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A Social-Ecological System (SES) that Integrates Carrying Capacity for the Sustainable Management of Bivalve Aquaculture

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Summary

Sustainable resource management requires improved understanding of complex ecological processes and the socioeconomic drivers shaping human-environment interactions. To better understand complex interconnections and feedback loops among ecological and economic systems, this study integrates a coastal marine ecosystem model with a model of the associated coastal economy. Through simulations of different ecological and socioeconomic scenarios, the integrated model can be used to generate predictive ecological and economic values for policy analysis, providing an opportunity for more rational and informed debate concerning sustainable marine resource development. To demonstrate utility of this integrated model, it was applied to coastal shellfish aquaculture production in Narragansett Bay, Rhode Island, US, a coastal social-ecological system that provides important ecosystem services and contributes to the local, regional and national economy.

Introduction

Improved understanding of complex ecological processes and the socioeconomic drivers shaping human-environment interactions can inform on-going policy discussions about sustainable marine resource development in general (Hughes *et al.* 2005) and sustainable aquaculture development more specifically. In this study, an approach is presented for integrating a coastal marine ecosystem model with a model of the associated coastal economy to better understand complex interactions within integrated ecological-economic systems. The economic-ecological modeling framework that we present is an extension of the traditional bioeconomic approach based upon simple biological growth functions. In order to analyze systems with a large number of interacting elements, such as industries and consumers in an economy or species in an ecosystem, economists and ecologists have explored the use of linear models, which can be linked (Jin *et al.* 2003).

Materials and Methods

We developed an integrated modeling framework for assessing resources in a coupled ecological-economic system that was then applied to a well-studied area, to demonstrate its potential as a decision-support tool for sustainable aquaculture development (Figure 1). To simulate the effects of marine resource development, this study utilized Ecopath (www.ecopath.org), a static mass balance food web model, to characterize the ecosystem and IMPLAN (https://implan.com), economic input-output (IO) modeling software and database, to characterize the economy. A regional IO model gives one an understanding of the effects of activities in one sector on all other industry sectors from which it purchases and to which it sells products. Thus, we can use an IO model to understand the economic "influence" of an industry in the study region on the other sectors of the economy to which they are linked. Different scenarios of aquaculture development were applied to this modeling framework: (1) its current state, (2) 5% of the surface area of the water body, and (3) ecological carrying capacity (Byron *et al*. 2011).

Results and Discussion

By linking an ecosystem model with a model of a coastal economy, we demonstrate ecological and economic effects of different levels of sustainable aquaculture development. The production scale, measured as US$ output (US$) and employment (number of people), increased one order of magnitude from the current state to the 5% scenario and two orders of magnitude from the current state to the ecological carrying capacity scenario. The use of two distinct models that share information at different stages maintains the complexity in each model (Bockstael *et al.* 1995; Dalton 2004). For instance, the ecosystem model incorporates the full trophic spectrum of species, making it appropriate for use in estimating ecological carrying capacity, and the economic model captures linkages among all the industries in the region. By using results from the ecosystem model as input for the economic model, we developed and tested different scenarios for aquaculture development that were based on a more comprehensive understanding of the ecological and economic conditions of the area. We demonstrate a methodology for coupling human and natural perspectives in a modeling framework. It is not enough to examine resource needs, uses, and impacts from a single perspective. By acknowledging that aquaculture is an integrated ecological-economic system and creating tools to evaluate it as an entire intact system we can better understand limitations, tradeoffs, and alternative management scenarios. As additional model components are refined, we intend on applying this framework to alternative project areas at different scales and for other resources.

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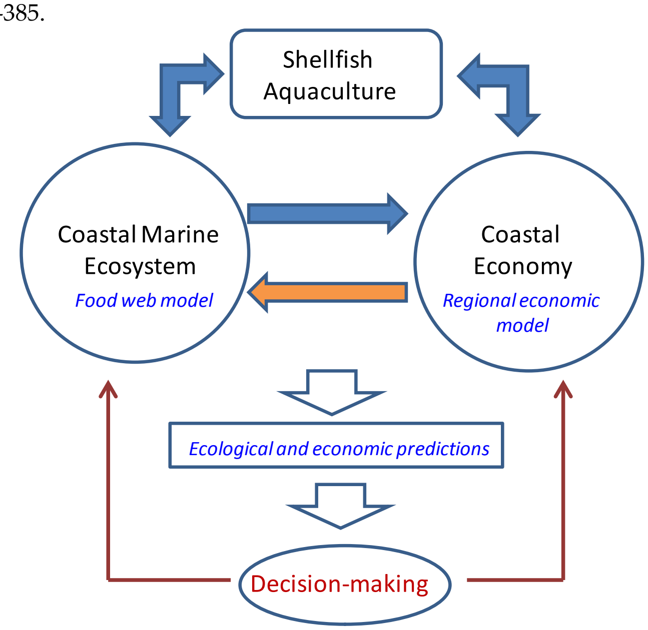

Figure 1. Integrated Ecological and Economic Model Framework for Sustainable Aquaculture Development