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Emergy assessment of tilapia cage farming in a hydroelectric reservoir

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ABSTRACT

Considering that most of the energy supply in Brazil is derived from hydroelectric sources, the government has been strongly encouraging cage farming in federal water bodies. The government limited the aquaculture parks in hydroelectric reservoir to only 1% of its total area and, inside the parks, a ratio of 1:8 referring to the park and organic load dilution area. However, no objective evaluations proved that limit is suitable, and the absence of a methodology to evaluate this impact is a considerable problem. The aim of this study was to evaluate the Nile tilapia cage farming sustainability in a hydroelectric reservoir in Brazil using an emergy assessment and to simulate management techniques and public policies that contribute to the sustainability of this farming system. The results of the emergy assessment indicate that this production model has low renewability, is inefficient (mostly due to feeding), does not use local resources and presents high environmental impact. Therefore, we have analyzed three scenarios, in which reducing the inputs of non-renewable resources and enhancing environmental inputs were considered. Reducing the stocking density from 100 to 20 kg/m^3 in the initial farming stage and enhancing the dilution area from 1:8 to 1:100, referring to the cage and organic load dilution area, makes the current production system a sustainable model based on the use of natural renewable resources.

1. Introduction

Tilapia is the second most cultured fish in the world after carps. The total tilapia production accounted for 3,957,843 t in 2011 (FAO, 2013), and the production continues to grow. Tilapia's popularity is due to its hardiness and omnivorous feeding characteristics, which makes it suitable for farming under less optimal environmental conditions (Rojas and Wadsworth, 2007). Seventy-two percent of tilapia production is in Asia, particularly in China and Southeast Asia, 19% is in Africa and 9% is in America (FAO, 2012). Tilapia is farmed both in ponds and cages in semi-intensive and intensive systems. In recent years, cage farming has been spread all over the world because it features a relatively lower investment requirement compared to ponds and raceways (Rojas and Wadsworth, 2007), is quick and easy to start up and enables more production cycles (Baliao and Dosado, 2011).

In Brazil, 82% of the total fish production is derived from continental aquaculture, with tilapia representing the most farmed aquatic species. The production of tilapia was 155,450 t in 2010, which corresponded to over 39% of the total fish production (MPA, 2010). Brazil has a huge potential for aquaculture due to its water availability, and the Brazilian government has encouraged aquaculture development, as indicated by the recent creation of the Ministry of Fisheries and Aquaculture.

In a number of countries similar to Brazil, most of the energy supply is derived from hydroelectric sources; thus, there is a huge potential to establish fish cage-culture systems in reservoirs. Brazil alone has over 6.5 million ha of reservoirs, lakes and dams, with a potential capacity to produce 700,000 t of tilapia annually (Rojas and Wadsworth, 2007). Considering this scenario, the Brazilian government has been strongly encouraging cage farming in federal water bodies. Since 2004, the Brazilian government has delimited six reservoirs totaling 28,503 hectares of water, in which 42 aquaculture parks have been installed (BRASIL, 2011). The Ministry established policies for aquaculture occupation in reservoirs to avoid adverse environmental impact and ensure multiple water use, which corresponded to limiting aquaculture parks in hydroelectric reservoir to 1% of its total area and, inside parks, a ratio of 1:8 referring to cage and organic load dilution area is required (BRASIL, 2004).

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Tilapia cage farming in Brazil can be considered as a relatively new production system. This production model emerged in the first decade of the 21st century. Most cages are 6–18 m^3, in which the most cultured species is Nile tilapia, *Oreochromis niloticus*. Tilapia feeds exclusively on a commercial extruded diet, which is produced by large factories, and each fish spends five to seven months to reach 800 g, at which point they are harvested and sold to be processed into skinless, boneless filets. The usual stocking density adopted in Brazil is 100 kg of fish per m^3, while in other countries, the densities range from 2 to 50 kg/m^3 (Gibtan et al., 2008; Ouattara et al., 2003; Watanabe et al., 1992; Chakraborty et al., 2010).

Despite the environmental concerns presented by the regulations, no objective evaluations have been performed to determine whether this limit is suitable (David et al., 2011) to ensure sustainable fish production in reservoirs. Fish farming is not only constrained by economic factors and site-specific characteristics; it may also become constrained by a reduced or over used capacity of ecosystems to produce inputs (Zhao et al., 2013). Therefore, evaluations must be performed to guide the establishment of regulations. To reconcile conflicts between economic development and environmental protection, a science-based evaluation system known as emergy considers both values within a common measure. Emergy regards both the work of nature and that of humans in generating products and services and is a measure of the available energy of one type used up in transformations directly and indirectly to produce a service or product (Odum, 1996). Emergy analysis is a type of embodied energy analysis that provides common units (solar emergy joules [sej]) for the comparison of environmental and economic goods by summing the energy of one type required directly or indirectly for the production of goods (Odum, 1988). Thus, all inputs (from nature and economy) used in a production system are put together in a common basis: solar energy. Therefore, it is possible to interpret quantitative results from the calculated emergy indices that relate the emergy flows of the system being evaluated with those of the environment and larger economy within which it is embedded (Brown and Ulgiati, 2004).

In this context, the goals of this study were (1) to evaluate the first stage of Nile tilapia cage farming sustainability in a hydroelectric reservoir in Brazil using emergy assessment and (2) to simulate management techniques and public policies that contribute to the sustainability of this farming system.

2. Method

2.1. Characteristics of the studied area

The data used in this study were obtained from a fish farm located in the Ilha Solteira Reservoir on the Paraná River in the state of São Paulo, Brazil (20°12′10″ S, 50°58′31.15″ W). This farm has a total of 100 cages. Each cage measures 6 m^3 (2 m × 2 m × 1.5 m). The Ilha Solteira reservoir has 49,200 ha of water, with depths ranging from 0 (at the border) to 326 m (at the hydroelectric dam). The surrounding area is comprised mainly of pastures used for the production of beef and dairy cattle.

During the process of delimitation of aquaculture parks by the government, streams appropriate for cage farming were defined across studies on hydrology and hydrometrics parameters, geotechnology, geomorphology, ichthyofauna, socio-economy and fisheries biology. Due to insufficient data on the carrying capacity of reservoirs and complexity to determine its value, the government determined that the size of the aquaculture parks could not exceed 1% of the reservoir. The government mandated that inside each aquaculture park must be an organic load dilution area of 1:8 (BRASIL, 2004).

Table 1
Indices and ratios used for evaluating tilapia cage farming in the present work (Odum, 1996).

Renewability (%)	%R = 100 * (R/Y)
Emergy yield ratio	(EYR) = Y/F
Environmental loading ratio	(ELR) = (N + F)/R
Emergy sustainability index	(ESI) = EYR/ELR

Sex-reversed Nile tilapia fingerlings (1–2 g) were purchased in a hatchery located in Paraná State, which is 450 km far from the farm. Tilapia cage farming consists of two stages: in stage I, 420 juveniles (40 g) per m^3 are stocked until they reach 250 g, when they are selected and redistributed among the stage II cages at a stocking density of 130 fish per m^3. In both stages, the final stocking density is 100 kg/m^3. Fish farming management involves the removal of dead and dying fish in the morning and feeding with a commercial diet twice a day (8:00 am and 4:00 pm) following the manufacturer's recommendations. Fish from 50 to 250 g are fed a 2.5-mm diet (dry matter: 88%; digestible energy: 3800 kcal/kg; crude protein: 42%; lipids: 9%) and those from 250 to 800 g are fed a 5-mm diet (dry matter: 88%; digestible energy: 3500 kcal/kg; crude protein: 32%; lipids: 7%). The commercial diet is produced more than 200 km from the fish farm. Depending on the season (water temperature) and stocking density, each tilapia requires five to seven months to reach 800 g. After harvesting, the fish are sold to a cold storage plant. Frozen tilapia filets are sold in large markets in Brazil, and fresh filets are exported, mainly to the USA, depending on market conditions. In this study, data of the stage I of a summer productive cycle was considered, which started on October and finished on March, because in their young age, tilapias can take more advantage of natural food – phytoplankton and periphyton (renewable resources). In stage I, this feeding habit allows changes on the current productive model to improve the entry of these renewable resources in place of non-renewable sources, mainly commercial diet and the fuel to transport it.

2.2. Emergy assessment

In an emergy assessment, the comparison of several products is possible by considering all energy inputs on a common basis: solar energy. Emergy analysis considers the quality of each form of energy by multiplying each energy quantity by its solar transformity, which is defined as solar emergy by unit of energy (sej/J) (Odum, 1988). This methodology classifies the emergy aggregated fluxes into inputs from nature (I), formed by renewable (R) and nonrenewable resources from nature (N), (I = R + N), feedbacks from the economy (F), formed by materials (M) and services (S) (F = M + S) and the total emergy used (Y = I + F). Based on these concepts, Odum (1996) proposed emergy indices and ratios to evaluate systems, which were used in the present work (Table 1).

Fig. 1 displays the diagram of tilapia cage farming based on the emergy systems language described by Odum (1996). The unit of emergy evaluation was the production of one cage, although data from all cages in the farm was used in the analysis. To determine the values of renewable environmental inputs (sun, wind, rain and spring water), we considered that each cage (4 m^2 of surface) occupies 3200 m^2 of area according to the Brazilian law, which allows aquaculture parks to occupy 1% of the superficial area of reservoirs and with a dilution area of 1:8. The renewable environmental inputs considered were the ones with major importance on fish farming, which were previously reported in other fish farming studies, such as Zhang et al. (2011) and Vassallo