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Indicators of sustainability to assess aquaculture systems

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ABSTRACT

Aquaculture is one of the fastest-growing food-producing sectors worldwide, making it desirable to assess the sustainability of aquaculture systems. The objective of this study was to develop a portfolio of quantitative indicators of economic, environmental and social sustainability to assess different aquaculture systems. The indicators were developed from 2003 to 2016, combining top-down and bottom-up methods, together with practical observations in experimental and commercial aquaculture facilities. A total of 56 economic (14), environmental (22) and social (20) indicators are proposed. Economic sustainability indicators reveal the degree of efficiency in using financial resources, the economic feasibility, resilience, and the capacity to absorb negative external costs and to generate funds for reinvestment. Environmental indicators reflect the use of natural resources, the efficiency in using resources, the release of pollutants and unused byproducts, and the risk of reducing biodiversity. Social sustainability indicators reflect the capacity to generate benefits for local communities, including jobs and food security, equitable income distribution, equality of opportunity, and inclusion of vulnerable populations. The indicators thus developed can be used on farm, regional, global or sectorial scales. They are quantitative, broad, scientifically sound, easy to understand and interpret, feasible to obtain on farms or on research stations, and permit comparison at different scales of space and time. Thus, they can be used to assess production systems and to compare different experimental treatments in research experiments. They also can be used by certifying organizations, investors, and policymakers. They allow performing diagnostics, identifying strengths and weaknesses, setting goals and determining actions, and assessing the effectiveness of actions and public policies.

1. Introduction

Aquaculture development has yielded many positive socio-economic results. This is one of the fastest-growing food-producing sectors worldwide and provides slightly more than half of all fish for human food (FAO, 2016). Nonetheless, the impact of aquaculture farming on the environment and the prospects for its sustainability have raised concern since the early 1990s (Folke and Kautsky, 1992; Naylor et al., 2000; Samuel-Fitwi et al., 2012; Perdikaris et al., 2016). These impacts may generate costs for society as a whole as well as problems for the farmers themselves, via negative feedback on production (Neiland et al., 2001). Estimating the magnitude of these external factors and including them in the cost of production has been a challenge for environmental economists and scientists involved with aquaculture sustainability. In addition, the impacts of aquaculture on the local economy, food security, and social development of rural communities are key topics for policies of sustainable development (Costa-Pierce, 2010; Béné et al., 2016).

Sustainability has been described in many ways by different authors and institutions (see Johnston et al., 2007). However, there is agreement on some fundamental points. Thus, one can define sustainability as the management of financial, technological, institutional, natural and social resources, ensuring the continuous satisfaction of human needs for the present and future generations. Sustainability is an anthropocentric concept that considers human needs above everything, excluding other kinds of life, unless they affect the human species. Moreover, sustainability involves perenniality in time. Time scale is the duration of the human generations. Therefore, sustainable ventures should persist throughout human generations. Every future generation must inherit a stock of natural resources, equal to or larger than the one

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inherited by the previous generation (WCED, 1987). Sustainability requires a human lifestyle within the limits imposed by nature; we must live within the capacity of the natural capital.

Nowadays, there is a consensus that production systems such as aquaculture should be sustainable. However, it is essential to define what is sustainable and to know how sustainable systems really are. Totally sustainable systems are still far from being realized. However, there is a gradient between unsustainable and sustainable systems, and therefore we can recognize different levels of sustainability. Achieving sustainability is an awkward task that must be carried out step by step, based on sustainable interventions in the existing systems. The main rationale of sustainable actions is assuming that natural resources are finite, changing the neoclassical economic vision that there are no limits to growth. The adoption of more-sustainable practices, such as the use of best management practices (Boyd, 2003), is a start on the long road to attainment of sustainability, but it is not enough. Production systems are not necessarily sustainable just because best management practices are applied (Belton et al., 2009). Thus, it is essential to measure sustainability to assess the strengths and weaknesses of each current aquaculture system, the new technologies available, and the efficacy of interventions toward sustainability.

Nevertheless, methods to assess aquaculture sustainability are not commonly used. The major difficulty is the challenge of exploring and analyzing the production systems in a holistic way. It is essential to contemplate the economic, environmental and social dimensions of sustainability (UN, 1992). Thus, comparing measurements of variables of a very different nature is mandatory. Some complex methods that are sometimes used to evaluate aquaculture sustainability are ecological and carbon footprint (Folke et al., 1998; Gyllenhammar and Håkanson, 2005; Madin and Macreadie, 2015), life cycle assessment (Gronroos et al., 2006; Aubin et al., 2006, 2009; Santos et al., 2015; Medeiros et al., 2017) and emergy analysis (Cavalett et al., 2006; Vassallo et al., 2007, 2009; Lima et al., 2012; Shi et al. 2013; Zhao et al., 2013; Garcia et al., 2014; Wang et al., 2015; Williamson et al., 2015). These methods give an integrated overview of the systems. However, they require a vast amount of data that are difficult to obtain. In addition, the first method focuses mainly on the environmental dimension, and the results of other methods are very difficult to interpret.

On the other hand, aquaculture sustainability can be divided into parts that can be evaluated using sets of indicators. Indicators are variables defined to reflect a phenomenon or a process in a simplified way. They measure specific attributes of a system. Indicators are a powerful tool to reduce system complexity and can be used to compare different systems or the evolution of the same system over time. Their fluctuations reveal the variation in the elements that they represent. Indicators allow incorporating science-based knowledge into decision-making (UN, 2007) and afford a connection between objectives and actions (FAO, 1999). They can be used individually or as aggregated indices, in which individual scores are combined (Waas et al., 2014). The development and choice of indicators are related to the adopted concept of sustainability and the purpose of the indicator set (UN, 2007).

Following the Rio Conference in 1992 (UN, 1992), many indicators were developed mainly to assess environmental sustainability. In this context, some groups of indicators have been proposed to evaluate aquaculture sustainability (FAO, 1998, 1999; EAS, 2005; Boyd et al., 2007; Pullin et al., 2007; Rey-Valette et al., 2008, 2010; Valenti, 2008; FOESA, 2010; Valenti et al., 2011; FAO, 2011; Fletcher, 2012; Hofherr et al., 2012; Fezzardi et al., 2013). Only a few of them were published in scientific journals and thus, most of the information is hidden in grey literature. On the other hand, particular certifier institutions have developed indicators to assess the compliance of production systems with legislation, rules, and regulations defined in response to the consumers' desires. The most known are the Aquaculture Stewardship Council (ASC Certification; Aquaculture Stewardship Council, 2017) and Global Aquaculture Advocate (BAP Certification; Best Aquaculture Practices, 2017). Others have developed guides to responsible consumption, such as Monterey Bay Aquarium (Seafood Watch, 2017). Certifiers and guiders aim to help the consumers select products that match their food postures and preferences (Alfnes et al., 2017); thus, they define indicators based on the market. They try to measure responsible farming practices instead of focus on the central rationale of sustainability that is the capacity of a system persists in time. Some articles using indicators of sustainability to assess aquaculture systems have been published (Dalsgaard et al., 1995; Lightfoot et al., 1996; Dalsgaard and Oficial, 1997; Caffey et al., 2001; González et al., 2003; Stevenson et al., 2005; Tipraqsa et al., 2007; Bergquist, 2007; O'Ryan and Pereira, 2015; Chowdhury et al., 2015; Ting et al. 2015, Moura et al., 2016). However, most of the indicators proposed are qualitative, restricted to environmental dimension, specific regions, species or systems, must be obtained from secondary data (which often are not available), or were developed to help the consumer decisions. In addition, generally, their efficacy in comparing different systems remains to be demonstrated. Therefore, much more science-based information is necessary in this field.

The objective of this study was to develop a portfolio of quantitative indicators of economic, environmental and social dimensions of sustainability, based mainly on primary data, to assess aquaculture systems. The indicators developed are easy to obtain worldwide, enable comparison of the enormously diverse aquaculture systems in different regions and using different species, allow monitoring the evolution of aquaculture on different time scales, and are clearly understandable. In addition, they reflect the concept of sustainability instead of other concepts based on conventions of farmers or consumers, frequently used by certifier institutions.

2. Methods

The set of indicators were developed based on studies performed in Brazilian universities, public agencies, and commercial farms from 2003 to 2016. Generally, indicators are defined according to criteria proposed by committees of experts or by panels involving all actors and stakeholders of the production chain. The first situation is called top-down and the second, bottom-up method. In the present study, we used a combination of both methods, combined with practical observations in experimental and commercial aquaculture facilities.

From 2003 to 2008, we conducted several discussions among scientists and graduate students from different institutions, combined with practical tests carried out in experimental aquaculture units at the Aquaculture Center, São Paulo State University. This included two international and some local workshops. During this time, we have established a set of indicators by the top-down method (Valenti, 2008; Valenti et al., 2011). In 2009, we discussed them with a panel of actors and stakeholders of aquaculture in Brazil during meetings promoted by the Brazilian Ministry of Fisheries and Aquaculture. Thus, we created a new set of indicators approved by all groups.

From 2010 onward we started the validation phase. This set of indicators was tested on 22 commercial aquaculture farms in all regions of Brazil. These included different grow-out system farms of marine shrimp, freshwater prawns, oysters, mussels, carps, tilapia, tambaqui (cachama), lambari (bait fish) and multitrophic culture systems. One fish and one prawn hatchery were also studied. Besides, the same indicators were used in Master's and Ph.D. dissertations to assess different treatments in experiments (Boock, 2012; Proença, 2013; Dantas, 2016). Data on economic and social indicators were obtained by interviews conducted with farm owners and employees, using semi-structured questionnaires. Direct observations "in loco" were also conducted to check and complete the information. Secondary data including gender, race, ethnicity, and mean income of the local populations were obtained from official local institutions, generally available at the certified websites. To obtain and process the environmental samples, we selected the relevant methods and units defined in the Standard Methods for the