Aquaculture 447 (2015) 15–22

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aqua-online

Review

An Integrated ecological–economic modeling framework for the sustainable management of oyster farming

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ARTICLE INFO

Article history:
Received 31 January 2014
Received in revised form 8 August 2014
Accepted 18 August 2014
Available online 23 August 2014

Keywords:
Carrying capacity
Aquaculture
Bivalve
Shellfish
Ecopath
IMPLAN

ABSTRACT

Sustainable resource management requires improved understanding of complex ecological processes and the socioeconomic drivers shaping human–environment interactions. To better understand complex interconnections 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 ecological–economic system that provides important ecosystem services and contributes to the regional economy.

Contents

1. Introduction

As the world demand for seafood products continues to expand, it is unlikely that the annual harvest of fish from wild stocks can be increased significantly. Thus, aquaculture, where practicable, now is recognized as the only means of increasing the supply of protein from seafood. Most seafood products today are traded in a competitive international market. The United States today imports about 70% of its seafood consumption, with a sizable seafood trade deficit, largely because seafood is produced inexpensively abroad. Based on ecological and market considerations, the most likely growth areas for US aquaculture include bivalve mollusks (Hoagland et al., 2007). Thus, shellfish

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http://dx.doi.org/10.1016/j.aquaculture.2014.08.030
0044-8486/

aquaculture will continue to be a driving force for socioeconomic and ecological change in complex coastal systems.

Although the potential benefits associated with sustainable coastal aquaculture in the United States are arguably significant (Chopin, 2006), development of coastal aquaculture has been limited due to constraints in the regulatory system or lease-permitting process (Hopkins et al., 1995), user conflicts in an inherently multi-use environment, and environmental and ecological concerns (Chu et al., 2010; Whitmarsh and Palmieri, 2009). 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 (e.g., Clark, 1976). Although the bioeconomic approach can involve nonlinear biological and technological inter-relationships, most multispecies bioeconomic models incorporate only two species. 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 (e.g., IMPLAN and ECOPATH). The economic effects of different ecosystem conditions can be analyzed by linking ecological and economic models (Jin et al., 2003)

Most of the existing ecological models for shellfish aquaculture have been developed for and implemented at the production or farm scale (Bacher et al., 1998; Carver and Mallet, 1990; Nunes et al., 2003; Raillard and Ménesguen, 1994), neglecting all trophic levels equal to or higher than bivalves. This approach is useful on a farm scale but ignores the impacts of aquaculture development on the stability and sustainability of the entire system. The integrated model presented here incorporates an ecosystem approach to model bivalve aquaculture that has been developed in a small number of recent studies (Byron et al., 2011a,b; Jiang and Gibbs, 2005).

Food web models can be used to examine species interactions and carrying capacity for aquaculture (Byron et al., 2011a,b). It must be recognized that bivalves feeding on ambient sources of nutrients directly connects them with the food web of the body of water in which the farm is located. Changes in primary production and detrital production in the coastal environment have potential to influence bivalve production. Food web modeling can be used to examine how different environmental conditions may influence standing stock biomass on the farm. Conversely, food web modeling can be used to examine different standing stock biomass levels on the rest of the ecosystem for the purpose of calculating carrying capacity of aquaculture in a system or identifying other species that may be strongly influenced by aquaculture (Byron et al., 2011a,b).

The integrated model is composed of links between a food web model that includes aquaculture and an economic model of the associated coastal economy. In this study, we describe the integrated ecological–economic model and demonstrate how it can be used to assess the socioeconomic and ecological impacts of aquaculture development in a particular area. We will show that the model can be used to characterize existing economic and ecological conditions and demonstrate the potential wealth to society that may be derived from alternative scenarios of sustainable aquaculture development.

2. 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, Rhode Island, US, to demonstrate its potential as a decision-support tool for sustainable aquaculture development (Fig. 1). The study area and methodology for each of the model components are described below.

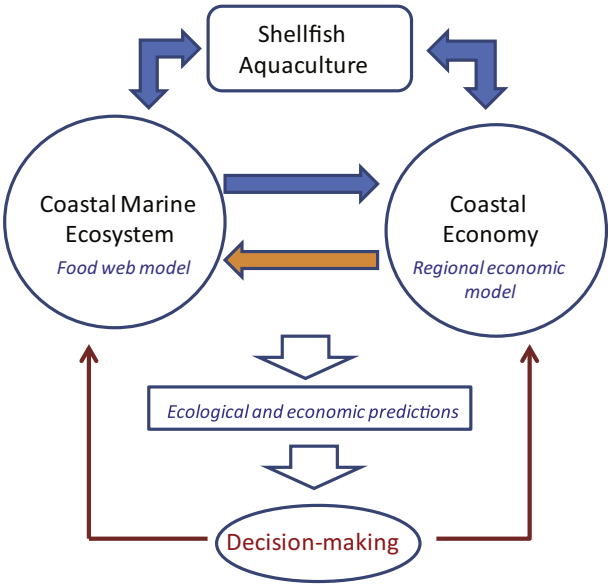

Fig. 1. Integrated Ecological and Economic Model Framework for Sustainable Aquaculture Development. The coastal marine ecosystem is represented by a food web model. The coastal economy is represented by a regional economic model. These two model components interact with each other to make ecological and economic predictions that can be used for decision making in the management of shellfish aquaculture. The arrows represent how information is shared between nodes.

2.1. Study area

We applied the integrated ecological and economic framework to the issue of oyster aquaculture development in Narragansett Bay,

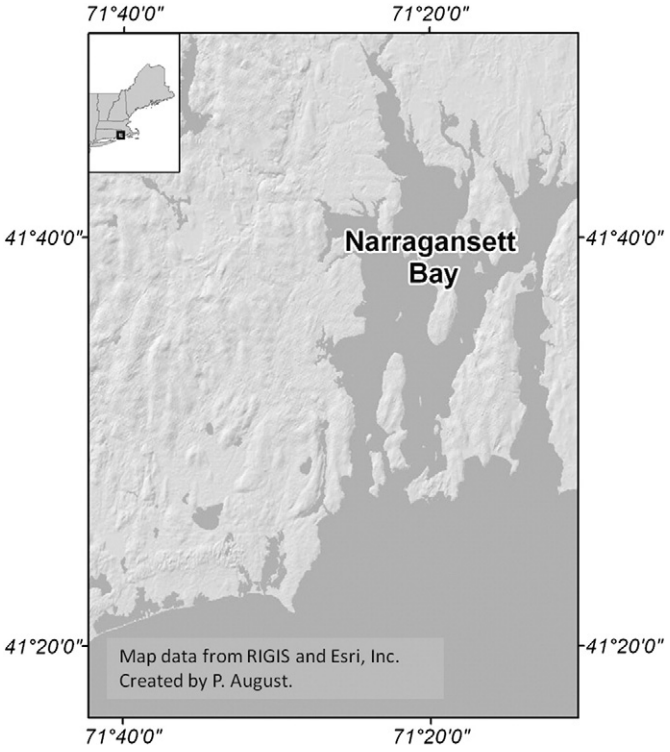

Fig. 2. Study area: Narragansett Bay, Rhode Island, US.