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Impacts of fishing on the marine mean trophic level in Chinese marine area

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ABSTRACT

Studying the long-term effects of fishing on the marine mean trophic level (MTL) is very important for understanding the status of marine ecosystems, and it will help in the design of appropriate conservation management strategies. Using data on fishery landings from the FAO Fishery Statistics (FishStatJ_2.0.0_win32, 1950 to 2011), we analyzed changes in the fishery landings of 51 marine species/groups in the Chinese marine area and their impacts on MTL. We obtained the following results: China's fishery landings increased gradually from 0.72×10^6 t to 3.29×10^6 t between 1950 and 1977; it increased sharply from 2.74×10^6 t to 13.21×10^6 t between 1981 and 1998, declined to 12.00×10^6 t in 2002 and remained relatively stable until 2008, and increased again to 12.86×10^6 t between 2009 and 2011. The percentage of landings from species/groups whose trophic level was higher than 3.5 was about 28% in 1975–1977; it declined to 17.1% in 1979–1981, increased to 27.00% in 1979–1981, declined from 24.57% to 13.64% in 1982–1988, fluctuated around 19.43% in 1997, and then increased steadily to 35.8% from 1997 to 2011. China's MTL remained stable from 1950 to 1974, fluctuated slightly around 3.45, declined to 3.35 in 1975–1978, and increased to 3.45 in 1979–1981. However, the MTL declined sharply to 3.25 in 1982–1987 and remained stable 10 years afterwards. The decreasing rate of MTL was 0.05 per decade during 1950–1997; it increased gradually to 3.34 from 1997 to 2011, during which the increasing rate was 0.12 per decade. The fishing in balance index of Chinese marine area showed a clear increasing trend since 1950; the trend was greater than 0.5 since 1959, and it increased to greater than 1 since 1995. The changes in MTL were closely related to the composition of the fish species/groups in the total fishery landings, especially the fish species/groups of which the MTL was greater than 3.5, such as *Trichiurus haumela*, *Larimichthys polyactis*, *Larimichthys crocea*, *Engraulis japonicas*, and *Decapterus* spp. The general declining trend of MTL indicates that the dominant fishery landings changed from benthic fishes with a long life span and high trophic level (e.g., *T. haumela*) to invertebrates and pelagic fishes with a short life span and low trophic level (e.g., *Decapterus* spp.). The increase in MTL in China from 1997 to 2011 may be attributable to a series of fishery management countermeasures, such as setting up closed fishing seasons and non-fishing zones, establishing marine protected areas for fishery restoration. We also found that MTL may differ when statistical landings data and species richness data are used, and may be affected by the quality of the fisheries statistics. Moreover, species' trophic level, which is assumed to be constant, may have changed over time. The effects of these factors on MTL should be explored in the future.

Monitoring and assessment of marine ecosystems is a key topic in marine scientific research as well as marine conservation and management [1,2]. One of the key indicators to monitor the changes of marine ecosystems is the marine mean trophic level (MTL), which is measured base on fisheries landings and species richness. As no sufficient data are available currently for the species richness measurement in a long-term scale [3,4], the MTL measured by fisheries landings reflecting the changes of the fishery catch and their tropic levels has been widely used as an indicator to indicate the integrity, diversity and health of the marine ecosystems [5,6]. The MTL has been designated as a key indicator for biodiversity assessment in 2010 by the conference of the parties to the Convention on Biological Diversity (CBD) [7], the higher MTL indicates a higher marine biodiversity and the marine ecosystem integrity at a higher level [5].

Long term trends in MTL help us to understand the status of marine ecosystems and inform decision making for marine conservation. Scientists in the US, Canada and some European countries have already undertaken an in-depth study in this area. For instance, Pauly et al. studied the impacts of catch from 1950 to 1994 on 220 marine species' MTL, and found that the main landings changed from the fishes with long life span and high trophic level to the fishes with short life span and low trophic level, thereby proposing the theory of "Fishing Down

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Marine Food Webs" [8–10]. In addition, other studies showed that intensive fishing caused the decline of the MTL in Canada, Uruguay and Portugal [11–13]. In China, the intensive exploitation of marine fish resources is a major pressure for their decline [14,15]. However, long term studies of status of marine ecosystems as indicated by MTL are limited [16–21]. Xu et al. did a preliminary study of the MTL changes from 1950 to 2006 using FAO data, but did not explore the underlying reasons of the changes [22]. Therefore, this study mainly adopted the data on fishery landings from the FAO Fishery Statistics from 1950 to 2011, and analyzed changes in fishery landings and MTL in Chinese marine area. The results of this paper could serve as a scientific reference for decision making in Chinese marine ecosystem conservation and management.

1. Material and methods

1.1. Data

Comparing the data on fishery landings from China reported in the FAO Fishery Statistics (FishStatJ_2.0.0_win32, 1950 to 2011) and those from China's fisheries yearbook (from Bohai Sea, Yellow Sea, the East China Sea and the South China Sea), the two datasets have the same reported landings. Thus, the FAO's data on fishery landings of 51 marine species/groups in the Chinese marine area were used to analyze the changes and their impacts on MTL. The values of trophic level of the 51 species/groups were obtained from the Sea Around Us project (www.seaaroundus.org) and FishBase (www.fishbase.org) (Appedix I). Species with trophic level value bigger than 3.5 is categorized as high trophic level species [9].

1.2. Data processing

MTL ($\overline{TL_k}$) was computed for each year k from the following equation [8]:

$$\overline{TL_k} = \sum_{i=1}^{m} TL_i Y_{ik} / Y_k$$

where TL_i is the trophic level of species/groups i and Y_{ik} is the landings of species/group i in year k.

The FiB indicator is an index being used to assess whether a fishery is balanced in ecological terms or not. The FIB indicator for any year i in a series is defined by the following equation [23]:

$$FiB = \log\left[Y_i \left(\frac{1}{TE}\right)^{TL_i}\right] - \log\left[Y_0 \left(\frac{1}{TE}\right)^{TL_0}\right].$$

Y_0 is the landings of the base year (1950), TL_0 is the mean trophic level in the base year, and TE is the transfer efficiency, which is usually set as a constant value of 0.1.

All the data were computed in SPSS 16.0. The correlation between the proportion of the species/groups with trophic level bigger than 3.5 and the value of MTL was tested using Pearson Correlation analysis. Differences between the MTL calculated without major economic fish species/groups and those with major economic fish species/groups were analyzed with Student's *t*-test.

2. Results

2.1. The changing trends of the fishery landings in Chinese marine area

Fishery landings increased gradually from 0.72×10^6 t to 3.29×10^6 t between 1950 and 1977; it increased sharply from 2.74×10^6 t to 13.21×10^6 t between 1981 and 1998, but then declined slightly to 12.00×10^6 t in 2002 and remained stable until 2008; it increased slightly again to 12.86×10^6 t from 2009 to 2011 (Fig. 1).

2.2. Proportion of high trophic level species/groups

The proportions of high trophic level (>3.5) species/groups in China's fishery landings are presented in Fig. 2. The proportion is about 28.00% during 1950–1974, declined to around 20.00% between 1979 and 1995 and then increased again to 35.80% during 1996–2011. The proportion of high trophic level species/groups landings and the value of MTL are significantly correlated ($r = 0.455$, $P < 0.01$).

2.3. The changing trends of commercial fish species/groups landings

Landings of some major commercial species drived the change in total fishery landings in Chinese marine area, such as largehead hairtail (*Trichiurus haumela*), large yellow croaker (*Larimichthys crocea*), small yellow croaker (*Larimichthys polyactis*), Japanese anchovy (*Engraulis japonicas*), and scads (*Decapterus* spp.) (Fig. 3). Landings of largehead hairtail increased from 0.13×10^6 t to 0.40×10^6 t during 1950–1970. It increased gradually from 0.43×10^6 t to 0.50×10^6 t during 1971–1981, but increased sharply to 1.07×10^6 t from 1988 to 1996, and remained at about 1.10×10^6 t from 1997 to 2011. Landings of large yellow croaker increased sharply to 0.20×10^6 t from 1950 to 1974, which was about five times the landings in 1950. It however declined sharply to 0.017×10^6 t in 1987 because of severe resource depletion. It then recovered slightly to 0.08×10^6 t during 1975–1996, and remained at 0.065×10^6 t afterwards. Landings of small yellow croaker were below 0.03×10^6 t before the 1990s, but increased sharply to be 0.25×10^6 t in 1996. It declined to 0.13×10^6 t in 1997 but increased steadily again after that to 0.41×10^6 t in 2010. Landings data of Japanese anchovy starts from 1990, showing sharp increase from

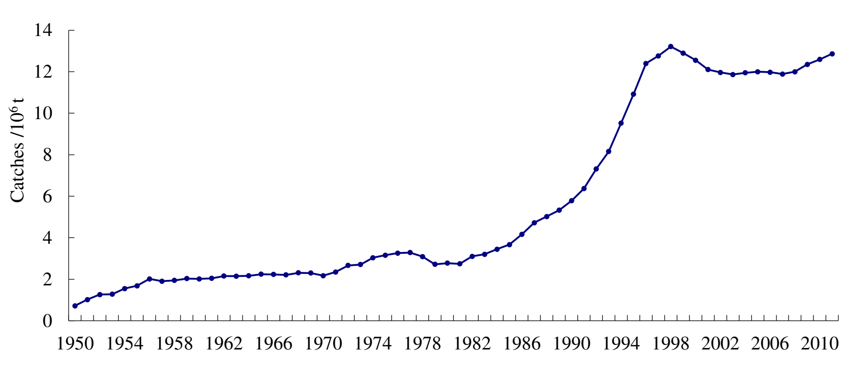

Fig. 1. The changes of fishery landings in China's offshore (1950–2010).