Ecological Modelling 222 (2011) 846–856

Contents lists available at ScienceDirect

Ecological Modelling

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

Assessing the carrying capacity of tilapia in an intertidal mangrove-based polyculture system of Pearl River Delta, China

Shannan Xu[a,*], Zuozhi Chen[a], Chunhou Li[a], Xiaoping Huang[b], Shiyu Li[c]

[a] *Key Laboratory of Mariculture, Ecology and Quality Control, Ministry of Agriculture, South China Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, Guangzhou 510300, China*
[b] *Key Laboratory of Marine Bio-resources Sustainable Utilization, South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou 510301, China*
[c] *School of Environmental Science and Engineering, Sun Yat-sen University, Guangzhou 510275, China*

ARTICLE INFO

Article history:
Received 7 June 2010
Received in revised form 9 November 2010
Accepted 10 November 2010
Available online 10 December 2010

Keywords:
Ecopath
Energy flow
Detritus
Carrying capacity
Aquaculture
China

ABSTRACT

A trophic model of an intertidal mangrove-based polyculture system in Pearl River Delta, China, was constructed using the Ecopath with Ecosim software. This polyculture system was chosen since it is the first integrated multi-trophic aquaculture (IMTA) system that was constructed on the basis of mangrove planting in China. The energy flows, ecosystem property, and carrying capacity of tilapia in the polyculture system were analyzed and evaluated. The results show the trophic level of 1.00 for primary producers and detritus to 2.85 for grass carp. The geometric mean of the trophic transfer efficiencies was 7.0%, with 7.2% from detritus and 6.8% from primary producers within the system. The ecosystem property indices show that this polyculture system has a high value of total primary production/total respiration (TPP/TR) and total primary production/total biomass (TPP/TB), together with low Finn's cycled index (FCI), Finn's mean path length (FML), and connectance index (CI), indicating that this system is at a development stage according to Odum's theory. The principal fish cultured in the system is tilapia, and mixed trophic impacts (MTI) show that tilapia has a marked impact on most compartments in this system, and the carrying capacity was found to be a tilapia culture biomass of 5.8 t ha^{-1} in the system.

1. Introduction

China is the world's largest fishery nation in terms of total seafood production volume, a position it has maintained continuously since 1990 (Qian, 1994). Accelerated development of mariculture in the past 30 years, particularly in the recent decade, has raised increasing concerns regarding the environmental impacts of water quality deterioration, together with other contaminants, high nitrogen and phosphorus flux, and all other processes associated with eutrophication (Wu et al., 1994; Liu and Liu, 2001). New approaches are required to minimize the negative effects of a growing aquaculture industry on coastal ecosystems (Naylor et al., 2000; Costa-Pierce, 2002). In recent years, integrated multi-trophic aquaculture (IMTA) has been widely documented in the literature as a means to develop environmentally sound aquaculture practices and resource management through a balanced ecosystem approach to avoid pronounced shifts in coastal processes (Chopin et al., 2001; Troell et al., 2003; Neori et al., 2007; Buschmann et al., 2008).

Mangrove forests are among the primary features of coastlines throughout the tropics and subtropics of the world (Islam and Mahfuzul, 2004). The importance of mangrove ecosystems to coastal fisheries has been described and the linkage between mangrove and associated fisheries have been emphasized and discussed by many authors (Chong et al., 1996; Twilley et al., 1996). The mangrove forest provides a unique ecosystem and extensive habitats for a wide variety of faunal species (Sasekuar et al., 1992). A positive correlation between mangrove area and shrimp/fish catches has been documented for the Philippines, Malaysia, Indonesia, and Australia (Primavera, 1995, 1998). Mangrove ecosystems are important in trapping sediment and organic material from land sources, and interact with seagrass and coral reef ecosystems by maintaining water quality, nutrient balances, hydraulic characteristics, and habitat for fish species that move between these ecosystems during different life stages (Kathiresan and Bingham, 2001). In the Pearl River delta (PRD, Fig. 1), China, mangroves is one of the major important coastal habitats and a major component of the vegetative cover in the coastal region. Therefore, we constructed a newly Mangrove-Aquaculture Coupling System (MACS) in the Shenzhen Water-lands Tourism Development Ltd. (SWTDL), PRD in 2006.

It has been widely recognized that ecosystem structure and function need to be taken into account with respect to ecosystem's

* Corresponding author.
E-mail address: creacy_2000@yahoo.com.cn (S. Xu).

0304-3800/$ – see front matter
doi:10.1016/j.ecolmodel.2010.11.014

sustainability of living aquatic resources, particularly the trophic structure and flows of biomass through species interactions (Christensen and Pauly, 1995).

Measurements of biomass transfer between functional groups and trophic efficiency provide the needed information for evaluating the impact of changes on some groups and their interrelations within the ecosystem via trophic interactions (Christian et al., 1996). Using ecosystem models, changes in the species within an ecosystem can be summarized and viewed as part of a whole. Both direct and indirect effects of species on others within the ecosystem can be explored and the overall functioning of ecosystem can be compared (Heymans et al., 2004). The carrying capacity of finfish aquaculture is determined by the interaction of cultured species with the ecosystem, particularly food availability to suspension feeders. Ecopath with Ecosim (EwE) is an ecosystem-based analysis software designed for straightforward construction, parameterization and analysis of mass-balance trophic models of aquatic and terrestrial ecosystems (Christensen et al., 2000). It is a useful tool to investigate effects of the biological community changes induced by external sources of disturbance on the ecosystem structure. The prominent advantage of this approach lies in its suitability to the application of a broad field of theories that are useful for ecosystem studies, which includes thermodynamic concepts, information theory, trophic level description and network analysis. Hence, a mass-balance trophic model of the mangrove-based polyculture of PRD was developed to describe the trophic functioning of the ecosystem using holistic ecosystem properties and flow indices, to gain insight into the development level of this ecosystem and its state of maturity, and to determine the carrying capacity for the tilapia, which is the most cultured species in the PRD mangrove-based polyculture system.

2. Materials and methods

2.1. Study area

The Pearl River ("Zhujiang" in Chinese) Delta, China, is located between latitudes 21°40′ N and 23° N, and longitudes 112° E and 114°20′ E (Fig. 1). It is the third largest river delta in the nation (next to the Yangtze and Yellow River Deltas), with an area of 17,200 km^2 (Hong et al., 1999). The delta has a subtropical climate with an average annual temperature between 21.0 and 23.1 °C, and an average precipitation from 1600 to 2600 mm (Zeng et al., 1989). Because of the impact of the East Asian monsoonal circulation, about 80% of the rainfall comes in the period of April–September with a concentration in the months of May–July, when flooding is prone to occur (Yin et al., 2004). Such weather conditions are favorable for mangrove tree growing, silviculture, and fish farming.

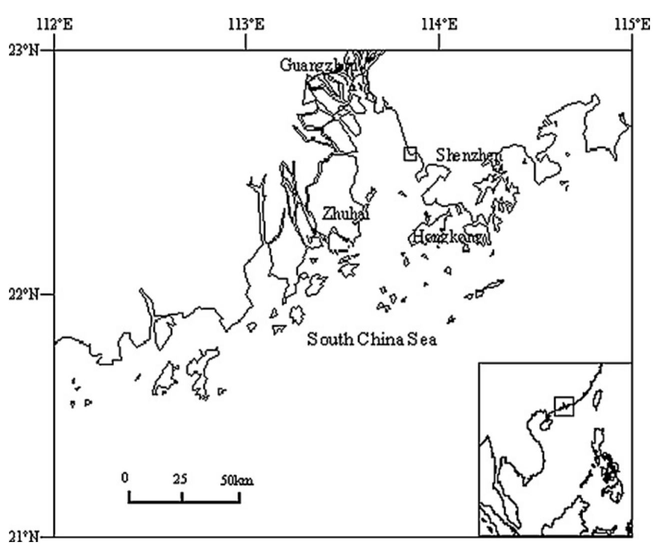

Fig. 1. Sketch map of the mangrove-based polyculture system in Pearl River Delta, South China.

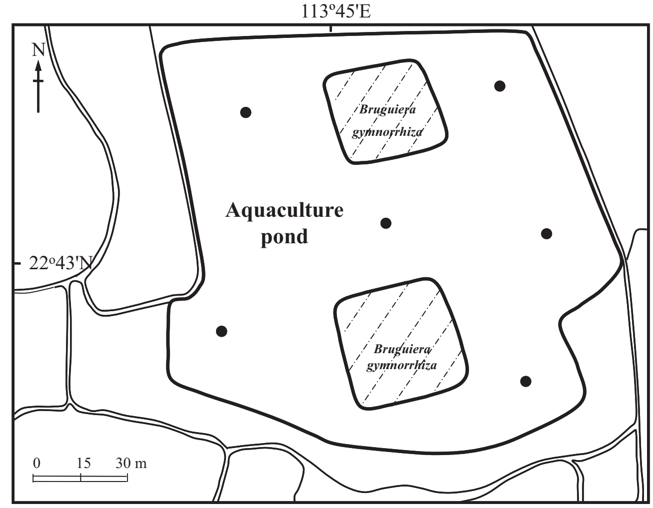

Fig. 2. Map showing mangrove (*Bruguiera gymnorrhiza*)-based polyculture system.

The MACS was an extensive enclosed system with a total area of 1.5 ha. In the MACS, the mangrove tree (*B. gymnorrhiza*) stands consist of saplings age 1–2 years planted in pond at intervals of 30 cm, and the area of mangrove trees on two islands account for 15% of the total farming area in the polyculture system (Fig. 2). Water depth of MACS of 2.5 m, different species fish and invertebrates are raised at different water depths, and all animals were cultivated without artificial food added in the pond. The water exchange was controlled by sluice gate under the western embankment and the frequency usually twice a month. The resultant nutrient-enriched waters provide high biological productivity and consequently sustain important commercial fisheries of the pond (Chen and Peng, 2006). Along with the development of tourism and recreational activities in SWTDL, most fish are harvested by recreational fisheries during the experimental periods. Tilapia and common carp played important roles in fishing, although common mullet, oysters and shrimp were also important components (Chen and Peng, 2006). The cultured fish have stocked according to their biological characteristic in the system. The fishes include 25,000 *O. Niloticu* with body length (BL) ranging from 70 to 80 mm; 8000 Chinese carp (*C. idellus*, *H. molitrix* and *A. nobilis*) with BL range from 65 to 70 mm; and 1000 *M. cephalus,* BL range, 10–15 mm. The invertebrates include 700 kg of *Penaeus monodon* with shell length (SL) ranging from 5 to 50 mm; 2.4 × 10^5 *Metapenaeus ensis* with SL range of 6–8 mm, 100 kg of *Eriochier sinensis* with carapace length ranging from 20 to 40 mm. Additionally, we stocked the number and size of various macro-benthos, including *Crassostrea gigas*, *Mactra veneriformis*, *Ruditapes philippinarum*, *Macoma candida*, and *Scylla serrata* in the system also.

2.2. Modeling approach

The trophic model of the mangrove-based polyculture system in Pearl River Delta was constructed using the Ecopath with Ecosim software (Christensen et al., 2000; Christensen and Walters, 2004) to quantify organic matter flows within the food web. In Ecopath, mass-balance between groups is assumed, and their interactions are described by linear equations (Christensen and Pauly, 1992, 1993). For each compartment (i), a mass-balance budget can be