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Ecosystem structure and functioning of Lake Taihu (China) and the impacts of fishing

Yunkai-Li[a,b], Yong Chen[b], Bing Song[a], Derek Olson[b], Na Yu[a], Liqiao-Chen[a,*]

[a] College of Life Science, East China Normal University, Shanghai 200062, PR China
[b] School of Marine Sciences, University of Maine, Orono, ME 04469, USA

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ABSTRACT

Lake Taihu is the third largest freshwater lake in China and has provided local communities with valuable fisheries for centuries. However, we have only a limited knowledge of its ecosystem. In this study, a trophic model was constructed for the Lake Taihu ecosystem. This model was used to evaluate and analyze the food web structure and other properties of this ecosystem using data covering the period from 1991 to 1995. Using the model, we evaluated the impacts on local fisheries of various management scenarios comprising two basic management regimes: (1) setting fishing mortality for the top predator (large culters, *Erythroculter mongolicus* and *Erythroculter ilishaeformis*) to 0, 0.3, 0.6, 0.9 and 1.2, and (2) adjusting overall fishing effort to 0.25, 0.5, 0.75 and 1.25 times the current level. For both scenarios, fishery profit and cost were evaluated to provide an understanding of how components of the ecosystem interact. We identified possible causes of fishery overexploitation in the lake ecosystem and described the necessity of developing ecosystem-based management. The results showed that Lake Taihu had six theoretical trophic levels (TLs), with the trophic flows primarily occurring through the first five TLs. System properties such as transfer efficiency, Finn's index, Finn's mean length, connectance index, system omnivory index, primary production/respiration ratio, and net primary production all indicated that Lake Taihu was an immature, fairly simple ecosystem in which a relatively low fraction of total primary production was utilized. At the same time, the ecosystem was also experiencing high fishing pressure. Yet despite this, the low ascendency index (25.9%) and high system overhead ratio (74.1%) indicated that the system was highly developed and relatively stable, a condition that might result from the high degree of recycling in the system. Among the harvesting strategies considered, a strategy of either decreasing the fishing mortality of the top predator (large culters) to 0.3 or, alternatively, reducing the overall effort on the system by a factor of 0.75 appeared to be most effective at increasing the efficiency of the fisheries.

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1. Introduction

The overexploitation of aquatic living resources is common in today's fisheries worldwide. Both the inland and marine ecosystems are heavily influenced by intense fishing activities (Mchich et al., 2006). In view of these facts, it is widely recognized that an ecosystem-based approach to fisheries management is important for maintaining sustainable fisheries and healthy ecosystems (FAO, 1995; NRC, 1999). Although the objectives of ecosystem-based management are difficult to define, a general awareness exists that quantitative modeling is an important tool for exploring the ecological consequences of fishing and improving our understanding of how ecosystems function (Cury and Chirstensen, 2005). Ecosystem models are complimentary to single-species fisheries models in that they are potentially able to predict the otherwise unforeseen effects of trophic interactions; however, their high degree of complexity and large input data requirements have kept them from becoming a commonly used tool in stock assessment and fisheries management (Christensen et al., 2004; Cury and Shannon, 2004; Fletcher et al., 2005; Coll et al., 2006).

Lake Taihu, located in the southern Jiangsu province and northern Zhejiang province, is the third largest freshwater lake in China with an area of 2338 km^2 (Fig. 1). The lake plays an important role in flood control, water supply, fishery, shipping, tourism and culture. There are 38 cities and 34.2 million people living around the lake. Gross Domestic Production (GDP) in the lake drainage area is about one-seventh of the total GDP of China (Sun and Huang, 1993; Hu et al., 2006).

Wild fisheries in Lake Taihu began nearly 10,000 years ago, and were both productive and valuable (Chen, 1989; Sun and Huang,

* Corresponding author. Tel.: +86 21 62233637; fax: +86 21 62233637.
E-mail address: Lqchen@bio.ecnu.edu.cn (Liqiao-Chen).

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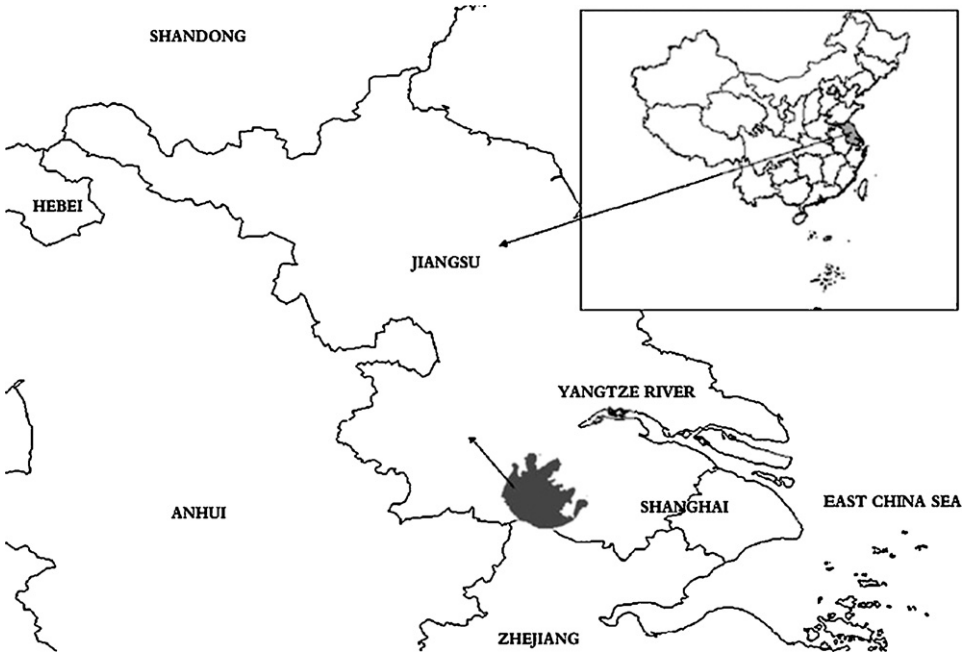

Fig. 1. The geographic location of Lake Taihu in Jiangsu Province and Zhejiang Province, China.

1993). Over the last few decades, Lake Taihu has sustained high stress from fisheries and pollution. The total catch (Fig. 2) and total fishing effort for commercial species has increased significantly. The top predators in Lake Taihu, such as the large culters (*Erythroculter mongolicus* and *Erythroculter ilishaeformi*), were subject to high fishing mortality (Xu, 1984). Because of prolonged intensive fishing pressure, we observed signs of "fishing down the food web" (Pauly et al., 1998) in Lake Taihu—in which the biodiversity declined significantly and the composition of landings was increasingly dominated by relatively small and less valuable species with high turnover rates from lower trophic levels, which also could be explained by the trend of catch started from 1994 (Fig. 2) (Sun and Huang, 1993; Yang, 1998; Yang et al., 2004; Zhu, 1999).

The Chinese government tried to solve the problems of eutrophication and resource degradation in Lake Taihu with an investment of 20.43 billion Yuan over the period from 1997 to 2010. At the same time, 4.1–9.24 million larval fishes were released into Lake Taihu every year in attempt to maintain fisheries resources (State Environmental Protection Administration of China, 2000). Although the pollution sources have been largely controlled, the attempted restoration of the aquatic ecosystem was not successful. Meanwhile, excessive aquaculture activity and the stocking programs continue altering the structure of the Taihu ecosystem. Furthermore, fishing intensity may still be too high. To better understand these issues, studies were undertaken concerning the environment and the biology of fish species. To support these studies, large quantity of data were collected on fisheries statistics, population parameters, diet compositions, and physical and chemical variables (East China Normal University, 1959; Geography Department of Chinese Academy of Science, 1965; Chen et al., 1997; Cai, 1998; State Environmental Protection Administration of China, 2000; Taihu Environment Protection Administration, 2000; Wu, 2001). However, limited efforts were put into the development of an ecosystem-based fisheries resource management strategy.

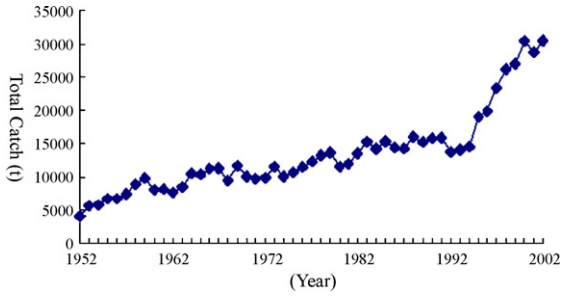

Fig. 2. Temporal trends in the total catch of Lake Taihu.

The objectives of this study are to (1) understand how components of the Taihu ecosystem interact; (2) evaluate the impact of the fishing activity on the entire ecosystem, and (3) characterize the need for developing an ecosystem-based management strategy for Lake Taihu. Using Ecopath with Ecosim we constructed a mass-balanced food web model focusing on biomass flows among functional groups and species of ecological and commercial interests (Walters et al., 1997; Christensen et al., 2004). The model was used for evaluating the impacts of different fishing strategies on the ecosystem.

2. Methods and materials

2.1. Study area

Lake Taihu is located from 119°53′45″ to 120°36′15″E and 22°00′ to 27°10′N (Fig. 1). At its northern tip is Lake Wulihu, a lagoon with an area of approximately 10 km^2. Several tributaries connect the two lakes with other bodies of water such as the Yangtze River (Zou et al., 1996). The average depth of Taihu is 1.89 m and the maximum is 2.6 m. The annual precipitation in the area is 1100–1400 mm, and the mean temperature is approximately 16 °C. The frost-free period is over 230 days (Sun and Huang, 1993; Cai, 1998; Hu et al., 2006).

2.2. Mass-balanced modeling approach

A mass-balanced trophic model was constructed for Lake Taihu using Ecopath with Ecosim, version 5.0 (Walters et al., 1997; Christensen and Walters, 2004; Christensen et al., 2004). The basic

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