Ecological Modelling 312 (2015) 406–416

Contents lists available at ScienceDirect

Ecological Modelling

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

Modeling the effect of the seasonal fishing moratorium on the Pearl River Estuary using ecosystem simulation

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ARTICLE INFO

Article history:
Received 12 February 2015
Received in revised form 5 June 2015
Accepted 11 June 2015
Available online 2 July 2015

Keywords:
Ecopath with Ecosim
Seasonal fishing moratorium
The PRE coastal ecosystem
Comparative analysis
Fisheries strategies exploration

ABSTRACT

The coastal ecosystem of the Pearl River Estuary (PRE) has been overfished and has received a high level of combined pollution in recent decades. Fisheries' stock assessments have shown a declining population and have led to the implementation of a number of management measures, including a fishing moratorium. This study evaluated the effect of a fishing moratorium on the sustainability of PRE fisheries through an ecosystem approach. Two Ecopath models of the PRE coastal ecosystem in 1998 and 2008 were applied to obtain snapshots of the ecosystem in different periods. An dynamic simulation of the period from 1998 to 2008 was developed using Ecosim based on the assumption that the seasonal moratorium was never applied to the PRE fisheries from 1999 onward, which resulted in the predicted ecosystem of 2008* (the so-called 2008* ecosystem). Then, the attribute indices of the 2008* ecosystem were compared with those of the actual 2008 ecosystem to investigate the effect of the fishing moratorium. Finally, a series of 100 years dynamics simulations was examined according to five scenarios based on the 1998 Ecopath model to explore better strategies for the fishing moratorium. The results show that the 2008* ecosystem was not supposed to feature a seasonal moratorium, as the system in 1999 was more deteriorated, immature and fragile than the actual ecosystem in 2008. The seasonal fishing moratorium did benefit ecosystem protection, although its effect on ecosystem recovery was limited. A comparative analysis of different scenarios indicates that most functional groups will decrease without executing a fishing moratorium (S1). The prolonged moratorium (S2) seemed to be slightly more beneficial to stocks recovery than S0, during which fishing operations were carried out following the present fishing moratorium policy. However, banning all fishing operations during the moratorium season (S3) has little effect on the recovery of fishing stocks from overexploitation. Moreover, reducing the fishing effort by 50% (S4) led to the largest increase in both fish stocks (28.0%) and total landings (43%).

1. Introduction

It has been generally believed that the estuaries of large rivers and their adjoining coastal waters are typical marine ecosystems. The Pearl River is the second largest river in China in terms of flow rate. It is also the largest river that discharges into the north of the South China Sea (SCS). Currently, the coastal region of the Pearl River Estuary (PRE) is a significantly and quickly developing economic zone. Because of rapid economic development, the PRE region has experienced overfishing and pollution over the past three decades. The high population density and rapid development of industry and agriculture have resulted in severe stress on the aquatic environment. A great amount of waste, excessive reclamation, overfishing and frequent oil spills, among other factors, has greatly affected the water-related environmental quality of the PRE. Deteriorating environmental conditions have increasingly exerted strong effects on the estuarine ecosystem (Huang et al., 1997; Ke et al., 2007; Li and Huang, 2008; Liang et al., 2005). Moreover, the PRE coastal ecosystem has sustained high stress due to fisheries since the 1980s, which have been proposed as the first major human disturbance to coastal areas (Jackson et al., 2001).

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http://dx.doi.org/10.1016/j.ecolmodel.2015.06.011
0304-3800/

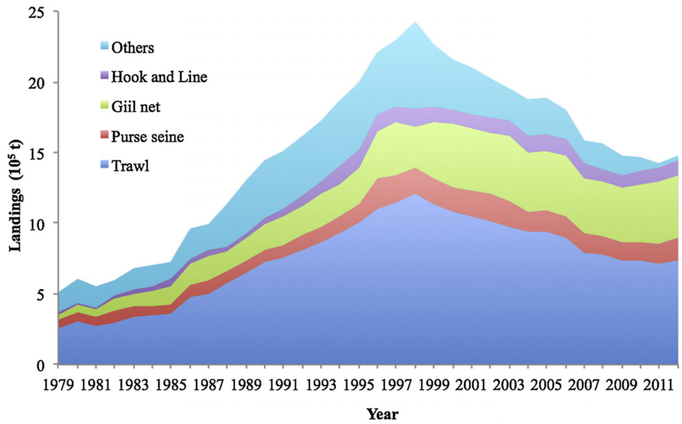

Fig. 1. Total number of landings of the coast of the PRE for different gear from 1979 to 2012.

Fishing fleets began to be privatized and investment in fisheries have increased since the economic reform initiated at the end of 1978, which resulted in a large increase in the number of fishing boats and improvement in fishing technology (Jia et al., 2005). Consequently, the landings of different fishing gear in the PRE experienced a substantial increase since 1979 and reached peak values in 1998 (Fig. 1). The total number of landings in 1998 was nearly five times as high as in 1979. Fig. 1 shows that trawling contributed to most catches among the fishing gear from 1979 through 2012, whereas the catch rates of trawlers in the PRE coastal sea dropped by more than 70% from 1986 to 1998 (Lu and Ye, 2001). Trawling had severely damaged groundfish stocks. The loss of groundfish stocks has been compensated for by a large increase in shellfish. Purse seining has likewise become problematic in the PRE. Purse seiners catch most juvenile species and fully exploited ones, strongly contributing to the overfishing of mostly fully exploited species. With anthropogenic activities exerting an increasingly strong effect on the estuarine ecosystem, it appears that the ecosystem has experienced large changes since 1979, switching from a large-size and high-value demersal fish-dominated ecosystem to an ecosystem dominated by small-size and low-value pelagic species (Duan et al., 2009a,b; Jia et al., 2005).

With Concern about overfishing, China put forward a zero-growth policy on fresh and seawater natural catches in 1999 and imposed a seasonal fishing moratorium. Beginning in 1999, the fishing moratorium was implemented from 1 June to 1 August every year in the northern South China Sea (SCS) (north of 12°N). During the fishing moratorium season, all fishing operations, excluding the use of gillnets, fishing cages and hooks and lines, are banned to conserve fisheries' resources and promote the sustainable development of the fishing industry. The approach is considered a concrete and effective measure for managing fishing effort and is expected to be beneficial to restoring the fisheries' resources. According to some researches (Dai et al., 2001; Liu et al., 2008b; Research Group of Summer Fishing Moratorium Effect of Guangdong Province in the South China Sea, 2014; Xiao, 2005), there was a considerable increase in fish catches in the two months immediately following the fishing moratorium, and the fishing moratorium was considered to be effective in protecting fisheries' resources and improving production. Until recently, the policy of fishing moratorium had been carried out for more than a decade. The effect of the fishing moratorium is still a matter of academic discussion. To data, there have been many studies on the effect of the seasonal moratorium (Chen, 2003; Hou et al., 2009; Huang, 2002; Liu and Chen, 2001; Wu, 2008; Yang and Zhou, 2013). These studies have been mostly extended qualitatively by comparing of community construction and the constitution of catches before and after the seasonal moratorium (Jiang et al., 2009; Robert, 1998; Schrank, 2005; Shi et al., 2008). Additionally, the advantages and disadvantages cancel out. Studies (Cheung and Pitcher, 2006; Pitcher et al., 2002) using ecosystem simulation models have suggested that the effects of the moratorium would be small given the sustained high fishing effort in the region. The published empirical studies that have evaluated the effect of the moratorium on exploited populations or ecosystem dynamics in the PRE are lacking. No detailed quantitative analysis has been conducted to data based on ecosystem simulation.

This study aimed to synthesize related information and time series data for dynamic simulation in Ecosim to quantify the changes of the coastal ecosystem under the moratorium as well as the possible effect of fishing on overall performance of the entire ecosystem. Moreover, fishing moratorium scenarios were simulated in Ecosim to explore better fishing strategies for the future.

2. Methods and materials

2.1. The study area

The Pearl River Estuary, located in the southern Chinese province of Guangdong, represents the typical coastal ecosystem of China. The coastal ecosystem of the PRE examined in our study, which extends from 112°30′E to 115°30′E, 21°00′N to 23°00′N, is a typical ecosystem of China's coastal sea with an area of 72,600 km^2 (Fig. 2). The area covers the shelf from the coast to depths of approximately 100 m and it has the characteristics of delta coastal waters driven by salinity gradients arising from the combined effects of watershed and the open sea, with a NE–SW orientation (Xue et al., 2001).

The Pearl River Estuary is subjected to the effects of three water sources: the discharge of the Pearl River oceanic waters from the South China Sea, and coastal waters from the South China Coastal Current (Yin et al., 2004). The resultant nutrient-enriched waters provide large biological productivity and sustain the most important commercial fisheries (Li et al., 2000; Wang and Lin, 2006). The coastal fish production is mainly dominated by *Trichiurus lepturus* (largehead hairtail), *Nemipterus virgatus* (golden threadfin bream), sharks, *Decapterus maruadsi* (Japanese scad), *Sardinella aurita* (round sardinella), *Trachurus japonicus* (jack mackerel), *Siganus puellus* (masked spinefoot), *Argyrosomus argentatus* (silver croaker), *Saurida tumbil* (greater lizardfish), *Upeneus bensasi* (Bensasi goatfish), *Psenopsis anomala* (melon seed), and *Thamnaconus hypargyreus* (lesser-spotted leatherjacket), which are mainly exploited by trawling, purse-seining, long lining and gill netting (Mai et al., 2007). The PRE coastal ecosystem also plays a role as a natural refuge and nursery area for hundreds of species, including some local and endangered species such as *D. maruadsi* (Japanese scad), *S. aurita* (round sardinella), and *Larimichthys crocea* (Croceine croaker). The entire system shows diverse productivity, strong fishing activity, and complex food web relationships (Zhang, 2004). The dramatic expansion of fishing fleets, accompanied with mechanization and other technological advancements, have resulted in over-exploitation of near-shore and, more recently, offshore fisheries resources (Cheung and Sadovy, 2004; Shindo, 1973). These existing fishing fleets are highly capable of promoting already fully exploited fish stocks to an even greater overfished state (Ju, 2012; Lin and Zou, 2014; Liu et al., 2008a). Although the fish stocks appear to be able to recover from fishing pressure (Myers and Worm, 2005), the recovery rate depends on the productivity of the stocks and the level of depletion (Safina et al., 2005). Many marine fishes species have collapsed due to overexploitation, and it has been reported that many stocks have shown little or even no sign of recovery after up to 15 years, which suggests that fishes would be depleted to a level at which their recovery may be impaired (Hutchings, 2000;