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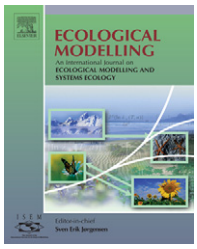

The food web structure and ecosystem properties of a filter-feeding carps dominated deep reservoir ecosystem

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ARTICLE INFO

Article history:
Received 4 January 2006
Received in revised form
23 November 2006
Accepted 27 November 2006
Published on line 8 January 2007

Keywords:
Ecopath model
Hypophthalmichthys molitrix
Aristichthys nobilis
Stocking
Ecosystem properties
Trophic level
Trophic flow
Throughput
Lake Qiandaohu

ABSTRACT

An Ecopath model was constructed to describe the ecosystem of Lake Qiandaohu, a stock-enhanced large deep Chinese reservoir with silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*) dominated in its pelagic community. The food web structure and ecosystem property of the reservoir were analyzed and evaluated. The results showed that there were seven trophic levels (TLs) in the system, with the trophic flows primarily occurring through the first four TLs. The food web structure of this ecosystem was characterized with a bulged intermediate trophic level, which was contrary to the wasp-waist food web structure occurred in most natural aquatic ecosystems. The corresponding trophic flow pattern showing by transfer efficiencies (TEs) between TLs indicated that the trophic flows primarily went through from TL I to II with a high TE (of over 50%) and through a flow loop or short cut between detritus and TL II but greatly reduced from TL II to III with a lowest TE of 2.5% due to the bulged biomass at TL II. The trophic flow loop greatly increased the throughput recycled, which, together with high connectance index (CI), system omnivory index (SOI), Finn's cycled index (FCI) and Finn's mean path length (FML), might be beneficial to the maintaining of ecosystem stability. Finally, ecosystem property indices showed that this reservoir had a high value of P_p/R and P_p/B, indicating this ecosystem of short history was immature, but highly productive. This silver carp and bighead carp dominated deep reservoir ecosystem had both the characteristics of high productivity of an immature ecosystem and the feature of high stability of a mature ecosystem.

1. Introduction

Food web structure and interactions have a decisive role in determining the dynamics of an ecosystem, and are of interests of many ecological studies (e.g., Halfon et al., 1996; Elser et al., 1998; Kitchell et al., 2000; Aoki and Mizushima, 2001; Angelini and Agostinho, 2005; Gamito and Erzini, 2005). Lakes and reservoirs in China are particularly in need of the study of the food webs for the following two reasons: (1) the food webs of these ecosystems are usually characterized with the dominance of the two artificially stocked filter-feeding planktivorous Chinese carps, silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*), and their ecological effects on aquatic ecosystems have been controversial and contradictive (e.g., Januszko, 1974; Kajak et al., 1975; Opuszynski, 1979; Smith, 1985, 1989; Spataru and Gophen,

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doi:10.1016/j.ecolmodel.2006.11.028

1985; Shi et al., 1989; Starling and Rocha, 1990; Li et al., 1993; Opuszynski and Shireman, 1995; Domaizon and Devaux, 1999; Xie and Liu, 2001; Lu et al., 2002; Radke and Kahl, 2002; Liu et al., 2004); (2) the studies so far of the impacts of the two carps on the aquatic ecosystems are usually limited to top-down effects (i.e., the direct effects of the two carps on the plankton communities and water quality), while the indirect effects of the two carps on other planktivores and/or fish at higher trophic levels and on the stability and development of ecosystems are often not evaluated.

Silver carps mainly filter-feed on phytoplankton (and some small zooplankton such as rotifers, protozoan and nauplii) with the particle sizes between 8 and 100 μm while bighead carps primarily on zooplankton (especially copepods and cladocera) and large size phytoplankton with particle sizes of 17–3000 μm (Cremer and Smitherman, 1980; Xie, 1999, 2001). The two Chinese carps used to only naturally occur in lakes with connections to large rivers such as the Yangtze River and Pearl River, where they become sexually mature and reproduce naturally. However, the presence of the two carps in lakes or reservoirs now can only be through artificial stocking because their migrating passages are blocked by various hydraulic constructions. It almost becomes a routine practice of lake fisheries management to massively stock the two carps in lakes and reservoirs in China. The two fish often account for over 40% of the total fish biomass and almost 70% of the pelagic fish biomass in the lakes and reservoirs. This dominance imposes great influences on the biomass and structure of planktonic community, which, in turn, can trigger further trophic cascading effects on other planktivorous fish species and top predators. Thus the ecosystem dynamics are greatly affected by stocking of the two filter-feeding carps, and it is necessary to evaluate the role the two carps play in lake/reservoir food webs.

Various ecological models have been developed for evaluating the food web interactions, analyzing ecosystem structure and functioning, or addressing ecological dynamics ranging from the conventional Lotka-Volterra predator–prey model to more recent ecosystem-based or multispecies fisheries models (see reviews by Robinson and Frid, 2003; Babcock et al., 2005). These models differ in their complexity, input data requirement and outputs. The mass-balanced Ecopath with Ecosim (EwE) model is among the most updated and widely used ecosystem models and is considered as one of the effective and straightforward methods for quantifying the food web interactions and fisheries ecosystem dynamics. First built for estimating biomass and food consumption of the elements of an aquatic ecosystem, EwE was combined subsequently with various approaches from theoretical ecology, proposed by Odum (1969) and Ulanowicz (1986), for the analysis of energy flows between the elements of ecosystems and to reveal the maturity and stability of ecosystems. Later, the system has been further optimized for direct use in fisheries assessment, as well as for addressing environmental questions with the integration of the temporal dynamic model, Ecosim, in 1995, and the spatial dynamic model, Ecospace, in 1998 (Christensen et al., 2000). Since its initiation by Polovina (1984) in the early 1980s, the mass-balance based software EwE has been developed for about 20 years, and has been widely used for constructing food web models of marine and other ecosystems, serving parameterized systems, and predicting the changes in biomasses and trophic interactions in time and space in different environments. The information derived is useful in multispecies management decision (Vasconcellos et al., 1997; Christensen and Pauly, 1998; Wolff et al., 2000; Bundy and Pauly, 2001; Moreau et al., 2001), in analyses of effects of the trophic cascade (Polis et al., 2000; Ortiz and Wolff, 2002; Schmitz et al., 2004), in verifying the relationship between stability and diversity (Hastings, 1988; Naeem and Li, 1997; Tilman, 1999). Because the required input data are moderate, EwE is an ideal approach to quantifying the ecosystem dynamics of lakes and reservoirs in China.

Lake Qiandaohu, renamed from the reservoir of Xin'anjiang, was chosen for this study because it is a typical silver carp and bighead carp dominated deep reservoir ecosystem in China. Both silver carp and bighead carp have been stocked in the reservoir since its foundation in 1959. In this deep reservoir ecosystem, littoral zone is limited. This, together with the frequent seasonal and inter-annual fluctuation of water level, results in almost no vascular plants in the reservoir. Thus phytoplankton becomes almost the unique primary producer, resulting in a dominant food chain from phytoplankton to planktivores and to piscivores.

The reservoir had been renowned for its limpidity of water and water quality had been maintained at the Chinese national surface water Class I before the large-scale cyanobacterial bloom occurred in 1998 and 1999. The low population levels of the two Chinese carps in 1998 and 1999 (Fig. 1) were hypothesized to be responsible for the algal bloom (Liu et al., 2004). In order to prevent the recurrence of algal bloom and to improve water quality, silver carp and bighead carp have been stocked massively and maintained at a high biomass level since 2000 to restore or re-establish the two carp populations, which now account for about 80% of the pelagic fish production and thus play a crucial role in the ecosystem. The cyanobacterial bloom has not recurred since and the water quality has been greatly improved since the stocking of the two Chinese carps with no measures of nutrient control (Liu et al., 2004; Liu, 2005).

The objectives of this study are: (1) to document and quantify the trophic web structure of Lake Qiandaohu; (2) to evaluate the role that the silver carp and bighead carp play in the Lake Qiandaohu ecosystem; (3) to gain insight into the properties and development status of the ecosystem (maturity and resilience).

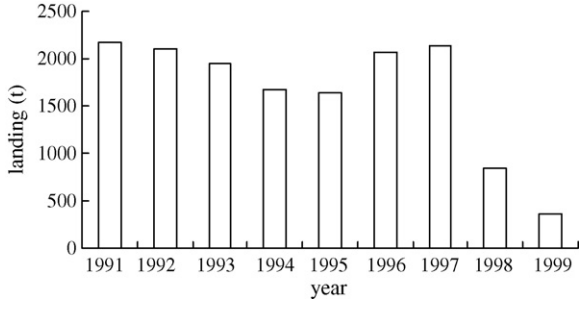

Fig. 1 – Historical landings of silver carp and bighead carp in Lake Qiandaohu.