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Modeling changes in the coastal ecosystem of the Pearl River Estuary from 1981 to 1998

L.J. Duan [a], S.Y. Li [a,*], Y. Liu [a], J. Moreau [b], V. Christensen [c]

[a] School of Environmental Science and Engineering, Sun Yat-sen University, Guangzhou, 510275, China
[b] Laboratoire d'Ecologie fonctionnelle UMR 5245 e, INP/ENSAT, Avenue de l'Agrobiopole Auzeville Tolosane, BP 32607F, 31326 Castanet Tolosan Cedex, France
[c] Sea Around Us Project, Fisheries Centre, University of British Columbia, 2202 Main Mall, Vancouver, BC, Canada, V6T 1Z4

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ABSTRACT

The coastal ecosystem of the Pearl River Estuary (PRE) has been overfished and received a high level of combined pollution since the 1980s. Ecopath with Ecosim was used to construct two ecosystem models (for 1981 and 1998) to characterize the food web structure and functioning of the ecosystem. Pedigree work and simple sensitivity analysis were carried out to evaluate the quality of data and the uncertainty of the models. The two models seem reliable with regards to input data of good quality. Comparing the variations of outputs of these two models aimed to facilitate assessment of changes of the ecosystem during the past two decades.

The trophic structure of the ecosystem has changed with an increase in the biomass proportion of lower trophic level (TL) organisms and a decrease in top predator biomass proportion. All the indices of ecosystem maturity examined show that the system was in a more mature condition in 1981 than in 1998, although the system has been in a condition of stress due to anthropogenic disturbances, such as environmental pollution and habitat destruction since 1981. The ecosystem was aggregated into six and seven integral TLs in 1981 and 1998, respectively, using the trophic aggregation routine of Ecopath. Most of the total system biomass and catch took place at TL II and III in both years. But the distribution of the total system biomass and catch at different TLs changed with decreasing proportions in higher TLs in 1998. The mean transfer efficiency was 9.1% and 10.2% in 1981 and 1998, respectively.

Comparative network analysis allowed quantification of the importance of direct and indirect trophic interactions among functional groups. Moreover, a method derived from the mixed trophic impact (MTI) analysis allowed estimating importance of groups in terms of "keystoneness" and identifying the keystone species in the two models over the past two decades. The results indicate that there were no clear keystone species in 1998 but two keystone species at medium trophic levels were identified in 1981. Moreover, organisms located at low trophic levels such as phytoplankton, zooplankton and benthic invertebrates were identified to have relatively high keystoneness in the ecosystem.

1. Introduction

It has been widely recognized that ecosystem structure and function need to be taken into account with respect to ecosystem's sustainability of living aquatic resources, particularly the trophic structure and flows of biomass through species interactions (Christensen and Pauly, 1995). Measurements of biomass transfer among functional groups and trophic efficiency provide information on ecosystem structure and function, which can be used to evaluate the impact of change on some groups and the way it is propagated through the whole ecosystem via the trophic web (Christensen and Pauly, 1993; Christian et al., 1996).

The Pearl River is the second largest river (2200 km) in China in terms of water discharge. The annual variation in discharge is significant and depends on the amount of rainfall that the catchment receives. The Pearl River Estuary (PRE) is located in the southern province of Guangdong. Currently, the coastal region of the PRE is a significantly and quickly developing economic zone. As a result of rapid economic development in recent decades, the whole region has experienced rapid industrialization and urbanization. The high population density and rapid development of industry and agriculture have resulted in severe stress to the aquatic environment. A great deal of waste, excessive shoal reclamation, overfishing and frequent oil spills, etc., greatly influenced the water-related environmental quality in the PRE (Liang et al., 2005; Ke et al., 2007; Li and Huang, 2008). The sewage discharged into the PRE increased from 1.62×10^9 t (in 1985) to 6.77×10^9 t (in 1998) (Cui, 2006). The water quality in the estuary has become progressively worse

* Corresponding author. Tel.: +86 20 84113620; fax: +86 20 84110692.
E-mail addresses: eeslsy@mail.sysu.edu.cn, cholice_shi@yahoo.com.cn (S.Y. Li).

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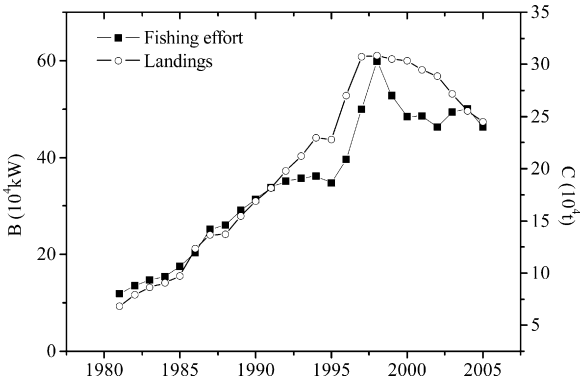

Fig. 1. The landings and fishing effort history in the PRE coastal ecosystem. B indicates fishing effort, C indicates landings.

in the last 20 years of the twentieth century. The most serious environmental issue in the Pearl River Estuary is eutrophication. Eutrophication has produced serious red tide events or harmful algal blooms in the estuary and its adjacent coastal waters since the 1980s. Over 146 red tides events have been recorded in the South China Sea since 1981 (Qi et al., 1996). The frequency of harmful algal blooms occurrences was high during late 1997 to early 1999 particularly in Hong Kong waters, which have posed a serious threat to the aquaculture and fisheries industries (Tang et al., 2003). In addition, the Pearl River Estuary is being reclaimed and estuarine waterways are getting narrower, 92% of shoal reclamation occurred in the 1980s and 80% of waterway reclamation happened during the 1990s (Chen et al., 2005). The PRE coastal ecosystem has sustained high stress from fisheries since the 1980s and been proposed as the first major human disturbance to coastal areas (Jackson et al., 2001). The total landings and the fishing effort in the PRE experienced substantial increase since 1981 and reached the peak values in 1998 (Fig. 1). The landings and fishing effort in 1998 have been almost five times as high as in 1981. It appeared that the ecosystem had experienced large changes since 1981, switching from large-size and high-value demersal fishes dominated ecosystem to an ecosystem dominated by small-size and low-value pelagic species (Jia et al., 2005). Increasingly anthropogenic activities exert great influence on the estuarine ecosystem. Therefore it is quite important to get knowledge of the development level of this ecosystem and its state of maturity, which facilitates profound understanding of the structure and function of the whole ecosystem for analyzing the impact of human influences.

With the development of an interdisciplinary research project on exploitation in the coastal ecosystem of the PRE, a vast amount of physical, chemical and biological information has become available (Li et al., 2002; Zeng et al., 2005; Yao et al., 2006). But no detailed ecosystem analysis has been carried out to date and there has been no attempt to summarize and integrate available information to obtain greater insights into ecosystem structure and trophic relationships. 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). 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., 2005). It allows analysis of different aspects of the resulting food web network. In mass-balanced models fisheries can be placed in the ecosystem context to obtain more effective and feasible strategies by incorporating knowledge of interspecific interactions of the groups, their physical environment and their habitat (Christensen et al., 1996). Furthermore, mass-balanced models enable comparisons between different ecosystems and between different periods of the same ecosystem. In this study, two mass-balanced models for the coastal ecosystem of the PRE were constructed using EwE for two years, 1981 and 1998. This paper aims to synthesize all information to quantify energy flows and to characterize some functional aspects of the system. The changes in the trophic interactions, the community structure and function of the ecosystem during two decades were analyzed and evaluated to gain an insight into the status of the ecosystem development. Moreover, the interactions between functional species and the trophic role of different species in the ecosystem were assessed as well as the possible impact of the fishing on overall performance of the whole ecosystem.

2. Methods and materials

2.1. The study area

The PRE is located midway along the northern boundary of the South China Sea (SCS) and flows into the northern part of the SCS. Its shape is like an inverted funnel with the narrow neck in the north and wide mouth opening to the south. The annual averaged river discharge is 10 524 m^{-3} s^{-1}, with 20% occurring during the dry season in October–March and 80% during the wet season in April–September (Zhao, 1990; Yin et al., 2004b). On the west side of the SCS adjacent to the PRE, a strong cyclonic western boundary current system is driven by the combination of the wind and the seaward gradient force in the dry season. In the wet season, the southwest monsoon drives the water northeastward. Moreover, the coast has a NE–SW orientation (Xue et al., 2001). Due to the asymmetry of the fresh water source, salinity in the PRE increases from the northwest to the southeast with strong seasonal variation (Hu et al., 2005). The bottom sediment particle sizes vary widely from 0.002 mm to 0.25 mm. Medium silts to fine sands (0.031–0.25 mm) are found in the western part and near the sea boundary of PRE. The bed sediments in the other parts of PRE mainly make up of clay and silt particles (http://www.cse.polyu.edu.hk/lab/PRE/SEDIMENT.htm).

The coastal ecosystem of the PRE in our study, extended 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 coastal ecosystem covers the shelf from the coast to approximately 100 m depth with the characteristics of estuary coastal waters driven by gradients due to the combined influence of river flow and sea. The PRE waters are subjected to the influence of three water sources: Pearl River discharge, oceanic waters from the South China Sea, and coastal waters from the South China Coastal Current (Yin et al., 2004a). The resultant nutrient-enriched waters provide high biological productivity and sustain important commercial fisheries (Li et al., 2000; Wang and Lin, 2006). Annual mean of primary productivity in the PRE is 55 mgC m^{-2} h^{-1}. And, the yearly total landings in the PRE were no less than 227 800 t since 1995 (Jia et al., 2005). The PRE plays a role as natural refuge and nursery area for hundreds of species, including some local and endangered species. It is also an important fishing ground in the SCS. The whole system has diverse productivity, strong fishing activity, and complicated food web relationships (Zhang, 2004).

2.2. Ecopath approach

The trophic mass-balanced models for the coastal ecosystem of the PRE were constructed based on EwE software, version 6.0 (Christensen et al., 2005; http://www.ecopath.org). Models represent the annual average situation of the ecosystem in 1981 and