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An assessment of "fishing down marine food webs" in coastal states during 1950–2010

DING Qi[1, 4], CHEN Xinjun[1, 2, 3, 4*], YU Wei[1, 4], CHEN Yong[5, 4]

[1] College of Marine Sciences, Shanghai Ocean University, Shanghai 201306, China

[2] Key Laboratory of Sustainable Exploitation of Oceanic Fisheries Resources of Ministry of Education, Shanghai Ocean University, Shanghai 201306, China

[3] National Engineering Research Center for Oceanic Fisheries, Shanghai Ocean University, Shanghai 201306, China

[4] Collaborative Innovation Center for Distant-water Fisheries, Shanghai 201306, China

[5] School of Marine Sciences, University of Maine, Orono, Maine 04469, USA

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Abstract

Mean trophic level of fishery landings (MTL) is one of the most widely used biodiversity indicators to assess the impacts of fishing. Based on the landing data compiled by Food and Agriculture Organization combined with trophic information of relevant species in FishBase, we evaluated the status of marine fisheries from 1950 to 2010 for different coastal states in Pacific, Atlantic and Indian Oceans. We found that the phenomenon of "fishing down marine food webs" occurred in 43 states. Specifically, 27 states belonged to "fishing-through" pattern, and 16 states resulted from "fishing-down" scenario. The sign of recovery in MTL was common in the Pacific, Atlantic and Indian Oceans (occurred in 20 states), but was generally accompanied by significantly decreased catches of traditional low trophic level species. In particular, 11 states showed significant declining catches of lower trophic levels. The MTL-based assessment of "fishing down marine food webs" needs to be interpreted cautiously.

Key words: coastal states, exploitation history, fishing down marine food webs, sustainability, marine fisheries, mean trophic level of fishery landings

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1 Introduction

Marine fisheries have undergone significant changes over the past 60 years with rapid geographical and bathymetric expansion (Pauly et al., 2003; Morato et al., 2006; Swartz et al., 2010). According to several recent assessments, about one-third of global fishery stocks are now overexploited or collapsed (Branch et al., 2011; FAO, 2014). Fishery sustainability has been commonly evaluated all over the world to ensure a continuous contribution of fisheries to the global food security, economic and social development (Pikitch et al., 2004; Jennings, 2005; Halpern et al., 2012; Watson and Pauly, 2013).

Stock assessment models are generally used to evaluate exploitation status of most economically important resources. Although those models are considered to be the best methods for estimating stock status, most of which require reliable estimation of temporal trends in stock abundance/biomass (i.e., abundance indices) and biological information, which are not available for most fisheries (Conn et al., 2010; Kleisner et al., 2013). Because of lack of fisheries data and stock assessment expertise (Kleisner et al., 2013), it is often difficult to determine stock status in developing states based on stock assessments which are usually carried out in the developed countries.

Biodiversity indicators have been suggested as a complement to fisheries stock assessment and are widely used to assess the impacts of fishing on structure and function of marine ecosystems (Shin et al., 2010). The biodiversity indictors are potentially less informative than traditional stock assessments but easier to estimate and compare over time and space based on readily available data. One of the most widely used biodiversity indicator, mean trophic level of fishery landings (MTL), evaluates the shifts in catches from long-lived and high trophic level piscivorous fishes toward short-lived and low trophic level invertebrates and pelagic fishes (Pauly et al., 1998). Based on the global database of fisheries landings assembled by the Food and Agricultural Organization of the United Nations (FAO), Pauly et al. (1998) found that MTL declined at a rate of about 0.10 per decade globally, and labeled this phenomenon "fishing down the food web". This finding initiated global concerns regarding trophodynamics. Later, MTL has been commonly employed as a biodiversity indicator to measure fishery sustainability by many international bodies, including the Convention on Biological Diversity, European Union, and Caribbean Large Marine Ecosystem and Adjacent Project (Pauly and Palomares, 2005; Foley, 2013).

The Pacific, Atlantic and Indian Oceans are main fishing

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*Corresponding author, E-mail: xjchen@shou.edu.cn

areas of marine fisheries, yielding over 98% of global marine catches (FAO, 2012). In addition, each coastal state has different fisheries and exploitation histories. Despite of efforts to quantify fishing-down effects in various states (Daskalov, 2001; Pauly et al., 2001; Arancibia and Neira, 2005; Jaureguizar and Milessi, 2008; Freire and Pauly, 2010; Alleway et al., 2014), limited integrated evaluation has been done on the variability in fishery resources among different maritime states. In addition, declining MTL can result from several alternative scenarios, and each scenario would signify a specific sequence of fishery evolution over time (Foley, 2013; Branch, 2015). It is necessary to further determine the multiple hypotheses and test which one is best supported by their data for each coastal state. In this paper we analyzed the trends of fishing the marine food web during 1950–2010 for each coastal state in the Pacific, Atlantic and Indian Oceans. This study aims to provide a scientific basis for a better understanding of MTL in relations to the exploitation history of each coastal state and the status of global marine fisheries.

2 Materials and methods

2.1 *Study area*

In order to precisely observe the impact of fishing, we only included annual landing data of each coastal state in their exclusive economic zones (EEZs) in the corresponding FAO fishing areas of Pacific, Atlantic and Indian Oceans. States with poor quality of catch data (catches dominated by the category of "Marine fishes not identified") and Pacific island states which have a relatively simple catch profile were not considered in this analysis is because our focus is on the assessment of fishing impact on marine food webs. The catch of 75 main coastal states included in our study accounted for over 88% of total catch in the Pacific, Atlantic and Indian Oceans.

2.2 *The data set*

The landing data in this study cover the period 1950–2010 and were obtained from the Food and Agriculture Organization of the United Nations (http://www.fao.org/fishery/Statistics/global-Capture-production/query/en). This data set consists of all the fish and invertebrates in the FAO ISSCAAP (International Standard Statistical Classification of Aquatic Animals and Plants) group. Trophic level (TL) of each species was obtained from the "ISSCAAP Table" of FishBase (http://www.fishbase.org/report/ISSCAAP/ISSCAAPSearchMenu.php). For several species without trophic levels defined in FishBase, we used the trophic information for their family. Table 1 illustrates trophic level values for the top 20 species used to compute mean trophic level. In addition, we excluded "marine fishes that were not identified", aquatic plant and mammals from this analysis, focusing on the impacts of fishing on fishery resources.

2.3 *Fishery ecosystem indicators*

Mean trophic level (MTL_i) for a given year i was estimated using the following equation by Pauly et al. (1998),

$$MTL_i = \frac{\sum_{ij} TL_j Y_{ij}}{\sum Y_{ij}},$$

where Y_{ij} is the landings of species j in year i; and TL_j is the trophic level of species j. According to Essington et al. (2006), decline in MTL higher than 0.15 units is an evidence of ecologically significant fishing down the food web. We identified "fishing down the food web" as any instance in which MTL exhibited a decline by at least 0.15 units in this study. In addition, if pelagic or invertebrates species of low trophic levels are intensely fished to depletion, MTL might increase after a decreasing trend and produce a false fishing up (Stergiou and Tsikliras, 2011). To provide an integrated picture of trend in MTL and reduce the possibility of overestimating "fishing down the food web", we discussed every time period with changes in MTL higher than 0.15 units for more than 10 years, reporting time periods of declines and increases in MTL.

Table 1. Trophic level values for the top 20 species (according to the catch in the year 2010) used to compute mean trophic level

Common name	Scientific name	Trophic level
Anchoveta	*Engraulis ringens*	2.70
Alaska pollock	*Theragra chalcogramma*	3.45
Skipjack tuna	*Katsuwonus pelamis*	4.35
Atlantic herring	*Clupea harengus*	3.23
Chub mackerel	*Scomber japonicus*	3.09
Largehead hairtail	*Trichiurus lepturus*	4.45
Yellowfin tuna	*Thunnus albacares*	4.34
Scads nei	*Decapterus* spp.	3.53
Japanese anchovy	*Engraulis japonicus*	2.56
European pilchard	*Sardina pilchardus*	3.05
Sardinellas nei	*Sardinella* spp.	2.82
Atlantic cod	*Gadus morhua*	4.42
Atlantic mackerel	*Scomber scombrus*	3.65
Jumbo flying squid	*Dosidicus gigas*	4.14
Croakers, drums nei	*Sciaenidae*	3.67
Marine molluscs nei	*Mollusca*	2.10
Araucanian herring	*Strangomera bentincki*	2.69
California pilchard	*Sardinops caeruleus*	2.43
Chilean jack mackerel	*Trachurus murphyi*	3.49
Natantian decapods nei	*Natantia*	2.20

In this study, regression analyses were preformed to quantify changes in MTL with time, and the goodness of fit was evaluated using the coefficient of determination R^2. R^2 was not used as an absolute measure of regression model fit but as a guide to the appropriateness of a linear trend over time, the statistical significance of trends was also analyzed. In addition, we only included time series of MTL for states in Africa and Latin America from 1990 because of concerns on their data quality prior to 1990.

2.4 *Underlying mechanisms for observed MTL trends*

Recent studies indicated that declining MTL could result from the following four alternative scenarios of fisheries including: predators catches declining while prey catches stable; catches of predators declining faster than catches of prey; predators catches were stable, but catches of prey expand over time; both catches of predators and prey were increasing, but predators increasing slower (Branch, 2015). The last two scenarios resulted in a decline in MTL due to the continuously addition of low trophic level fisheries, rather than to a decline of high trophic level fisheries, also termed "fishing through the food web".

We calculated the catches of both upper and lower trophic levels when "fishing down the food web" was occurring, using trophic levels equal to four as the dividing point between the high and low trophic level groups (Essington et al., 2006). We also continued to describe the trends in catches of upper and lower trophic levels when MTL reversed to an upward trend after the "declining pattern of MTL". We then fitted a linear regression of lg(catch) versus year t for each group to test for possible significant changes over time.

3 Results

3.1 *Exploitation state of world marine fisheries*

Global catches from the Atlantic, Pacific and Indian Oceans increased considerably from 14.86 million tonne in 1950 to 70.81 million tonne in 1989, but then remained stable around 65.62–73.50 million tonne (Fig. 1a). The global MTL initially declined from the value of 3.48 in 1950 to a minimum value of 3.21 in 1986 ($P<0.05$), and then reversed to an increasing trend. A dip occurred in the 1960s and early 1970s because of large increases in Peruvian anchovy (*Engraulis ringens*) landings (Fig. 1b). We calculated the catch of upper trophic level and lower trophic level taxa during the period of decline and recovery, and found that both upper and lower trophic level catches increased from 1950 to 1986, implying the occurrence of "fishing-through" phenomenon. However, lower trophic level significantly declined while upper trophic level catches steady increased from 1986 to 2010 in the Atlantic, Pacific and Indian Oceans ($P<0.05$).

The total marine catches in the world mainly came from European, Asian and Southern American waters during the period of 1950–2010 (Fig. 2). The percentage of catch in European states decreased from 38% in the 1950s to 18% in the 2000s, while the catch in the Asian states increased from 34% in the 1950s to 41% in the 2000s. The percentage of catch in the South America fluctuated between 5% and 28%, while the North America landed 18% of the total landings in the 1950s, then gradually decreased and stabilized to an average of 12% during the 1960s–2000s. The contribution of Africa and Oceania were stable around 5% and 0.7%, respectively (Fig. 2).

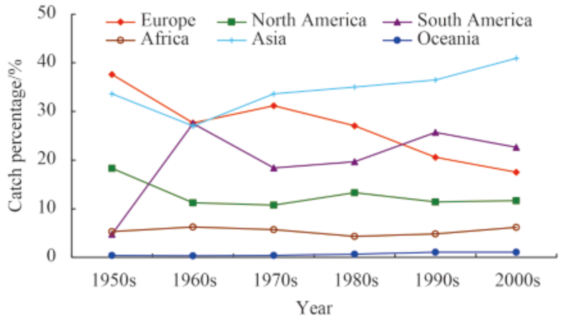

Fig. 2. Changes in marine catch percentage for the six continents.

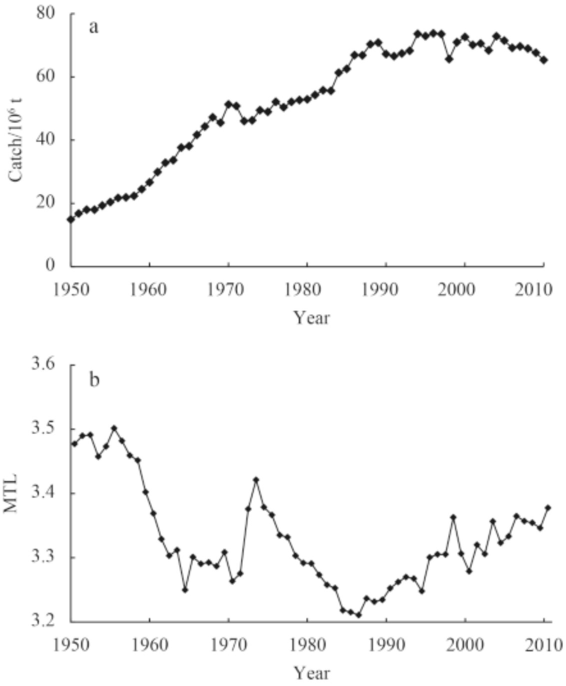

Fig. 1. Trend in indicators: a. annual landings; and b. MTL along the Atlantic, Pacific and Indian Oceans.

By analyzing trends in MTL for 75 main coastal states of the Atlantic, Pacific and Indian Oceans, we found that "fishing down the food web" was pervasive. Of the 75 coastal states, 43 showed evidence of substantial declining of MTL. The world map in Fig. 3 illustrated the trend of MTL over each decade during 1950–2010. During the 1950s, 16 states showed the sign of "fishing down the food webs". They were located in Europe (7), North America (2) and South America (4), Asia (2) and Oceania (1) (Fig. 3a). As fishing effort became intensified, MTL showed a strong declining trend in the 1960s for Belgium, Norway, United Kingdom, Greenland, Ecuador and Japan. In addition, MTL in 4 states reversed to an upward trend after the "fishing down the food web" occurred (Fig. 3b). World marine fisheries experienced accelerating development and the greatest southward expansion in the 1970s and 1980s, MTL in Denmark, Germany, Netherlands, South Korea and China showed a clearly decreasing trend of MTL (Fig. 3c), and MTL for France, Finland, Uruguay and Oman decreased gradually since the 1980s (Fig. 3d). Furthermore, the number of states that exhibited a recovery trend increased to 16 in the 1980s. By the 1990s, MTL in Cameroon, Liberia, South Africa and Egypt were in a state of declining trend. In addition, MTL for Mexico, Bahamas, Argentina, Yemen and Sri Lanka also showed a decreasing trend since the 1990s. Besides, another 2 states showed a recovery trend in the 1990s (Fig. 3e). After over five decades of intensive exploitation, Costa Rica, Saudi Arabia and New Zealand documented a clear "fishing down the food webs" phenomenon at the beginning of the 2000s, the number of states that showed the sign of "fishing down the food webs" increased to 43 (Fig. 3f), of which Europe, North America, South America, Africa, Asia and Oceania accounted for 15, 6, 7, 4, 9, and 2 states, respectively.

3.2 *MTL for global coastal states*

The phenomenon of "fishing down marine food webs" occurred in all the 15 European states probably because of their long-term exploitation history (Table 2), of which United Kingdom, Belgium, Germany, Denmark, Netherlands, Poland, Finland, Sweden, France and Ireland showed declining trends of upper-trophic level species when fishing down the food web was occurring. In contrast, the other five states exhibited significant increasing trend ($P<0.05$) or had no significant trend of upper-trophic-level catches when "fishing down the food web" was occurring, demonstrating an occurrence of fishing-through phenomenon. In addition, MTL in all the above five states shifted to a clearly and steadily upward trend after experiencing a significant decline ($P<0.05$). However, after calculating the catch of upper trophic level and lower trophic level taxa during the period of recovery, we found that lower trophic level catches all showed a strong declining trend (Table 2).

For coastal states in North America, MTL for El Salvador, Cuba, Nicaragua and Panama showed a continuous upward

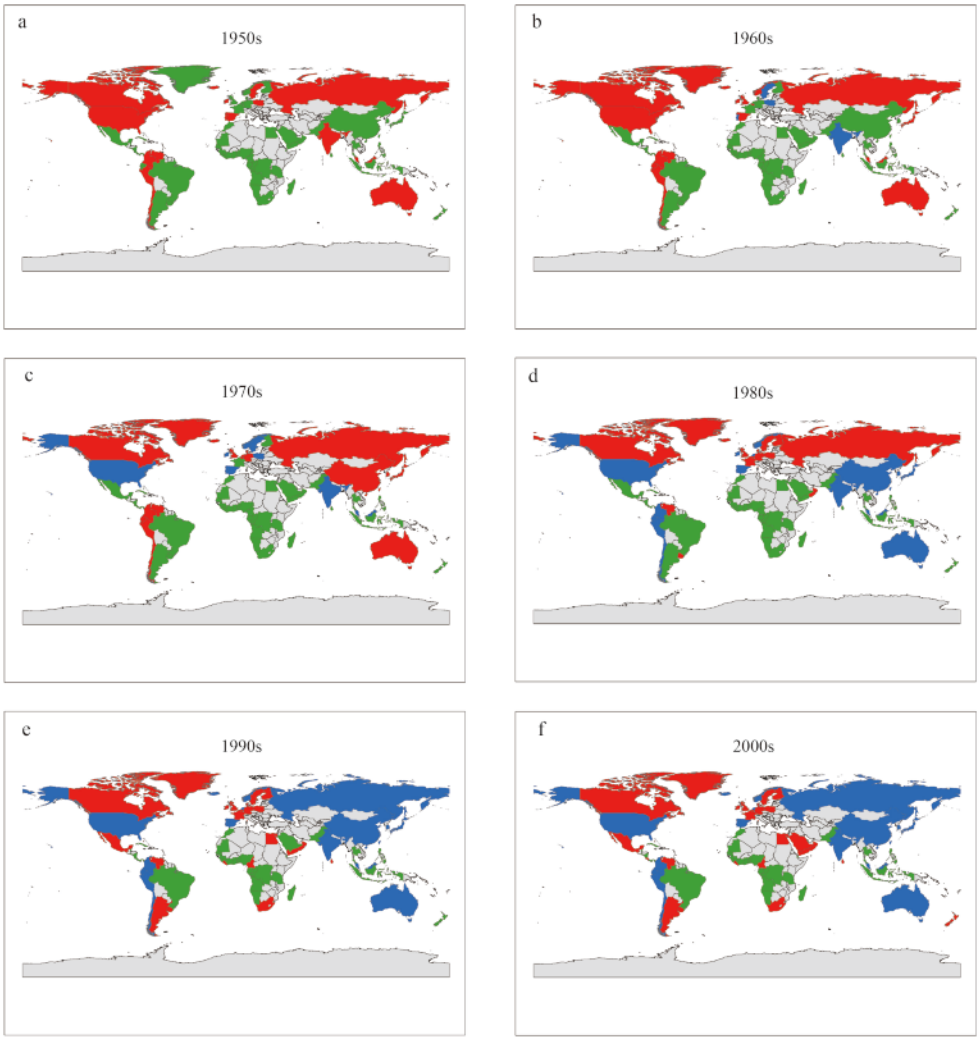

Fig. 3. Changes of mean trophic level in coastal states from 1950 to 2010. Different colors represent different trends of MTL, specifically, increasing or stable (green), decreasing (red), reversed to an increasing trend after "fishing down the food web" occurred (blue).

trend. Although MTL in US, Greenland, Canada, Mexico, Bahamas and Costa Rica all showed a dramatic declining trend, upper trophic level catches only decreased significantly in Canada and Costa Rica (Table 2). In contrast, upper trophic level catches increased in US and showed no significant change in Mexico and Greenland, supporting the "fishing-through" hypothesis. Furthermore, MTL in the US reversed to a steady upward trend after experiencing a significant decline. We examined the change in catch of upper trophic level and lower trophic level taxa, and found that catch of lower trophic level showed no significant change during the period of recovery (P>0.05).

South America was a net exporter of marine products and dominated the current fishmeal trade. Accompanied by the substantial decreased catch of predator species, MTL for Uruguay and Argentina decreased at a rate of 0.13 per decade in 1985–2010 and 0.18 per decade in 1991–2010. MTL first decreased at a speed of 0.24 per decade in 1950–1982 for Columbia and 0.39 per decade in 1960–1986 for Ecuador due to the addition of lower trophic level species, and both of them reversed to an upward trend afterwards (Table 2). However, instead of presenting an upward trend, lower trophic level catches in Ecuador significantly decreased (P<0.05). Due to the high fluctuation of catches of low TL species such as Peruvian anchovy, South American pilchard (*Sardinops sagax*) and Chilean jack mackerel (*Trachurus murphyi*), Chile and Peru showed wide-amplitude fluctuations of MTL, and declined at a rate of 0.26 per decade in the 1950–1983 for Chile and 0.30 per decade in the 1950–1985 for Peru. Both of the two states, later, changed to an increasing trend. However, instead of presenting an upward trend, lower trophic level catches in Chile showed a significant downward trend (Table 2). Brazil had a steady increasing MTL throughout the past six decades, while MTL for Venezuela tended to decrease continuously from 1950 to 2010 due to the addition of lower trophic level species.

Nations in Africa largely depended on marine resources for protein and seafood, and fisheries played a significant role in national economies. Due to its relatively short exploitation history, noticeable "fishing down the food web" sign was not obvious in most of African marine waters. In 25 coastal states included in this study, only South Africa, Liberia, Cameroon and Egypt showed evidence of descending trends of MTL, and the declining rates were 0.12, 0.16, 0.078 and 0.11 per decade respectively, but catch of predators in all the above four states did not exhibit a significant downward trend, implying an occurrence of "fishing-through" pattern (Table 2).

Table 2. Change rate of MTL in the fishery landings and corresponding change in predator and prey catches in the 43 coastal states with the occurrence of "fishing down the food web"

	Geographical entity	Year of regression	MTL decline speed per decade	Change in predator catch per decade	Change in prey catch per decade	Year of regression	MTL recovery speed per decade	Change in predator catch per decade	Change in prey catch per decade
Europe	Portugal	1950–1964	0.053	no clear trend	0.19	1964–2010	0.014	0.087	–0.037
	Poland	1950–1965	0.30	no clear trend	0.47	1965–1981	0.10	0.20	no clear trend
		1981–2010	0.19	–0.23	0.033				
	Spain	1950–1971	0.10	no clear trend	0.16	1971–2010	0.047	no clear trend	–0.068
	Ireland	1950–1970	0.11	0.15	0.40	1970–1998	0.047	0.19	0.27
		1998–2010	0.13	–0.28	no clear trend				
	Sweden	1950–1964	0.061	0.057	0.21	1964–1986	0.074	0.090	–0.11
		1986–2010	0.15	–0.27	no clear trend				
	Russia	1950–1990	0.10	0.05	0.27	1990–2010	0.10	0.11	–0.13
	Iceland	1950–1997	0.13	0.048	0.22	1997–2010	0.28	no clear trend	–0.35
	Norway	1962–1976	0.14	0.089	0.28	1976–2010	0.058	0.064	–0.042
	Belgium	1968–2010	0.12	–0.25	–0.022				
	United Kingdom	1968–2010	0.12	–0.15	0.021				
	Denmark	1976–2010	0.066	–0.24	–0.089				
	Germany	1976–2010	0.083	–0.16	–0.037				
	Netherlands	1978–1989	0.52	–0.40	0.36	1989–2010	0.12	0.27	–0.11
	Finland	1984–2010	0.047	–0.29	0.044				
	France	1986–2010	0.16	–0.13	0.043				
North America	United States	1950–1978	0.039	no clear trend	0.025	1978–2010	0.13	0.054	no clear trend
	Canada	1950–2010	0.13	–0.068	0.041				
	Greenland	1960–2010	0.28	0.04	0.32				
	Bahamas	1990–2010	0.055	0.25	0.05				
	Mexico	1999–2010	0.11	no clear trend	0.16				
	Costa Rica	2001–2010	0.23	–0.46	no clear trend				
South America	Peru	1950–1985	0.30	no clear trend	0.49	1985–2010	0.11	0.36	no clear trend
	Chile	1950–1983	0.26	no clear trend	0.59	1983–2010	0.095	0.19	–0.086
	Columbia	1950–1982	0.24	0.22	0.42	1982–2010	0.31	0.59	0.090
	Ecuador	1960–1986	0.39	0.11	0.90	1986–2010	0.45	0.38	–0.20
	Venezuela	1950–2010	0.048	0.12	0.14				
	Uruguay	1985–2010	0.13	–0.20	0.096				
	Argentina	1991–2010	0.18	–0.12	0.12				
Africa	Cameroon	1990–2010	0.078	no clear trend	0.070				
	Liberia	1997–2010	0.16	no clear trend	0.21				
	South Africa	1990–2010	0.12	no clear trend	0.082				
	Egypt	1990–2010	0.11	no clear trend	0.27				
Asia	India	1950–1968	0.20	no clear trend	0.15	1968–2010	0.050	0.12	0.10
	Malaysia	1950–1971	0.034	0.25	0.26	1971–2010	0.075	0.18	0.14
	Japan	1967–1987	0.31	–0.15	0.14	1987–2010	0.18	no clear trend	–0.22
	South Korea	1970–1986	0.24	0.090	0.26	1986–2010	0.081	0.088	–0.13
	China	1973–1988	0.27	no clear trend	0.30	1988–2010	0.095	0.26	0.24
	Oman	1988–2010	0.15	no clear trend	0.096				
	Yemen	1994–2010	0.20	0.16	0.22				
	Sri Lanka	1997–2010	0.12	no clear trend	0.17				
	Saudi Arabia	2001–2010	0.14	0.039	0.16				
Oceania	Australia	1950–1984	0.081	0.15	0.20	1984–2010	0.061	no clear trend	no clear trend
	New Zealand	2000–2010	0.17	–0.32	no clear trend				

Note: All the values in the table reached significant level ($P<0.05$), "no clear trend" in the table means the corresponding P value was not significant.

Exploitation history in the waters of Asia followed a different pattern compared to other regions. MTL in Japan, South Korea, China, Malaysia and India all initially decreased and then gradually reversed to an upward trend. However, only Japan showed a strong declining trend of upper trophic level catches with a significant trend, and MTL decreased at a rate of 0.31 per decade from 1967 to 1987. South Korea, China, Malaysia and India had the "fishing-through" pattern first, and then reversed to a continuous upward trend. However, unlike China, Malaysia and India which showed a continuous upward trend of both upper and lower trophic levels of species during the period of recovery, catch of lower trophic levels in South Korea decreased continuously. In addition, MTL of Saudi Arabia, Yemen, Oman and Sri Lanka decreased at a rate of 0.14, 0.20, 0.15 and 0.12 per decade respectively, but upper trophic level catches all showed no significant downward trend, belonging to "fishing-through" scenario (Table 2). Nevertheless, MTL in many other Asian states had a steady or increasing trend, such as Thailand, Philippines, Indonesia, Pakistan and Qatar.

Catches in Oceania mainly came from Australia and New Zealand. MTL of Australia reversed to a clearly upward trend after experiencing a significant "fishing-through" effect. But both upper and lower trophic level species showed large fluctuations with non-significant downward trends during the recovering period (Table 2). However, the MTL of New Zealand appeared declining at a rate of 0.17 per decade after a continuous large increase during 1950 to 1999, and a declining trend of upper trophic level catches was also observed during the period of decline of MTL, implying New Zealand had a "fishing-down" phenomenon.

4 Discussion

Global fisheries are at a crucial turning point, and monitoring and understanding the long-term changes in marine ecosystems induced by fishing activities have raised global concern (Butchart et al., 2010; Garcia and Rosenberg, 2010). As an indicator of biodiversity and fishery sustainability derived from readily available data and being typically sensitive to the dynamics of fish community, MTL have been widely used by international and national bodies. We calculated MTL of fisheries landings for the Atlantic, Pacific and Indian Oceans, and found MTL initially appeared to decrease in 1950–1986, and then shifted to a rising trend. Other recent global studies also reported similar trends and suggested that their trends differ from those reported by Pauly et al. (1998) was mainly caused by using updated estimates of trophic level for some major species according to FishBase (Branch et al., 2010; Butchart et al., 2010).

The results of the present work confirm, through quantifying fishing-down effects in various states, that fishing down the food web was most commonly associated with sequential addition mechanism (Essington et al., 2006). Of the 43 coastal states which showed evidence of substantial fishing down the food web, 27 states exhibited either no significant change or increase in high trophic level predators. In contrast, the sequential collapse model of fishing down the food web was common in Europe. Among the 16 states that associated with declining predators catches, ten states belong to Europe. Furthermore, despite the fact that MTL expected to recover under successful fishery management, our analysis indicated that the recovery of MTL trends was generally accompanied by declining catches of low trophic level species. Specifically, of the 20 coastal states which showed periods of recovery of MTL after occurring of "fishing-through" pattern, 11 states showed significantly decreased catches of lower trophic level catches. According to Pinsky et al. (2011), low trophic level species even collapsed twice more likely compared to those for high trophic level species. Thus we suggest to interpret with cautious for the areas showing a recovered MTL trend and identify the underlying mechanism of change.

The early development of commercial fishery result in Europe to be the first continent suffered from overfishing problem (Srinivasan et al., 2012). Marine fisheries catches in Europe declined continuously since the mid-1970s. Some traditional species such as North Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) have been compensated by the previous lower-valued species such as Sandeels (*Ammodytes* spp.) and blue whiting (*Micromesistius poutassou*), and the community structure significantly changed in the European waters (FAO, 2011). The declining rates of MTL in United Kingdom, Belgium, Netherlands, Poland, Sweden, France and Ireland were all higher than the rate (0.10 per decade) reported by Pauly et al. (1998) at a global scale. The decline in MTL (0.52 trophic level per decade) in Netherlands which was almost five times higher than the rate reported by Pauly et al. (1998) was due to the collapse of Atlantic cod and the expansion of low trophic level Common edible cockle (*Cerastoderma edule*) fishery, and the development of Blue whiting fishery resulted in MTL reversed to an increasing trend thereafter (FAO, 2011). Although MTL of Portugal, Spain, Netherlands, Norway and Russia reversed to an increasing trend in recent decades, it was mainly caused by substantial decreased catch of low trophic level species such as European pilchard (*Sardina pilchardus*), Atlantic horse mackerel (*Trachurus trachurus*), Capelin (*Mallotus villosus*) and Alaska Pollock (*Theragra chalcogramma*) as a result of environmental effects and heavy fishing pressure (FAO, 2011).

Fishing in the waters off North America has been intensive for decades, and catch and revenue losses to overfishing have been climbing steadily from 1970 to the mid-1990s (Srinivasan et al., 2012). For much of the past five decades, the predominant fishery product in Canadian waters was groundfish. Due to the collapse of demersal fish stocks such as Atlantic cod, haddock and Pacific hake (*Merluccius productus*), the declining rate of MTL in Canada was higher than the rate reported by Pauly et al. (1998) on a global scale. According to FAO catch statistics, species with low trophic levels such as herring, crustaceans and molluscs dominated the US fisheries landings, and the menhaden fishery was developed in the 1950s and 1960s and has sustained the largest fishery off the eastern US, but the recovery trend of MTL in the US since the late 1970s were accompanied by large fluctuations of low trophic level species. In fact, catches of Gulf menhaden (*Brevoortia patronus*) and Atlantic menhaden (*Brevoortia tyrannus*) have decreased substantially since 1980s (FAO, 2011).

The large inter-annual variations in catch from Chile and Peru were caused by the large fluctuations of three pelagic species Peruvian anchovy, South American pilchard and Chilean jack mackerel. The Peruvian anchovy fishery started in the 1950s and developed rapidly in the 1960s. Overfishing and the 1972–1973 El Niño caused the collapse of Peruvian anchovy fishery in the early 1970s, and this stock had a certain degree of recovery in the early 1990s (Chavez et al., 2003). Catches of South American sardine started to increase following the Peruvian anchovy fishery collapse during 1972–1973, but its abundance has declined to a very low level since the late-1990s, which might be caused by the heavy fishing in the 1980s coinciding with the onset of the declining phase of an environmentally driven long-term "regime change" in abundance (Schwartzlose et al., 1999). The catches of Chilean jack mackerel showed a significant decline in the 2000s, and the stock showed signs of overexploitation according to recent studies (FAO, 2011). While catches of Jumbo flying squid (*Dosidicus gigas*) largely increased in the 2000s. The increasing trend of MTL of Chile and Peru were largely caused by the sharply decreased catch of Chilean jack mackerel and substantial increased catch of jumbo flying squid. MTL of Venezuela gradually decreased since the 1950s because of the continuously increased catch of Ark clams nei (*Arca* spp.). Significant changes of fish community occurred in Uruguay and Argentina waters, and traditional fishery resources (i.e., Argentine hake, *Merluccius hubbsi*) showed a strong decline, while catches in crustacean, molluscs and cephalopods increased continuously (Milessi et al., 2005; Jaureguizar and Milessi, 2008).

The capacity of data collection, stock assessment and fishery management in the African states is generally poor in comparison with other regions. Liberia, Cameroon and South Africa in the Eastern Atlantic had decreasing MTL values, even though high trophic levels showed no significant trend. Recent studies found that most of the commercially important stocks in the Eastern Atlantic were classified as being fully exploited or overexploited, and the condition was more severe for the valuable demersal species with their number of overexploited stocks being much larger than that for pelagic species (FAO, 2011). Namibia is a beneficiary of the strong Benguela upwelling system, and fishery policy changed in Namibia after it gained independence in 1990 and implemented more conservative management measures, leading to the upward trend of MTL (Pitcher et al., 2009).

Fishing intensity has always been in high levels in Asia. Commercial fisheries in Japan started earlier in comparison with other states, and the phenomenon of "fishing down marine food webs" occurred in Japan in the 1960s. The subsequently reversed increasing trend of MTL in Japan was mainly induced by the successive collapse of Alaska pollock with a relatively low trophic level (TL=3.45). Similarly, the recovery trend of MTL in South Korea primarily resulted from a great increase in catches of Japanese flying squid (TL=4.28) and a significant decrease in catches of Alaska pollock. Marine fisheries in Asia have gone through an accelerating exploitation since the 1970s, due to the continuously increasing landings, both upper and lower trophic level catches in China and Malaysia showed a significantly increasing trend throughout the study period. In addition, according to Bhathal and Pauly (2008), MTL of India increased gradually since the 1970s, which may be related to the geographic expansion of fisheries. Indian shelf fisheries in 2000 covered about four times the area they covered in 1970, and this expansion had apparently reached its natural limits (Bhathal and Pauly, 2008).

Australia and New Zealand are often referred to as good examples in fisheries management (Mora et al., 2009). The number of stocks classified as overfished and/or subject to overfishing showed a decrease in Australia from 24 in 2005 to 18 in 2008 due to its successful management (Worm et al., 2009). Fisheries in New Zealand are managed by a system of individual transferable quotas (ITQ). There are currently 100 species or species groups covered by the quota management system (QMS), and only 14 stocks were considered to be overfished by 2010 (FAO, 2011). The sharply decreased catch of the dominant species blue grenadier (*Macruronus novaezelandiae*), which was believed to be related to the ENSO-induced abnormal oceanographic events (FAO, 2011), was probably responsible for the declining trend of MTL.

It is important to note here that we are not claiming that no decrease in MTL indicates that fishery have been properly managed. Owing to various technical confounding factors, there is no doubt that there might be cases in which fishing down will not be detected (Stergiou and Tsikliras, 2011). Furthermore, despite MTL showed non-significant declining trend for several states in Africa and Indian Ocean, spatial over-aggregation tended to mask the fishing-down effect (Pauly and Palomares, 2005). For example, MTL for the overall Brazilian fisheries showed a steadily upward trend, but disaggregation of catch data by states showed that the decline of MTL occurred through most of Northeastern Brazil at a rate of 0.16 per decade (Freire and Pauly, 2010). However, patterns in MTL are useful in understanding how fisheries change over time. The above 75 maritime states account for over 88% of total marine catches and are main commercial fishing states of the world. Consequently, their fishery development trend can generally reflect exploitation history of world marine fisheries.

It is worth noting that states which had "fishing down" signs or showed declining catches of lower trophic level during the recovery period were mostly classified as developed states with low undernourishment. In contrast, states with increasing trends in MTL or occurrence of "fishing through" scenario with continuous increased catch of both upper and lower trophic levels of species were mostly classified as developing states with high undernourishment. On the global scale, regions with high undernourishment are net exporters of seafood, and they benefit from this trade by exporting high-valued seafood to developed states, importing low-valued seafood, and using the surplus value to purchase other goods and services (Smith et al., 2010). Furthermore, fishery management and fisheries monitoring system in these states are generally inadequate at best. Sustaining seafood's contributions to world food security requires that developing countries govern their resources effective in the face of increasing pressure from international trade.

Fishing not only reduces populations of target species but also alters the structure of ecosystem (Rochet and Trenkel, 2003; Greenstreet and Rogers, 2006). The total productions of marine fishery resources have declined gradually after reaching a peak in landings in 1996. Not only can overexploitation cause negatively ecological consequences, can it also reduce fish production resulting in negative social and economic consequences (Zeller et al., 2006; FAO, 2014). Despite global MTL has increased gradually since 1987, it may accompanied by a decline in catches of traditional low trophic level species. The interpretation of MTL-based assessment of "fishing down marine food webs" needs to be cautious.

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