appropriate technology are necessary conditions (Belton et. al., 2012). The market for human consumption of lambari as a protein source rather than as an appetizer has potential but is underestimated by farmers and scientists in Brazil. 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). Studies show a large acceptance of lambari as food and demand can increase with new supplies (Silva et. al., 2011a).

Moreover, lambari aquaculture can be introduced in existing agriculture and/or livestock farms 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 adopt a diversified crop production system where part of production is for the family subsistence. Lambari could be introduced into these farms as a way to improve food security and income. Furthermore, lambari aquaculture by indigenous communities and poor communities living in reserves and protected areas is an environmentally sustainable opportunity. Economic activities that can be developed in harmony with environmental protection can ensure their permanency and offer sustainable livelihoods. Protected areas offer a growing niche market for sustainable, ecologically oriented aquaculture to produce fish for human consumption related to community-based tourism.

6. Conclusions

Lambari aquaculture can become an important tool in the sustainable development options of rural populations in Brazil, including its most sensitive zones of environmental protection. However, its aquaculture development remains in its initial stages. Poor management practices exist and current applied science studies still insufficient to provide sound technology to match rural farmers' realities or needs. A focused research program for them is needed that would have a well-designed on-station and on-farm research agenda and protocols (Costa-Pierce, 2002).

The development of aquatic food production systems that correspond to communities' needs and preserve ecosystems goods and services should be developed in mega biodiverse countries like Brazil. Sustainable aquaculture has such characteristics. These low trophic level, native fish systems promote social-economic development and are the most efficient ways to produce protein for the future world of 10 billion people (Costa-Pierce, 2016). If aquaculture is the solution for food production in the Anthropocene, indigenous, low trophic level, highly nutritious fish such as the lambari will play a vital role.

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Tables

Table 1. Management Practices Adopted by Lambari Farmers in São Paulo State, Brazil.

	Farm practices (Modified from Silva et. al., 2011)							
Management practices	Guanhanhã City Hall Aquaculture Farm (present study)	A	B	C	D	E	F	G
Hatchery	Hormone-induced spawning	Hormone-induced spawning	Hormone-induced spawning	Share post larvae to adult sizes with other producers	Share post larvae to adult sizes with other producers	Natural reproduction	Natural reproduction	Natural reproduction
Nursery	None	40 days inside a brood pond	30 days in earthen ponds	Earthen ponds 44 post larvae/m^2	None	None	None	15 days inside a brood pond

			250 post larvae/m^2					
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	7 months[c]	N/A	N/A	4 months	N/A	N/A	4 months	2-4 months
Fertilization regimes	Poultry manure (50 g/m^2) Chemical fertilizer (20 g/m^2)	Urea (3 g/m^2) and rice bran (10 g/m^2)	No fertilization	No fertilization	No fertilization	No fertilization	No fertilization	No fertilization
Protein contents of feeds (%)	32	28	56-40	36	55-40 ground[d]	40	38 ground[d]	32

Feeding frequencies	2/day	N/A	N/A	N/A	N/A	3/day	N/A	N/A
Fish stocking densities	150 post larvae/m²	10-30 juveniles/m²	50 juveniles/m²	17 juveniles/m²	66-88 post larvae/m²	No control	13 post larvae/m²	20 juveniles/m²
Initial length (cm)	Not measured	3	2	Not measured	Not measured	Not measured	Not measured	1
Final length (cm)	8	9-10	7	8	6-8	6	Not measured	5-12
Sale price	US$ 5.50/kg	US$ 3.70 - 4.60/kg	US$ 0.02/un (2cm) US$ 0.03-0.05/un (7cm)	US$ 0.17/un	US$ 0.04/un US$ 4.30/kg	US$ 0.04/un	US$ 0.04/un	US$ 0.04 – 0.06
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/m² and fed with 28 % protein diet. The production period is 12 months; Lambari are harvested selectively.

[b]Curimbatá (*Prochidolus lineatus*) is a native freshwater omnivorous fish. It's stocked at 0.3/m² and not fed.

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

[d]Manually or mechanically grounded to powder consistency.

N/A represents information is not available.

Table 2. Existing Management Strategies for Lambari Aquaculture.

	Guanhanhã City Hall Aquac. Farm (present study)	**Sabbag et. al, (2011)**	**Garutti (2003)**	**Gonçalves et. al. (2016)**	**Porto-Foresti et. al. (2005)**	**Vilela e Hayashy (2001)**
Production systems	Semi-intensive ponds	Semi-intensive ponds	Semi-intensive ponds	Net cages inside tilapia ponds	Semi-intensive ponds	Net-cages
Species	*Deuterodon iguape*	*Astyanax altiparanae*	*Astyanax altiparane*	*Deuterodon iguape*	*Astyanax sp.*	*Astyanax altiparanae*
Production periods (months)	7	4	3	4	3-4	1-2
Crops/year	2	N/A	4.3	3	3-4	N/A
Culture areas	100 m^2	820 m^2	150-200 m^2	1 m^3	N/A	<1 m^3

Fertilization regimes						
• **Organic fertilizers (g/m²)**	50[a]	None	None	None	None	None
• **Inoganic fertilizers (g/m²)**	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
Fish stocking sizes	Post larvae	Larvae	Larvae	Fingerling	Fingerling	Fingerling

Stocking densities	150/m²	Not controlled[b]	Not controlled[b]	700/m³	50/m²	124/m³
Water temperatures (°C)	20 - 23.2	N/A	15-30	N/A	25-28	N/A
Water exchanges (%)	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
Feed protein contents (%)	32	28	32	32	38-40	45
Feeding frequencies	2/day	1/day	3/day	N/A	3/day	3/day
Feed conversion ratios	3.9 – 5.3	7.4	N/A	1.4	N/A	1.3
Survival (%)	12 - 47	Not measured	N/A	88	70	100

Final fish weights (g)	1.5 – 4.5	N/A	10-20	9	15-20	56
Productivity (kg/m²)	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 farmers' practice. There was no water change during the first fortnight.

N/A represents information is not available.

Table 3. Environmental Indicators of Sustainability: Comparison Between Lambari Aquaculture and Other Aquaculture Systems.

	Lambari aquaculture	**Carp polyculture[a]**		**Shrimp-tilapia IMTA[b]**	**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 (m³/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

[a]Pucher et. al (2015).

[b]Integrated Multi-Trophic Aquaculture (Chopin, 2013; Proença, 2013)

[c]Modified from Boyd et. al. (2007), Costa-Pierce (2010), Gross et al (1998,2000) and Islam et. al. 2002)

[d]Moura et. al. (2016).

N/A represents information not available.

Table 4. SWOT Analysis of Lambari Aquaculture in Brazil.

Strengths	**Weakness**
Grows well in captivity	Poor systems management
Low trophic level species	Innapropriate diets used
Native species	Lack of scientific knowledge
Wide market acceptance	Large consumption of natural resources and wastes produced
High nutritional value	
Opportunities	**Threats**
Alternative management strategies possible	Lack of governance systems
Lambari aquaculture for poverty alleviation	Large gap between scientists and farmers
Lambari aquaculture in protected areas	Asymmetrical social power in the value chain

Table 5. Recommendations for Lambari Aquaculture Sustainable Development in Brazil.

	Current status	**Problems**	**Recommendations**
Seed	• Natural breeding in earthen ponds. Wild spawning, nursery and grow out occur in the same pond. • Hormone-induction of spawning using carp pituitary extracts is used for 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; predation and genetic issues. • Hormone-induced spawning requires knowledge and investment. • The dependency on hatcheries is a factor in the failures of many poor, rural fish farmers.	• Specialized hatcheries are not recommended. • Natural reproduction is a simple, efficient and cheap alternative for small and medium-scale farmers. Farmers can use hapas for broodstock and macrophytes as substrates for reproduction.
Feed	• Use of commercial feed. Producers choose a diet based on pellet size which the fish are able to swallow, generally of a high protein content.	• Commercial diets are incompatible with fish nutritional requirements, leading to low productivity and high wastes	• The use of natural foods improves sustainability. • Use fertilization procedures as performed successfully for other low-trophic level fish aquaculture

		discharged to the environment.	systems (as per Knud-Hansen et. al., 2003).
Management	• Semi-intensive system in earthen ponds. • No water flow, exchange or fertilization protocols. • Each producer has developed their own production strategies based on empirical practices or previous experiences.	• The lack of a protocol for better management practices leads to low productivities, low profits, and high wastes.	• Develop a management protocol to improve systems efficiency. • Explore polyculture and Integrated Multi-trophic Systems opportunities.
Market	• Bait for sport fishing is the largest market. • Restaurants and small shops sell fish.	• Human consumption is well underestimated.	• Introduce lambari into local markets for poverty alleviation and health benefits. • Integrate lambari into existing fish farms. • Develop community-based tourist markets for lambari aquaculture in the natural parks and protected areas.

Figures

Figure 1. Yellow tail lambari (*Astyanax lacustris*). Photographed by Dr. Fabio Sussel.

Figure 2. *Astyanax laticpes*. From Bertaco & Lucena (2010).

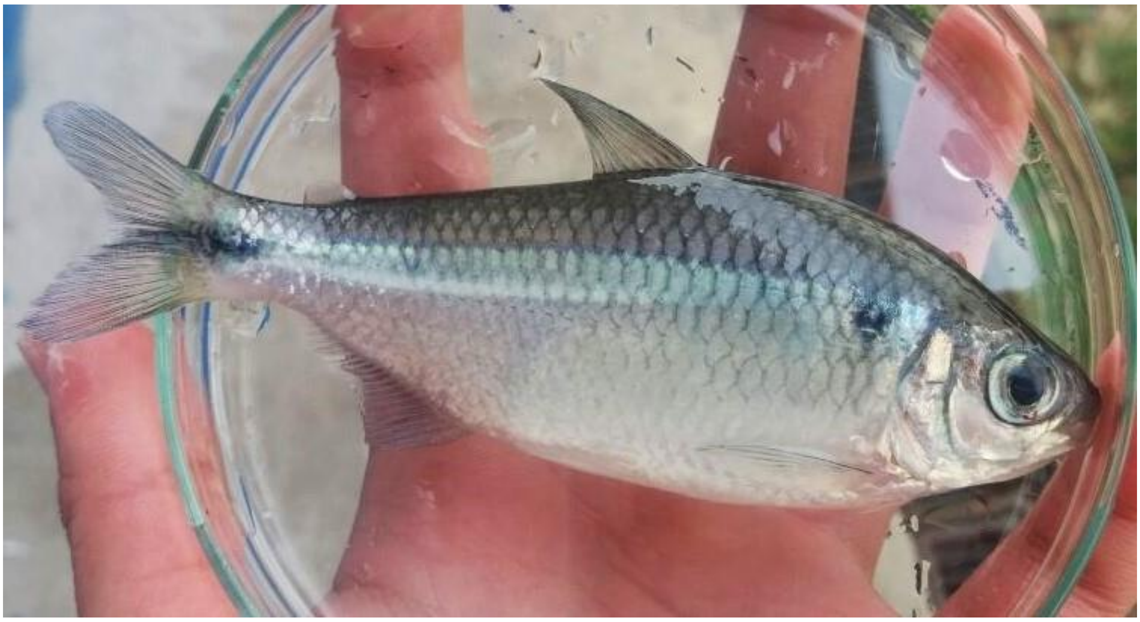

Figure 3. Atlantic forest Lambari (*Deuterodon iguape*). Photographed by Thais C. P. Araujo.

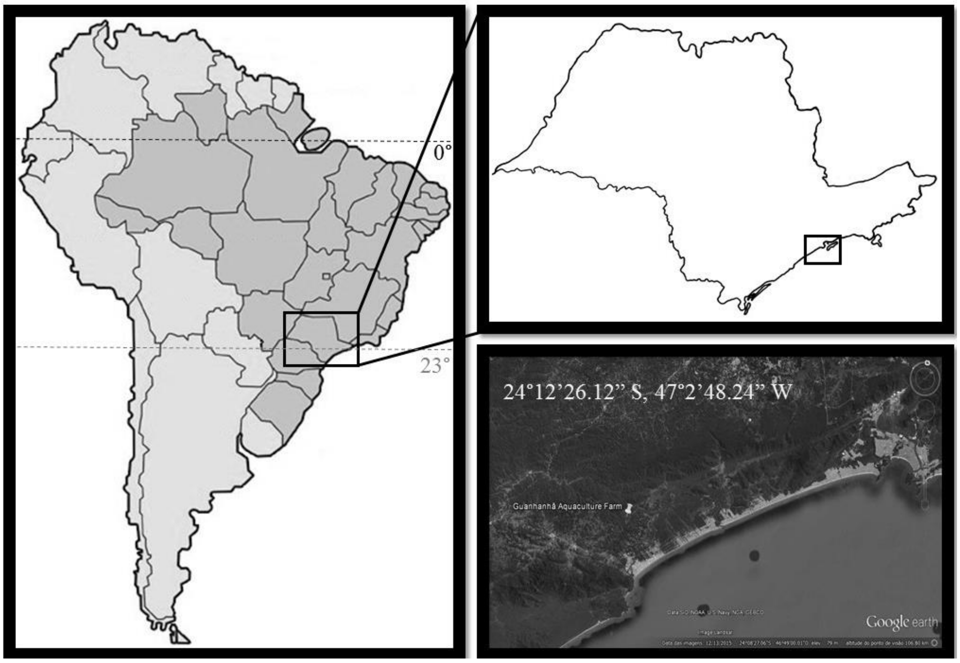

Figure 4. Guanhanhã City Hall Aquaculture Farm Location (24°12'26.12" S, 47°2'48.24" W).

CONSIDERAÇÕES FINAIS

A lambaricultura pode ser uma importante ferramenta para o desenvolvimento sustentavel de comunidades rurais no Brasil, especialmente em áreas sensíveis à conservação ambiental. Contudo, essa atividade encontra-se ainda nos estágios iniciais de desenvolvimento. Práticas de manejo inadequadas existem e grande parte da ciência aplicada tem sido desenvolvida sem levar em conta a realidade das áreas relacionadas à conservação ambiental. Um protocolo de pesquisa que apresente uma agenda integrada aos produtores, como descrito em Costa-Pierce (2002), é necessário.

A criação de sistemas de produção de alimento que corrrenspondam às necessidades locais e conservem os bens e serviços dos ecossistemas é urgente em países megadiversos como o Brasil. A aquicultura sustentável apresenta essas características e pode alcançar esses objetivos. Além disso, sistemas que utilizam espécies nativas, de baixo nível trófico promovem desenvolvimento socio-econômico e são mais eficientes na produção de proteína para uma população em grande expansão (Costa-Pierce, 2016). Se a aquicultura é a solução para a produção de alimentos no futuro, o uso de espécies nativas, de baixo nível trófico, como o lambari, será de extrema importância.