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Sustainability and technical efficiency of fish hatcheries in the STATE of MATO GROSSO do SUL, Brazil

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ABSTRACT

This study aims to analyze the level of sustainability of fingerling producers in the state of Mato Grosso do Sul, Brazil. We evaluated the level of sustainability taking into account social, environmental, economic and institutional dimensions. For each dimension, sub-indexes were calculated based on 24 variables. Sustainable Development Aquaculture Index (SDIA) was calculated for each production unit investigated. Subsequently, we used Data Envelopment Analysis for constant returns to scale, with input orientation to assess the environmental efficiency with regard to the use of production resources. Variables included exploration area in hectares, number of employees and income paid per employee (input), and SDIA (output). The results showed 20% of farmers used inputs rationally as reference for the other units; while 80% of producers operated inefficiently mainly due to the presence of increasing returns, thus reflecting the inefficiency in the resources allocation.

1. Introduction

Over the last few decades, the food production has been urgently growing to meet the global population growth. According to FAO estimates in 2012, the food demand is expected to increase by > 70% by 2050 (Alexandratos and Bruinsma, 2012). However, one of the major challenges in the coming decades is to meet the world demand for food without degrading ecosystems (Godfray et al., 2010). On the other hand, agricultural systems account for a considerable part of environmental impacts caused by anthropogenic activities (Foley et al., 2011; Godfray et al., 2010). In this scenario, aquaculture stands out as an important source of protein and micronutrients essential to human health worldwide (Béné et al., 2015; FAO, 2014).

The world fish supply for human consumption increased by 3.2% a year in the last five decades. It is strongly supported by aquaculture, which accounts for almost half of all fish aimed to human consumption (FAO, 2016). Brazil has considerably expanded its fish production over the last two decades, taking advantage of the natural resources available in the country and benefiting from several public policies directed to the aquaculture and fishery sector (Bueno et al., 2015). Despite the fast growth in Brazilian aquaculture, the economic feasibility and environmental impacts generated by this activity may limit a sustainable development of aquaculture (Moura et al., 2016).

Sustainable development meets the needs of current generations without compromising the ability of future generations to meet their own needs (Brundtland, 1987).Thus, sustainable aquaculture may be defined as the production of aquatic organisms in a cost-effective way with positive and continuous relationship with the ecosystem and communities. Moreover, products resulting from the production process must be suitable for consumption and meet food safety requirements (Rey-Valette et al., 2008; Valenti et al., 2011; Wurts, 2000).

The production of fingerlings in laboratory with structures specially built for this purpose is among the basis of aquaculture supply chain. At such locations, controlled fish breeding, egg hatching and fingerling rearing are carried out at a suitable sale condition (Saraswathy et al., 2015). In this sense, farmers are fundamental for a proper functioning of the entire production chain. Thus, the sustainability evaluation of such fish farmers is necessary to start the production on a sustainable way since that phase is essential to the fish supply chain (Galappaththi et al., 2016; Uppanunchai et al., 2015). In addition, the production of good and healthy fingerlings reduces the need for future treatments.

The development of strategies to minimize the possible negative environmental impacts of this activity, as well as the use of management tools aimed at the socioeconomic development along the entire

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supply chain are paramount (Klinger and Naylor, 2012).In this sense, a series of approaches have been adopted to evaluate the sustainability of producing aquatic organisms, including Carbon Footprint (Folke et al., 1998), Water Footprint (Pahlow et al., 2015), Life Cycle Assessment (Aubin et al., 2006; Henriksson et al., 2015), Emergy Evaluation (Cavalett et al., 2006) and Selection of Indicators (FAO, 2011; Moura et al., 2016; Rey-Valette et al., 2008; Valenti et al., 2011).

The selection of indicators stands out from other methodologies by making possible the simultaneous evaluation of environmental, social, economic and institutional factors. The use of indicators allows for a more holistic identification of weak and strong points in production systems (Moura et al., 2016). By this logic, the "*Guide to the co-construction of sustainable indicators in aquaculture*", a result of the *Evaluation of aquaculture system sustainability* project (EVAD), suggests a series of sustainability indicators specially designed for the fish supply chain.

In a holistic and multidisciplinary view, the framework proposed by the EVAD guide integrates the institutional dimension with three traditional pillars of sustainability (environmental, economic and social) (Lazard et al., 2014). In addition, this framework was tested and validated in a series of case studies (Rey-Valette et al., 2008). The EVAD guide also served as basis for developing a project aimed at choosing indicators for a sustainable development of aquaculture in the Mediterranean (In Dam project) (FAO, 2011).

The use of theoretical frameworks, combined to robust methods of analysis of impacts of productive activities, still represents a challenge to efforts promoting sustainable development (Samuel-Fitwi et al., 2012; Waas et al., 2014). In this sense, Data Envelopment Analysis (DEA) can be used to overcome such challenges. DEA was created by Charnes and collaborators in 1978 aiming at evaluating the relative efficiency of a set of entities called Decision Making Units (DMUs) (Charnes et al., 1978). DEA stands out as one of the most important methodologies for the evaluation of individual or organizational efficiency regarding the use of several resources in production.

Thus, DEA provides valuable information to support decision-making processes regarding the allocation of resources within productive and governmental sectors (Lampe and Hilgers, 2015). The DEA has been increasingly used for the analysis of agricultural systems (Fare et al., 2013), among them aquaculture (Sabbag and Costa, 2015). Thus, this linear programming technique may contribute to agricultural technical-economic sustainability (Fare et al., 2013).

In this context, through a set of indicators of social, environmental, economic and institutional sustainability, this study evaluates the level of sustainability of fingerling production systems used by producers in the state of Mato Grosso do Sul, Central-West region of Brazil. In addition, DEA was used to evaluate the degree of environmental efficiency in relation to economic productive factors during the production process.

2. Materials and methods

2.1. Study area

The study was conducted with fish farmers of the state of Mato Grosso do Sul (MS) in a region that occupies about 357,000 km^2 located in the Center-West region of Brazil (IBGE, 2015). Climate is Aw and Am categories[1]according to the Köppen classification (Alvares et al., 2013). The relief is flat to corrugated, and the area has two of the largest water basins of the American continent (Paraná and Paraguay), which provide the state with ideal characteristics for aquaculture. In addition, Mato Grosso do Sul has a large variety of native fish species that can be commercially produced (Resende, 2009; Dutra, 2014; IBGE, 2015).

[1] Aw with dry winter.

2.2. Sample

We identified and contacted all fingerling producers known by the technical assistance agency (Agrarian Development Agency and Rural Extension, AGRAER) and the Brazilian Agricultural Research Corporation - Embrapa. In total, ten producers were performing this activity in 2015, and all participated in the study. Fish farmers are distributed in six municipalities of the state, as shown in Fig. 1.

2.3. Selection of indicators

For the selection of indicators, we followed the recommendations and principles of the *Guide to the co-construction of sustainable indicators in aquaculture* (Rey-Valette et al., 2008). [2]The relevant indicators were selected aiming at evaluating environmental, economic, social and institutional dimensions of fingerling production companies in a balanced way. In total, a set of 24 indicators were selected. Each indicator was classified on a three-level scale, ranging from 1 (one) for the worst score, 3 (three) for an intermediate level and 5 (five) for the best score (Table 1), as suggested by Matias (2012).

So far, no specific references were found for the region. Therefore, we considered other methodologies to set adequate indicators used to meet the regional requirements (Candido et al., 2015; Guimaraes et al., 2015; Souza et al., 2015) Box 1.

2.4. Aquaculture sustainability index

The results of interviews supported the calculation and adjustment of the aquaculture sustainability index according to predetermined scores. Subsequently, the sustainability sub-index for each dimension was calculated using the arithmetic mean of single scores of indicators belonging to each dimension. Thus, the sub-index of Environmental, Economic, Social and Institutional sustainability was calculated for each company (Matias, 2012).

The Aquaculture Sustainability Index (ASI) of the projects was calculated by using the Eq. 1. The choice of weighting indexes among dimensions was made in combination, involving the stakeholders of the fish supply chain (Rey-Valette et al., 2008).

$$ASI = \quad (SoSI + EnSI + EcSI + InSI) \tag{1}$$

ASI = Aquaculture Sustainability Index.SoSI = Social Sustainability Sub-index.EnSI = Environmental Sustainability Sub-index.EcSI = Economic Sustainability Sub-index.InSI = Institutional Sustainability Sub-index.

Source: Adapted from Matias (2012).

No weighting was used because no works were found regarding other aquaculture indexes establishing the relative importance of different dimensions. Therefore, we considered all dimensions of the chain as assuming the same importance.

After obtaining the final ASI, companies were classified into three levels of sustainability: low level of sustainability (ASI ranging from 1 to 2.5), average level of sustainability (ASI ranging from 2.6 to 4), and high level of sustainability (ASI ranging from 4.1 to 5) (Matias, 2012).

2.5. Performance and sustainability of companies

According to Charnes et al. (1978), the technique known as Data Envelopment Analysis (DEA) has been used since the end of the 1970s.It originated in a study aiming at evaluating the efficiency of special school programs in the United States.

The DEA technique verifies whether each unit operates properly or not in relation to a specific set of resources; and the results are compared to units considered similar by managers in relation to the variables analyzed. It originated from an initial study entitled "Measuring

[2] Am (Monsoon) with hot summers and dry winters.