Opportunity for Marine Fisheries Reform in China

Ling Cao[1,2], Yong Chen[3], Shuanglin Dong[4], Arthur Hanson[5], Bo Huang[6], Duncan Leadbitter[7], David Little[8], Ellen Pikitch[9], Yongsong Qiu[10], Yvonne Sadovy de Mitcheson[11], Ussif Rashid Sumaila[12], Meryl Williams[13], Guifang Xue[14], Yimin Ye[15], Wenbo Zhang[16], Yingqi Zhou[16], Ping Zhuang[17], Rosamond L. Naylor[2,*]

[1] Institute of Oceanography, Shanghai Jiao Tong University, China
[2] Center on Food Security and the Environment, Stanford University, USA
[3] School of Marine Science, University of Maine, USA
[4] College of Fisheries, Ocean University of China, China
[5] International Institute for Sustainable Development, Canada
[6] Hainan University, China
[7] University of Wollongong, Australia
[8] University of Stirling, UK
[9] School of Marine and Atmospheric Sciences, Stony Brook University, USA
[10] South China Sea Fisheries Research Institute, Chinese Academy of Fishery Science (CAFS), China
[11] Swire Institute of Marine Science, Hong Kong University, China
[12] University of British Columbia, Canada
[13] Asia Pacific Fish Watch, Malaysia
[14] KoGuan Law School, Shanghai Jiao Tong University, China
[15] Fish and Aquaculture Department, Food and Agricultural Organization, Italy
[16] Shanghai Ocean University, China
[17] East China Sea Fisheries Research Institute, CAFS, China

[*]Correspondence should be addressed to R. L. Naylor (email: roz@stanford.edu).

Author contributions: L.C. and R.N. designed research; L.C., R.N., Y.Q., Y.Y., and W.Z. analyzed data; all authors wrote the paper. Author names, except that of the first and the corresponding authors, are listed in the alphabetical order by last name. The authors declare no conflict of interest.

Abstract

China's 13th Five-Year Plan, launched in March 2016, provides a sound policy platform for the protection of marine ecosystems and the restoration of capture fisheries within China's exclusive economic zone. What distinguishes China among many other countries striving for marine fisheries reform is its size—accounting for almost one-fifth of global catch volume—and the unique cultural context of its economic and resource management. In this paper, we trace the history of Chinese government priorities, policies, and outcomes related to marine fisheries since the 1978 Economic Reform, and examine how the current leadership's agenda for "ecological civilization" could successfully transform marine resource management in the coming years. We show how China, like many other countries, has experienced a decline in the average trophic level of its capture fisheries during the past few decades, and how its policy design, implementation, and enforcement have influenced the status of its wild fish stocks. To reverse the trend in declining fish stocks, the government is introducing a series of new programs for sustainable fisheries and aquaculture, with greater traceability and accountability in marine resource management and area controls on coastal development. As impressive as these new plans are on paper, we conclude that serious institutional reforms will be needed to achieve a true paradigm shift in marine fisheries management in China. In particular, we recommend new institutions for science-based fisheries management, secure fishing access, policy consistency across provinces, educational programs for fisheries managers, and increasing public access to scientific data.

\body

Introduction

China's 13th Five-Year Plan, launched in March 2016, maps a strategic vision for the country's socio-economic and resource development for the period 2016 to 2020. For the first time since the Chinese Economic Reform in 1978, this new Five-Year Plan places social equity and environmental protection as priorities on par with economic development. It also includes marine ecosystem protection as a significant component of the central government's environmental agenda. The opportunities that the 13th Five-Year Plan offers for the restoration and enhancement of wild fisheries, the protection of marine ecosystem services, and the amelioration of coastal pollution are momentous. Achieving the Plan's marine protection objectives will be challenging, however, and will require new approaches for state governance of marine resources, data sharing and use for policy implementation, and an expanded public appreciation of marine ecosystem services for sustained economic growth and environmental quality. Without serious institutional adjustments, even the most limited management strategy for conserving China's marine fisheries will be tenuous.

Here we trace the history of Chinese government priorities, policies, and outcomes related to marine fisheries since the 1978 Economic Reform, and propose a set of institutional initiatives that could help China realize a true paradigm shift in fisheries management. China is not unique in its challenges to sustain marine fisheries. Over the past two decades, most countries have recognized the need to improve fisheries management (1). Efforts to rebuild stocks have been most successful for large, data-rich fisheries that have formal assessments (representing ~20 percent of global catch volume and ~1 percent of marine fish stocks), and less successful for small, data-poor fisheries (2, 3). China's marine catch, like that of other Asian countries, is comprised largely of non-targeted and unassessed fisheries (or at least stocks for which public data are unavailable), and almost one-third of its total catch is classified as *nei* (not elsewhere identified or included) (3, 4). What distinguishes China among the many countries striving for fisheries reform is its size (accounting for almost one-fifth of global catch volume) (5) and the cultural context of its economic and resource management. China's centrally controlled economy combines strong incentives for state-owned enterprises with an open market system to promote industrial and social modernization. Its socialist market economy and its deep cultural traditions (often referred to as Chinese characteristics) provide major opportunities, but also potential impediments, for sustainable fisheries management.

China's opportunity for fisheries reform rests on the fact that its centralized government has the legitimacy and capability of commanding transformational change in economic and social outcomes according to its policy objectives. Such transformational power is evident by the country's success in reducing the incidence of poverty and food insecurity (as defined by calorie deficits) from over 50 percent to 8 percent of its total population within a single generation after the launch of the 1978 Economic Reform (6). Similarly, during the ensuing era of market-oriented growth and increased openness to the global economy in the 1990s and 2000s, China's real gross domestic product (GDP) grew, on average, at an astounding rate of around 10 percent per annum (SI Appendix, Fig. S1) (7). Overall, China experienced four decades of unprecedented economic expansion under centrally planned economic reforms, with the most significant growth occurring through urbanization and industrialization in its coastal provinces. The environmental repercussions of China's economic expansion have been substantial, however, as manifest by widespread pollution, ecosystem degradation, and biodiversity loss (8-12). The impediments to sustainable development in China are revealed in the unintended, and often poorly reported, consequences of economic growth on human health, welfare, and the environment.

In an effort to reconcile economic development with environmental quality and human well-being in recent years, the current leadership under President Xi has promoted an agenda of 'eco-civilization', which aims to "build a resource-saving and environment-friendly society based on environmental carrying capacity of resources, the laws of nature, and sustainable development" (13). Emphasis on the concepts of land-sea coordination, green development, and social-ecological balance provide a platform for a paradigm shift in China's marine fisheries management. This paradigm shift will only be realized, however, if concepts are effectively translated into action, compliance, and enforcement at the local level. In the sections that follow, we discuss some of the key Chinese characteristics that have shaped government objectives related to China's marine economy during the past 40 years, and show how fisheries management and catch have matched these objectives. We then address the critical question concerning China's 13th Five-Year Plan: How might institutions for fisheries management be re-configured so that local incentives align with the central objective of eco-civilization?

The Cultural Context

One of the biggest challenges for international scientists working in China is understanding the deep cultural roots that influence policy and management practices. Without such knowledge, recommendations for institutional or policy reforms are likely to be inappropriate. A comprehensive analysis of Chinese culture and philosophy is beyond the scope of this paper, but we highlight a few traditional beliefs and modern economic practices that are likely to influence the transition in China's marine fisheries management.

Like many other countries, China developed its economy with agriculture as a foundation, but the symbolism of agriculture extends well beyond the cultivation of crops. Agriculture depicts China's naturalistic view of life, its traditional orientation toward terrestrial systems, and its cultural principles of simplicity and human centrality in the process of ecological change. Agriculture also reflects a preference for taming nature over preserving natural habitats and wild species, despite the benefits of ecosystem services and biodiversity to society—ideas that are gaining greater appreciation in China today (14). It is no surprise that aquaculture accounts for roughly three-quarters of China's fish supplies, and that the country's long history of land-based fish farming has been at the core of its dominance in global aquaculture production (15). The concept of food security in China is associated mainly with staple agricultural systems, but aquaculture plays a central role in meeting national targets for fish supplies.

Chinese characteristics also encompass the yin-yang ideal of harmony and balance that extends to all segments of society, including the marine economy. China's cultural ethic of conservatism permits minimal waste, which helps to explain the country's widespread practice of non-selective fishing, in which all catch is used for some purpose (e.g., food, feed, fertilizer, and other industrial uses). Although moderation is a traditional Chinese value, there is no delusion that humans and ecosystems are in a steady balance. Instead, there is a general acceptance of oscillation from excessive to conservative resource use, as reflected, for example, by President Xi's current attention toward eco-civilization following decades of unrivaled economic expansion.

The challenge of meeting human needs and desires for a population of over 1.3 billion while sustaining natural ecosystem functions is non-trivial. The Chinese desire for avoiding extremes (e.g., social inequality and environmental damage) has been difficult to maintain in a rapidly developing and globalized economy, especially where full impacts of various activities such as use of fossil fuels were not appreciated until recently. In an earlier era, guiding marine resource management in China with the ecological ethic of “nature and man in one” was easier to achieve (16).

The principles embedded in the 1978 Economic Reform—socialism with Chinese characteristics—were derived, at least in part, from the increasing tension between the growing material and cultural needs of the Chinese population and the underdeveloped nature of its production system (17, 18). The socialist market economy emerged with strong central control over most sectors of society, but with openness to capitalist markets that allowed for growth in industry, non-farm employment, and personal incomes. Despite the apparent rise in western style capitalism, the Chinese culture demonstrates a greater respect for top-down decision-making, mutual responsibility, and deference to leaders and elders. This philosophy, which has no direct translation in the English language, is generally accepted by Chinese citizens as a means of preserving social stability and cultural pride. Most analysts agree that the central government, with its top-down control, has been successful in meeting its broad economic goals.

Like other sectors of the economy, policy priorities for fisheries management are governed by central policy objectives, as outlined in Figure 1. Three broad sets of policy goals have shaped the transition in China’s marine ecosystem and fisheries management since 1978: i) economic growth and food supply, ii) development of the blue economy and the expansion of economic activities outside of China’s borders (“going out strategy”), and iii) environmental protection and ecological civilization (“eco-civilization”). These objectives are cumulative; that is, food production and economic growth have been major objectives since the economic reform of 1978 and remain so today, but environmental protection and eco-civilization are now added as essential elements of sustainable development.

The stakes for improving the economic-social-ecological balance in China’s marine fisheries are high. China abuts four major seas—Bohai Sea, Yellow Sea, East China Sea, and South China Sea, and has a coastline of 11,200 miles (19, 20). Over 20,000 marine species are reported off its coasts, including 14 percent of the world’s fish species, 43 percent of mangrove species, and 33 percent of the Indo-west Pacific’s coral reef species (9). With such vast marine resources, China ranks as the world’s leading fishing nation, supplying roughly 15 million metric tons of marine catch in 2014 (13 percent of which came from distant water fleets; see SI Appendix, Fig. S2) (21). Accordingly, China has the largest fishing fleet and the greatest number of people employed in the fishing sector. Sustaining its capture fisheries and fishing communities is no small feat, and will require a long-run commitment to the health and resilience of marine ecosystems.

History of China's Marine Fisheries Management

Marine fisheries management in China reflects the yin-yang principle of unity of opposites—a shifting balance between anthropocentric and ecocentric paradigms. Figure 1 displays the history of marine policy initiatives since the Economic Reform of 1978. At that time, the government launched a major effort to develop its fisheries and coastal economy in line with its market-oriented approach. A production contract of responsibility for fisheries was established under the household responsibility system (by which local managers are responsible for the profits and losses of an enterprise), and a fishery licensing system was put in place. Given China's extensive marine resources, low level of economic development and bitter memories of famine, these measures were oriented mainly around the exploitation of fisheries resources and growth in the marine economy (19, 22).

China's annual marine catch, estimated at around 3 mmt in the mid-1970s, increased by only 2 percent each year through the mid-1980s to reach 3.7 mmt in 1985 (21). This catch level was less than half the estimated maximum sustainable yield (MSY>8 mmt)(3, 23) and fell far short of the country's self-sufficiency target for fish supplies. As a result, the Chinese government introduced the No. 5 Central Document in 1985, a policy directive that aimed to accelerate marine fisheries development within China's waters by promoting the privatization of fishing vessels and market circulation of seafood products (24). Acknowledging the common goods nature of marine fisheries, the government introduced its first comprehensive Fisheries Law in 1986, setting specific rules for the utilization and protection of fisheries resources, as well as the protection of fishermen's lawful rights (19). The No. 5 Central Document also encouraged aquaculture and distant water fishing as important supplements to coastal fisheries. Although aquaculture has historically played a vital role in China's total fish production (15), the No. 5 Central Document extended the scope of aquaculture production from mainly land-based systems to marine-based systems with varying trophic scales, from seaweeds to carnivorous species and multi-trophic systems. Investments in marine aquaculture and vessels for distant water fishing were further promoted in China's Five-Year Plans after the turn of the 21st Century as part of its "going out" strategy (Figure 1).

The No. 5 Central Document spurred innovation and improvements in fishing technology and operations, and generated remarkable growth in China's fisheries economy. Between 1986 and 1996, the volume of marine capture increased by 11.8 percent per year on average to reach a peak of 13.3 mmt in 1998 (21). China became the world's largest fishing nation in 1992, and by the mid-1990s its marine fishing fleet had exceeded 250,000 registered vessels (SI Appendix, Fig. S3). Poor enforcement of measures designed to sustain wild fish populations (e.g., the Marine Environmental Protection Law (1982), the Fisheries Law (1986), and the Resource Fee Collection Scheme (1988) as indicated in Figure 1), resulted in rising catch volume and the decline in numerous fish stocks. Peak fishing seasons for commercial fisheries, defined by times of the year when the catch rate is consistently high, disappeared in most fishing grounds due to stock depletion, as has been the case in many countries around the world.

Intense fishing pressure in the 1990s also corresponded with the increased focus by the central government on the "blue economy" (Figure 1). In addition to marine fishing activities, other industries, such as offshore petroleum, tourism, transportation, and shipbuilding, were promoted. Between 1990 and 2010, China's marine economy grew to become one of the nation's fastest growing sectors, contributing ~10 percent of China's annual GDP (9). Coastal reclamation for urban and industrial growth also proceeded at a rapid pace. A 6,800-mile seawall, lining ~60 percent of China's total coastline and exceeding the length of the ancient Great Wall, was constructed to enclose coastal wetlands for agricultural, aquaculture, and industrial development (10). The cumulative reclaimed area rose from an estimated 0.8 million hectares (ha) in 1990 (9) to over 1.5 million ha in 2015, with roughly one-third of the total area devoted to mariculture (SI Appendix, Fig. S4). Together, marine-based industries and other industries in coastal provinces contribute 60 percent of China's GDP and 90 percent of its imports and exports (9, 10).

Not surprisingly, coastal conversion and the rapid development of China's marine economy have placed tremendous pressure on the country's marine ecosystems (10). China has lost over half of its coastal wetlands, 57 percent of mangroves, and 80 percent of coral reefs, most of which are critical spawning, nursing, or feeding grounds for fish (9, 25). Pollutants from agriculture, urbanization, and other land-based industries have further eroded marine ecosystems and many key habitats of wild fisheries, resulting in an estimated economic loss of more than half a billion US dollars annually to the country's marine fisheries (9). Some large marine ecosystems, most notably in the Bohai Sea, have been degraded to the point of becoming dead zones (26).

In response to overfishing and the steady degradation of coastal ecosystems, the Chinese government has introduced a series of management measures to rebuild marine fisheries (19, 22, 27). These measures, listed in Table 1, include input and output controls, technical limits such as gear specifications and restrictions, spatial and temporal closures, ecological instruments, and economic incentives. There has also been a symbolic shift in policy language surrounding the exploitation of China's ocean resources. Following the China Ocean Agenda 21, which declared the sustainable development of oceans and coasts as a basic development strategy, the government has introduced a series of Five-Year Plans with greater emphasis on resource conservation, environmental protection, and marine awareness (SI Appendix, Table S1).

One of the most notable reforms in fisheries management was the seasonal moratorium on marine fishing, introduced by the government in the mid-1990s. Seasonal closures, which prevent all vessels from fishing for a certain period each year, were established in 1995 for 2.5 mo/year in the Bohai and Yellow Seas, 3 mo/year in the East China Sea, and extended to 2 mo/year in the South China Sea in 1999. Seasonal closures have helped to protect several spawning stocks and juveniles with negligible implementation costs, but these improvements have been offset by heavier-than-usual fishing pressure in the post-closure months (27), and greater pressure on women in fishing communities to find alternative income during the closed seasons (28).

China has established a number of spatial regulations to protect coastal habitats and wild fish resources, but these measures have been fairly weak and have not been carefully evaluated. The country officially has 49 marine protected areas (MPAs), but they span only 0.5 percent of its total marine area. A mere fraction of this MPA area -- 0.05 percent of China's oceans -- is strongly protected in no-take zones (29). China also has 51 marine germplasm resource conservation zones, although monitoring and enforcement of these protected areas has been deficient (30).

In addition to seasonal and spatial closures, the Ministry of Agriculture (MOA) introduced a “zero growth” strategy for total marine catch in 1999, and a “negative growth” strategy in 2000. This regime shift, from targeting for high growth in the 1980s to negative growth at the turn of the century, meant that high catches were no longer encouraged—a sharp contrast to earlier periods when an achievement of local governments was measured with the annual increment of catch. As a result, the reported total marine catch leveled off between 2000 and 2009, and has risen only slightly since that time (Figure 1). China’s overall fish production increased by 20 percent during the 2000s and by threefold over the past two decades, but virtually all of this growth came from aquaculture (21).

China’s seasonal closures, spatial regulations, and negative growth targets have served as blunt regulatory measures in the past. Ecological characteristics of individual species have not been incorporated into these management practices, and insufficient or erroneous catch monitoring has compromised their effectiveness, resulting in over- or under-exploitation of various fish stocks (9). China’s agenda for marine resource management has traditionally been set by central authorities in a top-down fashion, yet the data required to regulate and enforce fisheries management and spatial closures must come from the bottom up. Adverse incentives for local officials to increase reported fish catch have often conflicted with sustainable fisheries goals. The absence of transparent data on stock status and ecosystem impacts has hampered central control over marine protection, and there have been few institutional mechanisms in place to incorporate scientific input into the process of fisheries management reforms.

Meanwhile, stock enhancement programs (releasing cultured juveniles for harvest at larger sizes) have been promoted in all coastal provinces. Large-scale implementation of stock enhancement began in 1984 with the landmark case of the Chinese Prawn (*Fenneropenaeus chinensis*) in the Bohai Bay (31-33). By 2008, stock enhancement was practiced for over 100 species of finfish, crustaceans, and shellfish, and almost 20 billion juveniles were released annually (20, 33) (SI Appendix, Table S2). Monitoring has been weak, however, and scientific studies evaluating the economic and biological performance and impacts of enhancement programs have largely been lacking (34).

Various other policy instruments have also been introduced in China to reduce fishing pressure. A vessel buyback program was implemented in 2002, leading to a 31 percent contraction in the number of commercial fishing vessels between 2002 and 2014 (SI Appendix,

Fig. S3). In addition, the program attempted to reduce the engine power of individual vessels, but this dual control initiative was largely unsuccessful. Vessel tonnage increased by 20 percent and the average horsepower of fishing vessels rose by 5 percent, offsetting the gains from the reduced fleet. Total marine catch actually increased slightly between 2002 and 2014 by 1.6 percent per annum. In a further effort to downsize the fishing industry, the government implemented the Fishermen Transfer and Fishery Transition Program in 2003, with the aim of moving fishermen to other industries such as fish processing, coastal tourism, and mariculture. Like the dual control program, however, the fisherman transfer program had limited success. From 2003 to 2014, the number of professionals employed in marine fisheries fell by about 7 percent but still exceeded 1 million, while the number of traditional fishermen remained above 3 million (21). Overall, these programs have suffered from limited inspection by local governments, the continued presence of illegal fishing vessels, and new entrants into the industry in spite of the transfer program (27).

Further complicating the picture is a suite of government subsidies for marine fishing. These subsidies include, for example, direct funds for vessel purchases, fishing employment and vessel insurance, seasonal closure allocations, and various tax deductions. Fuel subsidies have also been provided to fishermen to improve their incomes, augment domestic fish supplies, and raise foreign exchange through exports. The fuel subsidy has been politically difficult to remove, but in July 2015, the Ministry of Finance and MOA announced a plan to lower it by 60 percent, from 3.7 billion US dollars in 2014 to 1.5 billion US dollars in 2019 (35). This plan, if effectively implemented, will have a profound influence on the number of vessels and capacity of China's marine fishing fleet. However, the Chinese government also provides a large subsidy for distant water fishing vessel construction. While the latter aims to maintain adequate fish supplies for the country without further depleting domestic fisheries, it has largely failed to meet this objective. Roughly half of China's distant water catch, mainly comprised of high value species, is sold to foreign markets in developed countries and is not transported back to China (36, 37).

Fishing for Volume or Ecosystem Resilience?

Despite the multitude of stresses on its marine ecosystems, China has been remarkably successful at maintaining a steady volume of wild fish catch over the past 25 years—and indeed at increasing total catch volume slightly since 2008 (Figure 1). In 2010, four-fifths of China's marine catch biomass within its EEZ came from stocks classified as fully exploited (65.5 percent), developing (15.1 percent), or rebuilding (0.6 percent), while less than one-fifth came from stocks that were overexploited (18 percent) or collapsed (0.7 percent) (Figure 2A) (38). By contrast, China's marine fishery status by the number of fish stocks tells a different story; roughly 57 percent of the country's fish stocks are overexploited or collapsed (Figure 2B). Putting these trends together, it appears that a limited number of highly abundant fish stocks are supporting the steady volume of China's wild fish catch over time, while the remaining fish stocks are in decline or have collapsed. The share of fish captured from stocks that are overexploited have doubled since the late 1990s (Figure 2A).

These trends are consistent with evidence on the changing trophic structure of China's marine catch. Half a century ago**,** China's catch volume was small and comprised mainly of large demersal species with high economic value (SI Appendix, Table S3). In recent decades, about 80 percent of the catch in China's EEZ has consisted of low-valued, small pelagic fish such as anchovies, mackerels, and scads—many of which are over-fished (see SI Appendix, Fig. S5, Table S4). Available data suggest that China has been substantially "fishing down the food web" (38). The mean trophic level of its marine capture fisheries has declined from 3.7 to 3.46 during the past half century, reflecting more than a 50 percent decrease in the primary production required to sustain its wild catch (39, 40). A similar pattern has occurred in many other countries and large marine ecosystems, although fishing up and fishing through the food chain has also been evident in several regions (40, 41) (SI Appendix, Fig. S6).

The combination of sustained catch volume and declining trophic depth, while not intentional, has been tolerated in China because it has provided short-term benefits in the form of domestic fish supplies and fishing incomes (42). Local authorities have been able to report progress in contributing to centrally planned targets for economic growth and food production by maintaining a steady volume of fish biomass. China's massive aquaculture sector, its expanding distant water fishing sector, and its rising fish imports have also helped the country to meet its rising domestic demand for fish—and have thus permitted government officials to skirt tough regulations on its capture fisheries. Until recently, it appears that restoring trophic balance through an ecosystem-based approach (43, 44)—in order to increase resilience, avoid the risks of fishery depletion, and obtain long-term profits—has ranked relatively low among government priorities, particularly when short-run economic or social costs have been incurred.

Reassessing the tradeoffs between conservation and exploitation for food and income has become increasingly critical in China as several of its coastal ecosystems experience irreversible decay. Two key goals of marine resource management in China (and in many other countries) are to preserve the option for future use and, accordingly, to build ecosystem resilience in the face of climate change and other anthropogenic stressors (45). To achieve these goals, there will need to be a concerted effort to preserve marine food webs and ecosystem structure through a combination of well-functioning MPAs and fisheries reform. In order to minimize social trade-offs, the government will need to continue to promote sustainable aquaculture development that does not damage marine ecosystems, and invest in new job opportunities for fishing communities. Lessons on sustainable fisheries management can be drawn from the successes and failures in other countries, particularly in neighboring countries that share some of China's cultural values on marine resource management (SI Appendix, Fig. S6).

A Paradigm Shift?

China's 13th Five-Year Plan now lays the foundation for significant policy reforms in marine fisheries. At least three important new initiatives are worth mentioning as the central leadership's agenda for eco-civilization unfolds. First, the Ministry of Agriculture (MOA) is developing a Five-Year Plan for fisheries (to be released by year-end 2016), which will focus on modernization of the traditional fishing industry, sustainable aquaculture, marine environment protection, and sustainable use of wild fish resources (47). Although the interpretation of the latter phrase remains unclear, the plan includes a reduction in the total marine catch volume to 10 mmt (from ~15 mmt currently) by 2020 (47). In Nov 2016, MOA convened a high level meeting on limits to distant water fishing fleets (48). In addition, various measures for domestic fisheries volume control are currently being tested in pilot projects in Zhenjiang and Shandong, which set the stage for future applications of volume control throughout China. Specific attention to volume control represents a pivotal change in Chinese fisheries management.

Second, there appears to be a genuinely stronger commitment toward accountability, compliance, enforcement of regulations, monitoring, and public data reporting in China's marine fisheries. Proposed amendments to China's Fisheries Law (2016) include the use of new technological applications such as electronic logbook systems (e-logs) for monitoring commercial fish catch (species and volumes). E-logs will also be used to improve public data collection for legal enforcement of catch volume, seasonal closures, and spatial restrictions. In addition, MOA has recently announced plans to extend seasonal closures to 4.5 months (from May 1 to Sep 16) per year in all of China's seas, effective from 2017. This specific action represents a critical step forward in tackling ecological degradation and eco-civilization reform in China's 13th Five-Year Plan.

Third, China's State Oceanic Administration (SOA) is introducing a new system of marine ecological redline regions (MERRs), which will delineate specific boundaries between shoreline development areas and ecologically protected zones. The proposed MERRs will cover at least 30 percent of China's total ocean area (49). Legal rights of use will be established in specific planning areas, and environmental impact assessments will be required before any type of construction in China's oceans begins. Under the new program, all sea use and coastline construction must be transparent and fully disclosed to the public (50). In addition, SOA plans to implement an ecological liability system whereby any party violating ecological restrictions will be subject to financial penalties for damages. The main intention of the MERRs program, however, is to prevent further ecological damage from occurring in the first place.

These initiatives are impressive and demonstrate a clear commitment to elevating the ecological objectives in fisheries management. By adding marine ecosystem protection as a policy priority alongside economic growth and food production, the Chinese leadership is making a strong investment in the health of future fisheries as well as other ocean uses. In a recent assessment of global fisheries stocks, Costello and colleagues (3) highlighted China's enormous potential for enhancing fisheries biomass, stocks, and profits in the next few decades through management reform, especially given the country's size and non-selective catch practices. There is no "one-size-fits-all" management strategy that will achieve the desired balance between food production, economic growth, and ecological resilience in all of China's fishing regions. Simply agreeing on the desired balance is a daunting task given China's large population, expanding labor force, and overarching goal of social stability. A more general conclusion from Costello et al.'s (3) assessment is therefore worth emphasizing: the greatest economic and ecological improvements in China's fisheries will come from re-shaping institutions. Without institutional change, China will be unable to implement widely accepted ideas on sustainable fisheries management.

What types of institutional change are needed in China to realize its plans for fisheries recovery and marine ecosystem resilience in the 13th Five-Year Plan? We suggest six specific measures:

- The introduction of regional science management councils, whereby all important stakeholder groups are well represented, and the best available science is used in the decision-making process for marine fisheries management. Within such a system, fishing limits would not exceed scientifically-determined sustainable levels, and fishermen would need to comply with these limits. Key stakeholder groups would include government, industry, independent scientists, and civil society.
- The introduction of incentives that improve fishing incomes without increasing fishing effort and aggregate fish catch, e.g., through the allocation of individual fishing limits or quotas. Funding programs to remove excessive fishing capacity and to promote alternative employment opportunities and workforce training would enhance the success of this initiative, as would the removal of most existing subsidies to the fishing industry.
- The expansion, effective implementation, enforcement, and sustained financing of marine protected areas (MPAs) throughout China's EEZ to enhance the recovery of fisheries stocks and the resilience of marine ecosystems.
- The implementation of uniform management and enforcement mechanisms across provinces in China to ensure that communities and the fishing industry throughout the country are subject to equivalent and effective fisheries regulations.
- The promotion of educational opportunities for scientists and fisheries managers to learn from the successes and failures of other nations in marine resource management.
- The establishment of a public process for data sharing and transparency on fisheries practices, catch, stock status, and ecological impacts.

If China is able to carry out these institutional reforms, it will likely experience a true paradigm shift in fisheries management. To be successful, however, the government will need to commit financial resources to cover the transition costs of institutional change. Without adequate funding, efforts to transform fisheries management in China will likely be futile.

Based on the cultural characteristics that underpin China's economic model and resource use, it is clear that some of these institutional changes will be easier to achieve than others. For example, promoting scientific education for fisheries managers and improved mechanisms for data sharing will be easier to implement than creating institutions for public participation in the decision-making process. Strengthening the ties between central and local leadership is feasible—and essential—for marine fisheries reform in China, as is the harmonization of regulations and enforcement mechanisms across all coastal provinces. Using the best available science in decision-making for all fishing regions and introducing secure access approaches in selected areas in line with science-based recommendations are also highly achievable goals.

This is a pivotal time for fisheries and marine ecosystems in China. The central government has the power to implement transformative change in marine fisheries management that could benefit its citizens substantially, as well as position the country to be a global leader in fishery reforms and marine protection. Reforms will not be easy, but firm groundwork has been laid, and policies are moving in the right direction. Because the window of time to make the transition is closing as wild fish stocks become further depleted, time is of the essence. As the classic Chinese saying goes, "Ten thousand years are too long. Seize the day, seize the hour." We urge Chinese leaders to pursue their agenda of eco-civilization reforms vigorously within the 13th Five-Year Plan.

Acknowledgment

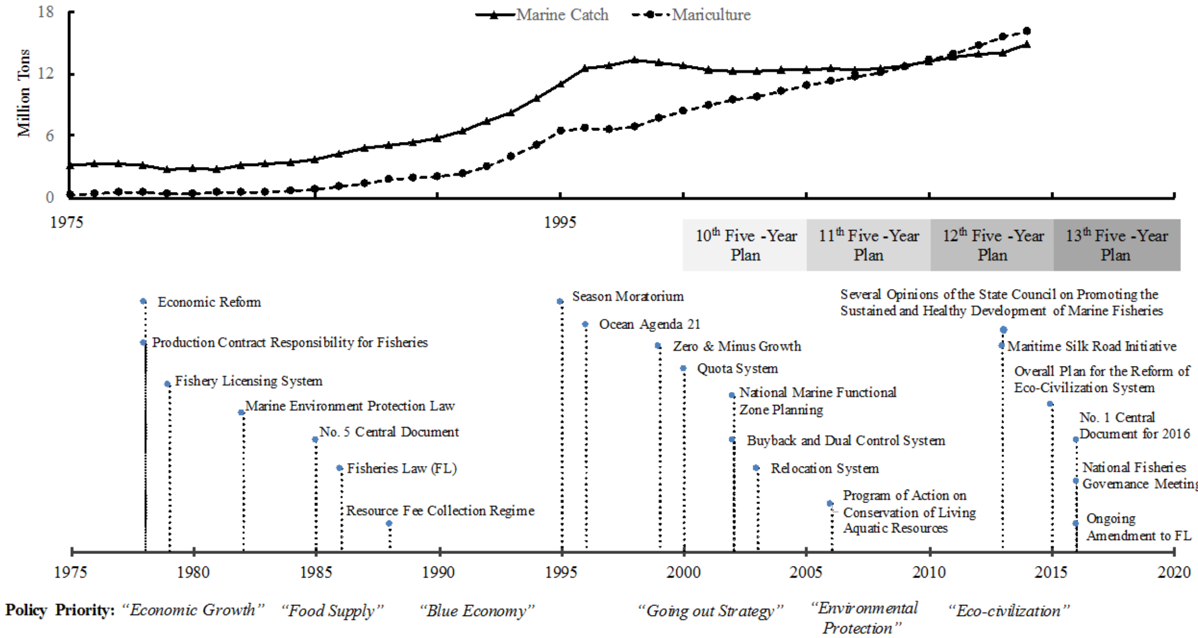
The Lenfest Ocean Program funded the initial collaboration and research for this manuscript, and the David and Lucile Packard Foundation provided supplemental funding. We thank J. Lubchenco and two anonymous reviewers for their constructive comments.

References

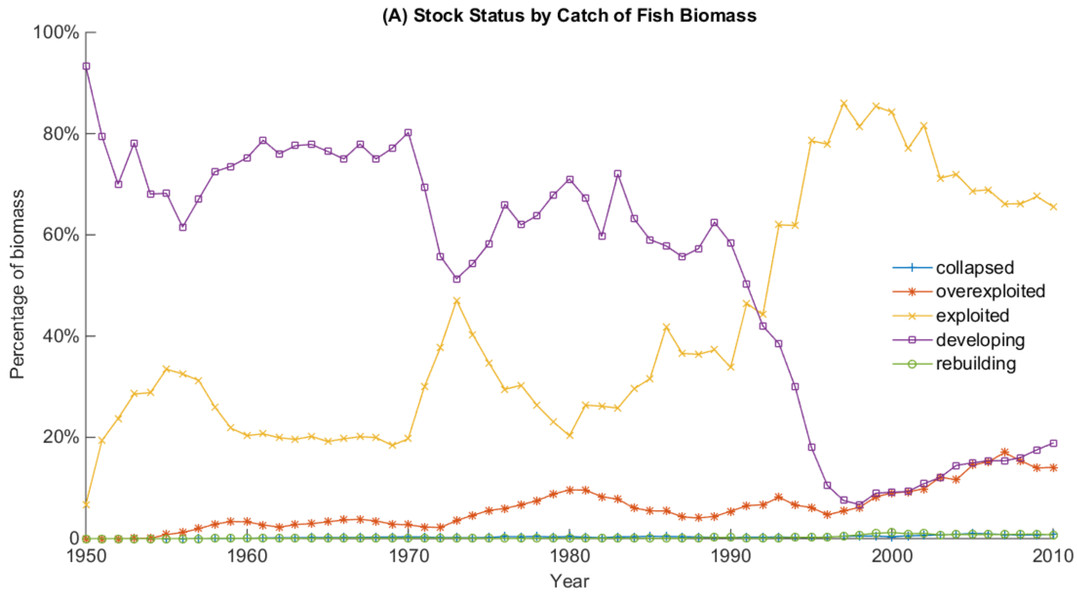
1. Worm B, *et al.* (2009) Rebuilding global fisheries. *Science* 325(5940):578-585.
2. Costello C, *et al.* (2012) Status and solutions for the world's unassessed fisheries. *Science* 338(6106):517-520.
3. Costello C, *et al.* (2016) Global fishery prospects under contrasting management regimes. *Proceedings of the National Academy of Sciences*:201520420.
4. Funge-Smith S, Briggs M, & Miao W (2012) Regional overview of fisheries and aquaculture in Asia and the Pacific 2012. Asia-Pacific Fishery Commision, FAO, Rome.
5. Food and Agriculture Organization of the United Nations (2016) FishStatJ - software for fishery statistical time series. http://www.fao.org/fishery/statistics/software/fishstatj/en. Accessed on April 30, 2016.
6. Ravallion M & Chen S (2007) China's (uneven) progress against poverty. *Journal of development economics* 82(1):1-42.
7. National Bureau of Statistics of China (2015) China Statistical Yearbook. http://www.stats.gov.cn/english/. Accessed on June 15, 2016.
8. Liu J & Raven PH (2010) China's environmental challenges and implications for the world. *Critical Reviews in Environmental Science and Technology* 40(9-10):823-851.
9. Su J (eds) (2013) *Ecosystem issues and policy options addressing the sustainable development of China's ocean and coasts* (China Environment Press, China).
10. Ma Z, *et al.* (2014) Rethinking China's new great wall. *Science* 346(6212):912-914.
11. Tian B, *et al.* (2016) Drivers, trends, and potential impacts of long-term coastal reclamation in China from 1985 to 2010. *Estuarine, Coastal and Shelf Science* 170:83-90.
12. Shen C, *et al.* (2016) Study on the cumulative impact of reclamation activities on ecosystem health in coastal waters. *Marine pollution bulletin* 103(1):144-150.
13. State Council (2015) Overall plan for eco-civilization reforms. http://www.gov.cn/guowuyuan/2015-09/21/content_2936327.htm. Accessed on June 15, 2016.
14. Ouyang Z, *et al.* (2016) Improvements in ecosystem services from investments in natural capital. *Science* 352(6292):1455-1459.
15. Cao L, *et al.* (2015) China's aquaculture and the world's wild fisheries. *Science* 347(6218):133-135.
16. Li M, Jin X, & Tang Q (2012) Policies, regulations, and eco-ethical wisdom relating to ancient Chinese fisheries. *Journal of Agricultural and Environmental Ethics* 25(1):33-54.
17. Hsu RC (1991) *Economic theories in China, 1979-1988* (Cambridge University Press).
18. Vogel EF (2011) *Deng Xiaoping and the transformation of China* (Belknap Press of Harvard University Press Cambridge, MA).
19. Xue G (2005) *China and international fisheries law and policy* (Martinus Nijhoff Publishers) p 326.
20. Tang Q (eds) (2012) *Regional oceanograhy of China seas: fisheries oceanography* (Marinetime Press, Beijing, China) p 450.
21. Fisheries Bureau, Ministry of Agriculture (2015) China Fisheries Statistics Yearbook 2014 (China Agricultural Press, Beijing, China).
22. Ferraro G (2013) *International regimes in China: domestic implementation of the international fisheries agreements* (Routledge).

23. Ministry of Agriculture (2016) Readjusting the structure and promoting the modernization of traditional fisheries in China. http://ft.agri.gov.cn:82/gate/big5/www.moa.gov.cn/ztzl/ncgzhy2015/zxdt/201603/t20160329_5075861.htm. Accessed on June 10, 2016.
24. Tang J (2006) *Studies on the fishing quota system in China* (Shanghai Science Popularization Publishing House, China).
25. Blomeyer R, *et al.* (2012) *The role of China in world fisheries* (European Parliament, Directorate General for Internal Policies, Brussels).
26. Gao X, Zhou F, & Chen C (2014) Pollution status of the Bohai Sea: an overview of the environmental quality assessment related trace metals. *Environment international* 62:12-30.
27. Shen G & Heino M (2014) An overview of marine fisheries management in China. *Marine Policy* 44:265-272.
28. Xu S, *et al.* (2012) Women's roles in the construction of new fishing villages in China, as shown from surveys in Zhejiang Province. *Asian Fisheries Society* 25(Special):229-236.
29. Marine Conservation Institute (2016) MPAtlas [Online]. Seattle, WA. www.mpatlas.org. Accessed Sep 27, 2016.
30. State Council (2015) National marine major functional zone planning. http://www.gov.cn/zhengce/content/2015-08/20/content_10107.htm. Accessed on June 15, 2016.
31. Li LP & Huang SL (2011) A study on management of stock enhancement in China. *Journal of Shanghai Ocean University* 9:765-772.
32. Lü H, Xu J, & Vander Haegen G (2008) Supplementing marine capture fisheries in the East China Sea: Sea ranching of prawn Penaeus orientalis, restocking of large yellow croaker Pseudosciaena crocea, and cage culture. *Reviews in Fisheries Science* 16(1-3):366-376.
33. Shan X, *et al.* (2012) Fish community structure and stock dynamics of main stocking fish species in the Bohai Sea. *Progress in Fisheries Sciences* 33:1-9.
34. Wang Q, Zhuang Z, Deng J, & Ye Y (2006) Stock enhancement and translocation of the shrimp Penaeus chinensis in China. *Fisheries Research* 80(1):67-79.
35. Ministry of Finance (2015) Annoucement of adjusting fuel subsidies for capture fisheries and aquaculture to enhance the sustainable development of fisheries. http://jjs.mof.gov.cn/zhengwuxinxi/zhengcefagui/201507/t20150709_1272152.html. Accessed on June 15, 2016.
36. Pauly D, *et al.* (2014) China's distant-water fisheries in the 21st century. *Fish and Fisheries* 15(3):474-488.
37. Mallory TG (2013) China's distant water fishing industry: Evolving policies and implications. *Marine Policy* 38:99-108.
38. Pauly D & Zeller D (eds) (2015) Sea Around Us Concepts, Design and Data. www.seaaroundus.org. Accessed on June 15, 2016.
39. Pauly D, *et al.* (1998) Fishing down marine food webs. *Science* 279(5352):860-863.
40. Essington TE, Beaudreau AH, & Wiedenmann J (2006) Fishing through marine food webs. *Proceedings of the National Academy of Sciences of the United States of America* 103(9):3171-3175.
41. Branch TA, *et al.* (2010) The trophic fingerprint of marine fisheries. *Nature* 468(7322):431-435.

42. Szuwalski CS, Burgess MG, Costello C, & Gaines SD (2016) High fishery catches through trophic cascades in China. *Proceedings of the National Academy of Sciences*.
43. Pikitch E, *et al.* (2004) Ecosystem-based fishery management. *Science* 305(5682):346-347.
44. Pikitch EK (2012) The risks of overfishing. *Science* 338(6106):474-475.
45. Jiao NZ, *et al.* (2015) Climate change and anthropogenic impacts on marine ecosystems and countermeasures in China. *Advances in Climate Change Research* 6(2):118-125.
46. Pauly D & Le Manach F (2015) Tentative adjustments of China's marine fisheries catches (1950-2010). Fisheries Centre Working Paper #2015-28, University of British Columbia, Vancouver.
47. Ministry of Agriculture (2016) Key work points in fisheries in 2016. http://www.moa.gov.cn/zwllm/tzgg/tfw/201602/t20160203_5007519.htm. Accessed on June 15, 2016.
48. Ministry of Agriculture (2016). Discussing the 13th Five-Year development plan for distant water fishing. http://www.moa.gov.cn/zwllm/zwdt/201611/t20161129_5382014.htm. Accessed on Nov 30, 2016.
49. State Oceanic Administration (2016) Establishing marine ecological redline regime. http://www.soa.gov.cn/xw/hyyw_90/201606/t20160616_52167.html. Accessed on June 15, 2016.
50. State Oceanic Administration (2016) Regulation of sea use for regional development. http://www.soa.gov.cn/xw/hyyw_90/201601/t20160129_49974.html. Accessed on June 15, 2016.



Marine Catch
Mariculture
Million Tons
18
12
6
0
1975
1995
10th Five -Year Plan
11th Five -Year Plan
12th Five -Year Plan
13th Five -Year Plan
Economic Reform
Production Contract Responsibility for Fisheries
Fishery Licensing System
Marine Environment Protection Law
No. 5 Central Document
Fisheries Law (FL)
Resource Fee Collection Regime
Season Moratorium
Ocean Agenda 21
Zero & Minus Growth
Quota System
National Marine Functional Zone Planning
Buyback and Dual Control System
Relocation System
Program of Action on Conservation of Living Aquatic Resources
Several Opinions of the State Council on Promoting the Sustained and Healthy Development of Marine Fisheries
Maritime Silk Road Initiative
Overall Plan for the Reform of Eco-Civilization System
No. 1 Central Document for 2016
National Fisheries Governance Meeting
Ongoing Amendment to FL
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Policy Priority: "Economic Growth" "Food Supply" "Blue Economy" "Going out Strategy" "Environmental Protection" "Eco-civilization"


(A) Stock Status by Catch of Fish Biomass
100%
80%
60%
40%
20%
0
Percentage of biomass
1950
1960
1970
1980
1990
2000
2010
Year
collapsed
overexploited
exploited
developing
rebuilding

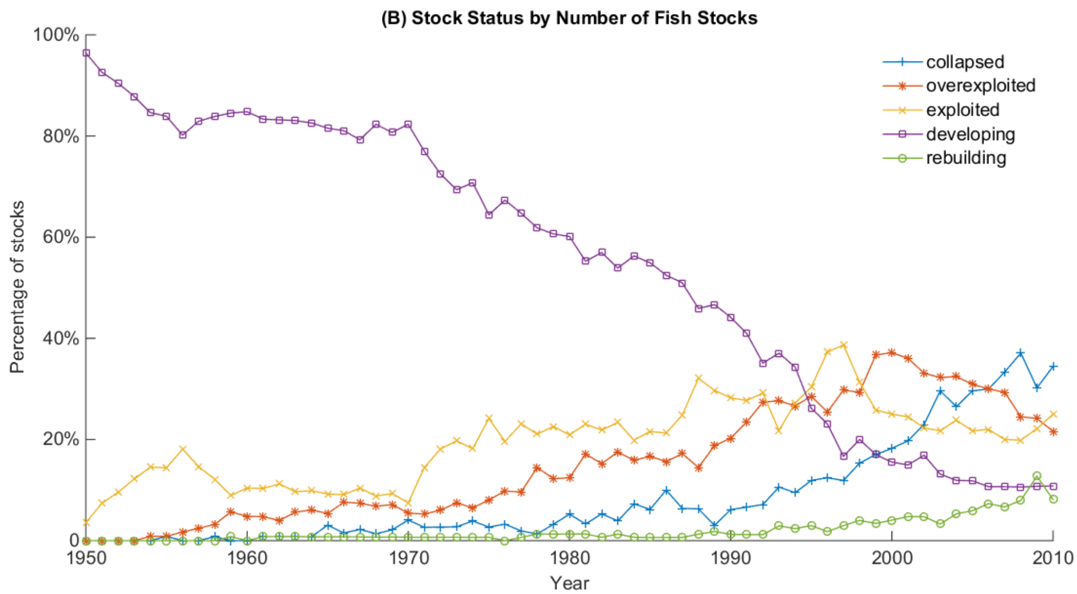

(B) Stock Status by Number of Fish Stocks
100%
80%
60%
40%
20%
0
Percentage of stocks
1950
1960
1970
1980
1990
2000
2010
Year
collapsed
overexploited
exploited
developing
rebuilding

Table 1. China's Major Management Instruments for Marine Fisheries (19, 22, 27)

Type	**Key Examples**
Input Control	Licensing System Vessel Buyback Program and Dual Control* Fishermen Relocation Program
Output Control	Closed Seasons and Zones Total Allowable Catch System§ Zero and Minus Growth Targets
Technical Instruments	Minimum Mesh Size of Fishing Nets Minimum Catch Size of Fishing Targets Ban of Destructive Fishing Methods Proportion Limit of Undersized Fish in Catch
Ecological Instruments	Enhancement Programs Construction of Artificial Fish Reefs Habitat Restoration
Economic Instruments	Fish Stock Damage Compensation† Resource Fee Collection Regime Subsidies on Fishing Vessel Construction and Fuel

Notes: * Dual control of both the total number of marine motorized fishing vessels and their total engine power. § In the amended Fisheries Law of 2000, the concept of a fishery quota system, or total allowable catch (TAC), was introduced and incorporated into bilateral fisheries agreements. However, TAC programs have not yet been applied species-specifically for fisheries in China seas, mainly because of inadequate data, monitoring constraints, lack of an appropriate institutional structure, insufficient enforcement, and the widespread indiscriminant fishing practices. † Ocean or coastal operations, if causing negative impacts to fish stocks, must compensate for the loss in fisheries, e.g., by funding stock enhancement and artificial reef construction.

Supplemental Information *for*

Opportunity for Marine Fisheries Reform in China

Ling Cao[1,2], Yong Chen[3], Shuanglin Dong[4], Arthur Hanson[5], Bo Huang[6], Duncan Leadbitter[7], David Little[8], Ellen Pikitch[9], Yongsong Qiu[10], Yvonne Sadovy de Mitcheson[11], Ussif Rashid Sumaila[12], Meryl Williams[13], Guifang Xue[14], Yimin Ye[15], Wenbo Zhang[16], Yingqi Zhou[16], Ping Zhuang[17], Rosamond L. Naylor[2,*]

[1] Institute of Oceanography, Shanghai Jiao Tong University, China
[2] Center on Food Security and the Environment, Stanford University, USA
[3] School of Marine Science, University of Maine, USA
[4] College of Fisheries, Ocean University of China, China
[5] International Institute for Sustainable Development, Canada
[6] Hainan University, China
[7] University of Wollongong, Australia
[8] University of Stirling, UK
[9] School of Marine and Atmospheric Sciences, Stony Brook University, USA
[10] South China Sea Fisheries Research Institute, Chinese Academy of Fishery Science (CAFS), China
[11] Swire Institute of Marine Science, Hong Kong University, China
[12] University of British Columbia, Canada
[13] Asia Pacific Fish Watch, Malaysia
[14] KoGuan Law School, Shanghai Jiao Tong University, China
[15] Fish and Aquaculture Department, Food and Agricultural Organization, Italy
[16] Shanghai Ocean University, China
[17] East China Sea Fisheries Research Institute, CAFS, China

[*]Correspondence should be addressed to R. L. Naylor (email: roz@stanford.edu).

Author contributions: L.C. and R.N. designed research; L.C., R.N., Y.Q., Y.Y., and W.Z. analyzed data; all authors wrote the paper. Author names, except that of the first and the corresponding authors, are listed in the alphabetical order by last name. The authors declare no conflict of interest.

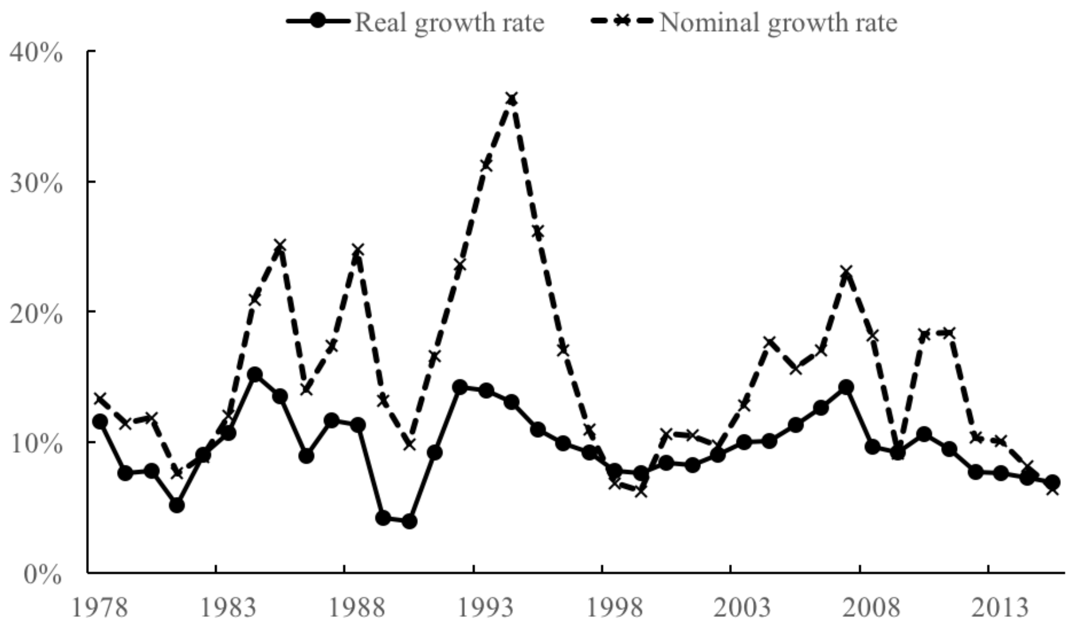


Figure S1. Growth of China's Gross Domestic Product between 1978 and 2015. (Data source: (1))

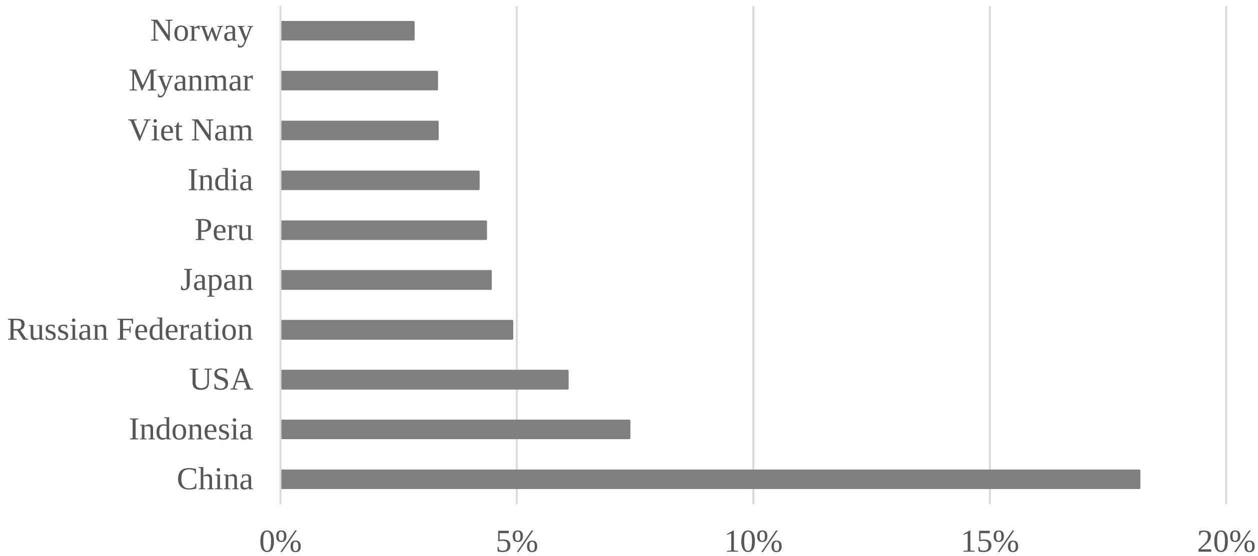
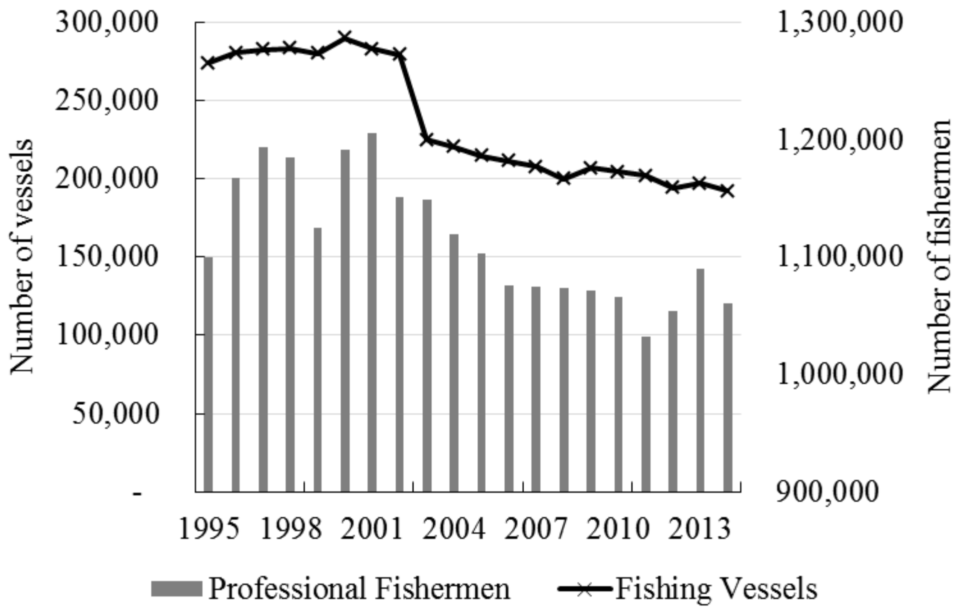


Figure S2. Share of Global Marine Fish Catch by the Top 10 Countries in 2014. (Data source: (2))

(A)



(B)

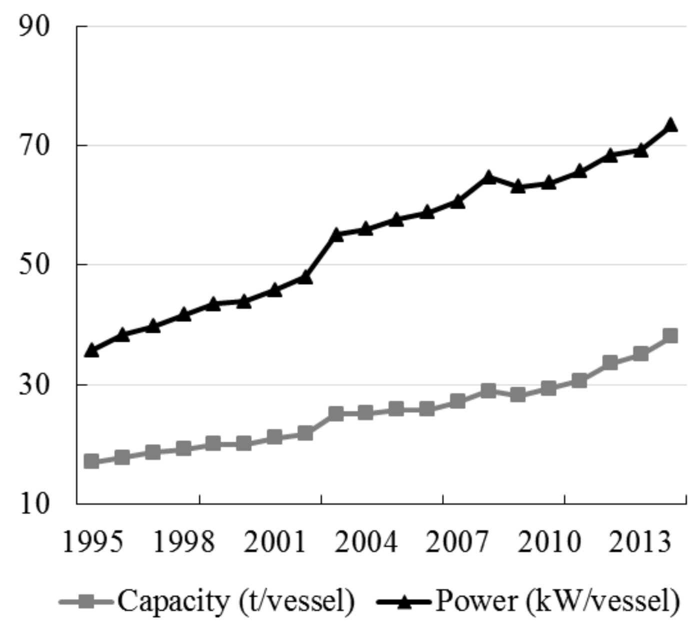


Figure S3. Marine Fishing Motor Vessels and Professional Fishermen in China from 1995-2014. (A): Number of marine fishing motor vessels and professional fishermen. (B): Unit power (kW/vessel) and tonnage (t/vessel) of marine fishing motor vessels. (Data source: (3))

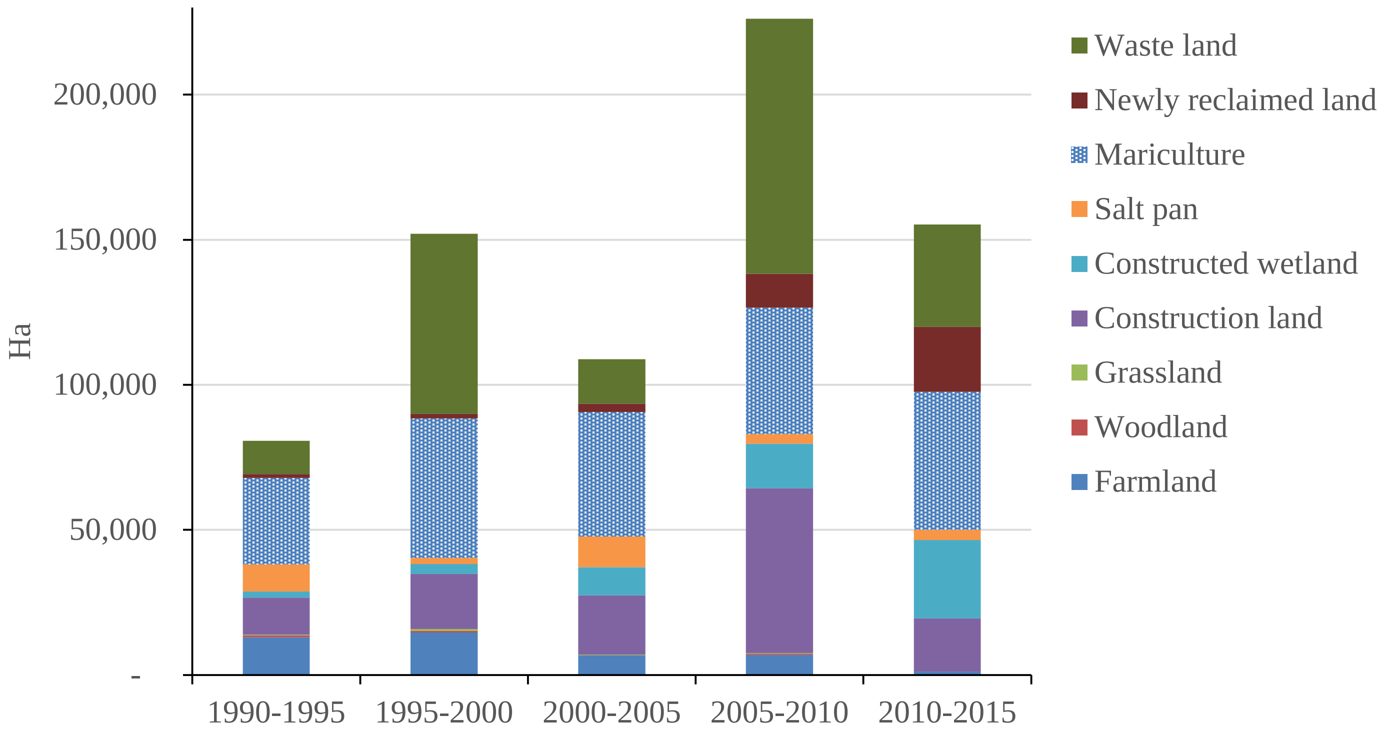


Figure S4. Coastal Reclaimed Land Use in China between 1990 and 2015. (Data source: (4)).

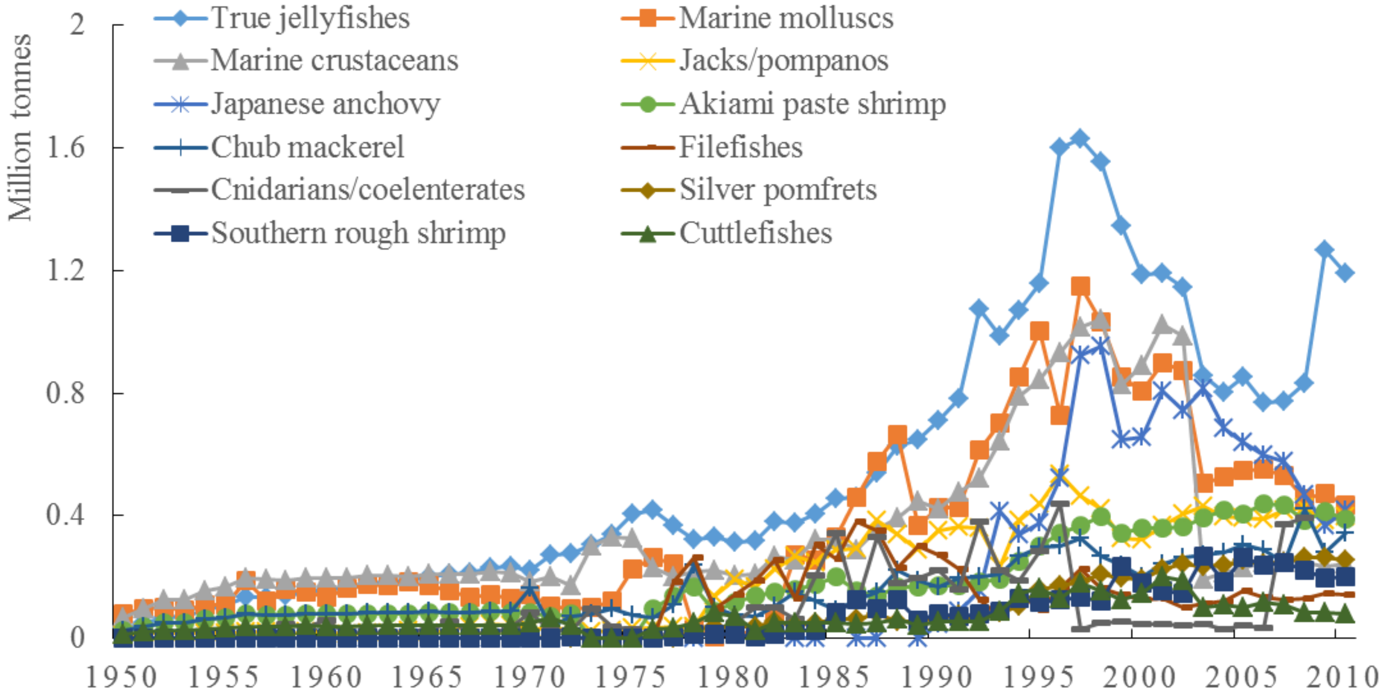


Figure S5. Reconstructed Catch of Low-trophic-level Species in China Seas (Data source: (5)). The reconstructed catch time series since 1950 show a general trend of increasing catches of low-trophic-level species in China seas. This is consistent with the decreasing trend in trophic level of catch. However, several important target species have shown declining trends in catches since the late 1990s. These include Japanese anchovy, crustaceans and cuttlefishes, and molluscs. Filefishes supported an important fishery and procession industry in the East China Sea between 1970s and 1990s; its fluctuation was attributed to climate influences. In the northern South China Sea, most low-trophic-level species are overfished. Catch index data show that the low-trophic-level fishes rose until the 1990s, but eventually decline under high fishing pressure.

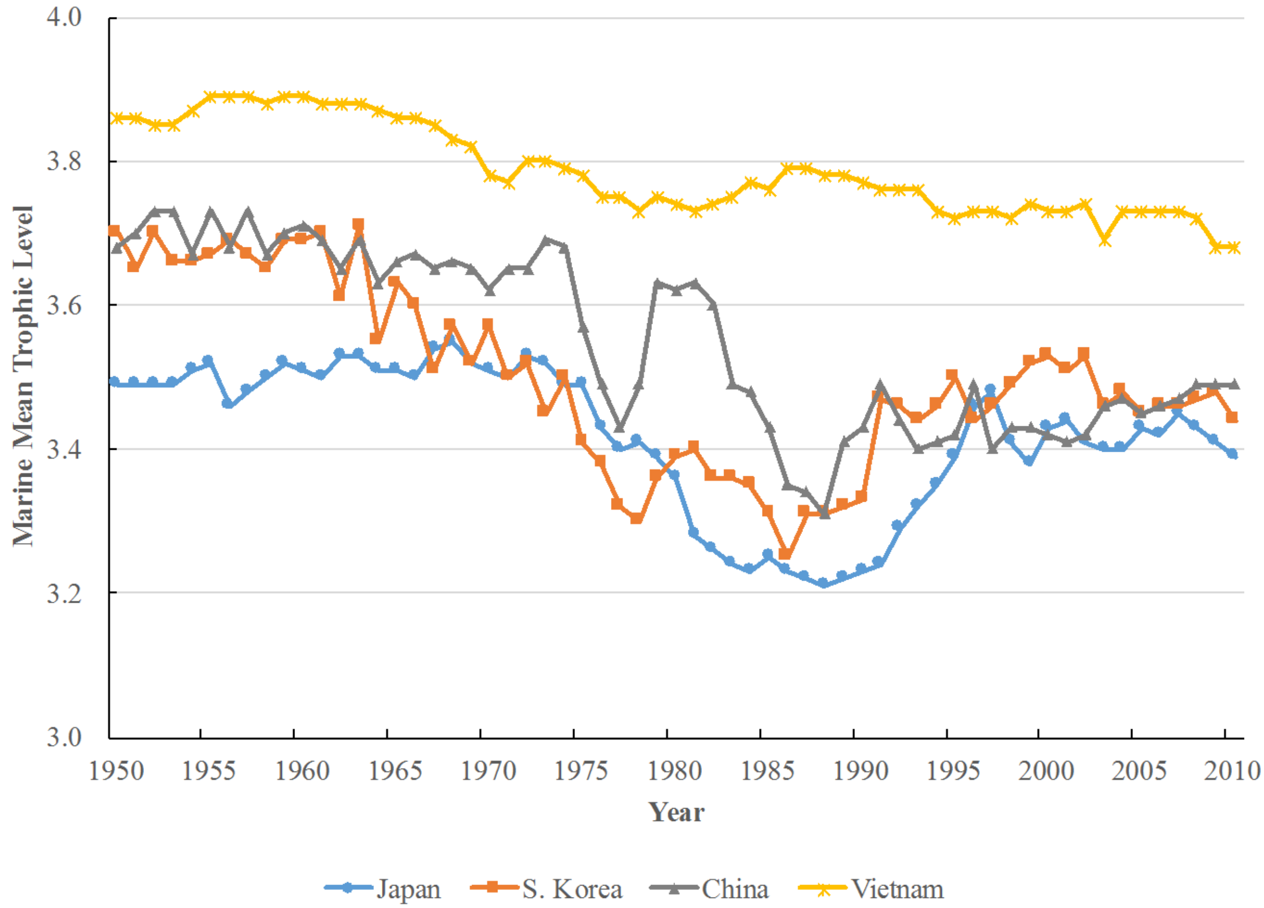


Figure S6. Comparison between China's and Neighboring Countries' Trophic Level of Marine Catch. (Data source: (5)). China and neighboring countries have had similar experiences of "fishing down the food web", but some have been more successful than others in terms of improving fisheries management. Here we use mean trophic level of marine catch as an indicator of catch quality and ecosystem health. Success of fisheries management is indicated by smaller decrease in mean trophic level of catch. Both Japan and South Korea have traditionally used an Exclusive Fishing Right system to manage inshore fisheries resources. They have also implemented a catch quota system to manage major fish stocks within their EEZs since the late 1990s. The mean catch trophic level of Japan's marine capture fisheries has declined slightly from 3.50 to 3.42 during the past half century. Its low catch trophic level between mid-1970s and 1990s was attributed to outbreak of Japanese sardine (peaking at ~500 mmt/year). During the same period, the mean trophic level of South Korea's marine catch has dropped from 3.68 to 3.48, while that of China has dropped from 3.70 to 3.46. China's mean trophic level was even lower (3.43) during 1990-2000. Since 1990, Vietnam's mean catch trophic level has continuously declined. In addition, its catch rate has dropped from ~1.1 tonnes/hp/year in 1985 to 0.3 tonnes/hp/year in recent years, although its reported annual marine landing has increased rapidly from 0.73 mmt in 1990, to 2.07 mmt in 2007, and to to 2.39 mmt in 2011 (6).

Table S1. China's National Five-Year Plans (FYPs) on Marine Ecosystems and Resources Protection.

FYP	Period	Highlights
10^{th} FYP	2001-2005	Economic growth is still the strategic goal, with priority shifted towards environmental protection. First time stated to strengthen research on marine resources protection.
11^{th} FYP	2006-2010	First time dedicated an individual chapter to ocean issues. This is a significant step towards the promotion of the sustainable development of marine economy. Proposed to strengthen marine awareness, protecting marine resources and ecological habitats.
12^{th} FYP	2011-2015	The protection of ocean and marine resources was given equal importance to energy strategies in the 12^{th} FYP (2011-2015), which introduced the concept of "land-sea coordination" to consider land and sea as a whole in the national developmental decisions.
13^{th} FYP	2016-2020	The current 13^{th} FYP has highlighted the following policy priorities: developing maritime power, protecting marine ecosystems, and establishing marine ecological redlines and an ecological damage compensation system.

Table S2. Main Species Involved in the Stock Enhancement Programs.

Sea Region	Species	Scientific Name
Bohai Sea	Oriental prawn	*Fenneropenaeus chinensis*
	Jellyfish	*Rhopilema esculentum*
	So-iuy mullet	*Liza haematocheila*
	Japanese blue crab	*Portunus trituberculatus*
	Asiatic hard clam	*Meretrix Meretrix*
	Ark shell	*Scapharca suberenata*
	Seabream	*Pagrosomus major*
	Bastard halibut	*Paralichthys olivaceus*
Yellow Sea	Oriental prawn	*Fenneropenaeus chinensis*
	Japanese tiger shrimp	*Marsupenaeus japonicus*
	Golden cuttlefish	*Sepia esculenta*
	Disk abalone	*Haliotis discus*
	Japanese scallop	*Pecten yessoensis*
	Blood clam	*Scapharca broughtonii*
	Jellyfish	*Rhopilema esculentum*
	So-iuy mullet	*Liza haematocheila*
	Japanese blue crab	*Portunus trituberculatus*
	Bastard halibut	*Paralichthys olivaceus*
East China Sea	Oriental prawn	*Fenneropenaeus chinensis*
	Jellyfish	*Rhopilema esculentum*
	Large yellow croaker	*Larimichthys crocea*
	Groupers	*Epinephelus spp.*
	Black seabream	*Acanthopagrus schlegeli*
South China Sea	Oriental prawn	*Fenneropenaeus chinensis*
	Redtail prawn	*Fenneropenaeus penicillatus*
	Banana shrimp	*Fenneropenaeus merguiensis*
	Abalone	*Haliotis diversicolor*
	Groupers	*Epinephelus spp.*
	Black seabream	*Acanthopagrus schlegeli*
	Seabream	*Pagrosomus major*
	Buffet clam	*Paphia undulate*
	Sea urchin	*Anthocidaris crassispina*

Note: Data source: (7, 8)

Table S3. Historical and Current Dominant Species in China Seas.

Sea Region	1960s	Current
Bohai Sea	Largehead hairtail (*Trichiurus lepturus*)	Japanese anchovy (*Engraulis japonicus*)
	Oriental prawn (*Fenneropenaeus chinensis*)	Scaly hairfin anchovy (*Setipinna taty*)
	Small yellow croaker (*Larimichthys polyactis*)	Japanese sardinella (*Sardinella zunasi*)
	Chinese herring (*Ilisha elongata*)	White pomfret (*Pampus argenteus*)
	Rays (Rajiformes)	Japanese Spanish mackerel (*Scomberomorus niphonius*)
	Flatfish (Pleuronectiformes)	Kammal thryssa (*Thryssa kammalensis*)
	Sea bream (*Pagrosomus major*)	Jellyfish (*Rhopilema esculentum*)
		Northern mauxia shrimp (*Acetes chinensis*)
		Japanese blue crab (*Portunus trituberculatus*)
		Mantis shrimp (*Oratosquilla oratoria*)
Yellow Sea *	Small yellow croaker (*Larimichthys polyactis*)	Japanese anchovy (*Engraulis japonicus*)
	Largehead hairtail (*Trichiurus lepturus*)	Scaly hairfin anchovy (*Setipinna taty*)
	Large yellow croaker (*Larimichthys crocea*)	Southern rough shrimp (*Trachysalambria curvirostris*)
	Oriental prawn (*Fenneropenaeus chinensis*)	Japanese flying squid (*Todarodes pacificus*)
	Flatfish (Pleuronectiformes)	Loligo squid (*Loligo spp.*)
	Chinese herring (*Ilisha elongata*)	Chub mackerel (*Scomber japonicus*)
	Pacific herring (*Clupea harengus*)	White pomfret (*Pampus argenteus*)
	Pacific cod (*Gadus macrocephalus*)	Pacific sandlance (*Ammodytes personatus*)
		Thryssa (*Thryssa spp.*)
		Japanese sardinella (*Sardinella zunasi*)
		Dotted gizzard shad (*Konosirus punctatus*)
		Japanese horse mackerel (*Trachurus japonicus*)
		Small yellow croaker (*Larimichthys polyactis*)
East China Sea	Largehead hairtail (*Trichiurus lepturus*)	Japanese horse mackerel (*Trachurus japonicus*)
	Small yellow croaker (*Larimichthys polyactis*)	Largehead hairtail (*Trichiurus lepturus*)
	Large yellow croaker (*Larimichthys crocea*)	Japanese anchovy (*Engraulis japonicus*)
	Daggertooth pike conger (*Muraenesox cinereus*)	Glowbelly (*Acropoma japonicum*)
	Rays (Rajiformes)	Filefish (*Thamnaconus spp.*)
	White pomfret (*Pampus argenteus*)	Japanese flying squid (*Todarodes pacificus*)

	Chinese herring (*Ilisha elongata*)	Loligo squid (*Loligo spp.*)
	Robust tonguefish (*Cynoglossus robustus*)	Small yellow croaker (*Larimichthys polyactis*)
	Stingray (Myliobatoidei)	White pomfret (*Pampus argenteus*)
	Mi-iuy croaker (*Miichthys miiuy*)	Japanese Spanish mackerel (*Scomberomorus niphonius*)
	Japanese spineless cuttlefish (*Sepiella maindroni*)	Chub mackerel (*Scomber japonicus*)
		Cardinal fish (Apogonidae)
		Round scad (*Decapterus maruadsi*)
		Southern rough shrimp (*Trachysalambria curvirostris*)
		Japanese blue crab (*Portunus trituberculatus*)
		Golden cuttlefish (*Sepia esculenta*)
South China Sea	Crimson snapper (*Lutjanus erythropterus*)	Greater lizardfish (*Saurida tumbil*)
	Chinese catfish (*Arius sinensis*)	Brushtooth lizardfish (*Saurida undosquamis*)
	Goatfish (*Upeneus spp*.)	Largehead hairtail (*Trichiurus lepturus*)
	Chinese herring (*Ilisha elongata*)	Chinese short-tailed hairtail (*Trichiurus brevis*)
	Threadfin big-eye (*Priacanthus tayenus*)	Swordtip squid (*Loligo edulis*)
	Bigeye snapper (*Priacanthus macracanthus*)	Golden threadfin bream (*Nemipterus virgatus*)
	Mi-iuy croaker (*Miichthys miiuy*)	Round scad (*Decapterus maruadsi*)
	Four finger threadfin (*Eleutheronema tetradactylum*)	Japanese horse mackerel (*Trachurus japonicus*)
	Large yellow croaker (*Larimichthys crocea*)	Threadfin big-eye (*Priacanthus tayenus*)
	Daggertooth pike conger (*Muraenesox cinereus*)	Bigeye snapper (*Priacanthus macracanthus*)
	Chub mackerel (*Scomber japonicus*)	Silver croaker (*Argyrosomus argentatus*)
	golden threadfin bream (*Nemipterus virgatus*)	Red-fin pargo (*Parargyrops edita*)
	Japanese butterfish (*Psenopsis anomala*)	Bensasi goatfish (*Upeneus bensasi*)
	Round scad (*Decapterus maruadsi*)	Japanese butterfish (*Psenopsis anomala*)
	Yellow spotted leatherjacket (*Thamnaconus hypargyreus*)	Mitre squid (*Loligo chinensis*)

Note: * Small yellow croaker used to account for 35 percent of Yellow Sea's total catch, but now over 85 percent of Yellow Sea's total catch is Japanese anchovy. Data source: (8)

Table S4. Change of Marine Catch Structure in China from 1950 to 2013*.

	1950-1969	1970-1979	1980-1989	1990-1999	2000-2013
Marine fishes nei	47.3%	47.4%	38.1%	34.0%	19.8%
Largehead hairtail	18.6%	16.3%	11.5%	8.6%	9.0%
Marine crustaceans nei	9.8%	9.7%	8.2%	7.9%	8.4%
Marine molluscs nei	7.5%	5.5%	9.1%	10.3%	6.2%
Large yellow croaker	5.9%	4.7%	1.0%	-	-
Akiami paste shrimp	3.9%	3.0%	4.6%	3.6%	4.4%
Chub mackerel	3.9%	4.2%	3.7%	3.2%	3.4%
Cuttlefish, bobtail squids nei	2.0%	1.4%	1.5%	1.6%	1.3%
Yellow croaker	1.0%	-	-	1.3%	2.5%
Filefishes nei	-	2.3%	7.5%	2.2%	1.5%
Pacific herring	-	2.1%	-	-	-
Seerfishes nei	-	1.0%	2.3%	2.7%	3.3%
Scads nei	-	-	6.0%	4.5%	4.3%
Southern rough shrimp	-	-	1.6%	1.6%	2.4%
Silver pomfrets nei	-	-	1.6%	1.8%	2.7%
Japanese anchovy	-	-	-	5.9%	6.7%
Gazami crab	-	-	-	2.1%	2.7%
Alaska pollock	-	-	-	1.7%	-
Daggertooth pike conger	-	-	-	1.2%	2.3%
Threadfin breams nei	-	-	-	1.2%	2.2%
Various squids nei	-	-	-	-	2.9%
Squillids nei	-	-	-	-	2.3%
Croakers, drums nei	-	-	-	-	2.0%
Natantian decapods nei	-	-	-	-	1.8%
Pacific sandlance	-	-	-	-	1.3%
Japanese pilchard	-	-	-	-	1.2%
Porgies, seabreams nei	-	-	-	-	1.1%
So-iny (redlip) mullet	-	-	-	-	1.1%
Jumbo flying squid	-	-	-	-	1.0%
TOTAL	100.0%	97.6%	96.7%	95.4%	97.6%

Note: * Only species above 1% of total catch (biomass) are listed. Data source: (2)

References

1. National Bureau of Statistics of China (2015) China Statistical Yearbook. http://www.stats.gov.cn/english/. Accessed on June 15, 2016.
2. Food and Agriculture Organization of the United Nations (2016) FishStatJ - software for fishery statistical time series. http://www.fao.org/fishery/statistics/software/fishstatj/en. Accessed on April 30, 2016.
3. Fisheries Bureau, Ministry of Agriculture (2015) China Fisheries Statistics Yearbook 2014 (China Agricultural Press, Beijing, China).
4. Li Y (2016) From coastal vulnerability to resilience: natural habitat role in a changing climate. Unpublished work at Xiamen University.
5. Pauly D & Zeller D (eds) (2015) Sea Around Us Concepts, Design and Data. www.seaaroundus.org. Accessed on June 15, 2016.
6. Funge-Smith S, Briggs M, & Miao W (2012) Regional overview of fisheries and aquaculture in Asia and the Pacific 2012. Asia-Pacific Fishery Commision, FAO, Rome.
7. Shan X, *et al.* (2012) Fish community structure and stock dynamics of main stocking fish species in the Bohai Sea. *Progress in Fisheries Sciences* 33:1-9.
8. Tang Q (eds) (2012) *Regional oceanograhy of China seas: fisheries oceanography* (Marinetime Press, Beijing, China) p 450.