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Improving the sustainability of tilapia cage farming in Brazil: An emergy approach

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A B S T R A C T

The accelerated and disorderly expansion of aquaculture can lead to economic, social, and environmental problems. In this sense, it is necessary to prioritize the adoption of practices that aim for sustainable production. The aims of the present study were to identify the contributions from nature and economy in the system of tilapia cage farming. In addition, emergy accounting was utilized to evaluate whether the use of periphyton as a complementary food and the reduction of storage density improve the sustainability of this production system. Three different production managements were evaluated and compared: using traditional stocking density adopted by farmers (80 kg/m^3) with 100% of the daily recommended feed and without substrates for periphyton (TRAD); traditional stocking density (80 kg/m^3) with 50% of the daily recommended feed and with substrates for periphyton (TDS); lower density (40 kg/m^3) with 50% of the daily recommended feed and with substrates for periphyton (LDS). We calculated using emergy accounting the transformity (Tr), renewability (%R), emergy yield ratio (EYR), emergy investment ratio (EIR), emergy loading ratio (ELR), emergy exchange ratio (EER), and emergy sustainability index (ESI) of the distinct production managements. The results showed that tilapia cage farming is highly dependent on resources from economy, and feed is mainly responsible for this. Thus, the decrease in stocking density and feed rate, combined with the use of periphyton, improved all emergy indices evaluated. This occurred because there was a decrease in the use of resources from economy and increase in the use of renewable natural resources. The study shows through the emergy accounting that the use of periphyton to feed cultured fish combined with a reduction in artificial feed use and a decrease in the stocking density should be encouraged to promote the sustainability on tilapia cage farming.

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1. Introduction

Population growth and the consequent increased demand for high quality food have contributed to the global expansion of aquaculture in recent years (FAO, 2016). However, the disordered development of this activity may have negative effects on the environment (Bronnmann and Asche, 2017). The intensification of systems based on the high use of non-renewable natural resources, combined with the non-adoption of best management practices to achieve high yields, can adversely affect the environmental balance and compromise the future growth of aquaculture (Boyd, 2003; Valenti et al., 2011).

In Brazil, fish farming is represented mainly by tilapia (*Oreochromis niloticus*) and tambaqui (*Colossoma macropomum*) in semi-intensive systems (IBGE, 2015). However, intensive production of tilapia in cages prevails in São Paulo State, which traditionally employs high stocking densities (>80 kg/m^3) and large amounts of feed to achieve high productivity in small cages (Marengoni, 2006). Sometimes this type of farming has caused undesirable consequences, such as accumulation of nutrients in the sediment (Mallasen et al., 2012), the high cost of inputs for the manufacturing of feed (Ayroza et al., 2011; Garcia et al., 2017), outbreaks of diseases and the consequent use of therapeutic products which can result in residue accumulation in the environment and in the fish (Garcia et al., 2013; Monteiro et al., 2016; Maciel et al., 2017).

Methods for sustainability assessment, such as emergy accounting, point out that sustainable production systems are those

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that emit low environmental pollutants, use local renewable resources as the main sources of energy, and have low dependence on non-renewable external resources (Brown and Ulgiati, 1997). In this way, it becomes necessary to guide aquaculture farmers to adopt practices that attend to this concept of sustainability to maximize productive efficiency, but also to reduce losses, costs, and negative environmental impacts, increasing the possibility of success over time (Wilfart et al., 2013). One strategy for this is to reduce dependence on feed (Garcia et al., 2014), for example, by reducing the stocking density (Garcia et al., 2013) and using periphyton as a natural food (Garcia et al., 2016). The periphyton community develops naturally on submerged substrates like rocks, woods, plants and sediments. It is comprised of green algae, diatoms, bacteria, fungi, protozoans, zooplankton and smaller invertebrates (Azim and Asaeda, 2005).

The use of periphyton to feed cultured fish combined with a decrease in the stocking density improves the growth performance, decreases the time of rearing, and reduces the feed conversion rate in tilapia cage farming (Garcia et al., 2016). This improvement in performance can also provide satisfactory economic results, such as annual yields of up to 57% and 87% higher profitability than the traditional production system (Garcia et al., 2017). However, technical and economic results are not enough to ensure the sustainability of the system because these evaluations do not consider the inputs of environmental resources by the productive activity (Valenti et al., 2011). The adoption of methods that measure sustainability can be a solution to this problem.

Emergy accounting is one such method able to consider environmental and economic aspects of the production systems (Odum, 1996). This method considers all inputs and outputs of natural, human labor and economic resources in the system, this allows to compare and calculate the part of each kind of energy flow (joules of solar emergy [seJ]) in the system, independent of the strictly monetary perception (Odum, 1996; Brown and Ulgiati, 1997; Copeland et al., 2010). It can be used in the decisions and definition of public policies for the use of natural resources, as reported by Lomas et al. (2008) in the evaluation of preservation policies in Spain, and by Pulselli (2010) in the monitoring of resource use by the communities of Abruzzo, Italy.

Thus, we formulate the hypothesis that reduced densities and the use of periphyton as a natural food can reduce the use of non-renewable resources and promote the sustainability of traditional tilapia cage farming. The aim of the present study is to evaluate by emergy accounting if these strategies improve the sustainability of tilapia cage farming. In addition, we identify the contributions from the nature and the economy of this production system.

2. Material and methods

2.1. Systems description

An analysis was conducted on the use of different densities of stocking and periphyton as complementary food (by the introduction of bamboo substrates in the cages and colonization of these microorganisms at the added surface) in an experiment carried out in a tilapia cage farm at the Nova Avanhandava Reservoir, Tietê River, São Paulo State, Brazil (21°11′27,41″ S, 50°03′00,79″ W) which produces 40 t per month. The experimental cages (6 m^3 each one) were installed inside the farm to evaluate different production managements, with three replicates (cages) per treatment (Garcia et al., 2016): using traditional stocking density adopted by Brazilian fish farmers (80 kg/m^3) with 100% of the daily recommended feed and without substrates for periphyton (TRAD); traditional stocking density (80 kg/m^3) with 50% of the daily recommended feed and with substrates for periphyton (TDS); lower density (40 kg/m^3) with 50% of the daily recommended feed and with substrates for periphyton (LDS). The treatment that received 100% of daily ration (TRAD) was fed twice a day (8:00 h and 16:00 h), and the treatments that received 50% of daily ration (TDS and LDS) was fed only in the afternoon (16:00 h). The aim of this management was to stimulate fish to eat periphyton during day time. The experiment details are described in Garcia et al. (2016). The production data used were obtained from Garcia et al. (2016) and the economics data from Garcia et al. (2017) (Table 1), all these data were submitted to the appropriate statistical analysis (two-way ANOVA) by these authors and represent real situations of commercial production.

2.2. Emergy accounting

Emergy accounting was used to evaluate the sustainability of the three production managements in tilapia cage farming: using traditional stocking density adopted by Brazilian fish farmers (80 kg/m^3) with 100% of the daily recommended feed and without substrates for periphyton (TRAD); traditional stocking density (80 kg/m^3) with 50% of the daily recommended feed and with substrates for periphyton (TDS); lower density (40 kg/m^3) with 50% of the daily recommended feed and with substrates for periphyton (LDS). From the knowledge of the energy flow of the production system, the diagram was built based on energy systems symbols (Odum, 1996), which presents the energy transformation ways within the systems, from the primary sources and inputs to the final product (Fig. 1).

Based on the understanding of all energy sources and resources used in the evaluated management, the inputs and outputs of resources were categorized into: renewable resources (R), economic resources (F) as inputs, and yield (Y) as output. The energy inputs were quantified in units of mass (kg) or energy (joules) to be compatible with the units used in the global productivity factor or transformity of each item. However, some items could not be accounted for in these units and they were valued in monetary unit and converted into emergy equivalents by multiplying the money flow (US$) with the ratio obtained from the national census values (ratio = gross national product dollars/emergy from the country in the reference year). The equations for the energy calculations of each input are described in Appendix A. The conversion calculations are described in Appendices B, C, and D.

The inputs of resources had their UEVs (Unit Emergy Value) determined according to the data available in the literature. All the UEVs found are on a baseline of 1.20E+25 sej/year (Campbell, 2016). When we verified divergences in the baseline, they were converted to obtain updated and comparable values (Campbell et al., 2005; Brown et al., 2016; Brown and Ulgiati, 2016).

For the emergy calculations, the area of one cage (4 m^2 in this

Table 1
Technical and economic characteristics of systems using periphyton as supplementary feed for tilapia in cages at different stocking densities.

Item	Unit	TRAD	TDS	LDS
Stocking density	kg/m^3	80.00	80.00	40.00
Feed	%	100.00	50.00	50.00
Substrates	–	No	Yes	Yes
Total production	kg/cage	411.79	417.84	214.54
Weight gain	kg/fish	0.72	0.65	0.71
Feed conversion ratio	–	1.84	1.29	1.06
Productive cycles	cycles/year	1.80	1.49	1.45
Human labor [a]	hours/cage	24.00	26.40	23.40
Cage capacity	m^3	6.00	6.00	6.00

[a] Labor (total hours spent by cage) for each activity to rear tilapia in cages with or without use of substrates.