China’s bottom trawl fisheries and their global impact

Xiong Zhang (✉ x.zhang@oceans.ubc.ca)
University of British Columbia  https://orcid.org/0000-0003-0132-734X

Amanda Vincent
University of British Columbia

Article

Keywords: CPUE, fishery management, fishery transition, fishing capacity, mean trophic level, sustainable fisheries, vessel buyback

DOI: https://doi.org/10.21203/rs.3.rs-36246/v1

License: © This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License
Abstract

China dominates the world’s highly destructive bottom trawl fisheries (BTF), active in 30 countries and landing 28% of BTF catch. We created the first time series for China’s BTF, from 1950 to 2018, and examined their national and global impacts. Between 1978 and 1997, China’s BTF fleet increased 47 fold (in numbers) and 26 fold (in engine power), driving enormous acceleration in Asia’s fishing capacity. China embarked on BTF globally from 1985, particularly in East Asia and Africa. Such distant water fisheries (DWF) absorb about 20% of China’s BTF capacity. China’s rampant BTF raises significant concerns: fish availability plummeted wherever China fished, domestically and in DWF; there are strong indications of fishing through the food web and fishing indiscriminately in China’s EEZ; and the mean trophic level of catch eaten by humans has declined. Urgent management interventions are needed to stem such ‘slash-and-burn’ fishing practices in China and worldwide.

1. Introduction

The expansion of bottom trawl fisheries (BTF)—fisheries that ‘bulldoze’ demersal marine life and habitat non-selectively—has long been a great concern around the world1,2. Studies have indicated that the number of global fishing vessels was twice the level that would produce maximum sustainable profits, losing potential benefits of at least $50 billion in 2004 alone3. As the world’s dominant commercial fishing practice, BTF has consistently contributed c. 25% biomass of global annual catches since late 1980s, including 60% of the discards from that biomass4. Substantial evidence has accumulated to show that BTF extracts non-targeted and rare marine species indiscriminately, degrades benthic marine ecosystems, unleashes contaminants from sediments5–7. BTF also come into conflict with small-scale and selective fisheries, engage in illegal activities and may be crewed by slavery or forced labor8. Moreover, BTF are generally unprofitable and rely on government subsidies to survive9. Therefore, curtailing BTF should be a high priority in developing sustainable marine fisheries and conserving biodiversity1, especially as we try to meet UN Sustainable Development Goal 14 (Life Below Water) by 203010.

Mitigating impacts of BTF requires countries to reduce both their fishing effort and constrain their footprints at seas. Historically, fishing efforts and footprints of BTF have generally moved offshore from domestic to distant waters, and from developed (e.g. European Union, North America) to developing regions (e.g. Asia, Africa)11–13, largely driven by resource availability, technology development, policies, and profitability6,14,15. Over the past few decades, some developed nations have stabilized their overall fishing effort and footprints both in domestic and distant waters16–19. But developing countries, especially in Asia, have been expanding their share for decades along with increasing their economic power, foreign investment, and global consumption20–24. It is thus vital for the world to understand the trajectory of bottom trawl fisheries (BTF) in these rising fishing powers... and their impacts on the ocean sustainability.
A great challenge in probing BTF is that many developing countries have not gathered or published data on their fishing capacity and fishing effort. In the past ten years, global fishing capacity and effort have been frequently reconstructed. A common trend is that such capacity and effort expanded rapidly from the late 1970s throughout 2010; notably this trend is dominated by Asian fleets which continue to grow. Such a prominent rise is likely due to the rapid development of trawling since 1970s in Asia, where BTF is massive (e.g. ~ 83,000 BTF vessels targeting shrimp) but poorly monitored and managed. In literature, however, few studies have focused on reconstruction of fishing capacity of BTs in developing countries in Asia. This knowledge gap makes it difficult for the world to understand their impacts on the ocean and for policy making to mitigate these impacts.

The People's Republic of China (hereafter, China) is a leading fishing power in Asia, largely due to its massive BTF. Currently, the estimated catch by Chinese BTF (domestic and distant waters) accounts for 28% of the total worldwide, dwarfing all other countries. Meanwhile, China is also home to the largest number of registered trawlers, with c. 30,000 trawlers registered in 2018. Although most Chinese vessels fish only in domestic waters, c. 3000 fishing vessels (with probably about half engaged in BTF) operate in distant waters under bilateral agreements with foreign nations. Notably, China's BTF in domestic waters contribute a large portion of the ‘trash fish’ (low-valued bycatch including juveniles of commercial stocks) used directly or indirectly in animal farms, especially its aquaculture, which has been the major supply of food fish in China and worldwide. Although China's Ministry of Agriculture has long generated policies intended to curtail BTF, most of these interventions have failed.

Understanding the evolution of China's BTF is thus valuable, but this is hindered by the nation's poor reports on the fishing capacity of its BTF. Although China has reported its total number and total horsepower of trawlers since 2003, information prior to 2003 is lacking and little is known about its BTF capacity for distant-water exploitation.

Here, we reconstruct the trajectory of China's BTF from 1950 to 2018 to understand their changing domestic and global impacts. First, we reconstructed timeseries for their fishing capacity (vessels and horsepower) & yield (catch and landed value) based on a variety of published and unpublished datasets (from China and Sea Around Us Project). To examine their impacts on fish availability (or fishing efficiency) over time and space, we derived catch per unit effort (CPUE) and value per unit effort (VPUE), both within and beyond China's four seas (hereafter, C4S; Supplementary Fig. S1.1). Second, to further understand the domestic impact of China's BTF, we examined their sustainability metrics (e.g., mean trophic level) and catch composition in China's claimed Exclusive Economic Zone (EEZ, including disputed areas; Fig. S1.1) over the history. Third, we examined the changing global contribution of China's BTF (% landings) and their footprint (fishing areas) in comparison with BTF of other leading fishing countries. In evaluating trends, we considered changes in government policy and socioeconomic factors.

Our results suggest China's BTF have grown enormously since China's economic reform (1978), with prominent impacts on both domestic and other nations’ waters. Urgent management interventions, in China and worldwide, are needed to constrain BTF given their destructive impacts.
2. Results

Development phases. We found that the history of China's BTF could be split into four eras:


Total fishing capacity. We showed that the total capacity of Chinese BTF was very low (in relative terms, < 1500 trawlers) in E1 and E2, but increased dramatically from E3 after China embarked on a policy of economic reform (1978) (Fig. 1a). The tally peaked at very large numbers (~ 70,000 trawlers, 8 GW) around 1997 (Fig. 1a)—the highest known for any nation—and then declined to ~ 30,000 vessels in 2018 (6 GW, Fig. 1a). China's BTF capacity in DWF beyond C4S grew quickly in just two decades, once it had started in 1985 (45 trawlers per year, \( r^2 = 0.99 \); Fig. 1b). By 2018, their capacity accumulated to 1500 vessels and 1.2 GW (Fig. 1b), equal to 20% of the gross engine power of all Chinese trawlers.

Mean fishing capacity: Within C4S, the horsepower per vessel (HpV) of Chinese BTF has grown consistently (from 65 to 198 kW) except for a shock from 1978 to 1980 (Fig. 1c), when a large number of small private trawlers emerged after economic reform34,35. In contrast, the HpV of China's BTF beyond C4S fluctuated dramatically and peaked in mid–1990s (1500 kW); notably a new rise has occurred since 2013, as China's fisheries moved towards fewer, more powerful boats32 (Fig. 1c). We found Chinese trawlers were generally more powerful than its other marine fishing vessels. With C4S, the ratio between HpV of BTF and of other Chinese marine fisheries increased dramatically from 1980 to early 1990s, but then plummeted before stabilizing at around 5.0 (Fig. 1d). Such a ratio in fishing fleets beyond C4S showed a similar shape of trajectory with a quick rise in early 1990s but then declined to around 1.0 by 2010 and stabilized (Fig. 1d).

Total catch: Total landings by Chinese BTF grew fastest in E3, and then stabilized after 1996 before a large new growth after 2013 (Fig. 2a). The total landed value showed a similar trajectory, but generally increased more continuously (Supplementary Fig. S2.1). The percentage of Chinese marine catch derived from BTF increased consistently in the first three eras (Fig. 2b). The proportion peaked around 60%, and then leveled off until a new rise after 2013 to around 70% (from 2015 - 2018, Fig. 2b). The proportion of BTF landings from China's claimed EEZ gradually declined from ~ 98 to 70% by 1975, and then bounced back to 90% by 1984, before a new drop to ~ 40% (i.e., 60% were from distant waters; Fig. 2b). This indicates Chinese BTFs initially moved offshore, partly driven by the no-trawl zone policy (1955), and then moved inshore after the fishery agreement with Japan (effective in 1975)32. Chinese trawlers have, however, increasingly operated in distant waters since China started to develop DWF beyond C4S in 198532. The catch share from C4S then gradually declined from 100% in 1985 to 60% in 1997, then bounced back again slightly before dropping to ~ 55% after 2013 (Fig. 2b).
Fishing efficiency (CPUE & VPUE): Within C4S, catch per unit effort (CPUE) of Chinese BTF initially doubled from 1950 to 1954, peaking at 6.8 t / (kW · year), and then halved by 1962 (Fig. 2c). After 1962 CPUE was boosted again to 5.3, largely by technology development (Fig. 2c). But this rise did not last long and the CPUE plunged in 1970s to less than 1 t / (kW · year) by 1984 (Fig. 2c). After China implemented summer moratorium within C4S in 1981, the CPUE declined slower and then gradually rose to nearly 1.5 t / (kW · year) by 2018 (Fig. 2c). Beyond C4S, CPUE plummeted even more strikingly from 55 to 5 t / (kW · year) in just one decade from 1985 (when it was 118 times the value within C4S) to 1995 (when it became only 3 times the value within C4S) (Fig. 2d). Landed value per unit effort (VPUE) demonstrated similar trajectories in both analyses (Figs. 2c & d).

Mean trophic level (MTL) in China's claimed EEZ. Our results suggest that China's BTF in its claimed EEZ showed two signs of problematic fishing behavior (Fig. 3a). The first is fishing down/through the food web, which means increased representation of lower trophic levels in the catch. This behavior was evident in China's BTF and in its all marine fisheries within China's claimed EEZ, during E1, E2, and part of E3 (Fig. 3a). For instance, we found the MTL of China's BTF landings that were directly consumed by humans (hereafter, MTLh) declined at a rate of - 0.05 per decade from 1950 to 1971 (r² = 0.73) and more dramatically between 1972 and 1976 (-0.28 per decade, r² = 0.98, Fig. 3a). After a short period of increase between 1976 and 1981 (after the economic reform), the MTLh continued to decline quickly from 1981 to 1988, reaching the lowest record in its history (MTLh = 2.82), with humans eating lower on the food chain than in 1950 (MTLh = 3.12). The second behavior is greater biomass trawling after summer moratoria (started in 1981, but only implemented nationwide until 1995)32. This resulted in higher proportions of catches of juveniles from high tropic-level species (recruitment during the moratoria), driving the MTLs of both BTF landings and all marine landings returned to increase (Fig. 3a). However, MTLh did not follow a similar trajectory (of the two MTLs) and even declined from 1990 to 2006 (~0.02 per decade, r² = 0.41), given that these juveniles were not directly consumed by humans (Supplementary Figs S2.2 & S2.3). Only after 2006, when China extended the moratorium (by one month) and launched programs to combat illegal fishing32, MTLh started to rise slightly (0.06 per decade, r² = 0.80) and reached 2.92 by 2014 (the same level as in 1990). However, there remained a prominent gap between MTLh and MTL of all BTF landings (Fig. 3a).

Log-relative-price index (LRPI) in China's claimed EEZ. The LRPI represents the log-transformed slope of a linear relationship between price and trophic level of the fisheries stocks. In a healthy fishery, species at higher trophic levels generally hold higher prices and thus generate a positive LRPI value, while a bell-shape trajectory is common when high-valued fisheries stocks are gradually being depleted. In China's claimed EEZ, we found that the LRPI of all species (or fish species only) of China's BTF generally followed a bell-shape trajectory (Fig. 3b), suggesting a gradual decline on high trophic-level fish stocks, in line with the MTL (Fig. 3a). However, it should be noted that the negative values in the early eras likely arose from overestimates of prices for shrimps and fishes at lower trophic levels in previous studies (Supplementary Fig. S2.4).
Fishing-in-balance index (FIBI) in China’s claimed EEZ. The FIBI is commonly used to reflect fisheries’ geographic expansion (FIBI increase) or contraction (FIBI decrease). It goes up if catches increase faster than would be predicted by trophic level declines, and it goes down if catches fail to compensate for a decrease in trophic level.25 We found China’s BTF in its claimed EEZ gradually expanded in the E1 and E2 at a consistent rate (Fig. 3c), that expansion then sped up in E3 (after economic reform) and slowed down in E4 (after China ratified UNCLOS in 1996 and started to reduce total fishing capacity)32. This trajectory is generally in line with China’s all marine fisheries estimated by the Sea Around Us Project (SAUP)41, although the latter varied more prominently especially in E3 (Fig. 3c).

Catch composition in China’s claimed EEZ. We found prominent shifts in the dominance of different stock assemblages over the four eras in China’s claimed EEZ, again providing strong indications of (i) fishing through food webs, (ii) biomass trawling, and (iii) fishing based on availability (Fig. 4, see more details in Supplementary Figs S2.5–S2.10). For instance, in E1, large fish are the dominant stock assemblage, followed by shrimps and medium-sized fish in terms of percentages of landings. However, dominance of large and medium fish gradually declined (though not depleted, Supplementary Figs S2.5&2.6) as other species at lower trophic levels (e.g. jellyfish) increased their share (Fig. 4a), suggesting fishing through the food web. In E4, the dominance of shrimps and jellyfish vanished after 2002. Since then, the catch shares of most assemblages have tended to converge between 10 and 20% (Fig. 4a), meaning that Chinese BTF has become less selective. The catch share of crabs & lobsters (mainly crabs) increased (Fig. 4a), likely because they became relatively more available (Supplementary Fig. S2.9). In contrast, the dominance measured by landed value showed a totally different picture (Fig. 4b); this was dominated by the high prices of shrimps with surprisingly high relative values of jellyfish during parts of E3 and E4.

Global contribution. We found China has greatly increased its share in global BTF, especially between 1985 and 1996, when its contribution to global landings rose from 4% to 21% (Fig. 5a). Three other developing nations in Asia (i.e. Indonesia, Vietnam, and Thailand) also rose to sit among the top five exploiters between 1994 and 2014 (in terms of mean contribution to the landings). In contrast, the top five fishing powers between 1950 and 1970 (i.e. USA, Spain, Russia, Portugal, and Japan) have generally shrunk their shares, with only the USA still found within the top 5 contributors between 1994 and 2014 (Fig. 5a). Notably, the global landings of BTF peaked at 37.6 Mt in 1989 and then generally declined, although the catch remained relatively high (> 25 Mt; Fig. 5b). Such a transition roughly matches with the decline on CPUE (and VPUE) of China’s BTF beyond C4S (Fig. 2d).

Global footprint. Although China’s BTF operated only within C4S in E1 and E2 (Figs. 6a&b), their footprints have gradually expanded to distant waters beyond C4S since 1985 (in E3&E4, Figs. 6c&d). Over history, their footprints were found in a total of 32 nations (including China; Supplementary Table S2.1) and active in 30 countries in E4 (vs. only five in E1 & E2 and 27 in E3; Fig. 6). In terms of overall contributions across all years, most of China’s BTF catch in distant waters has come from East Asia (Japan, South Korea, and North Korea; total of 50%), followed by Northern Pacific (Russia & USA; 23%), Africa (across the Atlantic coast, 20%), Southeast Asia (e.g. Vietnam, Philippines, Indonesia; 6%), and
Middle East & South Asia (e.g. Iran, India, Pakistan; 2%) (Fig. 6e). From 1985 to 2018, China's BTF took a significant share (>22% of overall BTF landings) in each of 12 nations’ EEZs (Table S2.1, Fig. 7, see China's share in other nations in Supplementary Figs S2.11&2.12). These 12 nations together contributed 82% of China's distant-water landings by its BTF between 1950 and 2018. Interestingly, China gradually took over from other nations (e.g. Spain, South Korea, Russia) in half of these EEZs (Fig. 7a,e,h,I,j,k) and was also dominant in EEZs that BTF from other foreign nations hardly touched (e.g. Côte d'Ivoire; Fig. 7b,c,d,f,g,l).

3. Discussion

We reveal a seven-decade modification of China's BTF (in capacity, catch, and footprint) and identify its impacts on global fisheries and marine conservation. First, ours is the only reconstruction of a long-term timeseries of BTF in any developing countries, where fisheries data are poorly reported to FAO, and only the third such reconstruction for any BTF globally6,42. Our study suggests that the dramatic rise in fishing capacity of Asian fleets in the late 1970s was partly driven by Chinese bottom trawlers17,18. The reconstructed capacity data also enables us to reveal a dramatic decline on CPUE (and VPUE) for China's BTF both in and beyond C4S; notably, the CPUE for China's BTF beyond C4S decreased much more strikingly than the CPUE for all marine fisheries in the same regions, especially Asia and Africa18. The new findings highlight the importance of reconstructing fishing capacity6,18, especially for data-poor developing countries in Asia (with its considerable fishing power). Second, from a sustainability and conservation perspective, our study suggests China's BTF in its claimed EEZ included fishing through food webs, biomass trawling, and fishing based on availability43,44, rather than simply fishing down the food web37,45. Such destructive practices by China appear also to have penetrated to the distant waters, given the plunging CPUE in waters beyond C4S. Management actions to stem such ‘slash-and-burn’ fishing practices at sea are needed, though not only for China, if we are about to achieve the UN Sustainable Development Goal in marine fisheries by 203010.

Our reconstructed capacity timeseries reveals new insights on the effects of China's policies on BTF. The astonishing rise in BTF capacity since 1979 was largely due to the nation's economic reform, which privatized vessels and freed the seafood market32,46. The decline in BTF capacity since 1997 might have been driven by the Double Control (on vessels and horsepower) and the Asian Financial Crisis in 199746,47, as well as the low CPUE and VPUE. Interestingly, we suggest that China's vessel buyback programs (started in 2002), which aimed to reduce fishing capacity32, might actually have halted a decline in capacity. One explanation is that fishers remained in BTF in the hope of receiving yet higher buyback allowances in later years, and were facilitated in this intent by the fuel subsidies that started in 200632. Vessel buyback programs have been widely employed in many fisheries around the world (e.g. New Zealand, Australia, US, Canada) for capacity reduction or vessel modernization1,48. Studies have suggested that, when such a program is used to reduce fishing capacity, a catch-share system is often needed as an additional measure to prevent fishers remained in the fisheries from intensifying the race for fish48. The dearth of such a system in China's BTF may explain the intensified biomass trawling observed in recent decades32,46.
Our study raises significant concerns over sustainability and conservation in China's BTF, including a striking collapse in CPUE in both C4S and distant waters beyond C4S. The plunging CPUE (and VPUE) in C4S is most likely due to fisheries depletion, although it might also be affected by other factors (e.g. Sino-Japanese Fishery Agreement 1975). Such a plunge may not arise from China's BTF alone. For instance, in the 1960s and 1970s, Japanese bottom trawlers were much more powerful and may have driven the decline of some benthic fish stocks in the East China Sea. As well, many other fishing entities (e.g., Russia, EU, South Korea) have long been involved in the same distant EEZs where China operates. Fisheries in some of these waters (e.g. the Atlantic coast of Africa) may have already been depleted by these nations long before China started in 198551, as hinted by the decline in global BTF landings after 1989. However, we find that China has gradually overtaken other nations in fishing many of these waters in recent decades, while also expanding its footprints to foreign EEZs that other fishing powers rarely exploit. Many of these EEZs are in Africa which is most affected by IUU fishing, while some of them (e.g. the Persian Gulf) are homes to fragile coral reefs which have also been threatened by climate change. Worries about sustainability of BTF in a global sense are heightened by (i) the revealed history of destructive trawling by China within its claimed EEZ and (ii) China's current pattern of expanding its footprints by sending more powerful vessels to distant waters.

We find that China's BTF had disproportionally greater impacts upon species of higher trophic levels. Given that trawling is non-selective, with most taxa removed in proportion to their availability, we might imagine that MTL would not change much over time. The fact that MTL has declined in China's claimed EEZ from 1950 to 1988 might result from two reasons. First, initially, Chinese trawlers did selectively target the schooling fish stocks of higher trophic levels (e.g., large yellow croakers), causing higher fishing mortality of these species. Second, trawl pressure in this region was so high that it influenced resilience of species to varying extents, with higher trophic levels being most affected. It is likely that both mechanisms have played a role in driving the decline on MTL.

We propose a new metric to measure fisheries sustainability, i.e. MTL. MTL or marine trophic index has been widely adopted as an indicator for sustainable fisheries or ecosystem health by scientists. However, in line with other criticisms, we suggest that using MTL to measure sustainability could be misleading in the case of bottom trawling. Bottom trawling can show increases in MTL at certain times even under egregious fishing pressure. One example would be China's BTF after a fisheries moratorium directed at protecting high trophic level species and lasting several months. The consequent increase in juveniles of these species would help to disguise overfishing of their adults, by inflating the MTL, as shown by our results. In contrast, using MTL largely prevented such a misleading effect. We thus propose MTL as an important improvement that is suitable for monitoring the sustainability of fisheries, especially non-selective ones like BTF.

Although our study focused on China, the same worrisome trajectory of BTF has been found in many other countries. For instance, the trajectories of the fishing capacity and CPUE of China's BTF resemble those of UK's BTF over 118 years from 1889 to 20076. China's BTF have gradually moved offshore and increased fishing pressures in distant waters. Such changes are found in the footprints of the global
commercial fishing fleets12,13, as well as the development history of BTF in other nations in Europe, North America, and more recently in Asia6,15,27,56. This type of fishing practice resembles the ‘slash-and-burn’ agricultural practice on land and impairs our progress towards the UN Sustainable Development Goal 14—Life below Water by 203010. However, the development of BTF is often entangled with fish & animal farming22,23, increasing consumption demand32, and other short-term socioeconomic concerns (e.g., employment)57, especially in developing countries58. Such entanglements may explain the difficulty of curtailing BTF in China, although the Chinese Ministry of Agriculture has long indicated a plan to do so through national policies32. In the future, the focus must be implementing policy effectively through management interventions that decouple short-sighted socioeconomic interests from BTF, in favour of long-term stability of ocean ecosystems and human food security.

4. Methods

**Study area.** While examining China's BTF as a whole, we also compared fishery indices (as described below) for four ocean areas that overlapped each other (see detailed information in SI 1): (i) China's four seas (C4S; Fig. S1.1), (ii) waters beyond C4S, (iii) China's claimed EEZ (claimed in 1996; Fig. S1.1), and (iv) waters beyond China's claimed EEZ (i.e., distant waters in other nations’ EEZs).

**Fishery indices.** We sought to create a comprehensive profile of China's BTF and compare it to China's other (or all) marine capture fisheries. To this end, we collected and analysed data in four categories of fishery assessment: (i) total & mean fishing capacity, (ii) total yield & fishing efficiency, (iii) fishery health, and (iv) catch composition (see details in Table 1 and more on SI 1). These categories contained a total of 14 indices. Eleven of these are commonly used in fishery studies6,25,37–40,45,59–61. In addition, we devised an adjusted mean trophic level for catches directly consumed by humans (MTL$h$) and deployed two dominance indices of catch composition that are not commonly used (Table 1). We examined whether the MTL$h$ could indicate the extent of biomass trawling when compared with the original MTL for all BTF landings. The two dominance indices represented the (i) contribution of each stock assemblage to the total catch, and (iii) contribution of each assemblage to the total landed value of the catch. We defined seven stock assemblages for China's BTF (e.g., large fish, medium fish; Table 2).

**Data sources.** We derived our 14 fishery indices based on data collected from a total of five sources (Table 1): (i) China Fishery Statistical Yearbooks (CFSY, 1951–2018, capacity data)29; (ii) China's local data (fishing capacity and trophic levels); (iii) FishBase (trophic levels of fish species); (iv) SeaLifeBase (trophic levels of invertebrates); and (v) Sea Around Us Project (SAUP, 1950–2014, yield, fishery health, catch composition)39,62. The second source, China's local data, contained (i) two compilations of fishery statistics (including BTF) respectively in the East China Sea (1951–1985) and South China Sea (1980 - 2005)63,64, (ii) Chinese local records about fishing capacity of BTF33; and (iii) Chinese studies on trophic levels of most species / taxa examined in our study (see Supplementary Table S1.1). The fifth
source, SAUP data, contained reconstructed catch and landed value specifically for different fishery stocks (some even to the species/genus level) by different types of gears including bottom trawl and other sub-categories in the dataset (e.g. 'shrimp trawl', 'beam trawl', and 'dredge'). Here we considered all these demersal destructive gears as fishing gears used in BTF.

**Fishing capacity reconstruction.** The timeseries datasets for fishing capacity (i.e., vessels and engine horsepower) of China's BTF were reconstructed from 1950 to 2018. The reconstruction process was focused on three approaches: (i) interpolating missing data points within the time frame of collected data (using GAM & LOESS, ‘gam’, ‘loess.as’, and ‘loess’ functions from the ‘mgcv’ and ‘fANCOVA’ r packages)65,66, (ii) extrapolating data to earlier or later years beyond the time frame (using ARIMA, ‘auto.arima’ function in the ‘forecast’ r package)67, and (iii) calculating total capacity from regional records (e.g. BTF horsepower in the East China Sea) based on estimated ratios. We used a bootstrapping approach to estimate 95% confidence intervals wherever it was applicable17. Although similar approaches have been used by other studies17,18, our work differed in two ways. First, we validated our estimates with independent data whenever available (e.g. piecemeal regional records of bottom trawlers). Our primary rule was that the estimated metric for China's BTF (e.g. number of vessels) must fall between (i) the sum of the same metric across provinces for which data were available (lower bound) and (ii) the same metric for any category of vessel that included BTF (e.g. all motorized catchers; higher bound). Second, for extrapolation, we used other models (GAM or LOESS) instead of ARIMA when the latter derived less acceptable estimates (e.g. negative values or violated our primary rule)33.

**Fishery yield reconstruction.** The catch timeseries were originally derived from SAUP database and were updated for the period from 1950 to 1984. SAUP allocated many records (n = 9826) of ‘reported’ and ‘unreported’ catches from distant waters beyond C4S to China's BTF before 1985. Yet it is widely recognized that China's fishing fleets did not enter waters beyond C4S until 1985, as SAUP acknowledges68. Presumably mistakes occurred during the spatial disaggregation process in the original SAUP study62. These errors for the early period (1950–1984) were corrected by (i) removing the ‘unreported’ catches beyond C4S (mostly discards which are rare in China's fisheries) and (ii) reallocating the ‘reported’ estimates beyond C4S to the closest (and likely most appropriate) regions within C4S.

**Further calculations and mapping.** We used our collected and reconstructed data to calculate fishery indices for mean capacity, fishing efficiency, fishery health, and catch composition (see details in SI 1). We then calculated the global contribution of China's BTF and mapped their footprint (mean annual catch) over time. Finally, we also examined China's catch share in each EEZ, as well as the contribution of each EEZ to China's BTF catches over its history.

**References**


**Tables**

Table 1. Fishery assessment measures used to analyse China's bottom trawl fisheries (BTF).
<table>
<thead>
<tr>
<th>Category</th>
<th>Measure (timeseries)</th>
<th>Function</th>
<th>Area¹</th>
<th>Fishery²</th>
<th>Source³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total &amp; mean fishing capacity</td>
<td>Total number of vessels</td>
<td>Total capacity</td>
<td>a, d, e</td>
<td>BTF</td>
<td>CFSY, CLS</td>
</tr>
<tr>
<td></td>
<td>Total horsepower</td>
<td>Total capacity</td>
<td>a, d, e</td>
<td>BTF</td>
<td>CFSY, CLS</td>
</tr>
<tr>
<td></td>
<td>Horsepower per vessel (HpV)</td>
<td>Mean fishing capacity</td>
<td>a, d, e</td>
<td>BTF &amp; OF</td>
<td>CFSY, CLS</td>
</tr>
<tr>
<td>Total yield &amp; fishing efficiency</td>
<td>Total landings</td>
<td>Yield</td>
<td>a - e</td>
<td>BTF &amp; AF</td>
<td>SAUP</td>
</tr>
<tr>
<td></td>
<td>Total landed value</td>
<td>Yield</td>
<td>a - e</td>
<td>BTF &amp; AF</td>
<td>SAUP</td>
</tr>
<tr>
<td></td>
<td>Catch per unit effort (CPUE, tonnage per unit horsepower per year)</td>
<td>Fishing efficiency</td>
<td>d &amp; e</td>
<td>BTF</td>
<td>CFSY, CLS &amp; SAUP</td>
</tr>
<tr>
<td></td>
<td>Landed value per unit effort (VPUE, real 2010 US$ per unit horsepower per year)</td>
<td>Fishing efficiency</td>
<td>d &amp; e</td>
<td>BTF</td>
<td>CFSY, CLS &amp; SAUP</td>
</tr>
<tr>
<td>Fishery sustainability index</td>
<td>Mean trophic level (MTL)</td>
<td>Monitoring fishing impacts on marine food webs</td>
<td>b</td>
<td>BTF &amp; AF</td>
<td>CLS, FB, SB, SAU</td>
</tr>
<tr>
<td></td>
<td>Adjusted MTL for catches directly consumed by humans (MTLh)</td>
<td>Monitoring biomass trawling</td>
<td>b</td>
<td>BTF</td>
<td>SAU, CLS, FB, SB</td>
</tr>
<tr>
<td></td>
<td>Log-relative-price index (LRPI)</td>
<td>Monitoring the relationship between price and trophic level</td>
<td>b</td>
<td>BTF</td>
<td>SAU</td>
</tr>
<tr>
<td></td>
<td>Fishing-in-balance index (FIBI)</td>
<td>Monitoring fishing expansion or contraction</td>
<td>b</td>
<td>BTF &amp; AF</td>
<td>SAU</td>
</tr>
<tr>
<td>Catch composition</td>
<td>Contribution of each stock assemblage to the total catch</td>
<td>Monitoring changes in stock-assemblage composition</td>
<td>b</td>
<td>BTF</td>
<td>SAU</td>
</tr>
<tr>
<td></td>
<td>Contribution of each stock assemblage to the total landed value</td>
<td>Monitoring changes in stock-assemblage values</td>
<td>b</td>
<td>BTF</td>
<td>SAU</td>
</tr>
</tbody>
</table>
1 Area: a) all waters, b) China’s claimed EEZ, c) beyond China’s claimed EEZ, d) China’s 4 seas, and e) distant waters beyond China’s 4 seas (see SI 1 for definition and Fig. S1.1).

2 Fishery: BTF, bottom trawl fisheries; OF, other marine capture fisheries; AF, all marine capture fisheries (including BTF).

3 Source: CFSY, China Fisheries Statistical Yearbook; CLS, China’s local sources (including regional fishery statistics and peer-reviewed literature); FB, FishBase; SAUP, Sea Around Us Project; SB, SeaLifeBase.

Table 2. Seven stock assemblages for China’s bottom trawl fisheries (BTF) and their description and examples.

<table>
<thead>
<tr>
<th>Stock assemblage</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large fish</td>
<td>Marine fish with a maximum length (ML) ≥ 90 cm</td>
<td>Largehead hairtail, daggertooth pike conger</td>
</tr>
<tr>
<td>Medium fish</td>
<td>30 cm ≤ ML &lt; 90 cm</td>
<td>Large yellow croaker, small yellow croaker</td>
</tr>
<tr>
<td>Shrimps</td>
<td>-</td>
<td>Akiami paste shrimp, Chinese white shrimp</td>
</tr>
<tr>
<td>Cephalopods</td>
<td>-</td>
<td>Japanese flying squid, golden cuttlefish</td>
</tr>
<tr>
<td>Jellyfish</td>
<td>-</td>
<td>True jellyfishes</td>
</tr>
<tr>
<td>Crabs &amp; lobsters</td>
<td>Mainly crabs</td>
<td>Japanese blue crab, Indo-Pacific swamp crab, Longlegged spiny lobster.</td>
</tr>
<tr>
<td>Small fish &amp; other invertebrates</td>
<td>Marine fish with a ML &lt; 30 cm and miscellaneous invertebrates that were not identified to specific taxa</td>
<td>Threadfin breams, clams, sea snails, scallops</td>
</tr>
</tbody>
</table>

**Figures**
Figure 1

Timeseries of the total fishing capacity and yield of Chinese bottom trawlers (BTs) from 1950 to 2018: a) total number and horsepower of Chinese BTs, b) total number and horsepower of China’s BTs in waters beyond China’s 4 seas (C4S), c) horsepower per vessel (HpV) of Chinese BTs in and beyond C4S, d) ratio in terms of HpV between Chinese BTs and other motorized catchers in and beyond C4S. Solid lines are the estimated mean, shades are the 95% confidence intervals. Dotted lines and the black texts next to them are relevant policies or events. The cyan bands indicate the different development eras.
Figure 2

Timeseries of total yield and fishing efficiency measures: c) total landings by Chinese BTF in different waters, and d) the percentage measures (BTF in all landings, BTF landings from China’s 4 seas (C4S), and BTF landings from China’s claimed EEZ), c) catch per unit effort (CPUE, t per kW per year) and landed value per unit effort (VPUE, real 2010 US$1000 per kW per year) in C4S, and d) the same CPUE and VPUE variables for BTF beyond C4S. Solid lines are the estimated mean, shades are the 95% confidence intervals. Dotted lines and the grey texts next to them are relevant policies or events. The cyan bands indicate the different development eras.
Figure 3

Trajectories of the fishery health indices for China's bottom trawl fisheries (BTF) compared with all marine capture fisheries: a) mean trophic level (MTL) of two different catch groups (all landings vs. BTF landings) and an adjusted MTLh of BTF landings (directly consumed by humans); b) log-relative-price index (LRPI) for fish species and all species of the BTF in China's claimed EEZ; and c) fishing-in-balance index (FIBI) for China's BTF and all fisheries, with the relevant policies (black texts), and other explanatory
information (red texts) shown on the plots. The cyan bands indicate the different development eras. Segmented linear regressions for the MTLs are demonstrated with lines (mean) and shades (95% CI).

Figure 4

Contributions (%) of different fishery-stock assemblages to the a) total catch by bottom trawlers in China's claimed EEZ and b) the corresponding total landed value, with the relevant policies (grey texts), and other explanatory information (red texts) shown on the plots. Figure 4b should be interpreted with caution as the price of shrimp, at least, were probably overestimated. The cyan bands indicate the different development eras.
Figure 5

Contributions of China and other major fishing powers in the history to global bottom trawl fisheries (BTF): a) percentage of landings of global BTF; and b) stacked landings of global BTF. The dotted lines mark two events in China’s national policies respectively: (i) developing distant-water fisheries (DWF) in 1985 and (ii) ratifying the UNCLOS in 1996 (i.e., establishing EEZ).
Figure 6

Mean annual catch (or landings) of Chinese bottom trawlers globally in a) E1 (1950 – 1963), b) E2 (1964 – 1978), c) E3 (1979 – 1996), d) E4 (1997 – 2014), and e) stacked landings in different fishing areas: China, East Asia (North Korea, South Korea, and Japan), Northern Pacific (Russia far east, and Alaska, USA), Africa (Atlantic), Southeast Asia (Vietnam, Philippines, and Indonesia), Middle & South Asia (India, Pakistan, Iran), and Franklin Islands (UK). The dotted lines indicate the different development eras. Note that reconstructed catch data were not available after 2014. Note: The designations employed and the
presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 7

Stacked landings (Mt) by bottom trawlers in the EEZs of 12 foreign nations where Chinese bottom trawlers operated most actively from 1985 to 2014 (on average, contributing more than 22% of the landings in each EEZ). The nations are ordered by the extent of China's contribution to the total landings by bottom trawlers therein (in decreasing order). Cumulatively, these EEZs contributed c. 82% of the catches of China's bottom trawl fisheries in E3 and E4 (1978 to 2014). Note that Congo (ex-Zaire) did operated its BTF in its own EEZ between 1954 and 1989, and Russia continued to do so in its own EEZ in the Far East after 1989; but their shares are just too tiny to be visible in the graphs. In contrast, Guinea-Bissau did not operate BTF in its own EEZ.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SI1X22020616.pdf