

Establishing limits to aquaculture in a protected coastal lagoon: Impact of *Farfantepenaeus paulensis* pens on water quality, sediment and benthic biota

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Abstract

Aquaculture is perceived by governments and international agencies as an economic alternative for poor communities in developing countries. Nevertheless, aquaculture must address environmental issues as well as economic and social aspects to achieve a sustainable development. Aquaculture with native species under semi-intensive conditions is a sustainable production alternative that minimizes the impact on aquatic ecosystems. An aquaculture pilot project with pink shrimp (*Farfantepenaeus paulensis*) was tested in a protected lagoon in Uruguay (Laguna de Rocha). Shrimp were reared in pen enclosures within their native habitat, where natural currents drive water renewal, and the natural food supply was supplemented with commercial food. The aim of this study was to evaluate the impact of *F. paulensis* aquaculture on the water and sediment quality and the benthic community, and to estimate the maximum number of pen enclosures that Laguna de Rocha can sustain while maintaining the minimal environmental impact. A Before, After, Control Impact (BACI) sampling design was followed and the results of abiotic and biological variables were compared between treatment site (control, pens, and two areas at 15 and 50 m from the pens) and timing (before shrimp addition, during culture and after harvest), through ANOVA. The most significant impact was found inside the pens, where ammonium levels increased and benthos species richness and abundance decreased. A nitrogen-based-model was used to estimate the maximum number of pens in relation to the minimal impact on the ecosystem. Simulation indicated that up to 13 pens could be installed in the southern area of Laguna de Rocha without increasing the usual concentration of total nitrogen in other areas of the lagoon. The BACI design, the statistical analysis and the modeling tools proved to be effective, simple and low cost instruments to assess the environmental impact in a protected area.

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1. Introduction

Presently, management efforts in protected areas admit the feasible coexistence of economic activities and the conservation of biodiversity (Brockington et al., 2006; Wilkie et al., 2006). Native shrimp aquaculture under semi-intensive conditions (i.e.

pen enclosures or culture pens) could represent a sustainable production alternative that improves the welfare of human communities in conservation areas, minimizing the environmental impact of more intensive systems and avoiding the introduction of potentially invasive species. In pen enclosures, shrimp are reared in their indigenous habitat, shallow estuaries or brackish lagoons, where natural currents drive water renewal. The natural food supply, e.g. fisheries leftovers and benthic organisms naturally occurring inside the enclosures, is balanced with commercial food, particularly during early stages of development (Soares et al., 2004; Wasielesky et al., 2004).

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Pen enclosures circumvent several negative aspects of aquaculture (Wasielesky et al., 2004). Due to low implementation costs, fishermen own this family based production system, therefore avoiding their dependence on private intermediaries (González et al., 2003). Production in pen enclosures also contributes to the stabilization of shrimp production in comparison with the natural variability of landings, which depend on the post-larvae entrance into the estuaries during the marine intrusion (Reis and D’Incao, 2000). While this technique does not significantly modify the natural habitat nor compete with other fisheries because little area is required, the amplified areal grazing by shrimp on the benthic community is its major drawback (Nunes and Parsons, 2000; Soares et al., 2004). Nevertheless, this type of aquaculture has been successfully implemented with pink shrimp (*Farfantepenaeus paulensis*) in Lagoa dos Patos in southern Brazil and exhibited only minor environmental impact (Soares et al., 2004).

Following the experience in Lagoa dos Patos, a similar pilot initiative was implemented in Laguna de Rocha (Uruguay), a natural brackish coastal lagoon inside a National Park and Biosphere Reserve. This lagoon maintains one of the most traditional artisanal inland fisheries of Uruguay, sustaining more than 20 families. Decision makers and the local community perceive the pink shrimp initiative as an economical solution to cope with poverty, while for conservationists it represents a threat to the natural functioning of the lagoon. The commencement of this initiative in 2004 reestablished the discussion on how to limit emergent economic development in this protected coastal area. Should economic activities or biodiversity conservation be prioritized? Is there any possible in-between alternative?

Environmental impact studies (EISs) have been proposed as valuable tools to foster public scrutiny of economical activities in natural areas, allowing the evaluation of techniques and environmental alternatives (Bojórquez-Tapia et al., 1998). However, while the assessment could be designed to maximize the power of impact detection, EISs have methodological restrictions (Osenberg et al., 1996). The BACI design (Before, After, Control, Impact), on the other hand, reduces the degree of uncertainty of EISs, permitting the comparison of impacted and non-impacted sites. BACI seeks for an interaction between the effects of sites and time, since differences detected before and after the impact can provide an estimate of their magnitude (Osenberg and Schmitt, 1996). In addition, potential impacts not detected due to sampling limitations can be quantified, which is essential given the uncertainty resulting from the complexity of natural systems and the need to increase precaution in the decision making process (Mapstone, 1996; Osenberg et al., 1996).

Numerical modeling is another tool commonly used in the decision making process for coastal issues. For example, it allows the generation of different scenarios, the evaluation of the effectiveness of pollution control and the determination of the carrying capacity of specific water bodies, as well as the prediction of environmental impacts in coastal and estuarine ecosystems. Regarding aquaculture, several models of diverse complexity allow the prediction of the environmental impacts of specific cultures (Twilley et al., 1998; Dudley et al., 2000;

Handerson et al., 2001; Daglioli et al., 2004). However, even utilizing complex models, there are certain limitations to the prediction because most of the models were developed for different environments or for different species.

The aim of this study was to evaluate the impact of *F. paulensis* pen aquaculture on the benthic community and on the water and sediment quality in Laguna de Rocha Lacustrine National Park (Uruguay), as well as to estimate the maximum number of pens that the lagoon can sustain with minimal environmental impact.

2. Methodology

2.1. Study area

Laguna de Rocha (Rocha, Uruguay; 34° 35' S–54° 17' W) (Fig. 1) is a nursery and reproductive area for important regional fish resources (Fabiano et al., 1998; Vizziano et al., 2002; Norbis and Galli, 2004) and for resident and migratory aquatic birds (Morrison et al., 1989; Rilla, 1992, 1993). The lagoon is included in the MaB-UNESCO Reserve “Baños del Este” and is presently being inducted into the National System of Natural Protected Areas.

The lagoon (surface area 72 km²; average depth 0.6 m) connects periodically with the Atlantic Ocean through a channel that opens in the sandbar (Conde et al., 1999). The periodic interaction of water masses of limnic and marine origins is the driving force for the functioning of the whole ecosystem (Conde et al., 2000, 2002; Bonilla et al., 2005; Giménez et al., 2005). Fisheries of brackish and marine species depend on these hydrological dynamics because the entrance of fish and crustacean larvae and the spawning of adults are tightly coupled to the marine intrusion (Vizziano et al., 2002). In this system, the average concentration of dissolved inorganic nitrogen and reactive soluble phosphorus for the last decade was 27.3±29.2 and 133.2±315.4 µg l⁻¹, respectively, while their atomic relation was 13.4±28.4 (Bonilla et al., 2006).

Land use in the watershed has been committed predominantly to extensive cattle raising, but a substantial increase in agricultural area has occurred during the last decade (L. Rodríguez-Gallego, unpub.). The lagoon is influenced by several activities in the nearby beach resort, La Paloma, and receives, through its main tributary, the primary-treated wastewaters of Rocha City (30,000 inhabitants). There is evidence that the lagoon is experiencing a eutrophication process. For example, an increase of total phosphorus and chlorophyll, high epiphytic microalgal biomass (Conde et al., 1999), recent episodes of potentially toxic cyanobacteria (*Pseudoanabaena* sp. and *Microcystis*) (V. Hein, pers. comm.) and proliferation of submerged hydrophytes have all been noted. The natural hydrology is also modified (i.e. the artificial opening of the sand bar to avoid flooding and to allow entrance of commercial larvae). The above creates challenges to the environmental well-being of the lagoon.

Two artisanal fishing communities have developed a family based artisanal fishery based on *Paralichthys orbignyanus*, *Odontheistes argentiniensis*, *Micropogonias furnieri*, *Brevoortia aurea* among fishes, and *Callinectes sapidus* and *F. paulensis* among crustaceans (Santana and Fabiano, 1999). Annual income per family is less than US\$ 250. Pink shrimp trapping starts at the end of summer (March) and continues until mid autumn (May), and captures are highly variable between consecutive years. Littoral currents from the waters of Southern Brazil drive larvae to this coastal area, entering the lagoon in late spring (October–December) (Santana and Fabiano, 1992).

2.2. Experimental procedure and monitoring

2.2.1. Pink shrimp aquaculture in pen enclosures

In 2003 and 2004, the fishing community located in the Southern area of Laguna de Rocha (Fig. 1) carried out a pilot aquaculture experience. Pink shrimp larvae were produced at the Mariculture Laboratory of FURG and the post-larvae were transported in plastic bags at 19 °C under oxygenation to Laguna de Rocha. After acclimatization to water temperature, they were inoculated into nursery pens of 15 m in diameter and 2 m height, with a mesh of 0.1 mm pore size. Four pen enclosures were set up at ca. 100 m from the shore (depth range

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