Ecological Indicators 66 (2016) 574–582

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Sustainability of Nile tilapia net-cage culture in a reservoir in a semi-arid region

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ARTICLE INFO

Article history:
Received 28 September 2015
Received in revised form 20 January 2016
Accepted 27 January 2016

Keywords:
Aquaculture modeling
Sustainability indicators
DPSIR
MULINO

ABSTRACT

Among the tools used to measure sustainability in aquaculture, sets of indicators allow a holistic view of a system in its social, environmental, and economic dimensions. Approaches that align indicators with models such as the Drivers-Pressure-State-Impact-Response (DPSIR) framework can improve understanding of this sustainability. This study evaluated the sustainability of cage production systems for Nile tilapia in the Santa Cruz Reservoir, to determine whether a set of indicators used with the DPSIR conceptual model was effective to study the sustainability of the system. The 49 indicators used were calculated from information obtained from questionnaires and from monitoring the production system. Sustainability was also modeled and compared with hypothetical scenarios, with different fish stocking densities. The results indicated that the production system is economically feasible, generating profit and distributing income. However, the income generated benefits few people and is not fixed in the community. Environmentally speaking, the system is highly dependent on inputs, especially the nutrients nitrogen and phosphorus, and energy, as well as increasing sedimentation of nutrients in the reservoir. In the social dimension, the venture employs few workers. The modeling showed that the system is potentially sustainable, and that changes in stocking density decreased this sustainability. In summary, the system showed many sustainable features, whereas some others need to be modified to improve the general sustainability.

1. Introduction

Global consumption of aquatic foods has been increasing in recent decades, driven by the expanding human population and the growing preference for healthy sources of animal protein. Production from capture fisheries has not increased to meet the demand, and therefore aquaculture has dramatically expanded. Aquaculture is one of the fastest-growing food-producing sectors worldwide and provides almost half of all fish for human food (FAO, 2014). Tilapia is the second most-often farmed fish worldwide; production reached 4.82 million tons in 2013, with a farm-gate value of US$ 8.25 billion (FAO, 2015). In Brazil, aquaculture is expanding faster than farming of terrestrial animals (MPA, 2010), and Nile tilapia is the species that is most often farmed. The culture of tilapia in net-cages in reservoirs emerged early in this century, with a support from Brazilian government programs (Bueno et al., 2015; Garcia et al., 2014). Despite the rapid growth of aquaculture worldwide and in Brazil, sustainability issues may limit further development.

The concept of sustainability involves habitable environments that maintain themselves over time. Sustainable development was originally defined as a process that supplies present needs without compromising the ability of future generations to supply their own needs (WCED, 1987). Subsequently, many other concepts were added, to include economic features and human interactions with the biosphere (Johnston et al., 2007). It is generally accepted that human well-being is dependent on the interaction of natural capital with built, human and social capital (Costanza et al., 2014). The economic, environmental and social dimensions are referred to as the three pillars of sustainability (Frankic and Hershner, 2003), meaning that sustainable production must be economically feasible, environmentally friendly and socially beneficial. Thus, sustainable

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http://dx.doi.org/10.1016/j.ecolind.2016.01.052

aquaculture may be defined as the cost-effective production of aquatic organisms, which maintains a harmonious and continuous interaction with the local ecosystem and human communities (Valenti, 2011).

Establishing appropriate tools to evaluate sustainability remains a challenge for studies of sustainable development. Measuring the sustainability of aquaculture is essential in order to attain sustainable systems. Such assessments help investors and policymakers to evaluate different projects, and help scientists and farmers to move farming systems toward sustainable production (Valenti, 2011). The methods used to measure sustainability in aquaculture are the analysis of emergy (Odum, 1986), ecological footprint (Rees and Wackernagel, 1994), life cycle analysis (ISO, 2006), resilience analysis (Holling, 1973), and the use of a set of indicators (Boyd et al., 2007; Valenti, 2011). The first four give an integrated overview of the system, which is very useful. However, they require a huge amount of data, which is difficult to obtain, and focus mainly on the environmental dimension. Conversely, sets of indicators measure the individual components of a system, i.e., characteristics that affect its different features (Heink and Kowarik, 2010). Sets of indicators serve as descriptive tools that reflect scenarios through critical points, facilitating the identification of strengths and weaknesses for sustainable development, which are obscured by other methods.

The DPSIR (Drivers-Pressure-State-Impact-Response) theoretical framework and conceptual model has recently allowed the integration of information from several indicators with management actions, such as public policies applied to aquaculture. The DPSIR is a model of systemic evaluation that provides data about economic, social and environmental interactions in a system, highlighting which actions are the most sustainable to manage a resource, and indicating which indicators are more important (Nobre, 2009; Nobre et al., 2010). This approach has been applied to natural resources in Europe by using computational models such as MULINO mDSS (Giupponi, 2007), which permits an interface between researchers and managers to assist in decision-making.

The present study evaluated the sustainability of a tilapia net-cage production system in a reservoir in semiarid northeastern Brazil, by applying a set of indicators. In addition, we assessed whether the selected set of indicators and the DPSIR conceptual model are appropriate to evaluate the sustainability of this production system.

2. Materials and methods

2.1. Study area

The study was conducted at a fish farm founded by 10 aquatic farmers, who work together in the "Associação dos Aquicultores do Apodi" (AQUAPO, The Aquatic Farmers Association of Apodi). The system consists of ~120 net-cages of 4 m^3 each, which in 2012 produced ~33 tons of Nile tilapia (*Oreochromis niloticus*). The net-cages are installed in the Santa Cruz Reservoir, city of Apodi, Rio Grande do Norte, Brazil (Fig. 1). This reservoir is located in the watershed of the Apodi/Mossoró River and has an area of ~3413 ha, with a maximum storage capacity of ~600,000,000 m^3 and a maximum depth of 38 m during the study period. The climate is semiarid and very warm (BSw'h', according to the Köppen climate classification).

2.2. Sampling design

The production of a fish batch was followed for 150 days (April through September 2012), through the entire cultivation cycle. Approximately 21,000 Nile tilapia fingerlings weighing approximately 1 g were obtained from a hatchery in the state of Ceará. The rearing period is divided into two phases. In the initial growth phase, 3 net-cages of 6 m^3 are stocked with ~7000 fingerlings each, resulting in a density of about 1166 ind./m^3; the fry are then selected and stocked in 22 net-cages during the grow-out phase, with a density of 200 ind./m^3 until harvesting. The fish were measured and weighed weekly for 42 days (initial growth phase) and then biweekly until harvest. The fish are fed daily at frequencies ranging from 8 times daily (initial phase) to 4 times daily (late phase), with four kinds of commercial feed. The first feed used contains 50% crude protein and is offered to the fish until they reach 4 g; the second feed has 40% protein and is offered to fish up to 40 g, which concludes the initial phase of cultivation. In the second phase, the fish receive feed with 32% protein until they reach

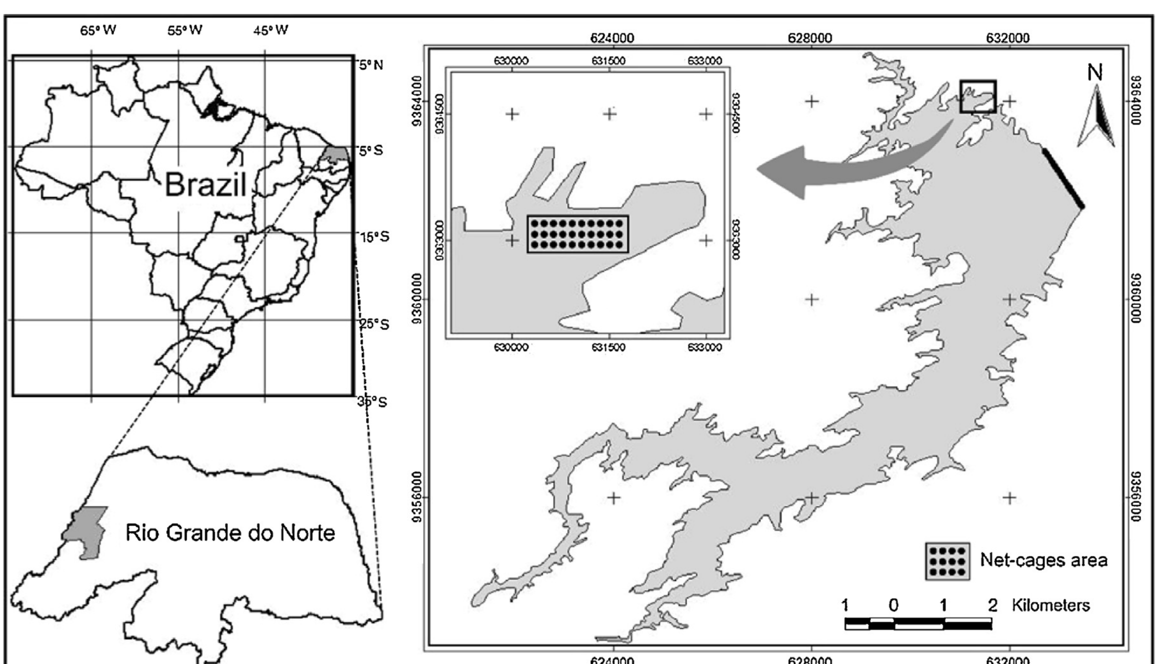

Fig. 1. Location of the Santa Cruz Reservoir, showing the Nile tilapia cage production area.