Masking and unmasking fishing down effects: The Bohai Sea (China) as a case study

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A R T I C L E   I N F O

Keywords:
- Bohai sea
- Trophic level
- Fishing down effect
- Skipper effect

A B S T R A C T

The Bohai Sea, in Northeastern China, which has been severely overexploited since the 1950s, is not only an exemplary case of the ‘fishing down’ phenomenon (where large, high-trophic level fish are replaced by smaller fish and invertebrates as the overall biomass is reduced), but also can be used to illustrate one of the masking effects for fishing down. Thus, the decadal decline in the mean trophic level of the biomass in the Bohai Sea is more pronounced than the decline of the mean trophic level of the catch extracted from that sea. This effect is similar to what occurred in the Celtic Sea, where previous authors called this difference ‘skipper effect’ (because skippers try to maintain catches of larger fish), and in the Gulf of Thailand. The skipper effect appears to be a powerful masking factor for the fishing down phenomenon, i.e., biomass tend to be more affected than suggested by time series of the mean trophic of catches.

1. Introduction

The Bohai Sea in China’s northeast is a semi-enclosed coastal sea with an area of 77,000 km² (Fig. 1), a mean depth of 18 m and whose food web structure was presented in Tong et al. (2000), based on previous studies, notably by Deng et al. (1988a, 1988b, 1988c) and Bai and Zhuang (1991). The Bohai Sea is surrounded by major urban areas, and thus was bound to suffer the various injuries inflicted on coastal marine ecosystems, foremost overfishing and industrial pollution (Jin, 2004; Ning et al., 2010; Wang et al., 2015).

The first comprehensive bottom trawl survey of the Bohai Sea was undertaken in 1959; for that year, Tang et al. (2003) documents a trawlable biomass, expressed as catch per unit of effort (CPUE), of 193 kg h⁻¹ (mean of May, August and October). Subsequent trawl surveys documented steadily declining biomass, down to 18 kg h⁻¹ in 2010, as well as change in the taxonomic composition of this biomass (Jin, 2004; Zhang et al., 2007).

Given the availability of these survey results, of fisheries catch data and the prior demonstration of declining mean trophic levels in the trawlable biomass of the Bohai Sea (Du et al., 2014), we focused on the discrepancy between the mean trophic level of the catch vs. that of the biomass. We did this because this discrepancy is a potential masking factor for the occurrence of the ‘fishing down’ phenomenon, i.e., the tendency of large, high-trophic level fish being replaced by smaller fish and invertebrates as the overall biomass is reduced (Pauly et al., 1998a; Liang and Pauly, 2017).

Specifically, we emphasize the difference, in the Bohai Sea and two other ecosystems (the Celtic Sea and the Gulf of Thailand), between the fishing down trend inferred from fisheries catches and that obtained from the changing taxonomic and size structure of the underlying fish and invertebrate biomass. This allowed testing the suggestion of Pinnegar et al. (2002) that skippers exploiting a multispecies biomass increasingly consisting of smallish, low-trophic level fish will attempt to maintain catches of larger, higher-trophic level fish.

2. Materials and methods

The biomass data used here were sourced from five scientific surveys (in 1959, 1982, 1992, 1998 and 2010) conducted in the Bohai Sea, documented in Tang et al. (2003) and Jin (2014) (Table 1). Except for 1959, when the research vessels and trawls were somewhat smaller than those in the later surveys, biomass data were collected using similar trawls and design, so that their results are comparable. The fisheries catch data originate from China Fishery Statistical Yearbook (Fisheries
two to the mean trophic level of catches as Marine Trophic Index (MTI), we refer as used by the same author for the TLs of North Sea fishes (Yang, 1982).

The trophic levels (TLs) of the main taxonomic group constituting the biomass and the catches from the Bohai Sea were taken from Yang (2001a, 2001b). These TL values were estimated using the same method as used by the same author for the TLs of North Sea fishes (Yang, 1982).

Expanding on Pauly and Watson (2005), who re-defined the mean trophic level of fisheries catches as Marine Trophic Index (MTI), we refer below to the mean trophic level of catches as MTI(c) when it is based on catch composition data, and MTI(b) when it is based on biomass data, or (relative) abundance, or ‘standing stock’ data.

The MTI(c) and MTI(b) were calculated for each year using:

\[ MTI = \frac{\sum_{i=1}^{n} (TL_i \cdot Y_i)}{\sum_{i=1}^{n} Y_i} \]

where MTI is the estimated mean trophic level in year k; m represents the number of species in year k; TL is the trophic level of the species i and Y is the catch or biomass of species i in year k.

The relative price index (RPI) during the last 15 years (from 2004 to 2018) was also calculated. The price of species in the Bohai Sea were originated mainly from a Chinese trade journal (Anonymous, 2004–2018). 17 species, for which a complete time series of price records were available, were included in the calculation (Table 1). For each year, the linear regression relationship between price and trophic level was examined, and the slope of the regression was taken as the relative price index (RPI) for that particular year. If the RPI increases, then it can be interpreted as that high trophic level species had become more valuable in relation to species feeding at lower trophic levels, and vice versa. More caveats were explicitly presented in Sumaila (1998).

3. Results

The 2 panels of Fig. 2 present a first set of results. Fig. 2A illustrates the massive decrease of biomass that occurred in the Bohai Sea. Fig. 2B demonstrates the changing taxonomic structure of the underlying fish and invertebrate biomass, revealing that the proportion of species with TL < 3.5 has increased in the Bohai Sea since 1992.

Fig. 3A displays the catches that were extracted from the Bohai Sea. Contrary to the trend of CPUE in the Bohai Sea, after a steady increase before 2000, the catches extracted from the Bohai Sea reached a peak in 2003, then declined somewhat and remained stable thereafter. Fig. 3B presents these catches in terms of the percent composition of their low-trophic level components. The proportion of catch with TL < 3.5 did not show noticeable increase.

The RPI remained relatively stable between 2004 and 2009, then it experienced a large increase since 2010 (Fig. 4). This might be attributed to the fact that the average market prices of several high-trophic level species, such as Japanese seabass and Spanish mackerel, strongly increased relative to lower trophic level species since 2010.

Fig. 5 compares, for 3 marine ecosystems, the declines of the MTI(c) that fishing down entails with the related decline in fishable biomass, i.e., the declines of MTI(b). As might be seen by comparing the slopes of the corresponding regression lines, the decline in MTI(b) in all three of these ecosystems, the Bohai Sea, the Celtic Sea and the Gulf of Thailand demonstrates the changing taxonomic structure of the underlying fish and invertebrate biomass, revealing that the proportion of species with TL < 3.5 has increased in the Bohai Sea since 1992.

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4. Discussion

The fishing down effect was originally described by Pauly et al. (1998a); it implying an increasing contribution of short-lived, low trophic level species to fishery catches, then was accepted as worldwide phenomenon confirmed in a number of aquatic ecosystems. Our results confirm that there have been major changes in the taxonomic composition of the catches of the Bohai Sea generally, with larger, high-trophic level fishes (for example largehead hairtail \textit{Trichiurus lepturus}) being replaced by smaller fishes and invertebrates. This very much corresponds to the original description of the ‘fishing down’ phenomenon.
(Pauly et al. 1998a), as also reported from the East China Sea (Liang and Pauly, 2017).

Compared with catch data, a more rapid decline was found in trophic level of survey data over the same period (Fig. 5). This implies that the Bohai Sea ecosystem has been experiencing stronger changes than observed in (largely targeted) fishery catches. Pinnegar et al. (2002), who first documented this effect based on MTI(c) and MTI(b) trends in the Celtic Sea (Fig. 4B) suggested that it was due to the skippers of fishing vessels who, when they exploit a multispecies ‘stock’ tend to target more valuable fish, which are usually larger, even though their biomass may be low. While this would not apply to the skippers of shrimp trawlers, who target small crustaceans and usually discard the fish bycatch (Zeller et al., 2018), this was not the case for any of the 3 fisheries in Fig. 5.

Fishing activities are typically driven by economic forces. Fishers tend to target high-trophic level, high-value species. When a desirable species become scarce, its average market price will increase; thus fishermen, to maintain a high value catch, will make an effort to targeting these, even if their abundance is low. The more notable decline in the mean trophic level of the biomass than in fishery catches might be attributing to the fact that some of the more abundant species in the Bohai Sea over recent years are not the targets of fisheries. The banded goby (Chaetodrurichthys sigmatias), for example, accounting for much of the biomass of low trophic level species in the 2010 survey, is a bycatch species in bottom trawling and has less commercial value; thus, it is not reported as a species in China Fishery Statistical Yearbook, where the catch data used here originated.

This confirmation of the hypothesis of Pinnegar et al. (2002) implies that trends of MTI(c) will tend to underestimate the underlying trend in MTI(b), i.e., this ‘skimmer effect’ acts as a masking factor against the detection of ecosystem change inferred from catch trends. Indeed, the ‘skimmer effect’ is quite strong compared with the other masking factors that were identified earlier as obscuring the occurrence of the fishing down phenomenon (Caddy et al., 1998; Pauly et al., 1998b, 2001; Pauly and Palomares, 2005; Kleisner et al., 2014; Liang and Pauly, 2017).

Both catches and biomass in the Bohai Sea exhibited reduction in the mean trophic levels, implying that substantial changes have occurred in the underlying structure of the Bohai Sea fish community. In fact, the fishing down effect in the Bohai Sea as demonstrated here is more the underlying structure of the Bohai Sea fish community. In fact, the fishing down phenomenon (Caddy et al., 1998; Pauly et al., 1998b, 2001; Pauly and Palomares, 2005; Kleisner et al., 2014; Liang and Pauly, 2017).

This work was supported by National Natural Science Foundation of China (grant number 31872568); NSFC-Shandong Joint Fund for Marine Ecology and Environmental Sciences (grant number U1606404), and Qingdao Postdoctoral Applied Research Project. Daniel Pauly is supported by the Sea Around Us, itself funded by a number of philanthropic foundations. We thank Mr. Gordon Tsui for the map (Fig. 1) and Ms. Evelyn Liu for drafting our Figs. 2–5.

References


Yang, J., 2001. A study on food and trophic levels of Bohai Sea invertebrates. Mod. Fish. Inf. 16 (9), 8–16 [In Chinese].

Yang, J., 2001. A study on food and trophic levels of Bohai Sea fish. Mod. Fish. Inf. 16 (10), 10–19 [In Chinese].
