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Estimation of catch losses resulting from overexploitation in the global marine fisheries

DING Qi[1, 4], CHEN Xinjun[1, 2, 3, 4*], CHEN Yong[4, 5], TIAN Siquan[1, 2, 3, 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

Many fish stocks in the world are depleted as a result of overexploitation, which reduces stock productivity and results in loss of potential yields. In this study we analyzed the catch trends and approximate thresholds of sustainable fishing for fished stocks to estimate the potential loss of catch and revenue of global fisheries as a result of overexploitation during the period of 1950–2010 in 14 FAO fishing areas. About 35% of stocks in the global marine ocean have or had suffered from overexploitation at present. The global catch losses amounted to 332.8 million tonnes over 1950–2010, resulting in a direct economic loss of US$298.9 billion (constant 2005 US$). Unsustainable fishing caused substantial potential losses worldwide, especially in the northern hemisphere. Estimated potential losses due to overfishing for different groups of resources showed that the low-value but abundant small-medium pelagics made the largest contribution to the global catch loss, with a weight of 265.0 million tonnes. The geographic expansion of overfishing not only showed serial depletion of world's fishery resources, but also reflected how recent trends towards sustainability can stabilize or reverse catch losses. Reduction of global fishing capacity and changes in fishery management systems are necessary if the long-term sustainability of marine fisheries in the world is to be achieved.

Key words: overfishing, catch loss, sustainability, exploitation status

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1 Introduction

Fisheries play an important role in global food security, employment and income (Smith et al., 2010; Ye et al., 2013). Meanwhile, it is well known that fisheries tend to have tremendous impacts on marine ecosystems, possibly reducing biodiversity and impairing ecosystem functioning and even resulting in changes in their states, exemplified by overfished stocks and economic loss of fishing industry (Butchart et al., 2010; Srinivasan et al., 2012; Sumaila et al., 2012). The period following the Second World War saw significant changes of fisheries; world's marine capture fisheries expanded continuously to a production peak of 86.4 million tonnes in 1996 but have since exhibited a general declining trend at an approximate rate of 0.4 million tonnes per year (FAO, 2014). In contrast, demand for fish is expected to grow given the increasing human population, rising incomes and growing urbanization (FAO, 2014). Fish consumption per capita in the world increased from an average of 9.9 kg in the 1960s to 17.0 kg in the 2000s, fishing pressures on fish resources continue to mount and the number of fishers has kept increasing over time (FAO, 2014). Ongoing declines in production of the world's capture fisheries may have serious ecological and socioeconomic consequences (Balmford et al., 2002; Mora et al., 2009).

Indeed, the poor state of global fisheries might have long been masked by improved technology and large geographic expansion of fishing grounds (Pauly, 2008). The growth in the global marine fisheries was driven through a sequential expansion, fisheries exploitation has spread from coastal waters off North Atlantic and Pacific to waters in the Southern Hemisphere and into the high seas (Swartz et al., 2010). With the decline of fish stocks in shallow coastal waters, increasing demand, and introduction of new technology, fisheries were evidently expanding offshore and into deeper waters. However, the era of great expansion seems to come to an end now (Morato et al., 2006). According to recent assessments, up to one-third of the world's fish stocks are now overexploited (Branch et al., 2011; FAO, 2014). Overcapacity in fishing fleets and overexploitation of fish resources are two major factors result in the unsatisfactory stock status of world fisheries (Ye et al., 2013). However, global fishing intensity con-

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

tinues to mount, and the number of fishers has kept increasing over time (Ye et al., 2013). To put fisheries on a path towards sustainability, international efforts have sought to improve management for avoiding overexploitation (Worm et al., 2009; Ye et al., 2013).

An understanding of the dynamics of marine ecosystems induced by fishing activities is important for formulating marine policy. Much effort has been spent to assess the status of many exploited stocks and fisheries globally (Worm et al., 2006; Branch et al., 2011; FAO, 2014). Nevertheless, few studies have been done to quantify the foregone catch due to overfishing of fish stocks. Srinivasan et al., (2008) estimated the foregone catch duo to overexploitation of fish stocks for low, middle and high income groups from 1961 to 2000 using catch data and maximum sustainable yield (*MSY*) that estimated by devising a conservative approach. The study provides new insight on understanding the global status of fisheries. However, species composition varies from area to area around the world, and exploitation history for different categories of species are significantly different (Caddy et al., 1998; Caddy and Garibaldi, 2000). For successful fisheries management, it will be necessary to further examine the exploitation state for different components of community structure in detail. Using the conservative approach described in Srinivasan et al. (2008), we examined the foregone catch trends at the level of FAO fishing areas. Contrary to early studies on the global fisheries losses due to overfishing, in which all the fisheries stocks were considered as a whole, in this study we further examined potential losses due to overfishing for different categories of resources in the marine ecosystems, which can provide more accurate estimates.

2 Materials and methods

The study, which covers the period from 1950 to 2010, aims to estimate the potential catch and revenue that have been lost as a result of overexploitation at the FAO fishing area level based on the *MSY* estimate methodology described in Srinivasan et al. (2008). To minimize the attribution of natural fluctuations in fish populations to overfishing, we classified the fish stock as overfished only if its time-smoothed landings fell below 50% of its maximum value for at least 10 years in a row or 15 years in total following the year of maximum recorded catch in this study (stocks, defined here as species-FAO area combinations) (Kleisner et al., 2013; Srinivasan et al., 2008, 2010, 2012). We included that stock in our analyses if cumulative catch from 1950 to 2010 exceeded 1 000 tonnes and smoothed the data using three-year running average. In accordance with stock status plots (SSPs) (Kleisner et al., 2013), we excluded taxonomic groupings higher than family and pooled groups from this analysis. It should be noted that the concept of “overfished” in this study refer to species that have or had overfished during the study period, so we also included stocks which were dropped to “overexploited” and “collapsed” status previously but recovered to “rebuilding” and “exploited” status nowadays.

The estimation of corresponding maximum sustainable yield for each species already identified as overfished was according to the method developed from simple, conservative guidelines based on species’ lifespans (t_{max}), as well as the maximum catch (C_{max}) over the period and selected *MSY* and catch estimates from the Northeast Fisheries Science Center (NEFSC) by Srinivasan et al. (2008). In this study, we used the medium value of the lower and upper assignments of *MSY* by Srinivasan et al. (2008) to estimate the foregone catch. Lifespans of fish species were obtained from Fishbase (www.fishbase.org), and lifespans for genus and family were taken as the mean lifespan of constituent species. For invertebrates taxa *MSY* levels, the estimates were an average of all invertebrates from Srinivasan et al. (2008), at about 35% of maximum catch. In order to provide more accurate estimates, we further revised *MSY* assignments for fish species that had *MSY* estimates calculated from NEFSC data and for invertebrates that have accurate lifespans according to Srinivasan et al. (2008).

Potential total catch losses (L, tonnes) in each FAO fishing area in year t were tallied for all overfished species-fishing area pair i for year t subsequent to the year of maximum catch in which the estimated *MSY* was greater than the recorded catch (C_{it}) (Srinivasan et al., 2010). It can be defined by the equation:

$$L_t = \sum_i (MSY - C_{it}).$$

Annual catch data were taken from the Sea Around Us Project (SAUP) database (www.seaaroundus.org). In order to more accurately measure fishing impact on different components of community structure in an ecosystem, all the exploited fish species/groups in each fishing area were grouped into four categories: demersal marine fishes (including demersal fish, benthic fishes, sharks and rays, and flatfishes), small-medium sized pelagics, oceanic and deep-water resources (consist of large pelagics and deep-water fishes), and invertebrates.

Price data were from the SAUP ex-vessel price database. In some cases, more than one price time series for a taxon is available; for example, when there are directed fisheries for a taxon in multiple regions. To maximize information content, we averaged across all available price records discounted to 2005 $US over time and space to construct the price index (Sethi et al., 2010). Using catch loss calculated by the above equation and price information obtained from the SAUP database, we estimated potential revenues lost due to overfishing in each FAO area. This study not only maps catch losses at fishing area-level that have not been analyzed previously, but also explores the foregone catch for different categories of resources in each fishing areas.

3 Results

3.1 *Exploitation status of global marine fishery resources*

Global fisheries statistics, which have existed since 1950 and been assembled by SAUP, provide the information for assessing the global status of fisheries. It is found that 35% of stocks in the Atlantic, Pacific and Indian Oceans were deemed to have or had been overfished, resulting total foregone catch mount to 332.8 million tonnes over 1950–2010. Estimates of global lost tonnage for the 14 FAO fishing areas were listed in Table 1. Summing over the whole study period of 1950–2010, Southeast Pacific was the first fishing area to register significant losses of about 115.1 million tonnes, followed by Southeast Atlantic, Northwest Atlantic and Northwest Pacific for losses of 62.2, 50.4 and 48.2 million tonnes, respectively. In contrast, Southwest Pacific, Western and Eastern Indian Ocean did not suffer serious loss to overfishing with the overall potential loss in the Southwest Pacific ocean being only about 1.0 million tonnes and a loss of mere 0.4 million tonnes for the latter two areas.

Based on the year and quantity of the historically maximum catch, which varied over the areas included in the analysis, the percentage of overfished stocks for each FAO area over the last six decades were listed in Table 1. The Northwest Atlantic ranked the 1st with a proportion of 62%. Followed by the Northeast At-

Table 1. Exploitation status of fisheries resources according to the catch-based method in the FAO areas of the Atlantic, Indian and Pacific Oceans

FAO areas	Percentage of overfished stocks in 2010/%	Overall potential losses in million tonnes, 1950–2010	Catch losses in 2010/%
Global ocean	35	332.8	15
Northwest Atlantic	62	50.4	59
Northeast Atlantic	53	25.5	16
Western Central Atlantic	34	3.2	11
Eastern Central Atlantic	34	3.8	3
Southwest Atlantic	35	2.8	3
Southeast Atlantic	43	62.2	138
Western Indian Ocean	9	0.4	1
Eastern Indian Ocean	13	0.4	0.2
Northwest Pacific	52	48.2	14
Northeast Pacific	49	9.8	15
Western Central Pacific	20	5.2	2
Eastern Central Pacific	45	5.0	10
Southwest Pacific	35	1.0	10
Southeast Pacific	48	115.1	29

lantic, Northwest Pacific, Northeast Pacific and Southeast Pacific with a proportion of about 50%. The Western Central Pacific and Indian Ocean had less than 20% of fish stocks overfished, and the lowest proportion was about 9% for the Western Indian Ocean. The other areas had 34%–45% of fish stocks overfished.

As a measure of catch contribution, Table 1 summarized the potential catch lost in 2010 as a percentage of actual total catch in that year. The Southeast Atlantic ranked the 1st with catch losses account for 138% of actual catch in the year 2010. This was followed by the Northwest Atlantic and Southeast Pacific, accounting for 59% and 29%, respectively. The proportion of lost catch by mass in 2010 was 16% for the Northeast Atlantic, 15% for the Northeast Pacific, 14% for the Northwest Pacific, and 11% for the Western Central Atlantic. For the remaining areas, the catch loss accounted for less than 10% of the corresponding overall catches in 2010 (Table 1).

3.2 *Spatial expansion of overfishing*

During the period of the 1950s and the 1960s, there was a massive increase in marine fisheries catch, and the collapse of fisheries due to overfishing did not begin to become obvious in global catch trends until the 1970s. According to Srinivasan et al. (2012), the geographic pattern of average losses by the 1970s reflects the distribution of fishing effort in previous decades, and the progression of estimated total overfishing losses in landings over the 1970s, 1980s, 1990s, and 2000s were listed in Table 2. The percentage of overfished stocks for each FAO area at the end of the 1970s, 1980s, 1990s and 2000s were shown in Fig. 1. In the 1970s, the Northwest Atlantic and Northeast Atlantic ranked the 1st and 3rd proportion of overfished stocks, resulting the corresponding catch losses reached 1.8 million and 4.9 million tonnes respectively. The Southeast Atlantic had 27% stocks overfished, which placed the Southeast Atlantic at the 2nd in total catch losses of 5.6 million tonnes. The collapse of Anchoveta placed the Southeast Pacific at the 1st in total catch losses of 24.7 million tonnes, although the proportion of overfished stocks only accounted for 17%. The overfished proportion in the other FAO areas all less than 20% in the 1970s, and total catch losses all less than 1 million tonnes expected for the Northeast Pacific.

As fishing effort intensified, catch loss increased in the regions of North Atlantic in the 1980s, at 8.2 million tonnes for the

Table 2. Potential losses in million tonnes over each decade from 1970 to 2010 in the FAO areas of the Atlantic, Indian and Pacific Oceans

FAO area	1970s	1980s	1990s	2000s
Northwest Atlantic	1.8	8.2	17.5	20.6
Northeast Atlantic	4.9	6.3	4.5	8.5
Western Central Atlantic	0.1	0.4	0.7	1.7
Eastern Central Atlantic	0.05	1.2	1.1	1.3
Southwest Atlantic	0.2	0.3	0.8	1.3
Southeast Atlantic	5.6	17.0	19.4	18.1
Western Indian Ocean	0.005	0.02	0.09	0.2
Eastern Indian Ocean	0.002	0.1	0.1	0.2
Northwest Pacific	0.6	1.3	14.8	28.5
Northeast Pacific	1.8	2.2	2.2	2.7
Western Central Pacific	0.9	0.7	1.3	2.0
Eastern Central Pacific	0.1	0.4	1.7	2.3
Southwest Pacific	0.009	0.07	0.3	0.5
Southeast Pacific	24.7	40.1	14.1	32.8

Northwest Atlantic and 6.3 million tonnes for the Northeast Atlantic respectively (Table 2). Furthermore, catch losses of the Southeast Pacific and Southeast Atlantic were also exacerbated in this decade, which placed them at the 1st and 2nd in the world catch losses, reaching 40.1 million and 17.0 million tonnes respectively (Table 2). The proportion of overfished species in the Eastern Central Atlantic, Southwest Atlantic, Northwest Pacific, Northeast Pacific, and Eastern Central Pacific Oceans were 20%, 24%, 29%, 24% and 24%, and the corresponding catch losses were 1.2, 0.3, 1.3, 2.2 and 0.4 million tonnes respectively. However, the percentage of overfished stocks in the other areas were all lower than 20% in the 1980s.

With global catch declining since the late 1980s, crashes due to overfishing intensified in the 1990s. In particular, the Northwest Atlantic jumped to the 2nd in total catch losses, with 17.5 million tonnes in the 1990s (Table 2). Catch losses in the Northwest Pacific sharply increased to 14.8 million tonnes and ranked the 3rd in this decade, and catch losses in the Southeast Atlantic also increased to about 19.4 million tonnes and ranked the 1st in this decade (Table 2). In addition, about 32% of stocks overfished in

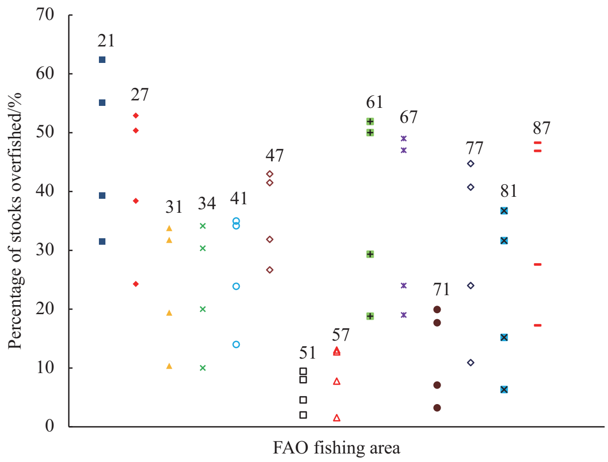

Fig. 1. Percentage of overfished stocks for each FAO area in the Atlantic, Indian and Pacific Oceans at the end of the 1970s, 1980s, 1990s and 2000s. "Overfished" in this study refers to species that have or had overfished, so the overfished percentage increase progressively over time. For each column, the symbols from bottom to top are the overfished percentage at the end of the 1970s, 1980s, 1990s and 2000s respectively. The number on the top of each column is the code of corresponding FAO fishing area: 21 represents Northwest Atlantic, 27 Northeast Atlantic, 31 western Central Atlantic, 34 eastern Central Atlantic, 41 Southwest Atlantic, 47 Southeast Atlantic, 51 western Indian Ocean, 57 eastern Indian Ocean, 61 Northwest Pacific, 67 Northeast Pacific, 71 western Central Pacific, 77 eastern Central Pacific, 81 Southwest Pacific, and 87 Southeast Pacific.

the Western Central Atlantic and Southwest Pacific Oceans in the 1990s, and the corresponding catch losses were 0.7 and 0.3 million tonnes. However, losses in landings appeared to level off from the 1980s to the 1990s in the Eastern Central Atlantic and Northeast Pacific Oceans, and the Northeast Atlantic and Southeast Pacific even reversed their losses to overfishing in this decade (Table 2).

Losses to overfishing tended to stabilize for the Southeast Atlantic in the 2000s (Table 2), while for the Northeast Atlantic and Northwest Pacific, their total loss increased greatly, at 8.5 million tonnes and 28.5 million tonnes in the 2000s respectively. The Southeast Pacific also reached a peak in the 2000s, with about 32.8 million tonnes. As fishing efforts continued to increase, losses for other areas were in a state of gradually upward trend. Our estimates of overfished proportion in the 2000s were likely conservative because we deemed a stock overfished if its time-smoothed landings remained depressed for at least 10 years in a row or 15 years in total. About 20% of stocks overfished in the Western Central Atlantic in the 2000s. In contrast, the Indian Ocean did not suffer serious losses to overfishing, and the overfished percentage were 9% for the Western Indian Ocean and 13% for the Eastern Indian Ocean.

3.3 *Exploitation status and revenue losses of global fisheries*

Different components of community structure had very different exploitation status. By estimating losses to overfishing by mass for different categories of resources in the marine ecosystems, summing over the whole 14 fishing areas, we found that small-medium pelagcis ranked the 1st with a weight of 265.0 million tonnes. Followed by demersal fishes, invertebrates, and oceanic & deep-water resources, at 43.1, 20.5, and 4.2 million tonnes respectively. Table 3 summarized the potential catch loss for four categories of resources in the year 2010 as a percentage of actual catches of corresponding category in that year in overall 14 FAO areas. Results showed that the percentage were 29% for small-medium pelagics, 9% for invertebrates, 7% for demersal fishes, and 2% for oceanic & deep-water resources.

By further examining potential total catch losses and catch loss in 2010 as a percentage of actual catch in that year for four categories of resources in each FAO areas, results showed that the Northwest Atlantic suffer from serious catch losses. Specifically, catch loss in 2010 as a percentage of corresponding actual catches were 195% for demersal fishes, 48% for oceanic & deep-water fishes, 43% for small-medium pelagics, and 15% for invertebrates. However, catch losses in the Northeast Atlantic and Southeast Atlantic were mainly came from small-medium pelagics and invertebrates, with catch losses in 2010 as a percentage corresponding actual catches were 29% and 244% for small-medium pelagics and were 11% and 90% for invertebrates, respectively. For the Western Central Atlantic, demersals lost 13% and oceanic & deep-water fishes lost 20% of their actual catches in 2010. In addition, for the Eastern Central Atlantic and Southwest Pacific, in 2010, the proportion of catch losses for invertebrates reached 27% and 69% respectively. The Southwest Atlantic lost 11% of actual catches for oceanic & deep-water fishes, while the Northwest Pacific and Southeast Pacific lost 48% and 35% of actual catches for small-medium pelagics. Catch loss in the Northeast Pacific mainly derived from small-medium pelagics, which lost 116% of actual catch in 2010. Furthermore, in 2010, the Eastern Central Pacific lost 21% and 13% of actual catches for demersals and small-medium pelagics. In contrast, for the Indian Ocean and Western Central Pacific, the potential catch loss accounted for less than 10% of actual catches for all the four categories in 2010 (Table 3).

Table 4 illustrated the potential revenue lost due to overfishing for 14 FAO fishing areas from 1950 to 2010. Summing over all of the 14 fishing areas, the accumulative economic loss reached US$ 298.9 billion (constant 2005 US$) over the past six decades. Given their massive losses in landings duo to overfishing, the high losses in revenue of the Northwest Atlantic, Southeast Pacific, Northwest Pacific, Southeast Atlantic, and Northeast Atlantic at $96.6, $56.1, $39.6, $38.3 and $17.6 billion, respectively, were not surprising. In contrast, the estimated loss in revenue for the Southwest Pacific and Indian Ocean were relatively low, only between $0.4–3.2 billion. Lost revenue in other fishing areas ranged from $5.0 million to $10.7 million.

As a measure of relative costs, potential revenue lost as a percentage of total values in each FAO area in 2010 were presented in Table 4. Globally, overfishing caused 12% of actual revenue in 2010. The Southeast Atlantic, Northwest Atlantic and Southeast Pacific ranked the top three in the revenue lost with a proportion of 67%, 35%, and 27% respectively. In contrast, revenue lost in the Western Central Pacific and Indian Oceans were less than 2% of actual revenue in 2010. For the remaining FAO areas, the foregone revenue of these potential landings in 2010 accounted for 5%–21% of actual revenue in that year.

4 Discussion

Overexploitation has long been recognized as a leading socioeconomic problem (The World Bank and FAO, 2009). Global landings are an indicator of benefits that human society can obtain from fisheries, and declines in landings mean loss of economic benefits (Ye et al., 2013). This study provides another aspect for understanding the exploitation history and status of

Table 3. Overall potential losses in million tonnes from 1950 to 2010 and catch losses in 2010 as a percentage of corresponding actual catches in that year for four categories of resources in 14 FAO areas of the Atlantic, Indian and Pacific Oceans

FAO area	Category	Potential catch loss in million tonnes, 1950–2010	Potential catch loss in 2010/%
Global ocean	demersal marine fishes	43.1	7
	small-medium pelagics	265.0	29
	invertebrates	20.5	9
	oceanic & deep-water resources	4.2	2
Northwest Atlantic	demersal marine fishes	29.6	195
	small-medium pelagics	13.6	43
	invertebrates	7.0	15
	oceanic & deep-water resources	0.2	48
Northeast Atlantic	demersal marine fishes	3.0	3
	small-medium pelagics	21.7	29
	invertebrates	0.4	11
	oceanic & deep-water resources	0.4	3
Western Central Atlantic	demersal marine fishes	0.9	13
	small-medium pelagics	0.8	9
	invertebrates	0.8	8
	oceanic & deep-water resources	0.7	20
Eastern Central Atlantic	demersal marine fishes	0.8	3
	small-medium pelagics	1.9	1
	invertebrates	0.8	27
	oceanic & deep-water resources	0.3	2
Southwest Atlantic	demersal marine fishes	0.5	1
	small-medium pelagics	1.2	3
	invertebrates	0.5	8
	oceanic & deep-water resources	0.5	11
Southeast Atlantic	demersal marine fishes	0.08	2
	small-medium pelagics	61.0	244
	invertebrates	0.5	90
	oceanic & deep-water resources	0.5	10
Western Indian Ocean	demersal marine fishes	0.05	0.1
	small-medium pelagics	0.3	2
	invertebrates	0.006	0.1
	oceanic & deep-water resources	0.004	0.04
Eastern Indian Ocean	demersal marine fishes	0.03	0.1
	small-medium pelagics	0.04	0.07
	invertebrates	0.3	1
	oceanic & deep-water resources	0.001	0.003
Northwest Pacific	demersal marine fishes	4.8	2
	small-medium pelagics	39.5	48
	invertebrates	3.8	7
	oceanic & deep-water resources	0.2	1
Northeast Pacific	demersal marine fishes	0.6	1
	small-medium pelagics	8.2	116
	invertebrates	0.8	40
	oceanic & deep-water resources	0.3	16
Western Central Pacific	demersal marine fishes	0.5	1
	small-medium pelagics	1.8	2
	invertebrates	3.0	9
	oceanic & deep-water resources	0.000 9	0.002
Eastern Central Pacific	demersal marine fishes	1.8	21
	small-medium pelagics	2.9	13
	invertebrates	0.2	3
	oceanic & deep-water resources	0.02	0.2
Southwest Pacific	demersal marine fishes	0.1	3
	small-medium pelagics	0.04	5
	invertebrates	0.8	69
	oceanic & deep-water resources	0.04	2
Southeast Pacific	demersal marine fishes	0.4	3
	small-medium pelagics	112.0	35
	invertebrates	1.7	6
	oceanic & deep-water resources	0.9	5

Table 4. Overall potential revenue lost in billion dollars from 1950 to 2010 and potential revenue lost in 2010 as a percentage of actual revenue for 14 FAO areas in the Atlantic, Indian and Pacific Oceans

FAO area	Overall potential revenue lost in billion dollars, 1950–2010	Revenue lost in 2010/%
Global ocean	298.9	12
Northwest Atlantic	96.6	35
Northeast Atlantic	17.6	12
Western Central Atlantic	10.7	15
Eastern Central Atlantic	8.6	7
Southwest Atlantic	5.0	5
Southeast Atlantic	38.3	67
Western Indian Ocean	0.4	0.5
Eastern Indian Ocean	1.7	0.8
Northwest Pacific	39.6	9
Northeast Pacific	9.3	21
Western Central Pacific	6.6	2
Eastern Central Pacific	5.2	9
Southwest Pacific	3.2	13
Southeast Pacific	56.1	27

global marine fisheries. This study confirms, through evaluating trends in potential catch lost and revenue lost for fishing areas in the Atlantic, Pacific and Indian Oceans, that global marine fisheries are currently underperforming due to overfishing. Based on the relatively conservative approach by Srinivasan et al. (2008, 2010, 2012), 35% of stocks in global oceans were deemed to be overfished in this study. The proportion of fished stocks that were considered overfished in this study also includes stocks that were overexploited previously but now recovered to be classified as “rebuilding” and “exploited”. Thus, this proportional value is more conservative than a recent assessment by Branch et al. (2011) in which 28%–33% of stocks were considered overexploited at the time of the study. Global catch losses caused by overfishing amounted to 322.8 million tonnes from 1950 to 2010, resulting in a corresponding value loss of US$ 298.9 billion (constant 2005 US$).

Historical data from marine ecosystems clearly suggest that intensive exploitation of fish communities often leads to substantial reductions in the abundance of target species and significantly reduce biodiversity in the global oceans (Pauly et al., 1998; Myers and Worm, 2003; Butchart et al., 2010). By the 2000s, fishery landings were three times annually more than what they were in the 1950s, global marine fisheries spread from the North Atlantic to the waters in the Southern Hemisphere (Swartz et al., 2010). Regarding the status of exploitation according to the catch-based method, up to half of fish stocks were deemed overfished in the Northwest Atlantic, Northeast Atlantic and Northwest Pacific Oceans (Table 1). Not unexpectedly, the above three areas ranked the 3rd, 5th, and 4th in the overall potential losses. Catch losses in the Northwest Atlantic Ocean were mostly from the collapse of demersal fishes such as Atlantic cod *Gadus morhua*, American plaice *Hippoglossoides platessoides* and redfishes *Sebastes* spp.. Marine ecosystem used to be dominated by demersal species in the 1970s and had changed to the one dominated by invertebrate and pelagic fish species in the 2000s, implying a regime shift (FAO, 2011). In addition, the increasing catch losses of invertebrates could be viewed as a warning to managers that management actions should be taken to prevent the collapse of these species (Foley, 2013). For the Northeast Atlantic Ocean, main target species have shifted from traditional species, such as Atlantic cod and haddock *Melanogrammus aeglefinus*, to formerly lower-valued species such as sandeels *Ammodytes* spp. and blue whiting *Micromesistius poutassou*. The sharply decreased catch of capelin *Mallotus villosus* together with the collapse of demersal species such as Norway pout *Trisopterus esmarkii* and *Sebastes* spp. led to a substantial increase in catch losses in the Northeast Atlantic in the 2000s (FAO, 2011). Despite recent developments in management measures, excessive fishing capacity is still one of the major issues in the Northwest Pacific Ocean, and CPUE has decreased rapidly since the late 1990s (Watson et al., 2013). Overall landings peaked in the late 1980s and have been declining ever since, making overfishing losses in landings increase greatly since the 1990s. Many important demersal fishes such as large yellow croaker *Larimichthys croceus* were overfished (FAO, 2011). In addition, Pacific sardine *Sardinops sagax*, which was once one of the largest single-species fisheries in the world, is now considered overfished, and the catch of *S. sagax* fishery has remained at an extremely low level since the mid-1990s, resulting in catch losses in the Northwest Pacific being sharply increased since the 1990s (FAO, 2011).

Catch-based method of stock classification for the levels of exploitation has been extensively used to assess the status of fisheries globally (Kleisner et al., 2013; Tsikliras et al., 2013, 2015). However, previous studies often emphasize the proportion of overexploited stocks, but fail to investigate the foregone catch behind it. When the catch-based method was applied in the 14 FAO areas, we found that the percentage of overfished stocks were all within the range 40%–50% in the Southeast Atlantic, Northeast Pacific, Eastern Central Pacific, and Southeast Pacific Ocean, but in 2010, these stocks lost 138% of the actual catch in Southeast Atlantic Ocean, while 15%, 10%, 29% for the latter three areas respectively. The small pelagic fisheries account for the highest proportion of the landings in the Southeast Atlantic Ocean, and the collapse of Southern African pilchard *Sardinops ocellatus* resulted in an increased catch loss in the 1980s, but its biological conditions had improved by a strict control of landings imposed by Namibia and Angola, causing a reverse in catch losses in the 2000s (FAO, 2011). Fisheries in the Northeast Pacific Ocean underwent a series of regulatory and market-driven reforms to reduce fishing effort to sustainable levels, which might contribute to a generally stable catch in most fisheries (FAO, 2014). The significantly increased overfishing loss in landings in the 1980s was resulted from the overexploitation of *Sebastes* spp.. In addition, the resources were still not recovered and required further rebuilding (FAO, 2011). Catch in the Eastern Central Pacific mostly consists of small and medium pelagic species. High fishing intensity and adverse environmental conditions might contribute to the collapse of Californian anchovy *Engraulis mordax* fishery since the early 1980s, resulting in rapid increases in catch loss from the 1980s to the 1990s in the Eastern Central Pacific, but the catch loss tended to be leveled off in the 2000s (FAO, 2011). According to FAO (2011), the Eastern Central Pacific had the highest proportion of non-fully exploited stocks, about 38% in 2009, which provides possible room for an increase in catch. Similarly, catch losses in the Southeast Pacific mainly resulted from the overfishing of small pelagic species. Intensive fishing effort together with natural environmental fluctuation played a significant role in large fluctuations of decadal catch losses. The collapse of the world’s largest single species fishery, anchoveta, placed Southeast Pacific the first in catch losses in the 1970s and the 1980s (Pauly et al., 2002). The sharply increased loss in catch in the 2000s was attributed to the collapse of South American pilchard *Sardinops sagax*, which was caused by the heavy fishing in the 1980s and the environmentally driven long-term fluctuations in stock abundance (Schwartzlose et al., 1999).

Despite the Western Central Atlantic, Eastern Central Atlantic, Southwest Atlantic, and Southwest Pacific Oceans all had about 35% of fish stock overfished, different categories of resources suffer from different degrees of overfishing losses. Catch in the Eastern Central Atlantic was dominated by small pelagic fishes, and fish stocks did not suffer from severe overfishing based on our analysis. In general, pelagic species were considered fully exploited (FAO, 2011). In contrast, the situation was more severe for the valuable invertebrate species, with a larger percentage of catch losses compared to the small pelagic species. Total landings in the Western Central Atlantic were in a state of downward trend since 1984, which was mainly caused by the diminished catches of Gulf menhaden *Brevoortia patronus*. However, its stock abundance was estimated to be between its target and limit reference points and, thus, not considered to be overfished nor subject to overfishing (Vaughan et al., 2007). Although the Western Central Atlantic did not seriously suffer from overfishing based on the method in this study, this area has a high incidence of stocks for which the state of exploitation is reported as uncertain. With an increased fishing pressure in this area, efforts should be concentrated to improve the quality of data and information to improve stock assessment and reduce the uncertainty. For the Southwest Atlantic and Southwest Pacific Oceans, peak landings were achieved in the 1990s. Fishery resources in the Southwest Atlantic were in a state of accelerating development since the 1980s, demersal species and squids were major contributors to the catches from this region. Although heavy catch loss did not showed in the Southwest Atlantic Ocean, excessive fishing pressure maintained main target small pelagic species such as Brazilian sardinella *Sardinella brasiliensis* under a state of overexploitation, and there was no sign of stock recovery (FAO, 2011). In contrast, the Southwest Pacific only included two countries, Australia and New Zealand, and they are often referred to having good practices in fisheries management (Pitcher et al., 2009). Catch loss in this region was mainly from the overfished invertebrates, however, rebuilding plans are in place in many fisheries to allow them to rebuild to target levels (FAO, 2011).

Although fishery resources in the Western Central Pacific and Indian Oceans are presently under stress, continuously upward trend of fisheries landings makes catch losses relatively low in these regions. We should note that many countries in these areas do not have well-developed management systems in place, and the capacity of data collection and stock assessment are generally poor in comparison with other regions (Mora et al., 2009). Recent studies also found that decrease in CPUE was consistent in both the Eastern and Western Indian Oceans, and monitoring programs are urgently needed (Watson et al., 2013).

Because of lack of information on the economic health of the world's fisheries, highlighting economic objectives and the current level of global economic revenue loss in fisheries has never been so important (The World Bank and FAO, 2009; Srinivasan et al., 2010, 2012). By exploring trend of global catch losses at the level of FAO fishing areas over a critical period in the history of fishing, it is clear that unsustainable fishing caused substantial potential losses worldwide, especially in the northern hemisphere. Estimated potential losses due to overfishing for different groups of resources showed that the low-value but abundant small-medium pelagics made the largest contribution to the global catch loss, and the sustainable fishery management practices together with favorable environmental conditions can even reverse the losses to overfishing.

Although overexploitation of global fisheries cannot be attributed solely to fishing, other factors such as pollution and climate change may also play a role (Pitcher and Cheung, 2013). However, fishing is considered the greatest single cause of such depletion (The World Bank and FAO, 2009). As human populations continue to grow, the future benefits that fishery resources can provide depend largely on how well they are rebuilt and managed. Awareness and understanding of potential and actual economic benefits for avoiding overexploitation can provide incentives to take the necessary actions to sustainably manage fish stocks.

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