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

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ABSTRACT

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 km^2 (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

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Fig. 1. Map of the Bohai Sea, with some of the major cities in, and 5 of the 40 rivers draining the surrounding basin. Liaodong Bay is in the northeast of the Bohai Sea.

Administration of the Ministry of Agriculture, 1979–2016), published by China's Bureau of Fisheries, Ministry of Agriculture. Note, however, that the *China Fishery Statistical Yearbook* provides no commercial CPUE data from the Bohai Sea.

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:

$$MTI_k = \sum_{i=1}^{m} (TL_i \cdot Y_{ik}) \Big/ \sum_{i==1}^{m} Y_{ik}$$

where MTI_k is the estimated mean trophic level in year k; m represents the number of species in year k; TL_i is the trophic level of the species i and Y_{ik} 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 (Anonym, 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

Table 1
Major species of fisheries resources in the Bohai Sea based on biomass data (sources: Tang et al. (2003) for the occurrences and Yang (2001a, 2001b) for the trophic levels).

Scientific name	Common name	1959	1982	1992	1998	2010	Trophic level
Pennahia argentata[a]	silver croaker		+				4.4
Konosirus punctatus	dotted gizzard shad			+	+	+	2.4
Thrissa kammalensis	kammal thryssa			+	+		3.2
Trichiurus lepturus[a]	largehead hairtail	+					4.5
Collichthys niveatus[a]	bighead croaker		+				3.7
Lateolabrax japonicus[a]	Japanese seabass		+	+		+	4.7
Nibea albiflora[a]	yellow drum		+				4.5
Setipinna taty[a]	scaly hairfin anchovy	+	+	+	+	+	3.6
Loligo beka	beka squid		+	+		+	4.1
Raja porosa[a]	ocellate spot skate	+	+	+			4.4
Oratosquilla oratoria[a]	mantis shrimp		+	+	+	+	3.7
Scomberomorus niphonius[a]	Spanish mackerel		+		+	+	4.6
Sepiella maindroni[a]	spineless cuttlefish		+				4.2
Chaeturichthys stigmatias	branded goby					+	3.8
Sardinella zunasi	Japanese sardinella		+			+	3.4
Charybdis japonica	Japanese swimming crab					+	3.9
Portunus trituberculatus[a]	gazami crab		+	+	+	+	3.2
Engraulis japonicus	Japanese anchovy		+	+			3.6
Larimichthys polyactis[a]	yellow croaker	+	+	+	+	+	4.3
Sebastes schlegelii[a]	Korean rockfish					+	4.7
Pampus argenteus[a]	silver pomfret		+		+	+	3.6
Trachypenaeus curvirostris[a]	southern rough shrimp		+				3.4
Platycephalus indicus[a]	bartail flathead					+	4.6
Penaeus chinesis[a]	fleshy prawn	+					3.5

+ species occurred as major species in a particular year.
[a] Species included in the relative price analysis.

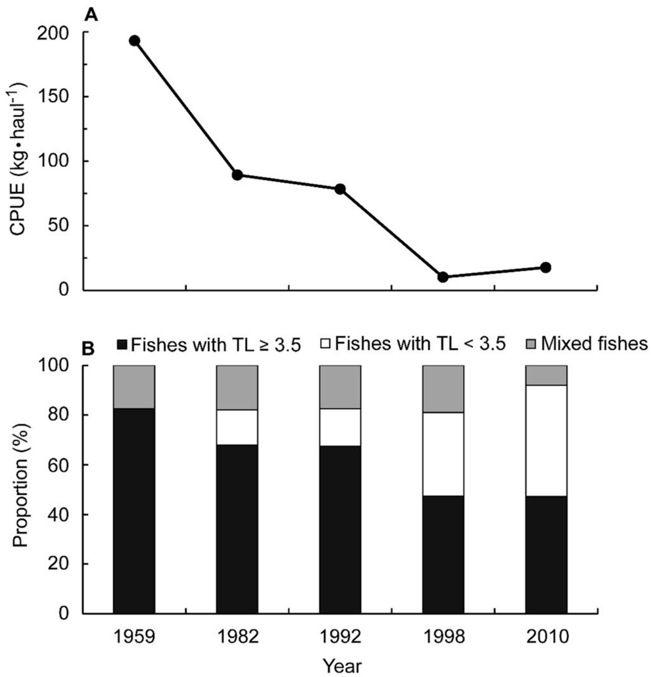

Fig. 2. Basic trends of biomass in the ecosystem of the Bohai Sea. A: Catch per effort of survey trawlers, suggesting a massive decline of the (trawlable) biomass; B: percentage of fish with TL ≥ 3.5 and fish with TL < 3.5.

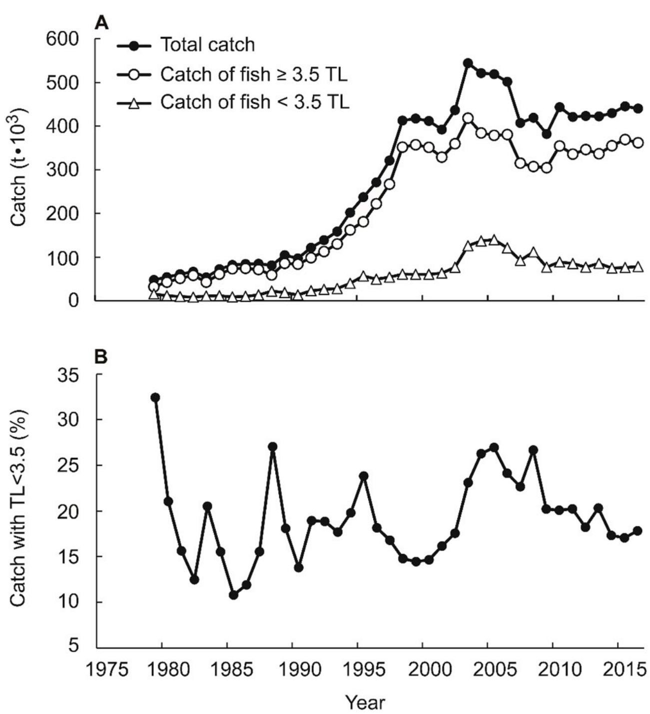

Fig. 3. Basic trends of catches in the ecosystem of the Bohai Sea. A: Total catch, catch of fish and invertebrates with TL ≥ 3.5, and catch of fish and invertebrates with TL < 3.5; C: percentage of catch with TL < 3.5.

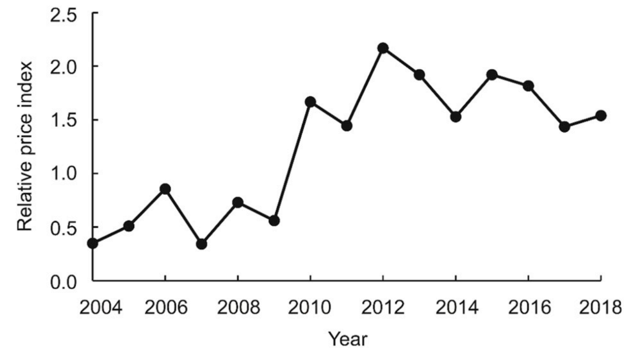

Fig. 4. Pattern of relative price index of 17 species for the Bohai Sea over a 15-year time-series.

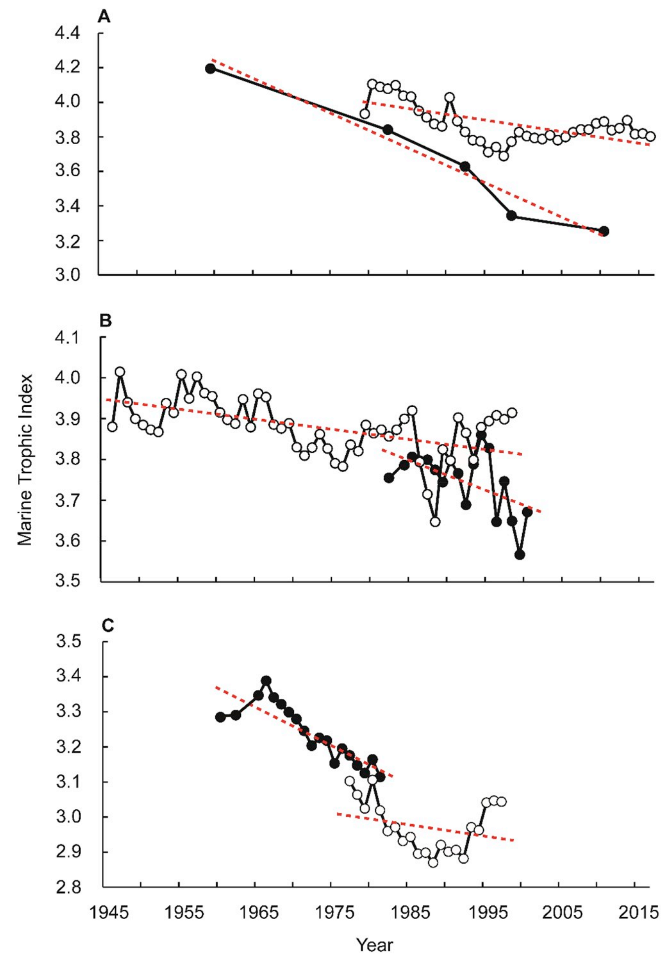

Fig. 5. Trends of MTI(c) (open dots) and MTC(b) (black dots) in three marine ecosystems. A: the Bohai Sea (this study); B: the Celtic Sea (adapted from Pinnegar et al., 2002), and C: the Gulf of Thailand (adapted from Pauly and Chuenpagdee, 2003). Note that in each, the regression lines (red) for MTI(b) is steeper than for MTI(c). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article).

are steeper than those of MTI(c).

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 *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 them, 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 (*Chaeturichthys stigmatias*), 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 'skipper effect' acts as a masking factor against the detection of ecosystem change inferred from catch trends. Indeed, the 'skipper 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 tropic 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 marked than computed by Pauly et al. (1998a) for the North Pacific as a whole. The observed changes in biomass were rapid at first. In 1959, because of the low technology that was deployed at the time, high trophic level species, such as largehead hairtail, constituted a large proportion of fisheries in the Bohai Sea. From 1970s to the mid-1980s, however, the increase of fishing effort and technological sophistication of Chinese marine fishing accelerated, which resulted in a decrease in CPUE. Also, the composition of fish community shifted, and the fraction of traditionally exploited species became lower.

While the biomass of high-trophic level species in the Bohai Sea was reduced (Fig. 2), total fishery catches increased (Fig. 3A), which might be attributed to three reasons:

(i) Reporting inaccuracies: political pressure may have resulted in catches being biased upward; also, catches from outside the Bohai Sea may have been reported as being caught inside;
(ii) Increased fishing effort. After the introduction of the No.5 Central Document in 1985, which promoted the privatization of fishing vessels, the fishing effort increased in all Chinese coastal waters. China now has the largest fishing fleets in the world, despite attempts in recent years to reconcile economic development with fisheries resource protection;
(iii) Increased productivity of low-trophic level fish. Given that trophic transfer efficiency is around 10% (Pauly and Christensen, 1995), removing predatory fish, i.e. shortening food chains made the ecosystem more "efficient" because less energy is lost to transfers among trophic levels, which as a whole may allow the system to generate higher fishery yields.

Except for fishing down effect, other factors, such as climate change and environmental pollution, also contribute to changes in composition of catches. Yet it is difficult for them to explain why catches for often larger, long-lived, high-value species decreased while some other species (often of low trophic level and less sought-after) increased. Since its first identification in 1998, the fishing down effect has been shown to be far more pervasive than previously perceived, and has a lot of explanatory power. In our case, "trophic cascades" explain almost all the reported massive changes in the Bohai Sea (Tang et al., 2003): the almost complete eradication of large fish (with TLs around 4) implies an initial increase of fish and jellyfish (TL near 3), which will reduce the biomass of herbivorous zooplankton (TL = 2). Then, as the small fishes are also depleted by fishing, the zooplankton biomass increased, and depressed the phytoplankton, which led to a decline of primary production declines – all of which occurred in the Bohai Sea.

Though the cascade effect has an opposite effect in the Baltic (i.e., the small fish there were not strongly exploited, and thus reduced the zooplankton, which led to massive phytoplankton blooms), the Baltic and the Bohai Seas resemble each other in that their simplified food webs react strongly to anthropogenic impacts (Österblom et al., 2007).

From this contribution, we conclude that the fishing down phenomenon not only appears to be ubiquitous (see also www.fishingdown.org for numerous cases from all over the world), but also stronger than previously thought prior to the documentation of masking factors.

Declaration of competing interest

There are no conflicts of interest in the submission of this manuscript, and the manuscript was approved by my co-author for publication. On his behalf as well, I would like to declare that the work described herein is original research that has not been published previously and is not under consideration for publication elsewhere, in whole or in part. All of the listed authors have approved the enclosed manuscript.

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