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Status, Trends, and the Future of Fisheries in the East and South China Seas

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Acronyms used

CPUE – Catch per unit effort
DHC – Direct Human Consumption
ECS – East China Sea
EwE – Ecopath with Ecosim
FAO – Food and Agriculture Organization of the United Nations
FMI – Fisheries Management Index
GDP – Gross Domestic Product
IUU – Illegal, unreported and unregulated fisheries
LME – Large Marine Ecosystem
MRM – Marine Resource Management score
MSY – Maximum Sustainable Yield
NSCS – North South China Sea
PVR – Present Value of Revenue
RCP – Representative Concentration Pathway
SCS – South China Sea
SST – Sea Surface Temperature
TL – Total Length
TURF - Territorial Use Rights in Fisheries

Director's Foreword

Asia's marine waters generate about half of the global marine fish catch estimated currently at ~ 110 million tonnes annually. This makes understanding the impact that the East and South China Seas fisheries have on our global marine ecosystem vital. These Large Marine Ecosystems border major fishing nations such as China, South Korea, Japan, Thailand, and Vietnam. Fisheries play important roles there, not only as a source of nutrition and employment, but also as part of the cultural and other economic landscapes. Currently, we know that fisheries in these areas have been in decline for years due to ineffective fisheries management, climate change, and coastal development, among other pressures. There is, therefore, an identified need to protect and rebuild marine resources of the East and South China Seas.

Our authors have looked to fill a gap in current research by providing a comprehensive picture of the substantial socio-economic contributions of East and South China Seas fisheries at the Large Marine Ecosystem scale. They have also endeavored to highlight the potential fisheries and ecosystem trade-offs under future management and climate change scenarios. Steps must be taken to improve current fisheries policy in this region and emphasizing the costs and benefits to local, national and regional societies and ecosystems can only help in this analysis.

This is critical research and I applaud the efforts of the authors.

Dr. Evgeny Pakhomov
Director, Institute for the Oceans and Fisheries
The University of British Columbia

Executive Summary

The East and South China Sea Large Marine Ecosystems (LMEs) contain globally significant biodiversity and habitats. These two LMEs border some of the world's most populous countries, among which are major fishing nations such as China, South Korea, Japan, Thailand, and Vietnam. Fisheries thus play a prominent economic, food security, social, cultural, and livelihood role in East (ECS) and South China Sea (SCS) countries. However, ECS and SCS fisheries have experienced decades of decline, and their future sustainability is undermined by weak and/or ineffective fisheries management and governance, uncontrolled coastal development, and climate change, among other global, regional, and local scale human and environmental pressures.

There is clearly an urgent need to improve marine resource management in the East and South China Sea LMEs. This report is intended to support the call for action to rebuild and protect the LMEs' marine resources. To do so, our research objectives are: 1) Provide a baseline assessment of the present status of East China Sea fisheries at the LME level; 2) Assess the potential impact of future management and climate change on ECS fisheries and marine ecosystems.

The report is split into 4 chapters: Chapter 1 sets the stage by introducing the Large Marine Ecosystems (LMEs) of Asia, and in particular provides indicators on fisheries productivity, trade, fishing capacity and management performance for the East and South China Seas. In Chapter 2, 'Taking Stock', we document the current economic and social contribution of fisheries to national economies of the East China Sea¹ at the LME scale, and review the present status of ECS fisheries governance. Chapter 3, 'Global Change', undertakes ecosystem modelling to assess the potential ecological and economic outcomes of fisheries in both the ECS and SCS under different future scenarios of management and climate change. Chapter 4 investigates the pressing regional issue of biomass fishing by comparing economic returns to the fishery from exploiting juvenile fish versus waiting for the fish to mature.

Collectively, the analyses in this report fill a present research gap by providing a comprehensive picture of the substantial socio-economic contributions of ECS fisheries at the LME scale, and showing the potential fisheries and ecosystem trade-offs under future management and climate change scenarios. By doing so, this report helps to inform fisheries policy by highlighting the costs and benefits to ECS society and ecosystems if steps are not taken to improve the current state of national and regional fisheries governance.

¹ A similar assessment for the South China Sea is published in Teh et al. (2017) and Sumaila and Cheung (2015).

Chapter 1: Large Marine Ecosystems of Asia

U. Rashid Sumaila

Abstract

Asia's marine waters are divided into 13 Large Marine Ecosystems (LMEs), which together generate about 50% of the global marine fish catch of ~ 110 million tonnes annually. Here, I carry out a comparative analysis and valuation of these 13 LMEs with a focus on fish values, even though marine ecosystem valuation is much broader than the valuation of fisheries. Comparative analysis needs careful selection of indicators. The following indicators were employed: Catch level, landed values, and subsidy intensity. These are key indicators of a fishery because (i) catch is an indicator of the amount of fish available in weight for food security purposes; (ii) landed value is the firsthand value from which wages, profits, and economic impact originate; and (iii) fisheries subsidy is a policy instrument, which if used incorrectly can lead to overcapacity and overfishing. In the second part of this contribution, I use the East and South China Sea LMEs to further illustrate the value of ocean fisheries and some of the threats they face. To carry out the comparative analysis, I extracted data from the *Sea Around Us* and Fisheries Economics Research unit databases at the University of British Columbia. I also relied on the data and analyses of the *OceanAsia* project, supported by the ADM Capital Foundation Ltd of Hong Kong. The analyses suggest that Asian LMEs are crucial in terms of food security, economic, and social benefits to tens of millions of people in Asia and around the world; are under strong overfishing pressure; and, that action is needed through effective management to stem the overfishing tide in order to ensure that these LMEs continue to sustain the delivery of goods and services through time.

Introduction

Asia is an important ocean and fisheries continent. Its 13 Large Marine Ecosystems (Sherman, 2014) generate over 50% of global marine fish catch of ~ 110 million tonnes annually (Pauly & Zeller, 2016). This implies that if the world were divided into two continents according to the quantity of fish taken from their waters, it would be Asia and the rest of the world, with the latter being the smaller of the two (Sumaila 2018). The larger implication of the overwhelming weight of Asia when it comes to ocean-based fisheries is that it would be impossible to have a healthy and sustainable global ocean without the LMEs of Asia being in a healthy state. This, then, is the motivation for creating the *OceanAsia* Project – to help us understand the state of Asia's large marine ecosystems (LMEs) so that we can increase our chances of ensuring a healthy and sustainable global ocean for the benefit of both current and future generations of people. In this particular contribution, we focus on the two most important Asian LME in terms of quantity of catch generated, i.e., the South China and East China Seas.

As would be expected, the problems of overfishing, pollution, including plastics, global warming, ocean acidification, deoxygenation, and other stressors, are posing a serious threat to large marine ecosystems in Asia and the rest of the world. More specifically, the marine ecosystems of the South and East China Seas have been threatened by these diverse human and environmental pressures. For instance, almost all large demersal and pelagic fish in the South China Sea are overexploited, while a large number of other economically important species such as chub mackerel are fully exploited (FAO 2010; Sumaila and Cheung, 2015; Teh et al. 2017 and 2018).

In addition, marine ecosystems are being degraded by land reclamation, and coastal development, among other pressures, which will only intensify as Asia's economies continue to grow. For example, coral reefs, mangroves, and seagrasses in the South China Sea are estimated to be declining by 1.6-3% per year (Vo et al. 2013). The

South China Sea is also projected to be a hotspot of biodiversity loss, and fisheries catches will likely decrease under climate change (Sumaila and Cheung, 2015).

First, we carried out a comparative analysis and valuation of the fisheries dependent on Asia's 13 LMEs. Second, we used the East and South China Sea LMEs to further illustrate the value of marine ecosystems and how climate change and overfishing are affecting them now and into the future under different scenarios. We concluded that the growing pressure on fish and fisheries from multiple stressors requires a serious look at resource management in the East and South China Seas and, by extension, all Asian LMEs, with a particular focus on taking action to rebuild and sustain these important resources.

Large Marine Ecosystems of Asia²

The 13 Asian LMEs are: The East China Sea; the South China Sea; the Bay of Bengal; Kuroshio Current; Sea of Japan/East Sea; Arabian Sea; Sea of Okhotsk; Gulf of Thailand; Yellow Sea; Indonesian Sea; Oyashio Current; Sulu-Celebes Sea; and, the West Bering Sea.

Using data compiled by the *Sea Around Us* and the Fisheries Economics Research Unit at the University of British Columbia for each of these LMEs, we computed the total catch (i.e. both reported and unreported marine catches including discards) extracted from each of the LMEs from 1950 to 2014. Similarly, we extracted the landed values or total revenues generated by each of these marine ecosystems. Next, we identified the catch of the peak-year, the average catch from 1950 to 2014, and the 2014 catch and landed values, respectively. The goal here is to provide a temporal view of the trends in these indicators over time. We also extracted subsidies information from our databases (Sumaila and Pauly 2006, Sumaila et al. 2016), computed and compared the subsidies intensity (i.e., the amount of subsidies provided by governments to vessels that operate in each LME divided by the landed value the LMEs generate). The aim was to provide an easy to understand indicator of fishing pressure resulting from the act of governments giving taxpayer money to the fishing sector.

Total catch, annual average catch, 2014 catch and peak-year catch

We see, from Table 1, that between 1950 and 2014, a total of ~2.5 billion tonnes of fish were taken out of Asia's LMEs. The South China Sea alone contributed ~20% of this total, making this LME one of the top five fishing grounds in the world (Sumaila and Cheung, 2015). The East China Sea was the next biggest contributor with over 10% of the total catch in this period. The average annual catch in this period was ~38 million tonnes while the equivalent number for 2014 was ~55 million tonnes, revealing the much lower annual catches in the 1950s compared to 1970s.

Table 1: Total catch (1950-2014); annual average catch; 2014 catch; peak-year catch. Catch in million tonnes.

Large Marine Ecosystem	Total catch 1950-2014	Annual average catch	2014 catch	Peak year catch	Peak year
South China Sea	504.35	7.76	12.63	14.52	2003
East China Sea	288.28	4.44	6.71	6.84	2013
Bay of Bengal	282.51	4.35	7.37	7.60	2009
Kuroshio Current	159.96	2.46	1.95	4.14	1988
Sea of Japan/ East Sea	228.69	3.52	3.49	5.95	1986
Arabian Sea	207.31	3.19	5.29	5.41	2012
Yellow Sea	133.29	2.05	3.36	3.70	2013
Gulf of Thailand	157.75	2.43	2.88	4.14	2000

² This section is based on Sumaila (2018). Comparative Valuation of Asian Large Marine Ecosystems with emphasis on the East and South China Seas. Deep Sea Research II (*under review*).

Indonesian Sea	125.21	1.93	3.53	3.94	2004
Sea of Okhotsk	171.17	2.63	3.51	4.98	1990
Oyashio Current	114.02	1.75	1.92	3.54	1990
Sulu-Celebes Sea	68.67	1.06	1.94	1.94	2014
West Bering Sea	32.45	0.50	0.75	0.82	1996
Total all LMEs	2,473.66	38.06	55.31	67.53	

The last two columns of Table 1 present the peak-year catch (i.e., the year the largest quantity of catch was fished) and the peak-year for each of the 13 Asian LMEs. We see that the total peak-year catch for all the LMEs combined is ~68 million tonnes, which is ~24% more than the 2014 total catch, an indication that we are gone past the peak catch for Asian LMEs combined. This statement is supported by the fact that the peak-year for all LMEs, except the Sulu-Celebes Sea, occurred before 2014. For the massively important South China Sea and East China Sea LMEs, the peak years were reached in 2003 and 2009, respectively.

Total value, annual average value, 2014 value, peak-year value

Table 2 reports that between 1950 and 2014, the 13 LMEs of Asia generated a total of ~ 2.8 trillion USD of catch value. While the rankings of the different LMEs in terms of value have not changed compared to when viewed in terms of weight, we see that the catch value of the SCS and ECS LMEs are much closer in the case of the latter, an indication that on average the catch of ECS are more valuable per unit weight than those of the SCS.

Table 2: Total value (1950-2014); annual average value; 2014 value; peak-year value. Values in billion USD.

Large Marine Ecosystem	Total sumLV	Annual average	Value 2014	Value peak year	Peak year
South China Sea	584.90	9.00	18.69	21.94	2013
East China Sea	410.12	6.31	12.59	13.96	2013
Bay of Bengal	303.78	4.67	10.78	11.43	2009
Kuroshio Current	254.71	3.92	2.90	8.74	1988
Sea of Japan/ East Sea	242.48	3.73	5.13	7.14	1988
Arabian Sea	237.95	3.66	8.23	8.80	1992
Yellow Sea	170.29	2.62	4.92	7.99	2013
Gulf of Thailand	151.83	2.34	4.24	4.53	1996
Indonesian Sea	128.94	1.98	5.44	5.44	2014
Sea of Okhotsk	113.18	1.74	5.14	5.14	2014
Oyashio Current	89.69	1.38	2.81	2.994	1986
Sulu-Celebes Sea	76.57	1.18	2.89	3.07	2013
West Bering Sea	24.32	0.37	1.11	1.11	2014
Total all LMEs	2,788.77	42.90	84.87	102.22	

An interesting difference when looking at the catch in value versus catch in weight is that the gap between the average annual and 2014 values is wider than in the case of catches. Similarly, the difference between the peak-year and 2014 values is much bigger here than in the case of catch in weight. The reason for these differences is that the price and quantity effects on value exert themselves in opposite directions. The quantity effect captures the fact that when the quantity of a normal good, e.g. fish catch, decreases (or increases), the catch value also decreases (or increases), everything being equal. On the other hand, the price effect captures the change in the price of such a good due to the relationship between supply and demand: When the quantity of the good increases (decreases), everything being equal, the price of the good decreases (increases). Thus, the real effect of a drop in catch depends on whether the price or quantity effect dominates. In this case, the price effect is likely to be the main reason in explaining the results reported in Table 2.

Total subsidy and subsidy intensity

Fisheries subsidies are defined as financial payments from public entities to the fishing sector, which help the sector make more profit than it would otherwise (Sumaila et al. 2008). In recent decades, subsidies have gained worldwide attention because of their complex relation to trade, ecological sustainability, and socioeconomic development. It is widely acknowledged that global fisheries are overcapitalized, resulting in the depletion of fishery resources (e.g., Pauly et al. 2005; Sumaila et al. 2012) and that harmful subsidies are part of the reason for this state of affairs (Milazzo 1998; Sumaila et al. 2010).

In Table 3 we present the total subsidies and subsidy intensities (i.e., total subsidy divided by the total catch value generated by each LME in 2009). We see from this table that estimated subsidies, to the tune of over 1.5 billion dollars, were provided to fishing enterprises operating in the top three LMEs – East and South China Seas, and the Sea of Okhotsk. It is worth noting that subsidy intensities of over 30% were estimated for 5 out of the 13 Asian LMEs, which is a strong signal that, everything being equal, these LMEs face extra fishing pressure from these subsidies.

Table 3: Total subsidy (2009) and subsidy intensity.

Large Marine Ecosystem	Subsidies (USD billion)	Subsidy intensity
South China Sea	1.89	0.22
East China Sea	1.82	0.31
Sea of Okhotsk	1.61	0.42
Arabian Sea	1.07	0.31
Yellow Sea	0.89	0.26
Sea of Japan/ East Sea	0.76	0.38
Bay of Bengal	0.70	0.14
Kuroshio Current	0.65	0.48
Sulu-Celebes Sea	0.41	0.31
Oyashio Current	0.34	0.42
Indonesian Sea	0.30	0.18
West Bering Sea	0.23	0.38
Gulf of Thailand	0.16	0.17

Discussion

We have provided, in this Section, an overview of the catch and values provided by the 13 Asian LMEs over the recent past as well as the subsidies provided by governments of the countries bordering these important ecosystems. In a nutshell, this analysis shows that the Large Marine Ecosystems of Asia, just like in other parts of the world, are providing valuable nutritional and food security to people, boosting the economics and livelihoods of people living in Asia and around the world. At the same time, they are facing threats from overcapacity, overfishing, climate change and other stressors, and therefore need urgent action to restore and effectively manage them for the benefit of both current and future generations of people.

Indicators of the current state of the East and South China Seas

East China Sea³

The East China Sea (ECS) Large Marine Ecosystem is situated in the western Pacific Ocean. It is a semi-enclosed marginal sea spanning an area of 744,000 km², and its boundaries are approximately 25° to 40° North and 119°31' to 129°30' East (Fig. 1). It is bounded to the north by South Korea's Jeju Island, to the east by Japan's Ryuku and Kyushu Islands, to the south by Taiwan (China), and to the west by mainland China. The ECS LME is relatively shallow, with an extensive continental shelf which accounts for nearly 80% of its total area; it has an average depth of 370m, and a maximum depth of 2332m. The ECS has a complex hydrology due to the influences of the Kuroshio Current, Kuroshio Branch Current, China Coastal Water, and Changjiang Diluted Water. The influence of these currents and water masses provides the ECS with high primary productivity during summer, making it a vital spawning and nursery ground for commercially valuable fish such as small yellow croaker (*Larimichthys polyactis*), hairtails (*Trichiurus* spp.), pomfret (*Pampus* spp.), and white Chinese croaker (*Argyrosomus* spp.). The region's rugged coastlines and well-developed continental shelf makes it suitable for marine fisheries and coastal aquaculture of finfish, shellfish, and seaweed. In addition, the ECS is characterised by high biodiversity, with up to 12,933 tropical and subtropical species. Importantly, almost half (48%) of ECS species are endemic.

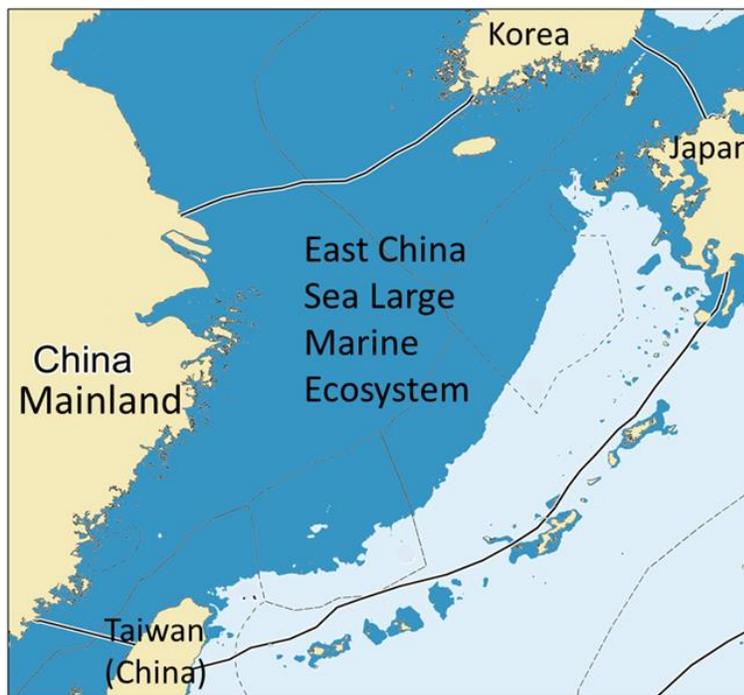


Fig. 1. Map showing the East China Sea Large Marine Ecosystem bounded by solid black lines. Map modified from *Sea Around Us*.

South China Sea⁴

The South China Sea LME covers an area of about 3.4 million km² in the western Pacific Ocean. Its southern part lies on the Sunda Shelf and contains coral reefs in waters less than 200 m in depth, while further north there are basins with depths reaching almost 5,000 m. The SCS includes over 200 islands and islets, and touches the coastlines of China, Hong Kong, Macau, Taiwan (China), Philippines, Malaysia, Brunei, Indonesia, Singapore and Vietnam (Fig. 2). The SCS is biologically diverse but knowledge of its marine fauna is relatively incomplete.

³ Based on Teh et al. (2018). Report on East China Sea submitted to ADM capital Foundation.

⁴ Based on Teh et al. (2017) and Sumaila & Cheung (2015).

The most comprehensive list of marine fishes in the SCS lists 3365 species in 263 families (Randall & Lim 2000), although pelagic and abyssal fishes are poorly represented.



Fig. 2. Map of the South China Sea (SCS). Note that the Gulf of Thailand is included as part of the SCS in this study. (Source: U.S. Energy Information Administration 2013).

Indicators for the East China Sea and South China Sea LMEs

In terms of productivity, a total of 504 and 288 million tonnes of fish were taken from the SCS and ECS large marine ecosystems, respectively, between 1950 and 2014 (Table 3). Even though the trade data available does not tell us what is actually caught from the ECS and SCS Large Marine Ecosystems, it reveals how important Asia is with regards to fish trade overall. The countries of the SCS and ECS engage heavily in fish trade via both exports and imports. As shown in Table 3, the total annual export and import value of fish from the SCS and ECS are USD 56 billion and USD 40 billion, respectively (Sumaila and Cheung, 2015; Teh et al. 2017). Clearly the food security, economic, and social value of the fisheries of these important Asian LMEs cannot be over-emphasized.

Of the 3.2 million fishing vessels operating in marine waters worldwide (Sumaila and Cheung, 2015), over half operate in the SCS and ECS (Table 4). This is huge given that the catch from these two LMEs is far less than 50% of the global total catch (Pauly and Zeller, 2016). This huge overcapacity is an indication of ineffective management of the two LMEs, which is confirmed by the management performance indicators presented in Table 4. We see from this table that for both LMEs, the peak-years are in the past (2003 and 2013 for SCS and ECS) and the peak-year catches are below the 2014 catch. As to be expected, this overcapacity has, over the years, resulted in significant drops in catch per unit effort - by up to 4 times in the case of the ECS (Table 4).

Compounding the problems of ineffective management are public policies such as subsidies and the problem of illegal, unreported and unregulated fisheries: Table 4 shows that both subsidies and unreported catches are issues for the East China Sea and South China Sea LMEs, with subsidy intensity of up to 31% in the SCS, and the proportion of unreported to reported catches of up to 50% in the case of the SCS.

Table 4: Indicators of productivity, trade and management performance.

Indicators	SCS LME	ECS LME	Source
Productivity			
Catch (million tonnes)*	504	288	Pauly & Zeller (2016)
Value (million USD)*	585	410	Tai et al. (2017)
Trade			
Exports (billion USD)**	39	17	Teh et al. (2018) for ECS;
Imports (billion USD)**	18	22	Sumaila & Cheung (2015) for SCS
Fishing capacity			
No. of vessels (thousands)	1,770	316	Teh et al. (2018) for ECS;
No. of jobs (millions)	3.7	2.0	Sumaila & Cheung (2015) for SCS
Management performance			
Peak year	2003	2013	<i>Sea Around Us</i> database
Peak year catch (million tonnes)	14.5	6.8	<i>Sea Around Us</i> database
2014 catch (million tonnes)	12.6	6.71	<i>Sea Around Us</i> database
Catch per unit effort decline in past few decades	3-4 times	~ 3 times	Teh et al. (2018) for ECS; Sumaila & Cheung (2015) for SCS
Subsidy intensity	0.22	0.31	Sumaila et al. (2016)
Unreported portion of total catch	0.50	0.12	Teh et al. (2018) for ECS; Sumaila & Cheung (2015) for SCS

* Quantity of fish caught in the South China Sea and East China Sea between 1950 and 2014

** Annual numbers

Conclusion

The computed and presented indicators on productivity, trade, fishing capacity and management performance, for the South China Sea and East China Sea LMEs highlights the food security, economic, and social importance of marine ecosystems of Asia, and the threats these ecosystems are facing from overfishing and ineffective management.

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Chapter 2. Taking Stock: Status and Trends of East China Sea Fisheries

Louise S.L. Teh, Tim Cashion, William Cheung, U. Rashid Sumaila

Abstract

The East China Sea (ECS) Large Marine Ecosystem is one of the most important fishing grounds in the west Pacific, and is bordered by 4 large fishing nations – China, Korea, Japan, and Taiwan. The dominant player in ECS fisheries is China, in terms of production quantity, number of people employed, and trade. The ECS is the most productive of China's four seas, contributing almost 40% to China's annual marine capture fisheries in recent years. As such, the ECS is also of significant importance to global fisheries, given China's leading role in worldwide marine fisheries production. Fisheries play a crucial food provision, economic, and cultural role in ECS countries; hence the sustainability of ECS fisheries resources and marine habitats is paramount to the future social-economic well-being of the region. However, intense fisheries development and exploitation over the past four decades has depleted fisheries stocks and changed the structure of ECS marine ecosystems. There has been a clear shift from valuable demersal fisheries to lower value pelagic fisheries. A decline in the mean trophic level, as well as a reduction in the size of captured fish has been observed throughout the ECS, and highlights the biological and ecosystem impacts of fisheries overexploitation. At the same time, rapid economic development and urbanisation in ECS countries has resulted in high levels of coastal pollution and habitat destruction and loss, thereby exacerbating the effects of overfishing. In particular, inshore fisheries resources are largely depleted – this has serious livelihood consequences for the estimated ECS fishing population of around 1.4 million, the majority of whom are engaged in small-scale fisheries.

At the national level, all ECS countries have implemented management measures to rebuild fisheries; however, overcapacity is still a persistent issue for the region's fisheries. Moreover, despite multiple bilateral fisheries management agreements between China, Japan, and Korea, ongoing territorial and political disputes inhibit multilateral management of the region's fish stocks. The lack of cooperative, multilateral management is a large barrier towards sustainable management of the ECS' commercially important fisheries stocks, many of which are migratory and move between the exclusive economic zones of ECS countries. The future of ECS fisheries also faces uncertainties arising from climate change, which has already been associated with shifts in species distribution and hence affected the spatial distribution of fishing effort.

While the fisheries of individual ECS countries have been extensively documented, there is a gap in recent studies which provide a cohesive assessment about the status and socio-economic importance of fisheries at the Large Marine Ecosystem level. The objective of this study is to fill the existing gap by providing a review about the recent socio-economic, governance, and biological status of, and threats to, ECS fisheries at the LME level. This allows us to identify the societal and ecological consequences of continued fisheries unsustainability in the ECS. By doing so, this study aims to provide an impetus for encouraging multilateral cooperation in ECS fisheries management in order to reduce present threats, rebuild fisheries, and manage future social-ecological and environmental risks. This is essential in order that ECS marine ecosystems are resilient and fisheries resources can continue to support the region's human, social, and economic well-being into the future.

Introduction

The East China Sea (ECS) Large Marine Ecosystem is situated in the western Pacific Ocean. It is a semi-enclosed marginal sea spanning an area of 744,000 km² (Heileman and Tang 2008), and its boundaries are approximately 25° to 40° North and 119°31' to 129°30' East (Fig. 1). It is bounded to the north by South Korea's (Korea

hereafter) Jeju Island, to the east by Japan's Ryuku and Kyushu Islands, to the south by Taiwan (China) (hereafter Taiwan)⁵, and to the west by Mainland China (hereafter China). The ECS is relatively shallow, with an extensive continental shelf which accounts for nearly 80% of its total area; it has an average depth of 370m, and a maximum depth of 2332m. The ECS has a complex hydrology due to the influences of the Kuroshio Current, Kuroshio Branch Current, China Coastal Water, and Changjiang Diluted Water (Chang et al. 2012). The influence of these currents and water masses provides the ECS with high primary productivity during summer, making it a vital spawning and nursery ground for commercially valuable fish, such as small yellow croaker, hairtail, pomfret, and white Chinese croaker (Lin et al. 2016). The region's rugged coastlines and well-developed continental shelf makes it suitable for marine fisheries and coastal aquaculture of finfish, shellfish, and seaweed (Kang 2006). In addition, the ECS is characterised by high biodiversity (Liu 2013a), with up to 12,933 tropical and subtropical species. Importantly, almost half (48%) of ECS species are endemic (Ding et al. 2008).



Fig. 1. Map showing the East China Sea Large Marine Ecosystem bounded by solid black lines. Map modified from *Sea Around Us* (www.searoundus.org).

As one of the most important fishing grounds in the west Pacific, the ECS has historically been fished by China, Japan, and Korea. Heavy exploitation of ECS fisheries has occurred since the 1980s, and the fisheries sector continues to play a key economic and food security role for ECS countries (Chen et al. 1997; Kang 2006; Li and Zhang 2012; Li 2015). Rapid and large-scale industrialization in East China Sea countries has had a huge effect on the region's marine and coastal environment and fisheries resources (Zhang 2016b). China, Japan, and Korea make up the first, second, and fourth largest economies in the Asia Pacific in terms of GDP, respectively, while Taiwan comes in as the 7th largest (IMF 2017). The population in coastal areas bordering the ECS totalled approximately 217 million⁶ in 2015. Given that China accounts for over 90% of ECS population, its human

⁵ Hereafter, Taiwan (China) is referred to as Taiwan and Mainland China is referred to as China.

⁶ East China Sea population was estimated by summing up the population living in prefectures or districts bordering the ECS in China, Japan, Korea, and Taiwan. The population breakdown is as follows:

China: 197,690,000 (Shanghai municipality and Jiangsu, Zhejiang, Fujian provinces) Source: China Statistics

environmental footprint is also large. Indeed, the Changjiang (Yangtze) Delta in China is the most industrial and densely populated area in the ECS LME (Heileman and Tang 2008), and the ECS is the most heavily polluted of China's maritime territories (Ding et al. 2008).

As urban coastal populations have grown, competition for the ECS's shared fish stocks have intensified; fish catch rates started to decline in the 1970s, and fell more sharply in the mid -1980s (Rosenberg 2005). The governments of all four ECS countries have implemented various programmes and regulations to reduce fishing capacity and fishing effort over the past two decades. The Chinese government imposed a summer fishing moratorium for the northern ECS since 1995 (Cao et al. 2017a), but there have been inconclusive results about the effectiveness of the moratorium. Surveys carried out in the 2000s suggest that the moratorium had no effect on fish community structure and ecological function (Jiang et al. 2009). While each ECS country has its own fisheries management approach, there is an absence of an LME wide, collaborative management for ECS fisheries. ECS fish stocks, due to their migratory behaviour, cannot be managed effectively without co-operation among the ECS coastal states (Kang 2006). However, multi-lateral cooperation is complicated by territorial disputes (Ou and Tseng 2010).

On top of anthropogenic stressors, the ECS has experienced abrupt ocean warming, with sea surface temperature increasing at a rate of 1.41 °C per decade, which is >10 times the global rate (Belkin 2009). The synergistic effects of hypoxia, eutrophication, and ocean warming may aggravate the impacts of overfishing, thus increasing the risk of fisheries depletion in the ECS. Against this backdrop, it is clear that improved management of ECS fisheries resources is necessary. Achieving fisheries sustainability in the ECS will not only support ecological and social-economic benefits, but also contribute to helping countries progress towards the United Nations' Sustainability Development Goals. To help inform this process, our study aims to provide a review of the present status of ECS fisheries, and based on this, investigate the potential ecological and socio-economic outcome for ECS fisheries under different fisheries management scenarios. This study will ultimately provide an understanding about the trade-offs involved in following the present fisheries trajectory, or taking steps towards improved management of fisheries and marine resources.

East China Sea Fisheries

Overview

The East China Sea (ECS) is one of the most productive and important fishing grounds in the west Pacific, and has been historically fished by China, Korea, and Japan. For the 3 decades spanning 1976-2007, the ECS accounted for around 44% of Taiwan's total fisheries production and 40% of landed value (Chen and Lee 2013). In the past decade, approximately 38% of China's total marine fish catch is from the ECS, while it accounted for about 12% of Japan's total national catch (based on 2011-2013 data). From 2000-2017, adjacent water fisheries from administrative divisions bordering the Korean ECS contributed 26% to total national fisheries production and 70% to total national adjacent fisheries production ⁷.

ECS fisheries are multi-gear and multi-species. Major targeted fish stocks in the East China Sea include inshore, offshore, and migratory species (Table 1). Many commercially important species, such as hairtail and Pacific herring, migrate across EEZ boundaries; in addition, spawning and wintering grounds straddle the jurisdictional lines of different countries (Kang 2006). Consequently, cooperative management of ECS fisheries is essential. Among ECS countries, China is the biggest fishing nation; ECS fisheries also make the largest national

Japan: 12,184,000 (Fukuoka, Saga, Nagasaki, Kumamoto, Kagoshima, Okinawa prefectures) Source: Japan Statistical Yearbook 2017

Korea: 623,332 (Jeju island) Source: Korea Statistics

Taiwan: 6,499,071 (New Taipei, Taoyuan, Keelung, Yilan districts) Source: Taiwan National Statistics

⁷ It is important to note that some of the catch reported from administrative divisions adjacent to the Korean ECS may be caught from other Seas of Korea's EEZ (i.e., Yellow Sea, East Sea) (see p. 12).

contribution to China relative to other fishing grounds. ECS fisheries expanded rapidly in the 1970s, with heavy exploitation occurring since the 1980s (Chang et al. 2012). In fact, overfishing in Zhoushan, China’s primary ECS fishing ground, already occurred as early as the 1920s during the Sino-Japanese fishing war, as well as from local interprovincial disputes in the 1930s and 1940s (Muscolino 2010).

Table 1: Types of fish species in the East China Sea LME (Modified from Kang 2006)

Fish Type	Spawning characteristics	Fish species
Inshore	Spawn and grow up along coasts and migrate inshore locally	Lizardfish, butterfish, black croaker, large yellow croaker, pomfret
Offshore	Spawn offshore, inhabiting deep continental margin year round and migrate locally	Yellow porgy
Migratory	Spawn and grow up in shallow coastal waters, migrate for food and overwintering offshore	Small yellow croaker, hairtail, red seabream, Pacific herring, flatfishes, fleshy prawn, sharp toothed eel

Threats

Overfishing remains a primary threat to East China Sea fisheries resources. All ECS countries have management measures in place to regulate fisheries (see Section 2 on Governance for details). Nevertheless, despite numerous national programmes to reduce fishing effort, overcapacity is still an overarching problem for ECS fisheries. Excess capacity is a key driver of illegal, unreported, and unregulated (IUU) fishing in the ECS, which occurs both at national and international scales. Domestically, IUU fishing involves using illegal gear (e.g., poison, explosives, electric gears) or catching prohibited or undersized species, fishing during closed seasons or in closed areas, and fishing without licences. In China, it was found that around 70% of boats without proper licences were small-scale boats (Yu and Yu 2008), suggesting that dwindling resources resulting from excess capacity is leaving small-scale fishers with no choice but to break regulations. At the regional scale, intrusion of ECS fishing boats into each other’s EEZs is a recurring problem arising from ongoing territorial disputes (Yu and Yu 2008; Goldstein 2013; Zhang 2015a; MAFF 2017).

High population levels, coupled with rapid and large-scale industrialization in ECS countries have also heavily impacted the region’s marine and coastal environment and fisheries resources (Zhang 2016b), especially in the Chinese ECS. The main pollutants in the Chinese ECS are nitrogen and phosphorus, with heavy metal, hydrocarbon, and microbiological pollution also affecting localised areas (Ding et al. 2008). Land based pollution such as sewage, nutrients, and sediment enter the sea with river runoff, and is particularly bad given the enormous human population of Chinese provinces adjacent to the ECS, which in 2015 reached almost 198 million (National Bureau of Statistics of China 2018). Nutrient over-enrichment leads to eutrophication and algal blooms - the frequency of red tide events rose from less than 10 in 1930s to over 80 per year in the 2000s (Chang et al. 2012). In addition, pollution has led to recurrent events of hypoxia over increasingly large areas around the Changjiang estuary (Zhang 2016b). Introduction of alien species and habitat modification have also seriously impacted ECS coastal ecosystems and species. In China’s coastal regions, reclamation of tidal wetlands, which serve as essential feeding and foraging habitat for fish and invertebrates, is the biggest driver of habitat loss (Ding et al. 2008).

Massive loss of coastal wetlands in China illustrates the temporal decline in ECS habitat quality. From 1950 to 2014, China lost 58% (8×10^6 ha) of their coastal wetlands (Sun et al. 2015). In particular, coastal wetlands in the ECS bordering provinces of Jiangsu, Zhejiang, and Fujian showed significant decrease (Sun et al. 2015, see Appendix Fig. A1). Moreover, the length of seawalls throughout China’s coastline increased 3.4 times over the past decades, reaching 11,000 km in 2010 and exceeding the length of the Great Wall of China (Ma et al. 2014).

Drivers behind wetland loss include increasing demand for land, lack of understanding about coastal wetland values, weak environmental laws and regulation, and misguided reclamation policies (Sun et al. 2015). This massive reclamation and conversion of coastal wetlands has reduced biodiversity and associated ecosystem services, produced pollutant sources, deteriorated inshore and oceanic environments, and overall contributes to making people vulnerable to extreme weather events (Ma et al. 2014).

On top of anthropogenic activities, climate effects have already had an impact on ECS fisheries (Rebstock and Kang 2003; Kim et al. 2007). For example, Ho et al. (2016) showed that changes in seasonal catch of migratory species in Taiwan coincided with trends in sea surface temperature (SST) fluctuations. Increases in SST may also have reduced catches and shifted fishing grounds for Grey Mullet north of the Taiwan Strait (Lan et al. 2014). The occurrence of major climate events such as typhoons can cool sea surface temperatures and enhance upwelling, thereby changing local fish communities and consequently, fishing activities. This occurred in Taiwan, where major target fish species changed from skipjack tuna pre-typhoon to squid post-typhoon; subsequently, major fishing grounds of the Taiwanese torchlight fishery shifted northwards from the northern tip of Taiwan to the southern ECS (Chang et al. 2014). Further, in Korean waters the major fishing grounds for hairtail shifted northwards closer to Jeju Island during the 2000s in response to changes in sea water temperature (Jung et al. 2014). This subsequently benefited the local coastal fishery due to decreased fuel costs; however, climate driven range shifts are expected to make artisanal and coastal fisheries less competitive relative to industrialised fisheries (Jung et al. 2014). Therefore, climate variation may not only change the structure of marine ecosystems, but also impact fishery economy and livelihoods in the ECS.

Country Overviews

China

Fishing is a traditional activity in China, where numerous cultural festivals are associated with fishing, and fishery production methods are handed down from generation to generation by traditional fishers settled mainly along the coast, rivers, and lakes (Guo et al. 2008). China's fisheries have experienced dramatic growth since the country's Reform and Opening Up in 1978. Over the past 3 decades, the total value of China's fishing industry has increased by more than 850 times, while annual fishery production increased by more than 13 times (Zhang, HZ 2015). Driven by urbanization and rising wealth, China's per capita seafood consumption has increased seven-fold since 1978, rising from around 5 kg/capita/year to 35 kg/capita/year in 2013 (Fabinyi 2016), and increased further to around 42 kg/capita/year in 2016 (OECD/FAO 2017). The consequent development and intense exploitation of China's fisheries resources has significantly changed the structure of Chinese fishery production in the past 30 years. First, fish production has shifted from capture fisheries to the current situation where 74% of the country's fish production is derived from aquaculture (China Fishery Yearbook 2015). At the same time, capture fisheries have shifted from inshore to offshore focused - in the mid-1980s almost 90% of marine catches were from inshore areas, whereas by the early 2000s inshore areas only contributed around 65% of total marine catches (Zhang, HZ 2015).

The East China Sea constitutes one of the four China Seas, and is bordered by Fujian, Jiangsu, and Zhejiang provinces, and Shanghai municipality. There are six main fishing grounds in the ECS. Zhoushan and Lusi, situated off northeastern Zhejiang Province and on the northern bank of the Yangtze River mouth, respectively, are the country's largest fishing centres. In particular, Zhoushan is the leading fishing ground among China's South China Sea, East China Sea, and Yellow Sea (Wang and Zhan 1992).

The fishing sector contributed 10.2% in economic value to China's agricultural sector in 2015 (China Fisheries Yearbook), representing a substantial increase from 1.6% in 1978 (Zhang 2015b). The relative importance of the

fishing sector is even higher in the ECS provinces, where fishing contributed 17.1%, 21.6%, 29.2%, and 29.1% to the agriculture output of Shanghai, Jiangsu, Zhejiang, and Fujian, respectively.

A wide variety of gears are used in the ECS. The main fishing gears include: i) Trawls, including otter and pair-trawling; ii) Purse seines using single, double, and multi-boat seiners; iii) Gillnets, including fixed, drift, surrounding, and dragging gillnets; iv) Stow nets, including frame swing-net, two-stock swing net, multistick swing-net, single-anchor stow-net, two-anchor stow-net, boat swing-net, wall swing-net; v) Lines, including drift longline, set longline, troll-line, and squid jigging. Other gears include beach seine, lift-nets, traps, and pots.

Inshore areas are reserved for small-scale gears such as stow nets, gill nets, and lines, which are done mainly from boats ranging from 25 to 125 GT. Offshore fishing is reserved for large-scale purse seines and trawl vessels ranging from 150 to 650 GT (Chen et al. 1997). Trawlers are the dominant gear in the ECS, accounting for almost half of all landings (Kang 2006; Szuwalski et al. 2017). Greater and little yellow croakers, hairtail, and cuttlefish are the four traditional species which formed the foundation of Chinese marine fisheries (Wang and Zhan 1992). While around 200 fish species are targeted commercially in ECS fisheries (Liang and Pauly 2017), only about 30 make up the bulk of the catch (Ding et al. 2008).

Fisheries development in China was slow until the 1950s, after which increases in fishing capacity and expansion into new fishing grounds resulted in steadily increasing landings (Ding et al. 2008). At the same time, the ECS fishery, which was entirely coastal prior to 1965, progressively moved offshore in the 1970s and 1980s, while total effort (measured in hours/year) increased by almost 215% from 1974-1980 (Chen et al. 1997). The ECS currently accounts for about 40% of China's total landings.

China's ECS landings have generally increased continuously since the 1950s to early 2000s, at which point there was a decline and then maintained at a consistent level of about 2 million t per year since 2008. This can be seen from historical trends of Chinese ECS landings compiled in two separate studies (Fig. 2 and 3). Fig. 2 shows that landings increased from less than 750,000 t in 1956 to a peak of around 2,750,000 t by early 1990s, an increase of over 250%. Continuing this trend, Fig. 3 shows a steep increase from 1992 to the late 1990s, with landings peaking at over 3.5 million t, then falling and maintained at a lower level of around 3 million t per year since 2009 (Note that ECS landings were made up of Zhejiang, Jiangsu, Fujian, and Shanghai landings in the Chen et al. 1997 study; however, Shanghai was not included in the ECS landings by Liang and Pauly (2017), resulting in overall lower catches for the overlapping years covered in both studies). Prior studies have indicated that China's catches are over-reported (Watson and Pauly 2001), but a recent analysis suggests that the persistent high catches reported for China and the ECS may be explained by intense fishing that induced an increase in the productivity of smaller 'low value' fish due to the removal of 'valuable' larger fish (Szuwalski et al. 2017).

Based on interviews conducted at fishing ports, a recent study found that trash fish caught by trawlers in Jiangsu, Zhejiang, and Fujian provinces accounted for on average, 32%, 48%, and 34%, respectively, of total catch. The proportion of trash fish in ECS provinces' catch is comparatively lower to other provinces, where trash fish made up to 66% of the catch (Greenpeace East Asia 2017).

In 2014, there were 231,924 motorised fishing vessels recorded in the 4 ECS provinces, accounting for about 34% of China's total motorized vessels (China Fishery Yearbook 2015). Nation-wide, China's fishing fleet is primarily made up of small-scale fishing vessels (Chen and Tang 2014). Of China's motorized vessels, over 80% were below 12 m in length, indicating that the large majority of fishing boats are used for small-scale, inshore coastal fishing. Moreover, non-motorised vessels accounted for 55% of China's total fishing vessels (China Fishery Yearbook

2015). It is reasonable to assume that all non-motorised vessels are also restricted to small-scale fishing. Thus, based on the number of registered vessels alone, it is clear that China’s fishing fleet predominantly operates in inshore, coastal areas. Nation-wide, there were 8,416 fishing villages in 2016, and 6.6 million traditional fishers (China Fishery Yearbook 2017).

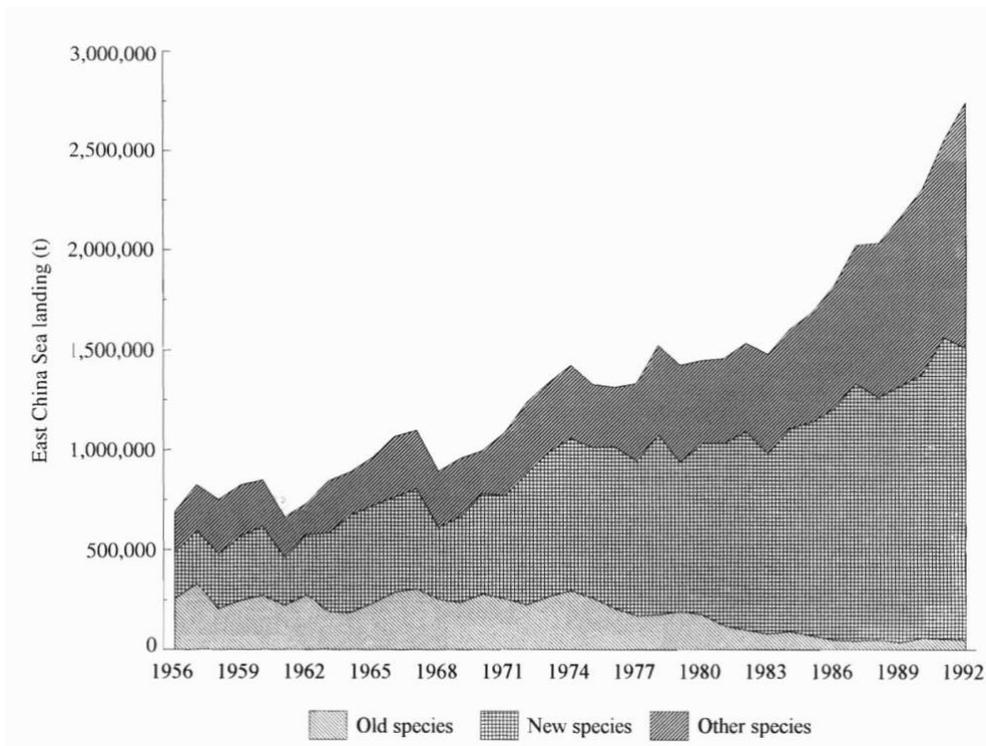


Fig. 2. Landings from the Chinese East China Sea 1956-1992. Old species = low volume, high value species, New species = high volume, relatively low value species, Other species = low value species used primarily for aquaculture feed and fish meal (Source: Chen et al. 1997)

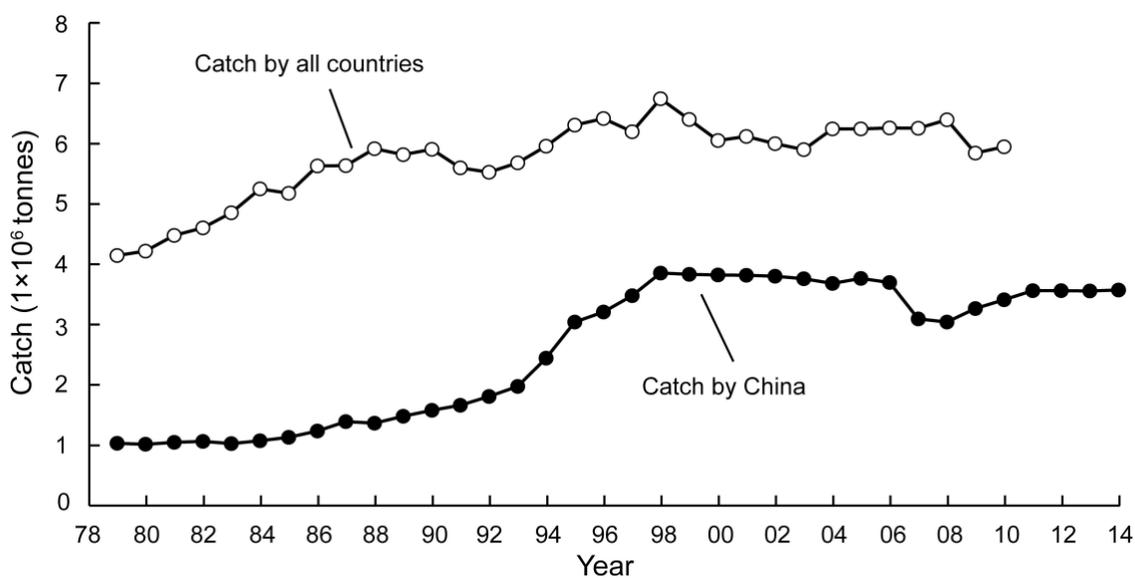


Fig. 3. Time series of China’s catches from the ECS LME and catch by all countries whose fleets operate in the ECS (Source: Liang and Pauly 2017).

Surveys conducted at coastal fishing villages and fishing ports in ECS provinces found that the small-scale sector faces numerous challenges compared to the commercial, large-scale sector, including backward fishing infrastructure, low safety at sea, and inadequate management which does not consider the special needs of small-scale fisheries (Chen and Tang 2014). Moreover, due to rising competition for dwindling marine resources, small-scale fishers face serious livelihood and economic difficulties (Liu and Gao 2009), which is exacerbated by being largely excluded from social welfare systems (old-age pensions), and inability to switch occupations (Chen and Tang 2014).

Nevertheless, this situation is not reflected in national statistics, which instead shows a predominantly steady temporal increase in per capita net income for fishermen – for all 4 ECS provinces, net income increased over 200%, from RMB 6,300 in 2000 to RMB 20,700 in 2015 (Fig. 4). Average increase for the period 2000 – 2015 was 11%, 12%, 6%, and 9% in Shanghai, Jiangsu, Zhejiang, and Fujian, respectively (Fig. 4); in comparison, average increase for the whole of China was 8% for the period. This positive trend in net income is likely due to the aggregated nature of the data, which does not separate small-scale from commercial large-scale fishermen.

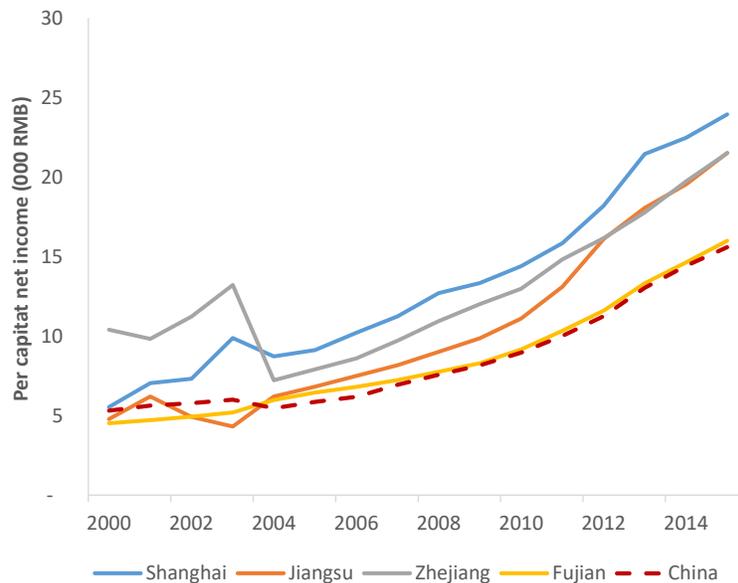


Fig. 4. Temporal trend in per capita net fishing income for ECS provinces and China, 2000-2014.

Japan

Fisheries have been an integral part of Japanese culture and tradition since ancient times, and Japan is one of the largest seafood consumers in the world (Makino 2011). There are more than 5,000 fishing communities along Japan’s 35,000 km coastline (Makino 2011). The Japanese portion of the East China Sea consists of the waters surrounding the western part of Kyushu Island and the Ryuku Islands, located in the southern part of Japan. These areas include the prefectures of Fukuoka, Kagoshima, Kumamoto, Nagasaki, Saga, and Okinawa.

Fisheries products provide the largest source of animal protein intake for the average Japanese (Makino 2011). In 2014, consumption of fish and fishery products was 27.3 kg/capita/year (MAFF Annual Report 2015). Although the fisheries sector makes a very small contribution to Japan’s national economy (less than 1% of GDP), it plays a crucial role by acting as a source of employment and key industry supporting the local economies of fishing communities (Makino 2011; MAFF Annual Report 2015), especially in isolated island areas where alternate employment opportunities are limited.

Capture fisheries in Japan are categorised as coastal, offshore, distant-water, and inland. Coastal fishing is mainly small-scale, which takes place at fishing grounds close to shore. These fisheries are mainly done by family run fishing operations using small-scale vessels of less than 10 gross tons (Makino 2011). Almost 80% of all fishery workers in Japan are engaged in coastal fishing, which also includes marine aquaculture (MAFF Annual Report 2015). Offshore fisheries are industrialised fisheries which operate within the Japanese EEZ using vessels up to 100 gross tons. There have been multiple conflicts between coastal and offshore fisheries due to the higher catching efficiency of the industrial fishing vessels. Distant-water fisheries are highly industrialised, and operate in the high seas and EEZs of other countries. Offshore fisheries make the biggest contribution to Japan’s annual fisheries production in terms of quantity, whereas the contribution of distant-water fishing has been gradually declining (MAFF 2015).

Marine fisheries catch from ECS portion of Japan makes up about 12% of total national catch (based on 2011-2013 data). The ECS is highly important socio-economically, as 65,740 household members, accounting for 25% of Japan’s total fishery household members, resided in the ECS in 2014 – this makes it the sea region which accounts for the largest proportion of Japan’s fishery household members (Fig. 5).

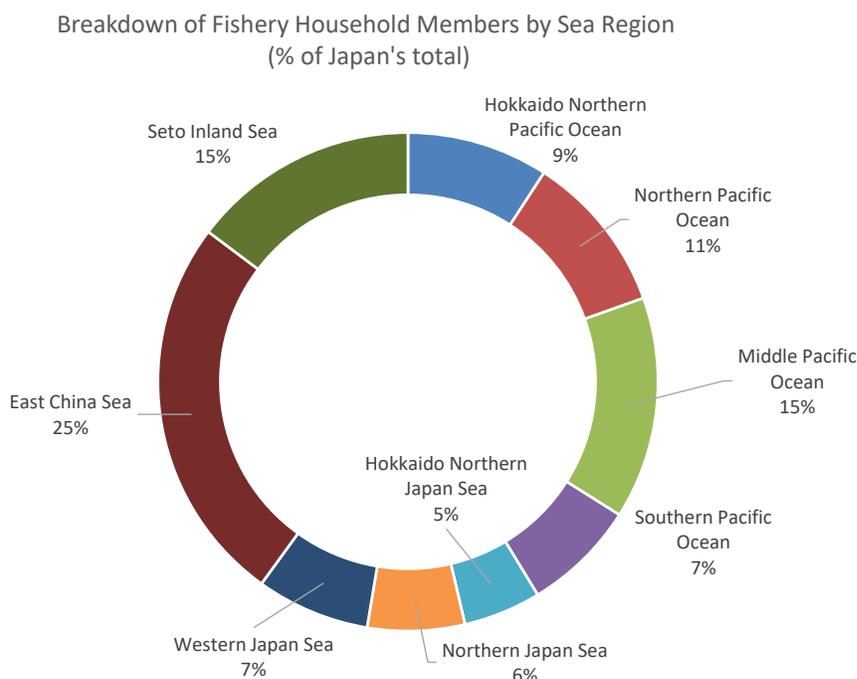


Fig. 5. Breakdown of fishery household members by sea region in Japan, 2014. Derived from MAFF 90th Statistical Yearbook (2015).

Throughout Japan, the number of fishers, as well as fisheries production, has been declining (MAFF Annual Report 2015). The number of fishery household members has steadily declined, dropping from 321,590 in 2010 to 259,690 in 2014 – a decrease of 20%. At the same time, coastal fishing production per fisher has been increasing gradually over the past 20 years, from 11.4 t/capita in 1993 to 14 t/capita in 2013. However, despite increased revenue, the income of coastal fishing households has been declining since 1994 due to increasing fishing costs. Similar to Korea, the fishing community population is decreasing; the number of fishery workers in Japan has been dropping since the 1980s, and is predominantly made up of old workers (MAFF Annual Report 2015). According to the latest Fisheries Census of 2013, 85% of fishery household members working at sea in Japan’s ECS region were over 50 years old.

South Korea

The East China Sea is one of 3 marine ecosystems – along with the Yellow Sea and Japan/East Sea - surrounding the Korean peninsula. The Korean ECS is mainly pelagic (Zhang et al. 2007) and consists mostly of warm water fauna; it has comparatively higher species diversity than the Korean Yellow Sea (Rebstock and Kang 2003). The main fishing grounds in the East China Sea are around the island of Jeju off the southern tip of the Korean peninsula. Fishing has a long tradition in Jeju Island, which is known for the *Haenyeo*, female divers who free dive to collect invertebrates and seaweed as a way of supporting their families through many centuries. This area is also an important spawning ground and migratory route for commercially important fish such as hairtail and chub mackerel (Kim et al. 2007). Fish catches per unit area were higher in ECS (3.92 t/km²) than in Yellow Sea (2.25 t/km²) (Rebstock and Kang 2003).

In this study we included four administrative divisions – Busan, Jeollanam-do, Gyeongsangnam-do, and Jeju-do, as the areas bordering the Korean East China Sea. It should be noted that while these administrative divisions represent the areas adjacent to the East China Sea, Korean fishing vessels are allowed to fish anywhere within the Korean EEZ, and unload their catch at any fishery port. As such, fish caught in the Korean Yellow Sea or East Sea can also be unloaded at ports of the ECS administrative divisions, especially at Busan, a major port where most of the catch by Korean fishing vessels is unloaded and traded. Nevertheless, as saving fuel cost is a priority for Korean fishers, they normally prefer ports closer to their home base. Thus, catch data from the ECS administrative divisions can roughly represent the catch by Korean fishing vessels in the Korean East China Sea (S. Jung, pers. comm.)

Korea's fishery sector plays an important role in the national supply of animal protein (Teng 2007), even though fisheries contribute less than 1% to the country's economy (Shon et al. 2014). Seafood is regularly consumed by most Koreans, and annual per capita seafood consumption in 2013 was 53.8 kg (Yoo 2016); of this, 68% (36.4 kg) was fish and shellfish products, with the remainder being seaweed. In contrast, a much lower consumption rate of 26.5 kg/person/year was provided in Shon et al. (2014) for 2007. The major seafood species consumed are anchovy, shrimp, squid, tuna, Alaskan Pollack, mackerels, yellow corvina, saury, hairtail, flat fish, monk fish, eel, rock fish, and cod (Yoo 2016).

Korean fisheries can be divided into an offshore and inshore sector, as well as a sizable distant water fleet. Offshore fisheries include trawl, purse seine, anchovy drag nets, offshore angling, offshore gill nets, large stow nets, diving, offshore traps, dip nets, shellfish dredge nets, and offshore long lines. The inshore coastal sector consists of coastal purse seines, coastal angling and lift nets, coastal gill nets, coastal traps, set nets, coastal beam trawls, and large coastal stow nets. The majority of Korea's fisheries are small-scale fisheries which operate in the coastal sector, with over half the registered vessels in Korea classified as small-scale vessels (Lee and Midani 2014).

Before the 1960s, fishing activity in Korea was limited by war and social unrest. Fish catch during this period was dominated by cod. Beginning in the mid-1960s, the introduction of new fishing technology in conjunction with economic development rapidly expanded Korea's fisheries, such that catch increased by over 350% between 1965 and 1996 (Hyun et al. 2005). Rapid expansion and industrialization of Korean fisheries occurred in the mid-1970s, driven by fishery promotion and export, distant water operations, and high national and international demand for fish (Hyun et al. 2005). Small yellow croaker was the most caught species during this period. From the early 1980s to 1990s, Korea's technology intensive economic growth corresponded to a noticeable change in the type of species caught – from demersal to pelagic. During this period and onwards, pelagic species such as saury, sardine, and chub mackerel dominated the catch (Hyun et al. 2005), but were subject to population fluctuations. For instance, sardine and filefish (*Navodon modestus*) catches declined in the northern ECS in the

1990s, while anchovy (*Engraulis japonica*), mackerel, and jack mackerel (*Trachurus japonicus*) catches increased, reflecting climatic regime shift on the marine ecosystem (Rebstock and Kang 2003).

Jeju Island is one of the main fishing grounds for the large purse seine fishery, which accounts for more than 20% of Korean total coastal and offshore catch, and is one of the country's major fisheries (Zhang et al. 2009). The main species targeted by the large purse seine fishery include common mackerel (*Scomber japonicus*), jack mackerel (*Trachurus japonicus*), common squid (*Todarodes pacificus*), hairtail (*Trichiurus lepturus*), Spanish mackerel (*Scomberomorus niphonicus*) and yellowtail (*Seriola quinqueradiata*) (Zhang et al. 2009). Adjacent water fisheries production from Korea's ECS administrative divisions have generally declined since 2000, from 814,000 t to 633,000 t in 2017 (Fig. 6). Reflecting the trend in fisheries production, Korea's fisher population has been dropping since the 1980s (FAO 2003). Between 2000 and 2015, the number of fishery households on Jeju Island decreased by almost 40%, falling from approximately 6,700 households in 2000 to 4,080 households in 2016. The decrease in Jeju's fishery population was even greater, dropping by 54%, from around 21,200 people in 2000 to 9,880 people in 2015. At the same time, the number of fishing villages and traditional fishing activities is on the decline; in particular, the number of *haenyeos* has decreased from 23,081 (21% of Jeju's females) in 1965, to 4415 in 2014, making up just 1.4% of Jeju females. Indeed, the future of *haenyeos* is uncertain as the majority of them are 50 years or older (Choa and Kang 2015).

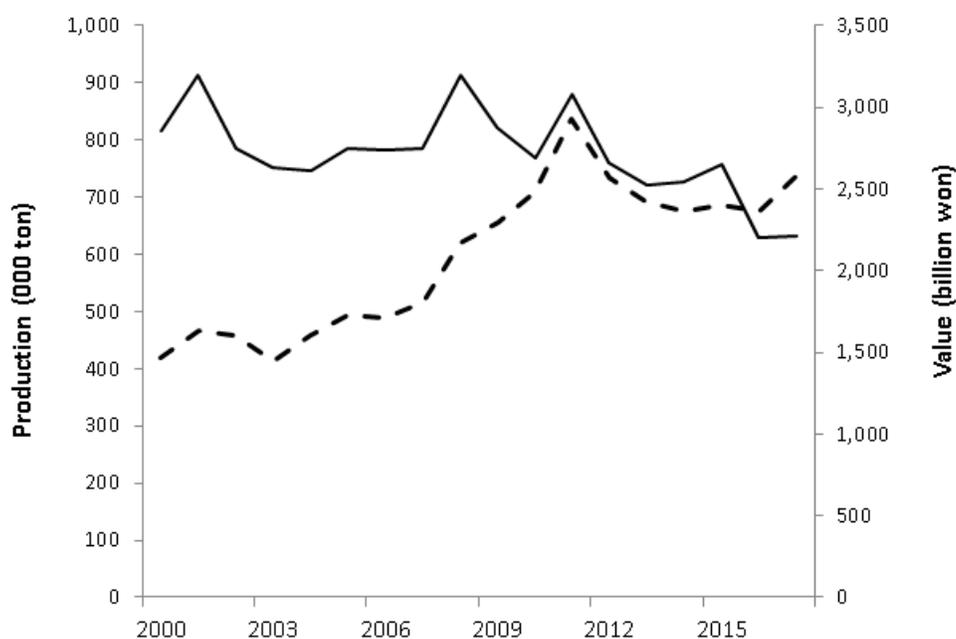


Fig. 6. Temporal trend in fisheries production and landed value for provinces bordering the Korean East China Sea (Busan, Jeollanam-do, Gyeongsangnam-do, Jeju-do) 2000-2016 (Source: Statistics Korea).

The Korean government has implemented nation-wide capacity reduction programmes since the 1990s in response to overexploitation of the country's fisheries resources. For instance, a fishing vessel buy-back programme implemented in 1994 removed around 60,000 vessels over a span of 20 years. While the buy-back may have been a contributing factor to stock recovery and improved productivity in the offshore sector, the coastal small-scale sector still needs to be reduced (Lee and Midani 2014). Further, a Total Allowable Catch based quota management system implemented since 1999 improved sustainability of the large purse seine fishery (Zhang et al. 2009). Part of this was due to fishermen being actively involved in management, resulting in increased recognition about the importance of reducing dumping, improving habitat, and self-monitoring

against illegal fishing. Overall, the capacity reduction programmes had a positive impact on coastal and offshore fisheries in terms of stabilizing fishing effort (Teng 2007).

Taiwan

Taiwan is a major fishing nation, but in recent years the majority of its catch has been from outside its exclusive economic zone (EEZ). The fisheries sector does not play a major role in Taiwan's economy - in 2015, the combined contribution of agriculture, forestry, fishing, and animal husbandry to national GDP was less than 2% (1.8%) (Taiwan National Statistics <https://eng.stat.gov.tw>). Nevertheless, fish is commonly consumed in Taiwan. A nationwide survey on food consumption found that 84% of Taiwanese had a strong preference for eating fish, and regularly consumed 3 or more fish meals per week, for an estimated annual consumption rate of 42.35 kg/person (Li et al. 2001). We note that this is a dated study, as it was conducted in the late 1990s. Nonetheless, seafood consumption in Taiwan remains high. According to FAOSTAT, supply of marine fish and aquatic products was 28.5 kg per capita per year in 2013.

The East China Sea shelf lies off the northern edge of Taiwan's continental shelf. This region is high in primary productivity and rich in nutrients due to the seasonal influences of the Kuroshio Current, which flows along the eastern side of Taiwan, and the influx of water from the Yangtze River, which is driven by the China Coastal Current. As such, the ECS has been one of Taiwan's most important fishing grounds since the 1960s; for the 3 decades spanning 1976-2007, it accounted for around 44% of Taiwan's total fisheries production and 40% of landed value (Chen and Lee 2013).

ECS fisheries operate from Keelung City, Taipei County, and Yilan County (Chen and Lee 2013). Yilan County is the biggest contributor to northern Taiwan's annual fisheries landings (Chen et al. 2018); Suao, located in Yilan, is one of Taiwan's three major landing areas for the tuna longline fleet. Between the late 1970s and 2000s, at least 16 fishing gears targeting 50 species were used off northern Taiwan. The dominant fishing gears used in the ECS are trawls, purse seines for mackerel, and torch-light nets, which accounted for 39%, 20%, and 9%, respectively, of total fisheries production off northern Taiwan for the period 1976-2007 (Chen and Lee 2013). Main targeted species include mackerel, scad, shrimp, and neritic squids. While coastal and neritic fisheries landings for Taiwan have declined overall since 1960, the decrease off northern Taiwan has not been as substantial (Chen and Lee 2013).

Taiwan has two distinct fisheries – coastal and distant water. Following the Second World War, government driven policies on vessel building led to the development of coastal and offshore fisheries. Consequently, coastal fisheries production increased rapidly throughout the 1950s until the late 1970s (Fig. 7). In the present time, coastal fisheries still play an important social role relative to offshore fisheries in the ECS. In 2016, about 85% of the ECS fisherman population of 71,227 were from the coastal sector (Taiwan Fishery Yearbook).

Between the 1960s to 2000s, the number of fishing vessels throughout Taiwan increased over 3 times, while total vessel tonnage and horsepower increased by almost 8 and 35 times, respectively (Liu 2013b). Inshore fishing grounds were already considered to be overfished by the 1960s, resulting in the development of Taiwan's distant water longline fleet that targets high seas tuna (Chen 2007). In recent years, there has been international concern over Taiwan's tuna fishing practices, including illegal fishing and labour and human rights abuses at sea (van der Horst 2016). The main centres of Taiwan's offshore tuna fisheries are Taihoku Prefecture, in northern Taiwan, and Takao Prefecture, in the south (Chen 2014). While Taiwan's fisheries landings decreased throughout the 1980s, the number of fishing vessels continued to increase (Fig. 7), resulting in a state of overcapacity. Consequently, socio-economic benefits from fisheries also decreased (Liu 2013b).

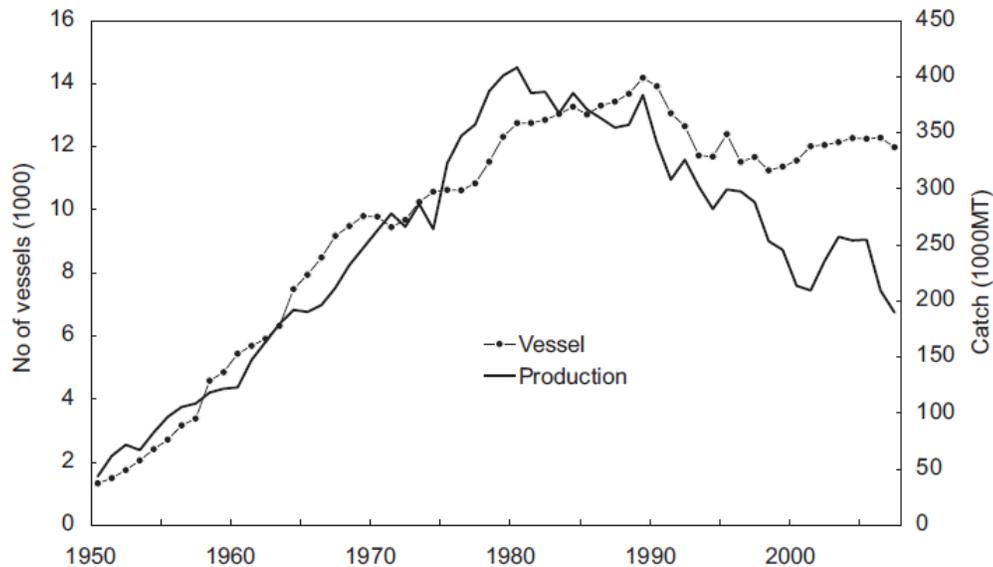


Fig. 7. Historic trend of number of fishing vessels and production for Taiwan's coastal fisheries 1950-2007. Source: Huang and Chuang (2010).

In order to reduce coastal and offshore fishing effort, the Taiwanese government put in place two voluntary vessel buy-back programmes – the first in 1991-1995, followed by the second in 2000-2004. In addition, there is a voluntary layoff programme wherein fishing vessels qualify for subsidies if they suspend fishing activities for a fixed period. The number of fishing vessels participating in fishing layoffs has increased annually, from 5,620 vessel/trips in 2003 to 10,047 vessel/trips in 2013 (Taiwan Fisheries Agency website). At the same time however, Taiwan continues to provide a 14% fuel subsidy to help fishers maintain competitiveness in fishing (Taiwan Fisheries Agency website). Taiwan's coastal fisheries thus remain overfished, as statistics from Taiwan Fisheries Yearbook showed that total landings in 2012 were 32,950 t, compared to 49,511 t in 2002⁸. The decrease in fisheries resources has negatively impacted fishing livelihoods, as the ratio of fishers' average wage relative to the average civil wage has decreased. Further, despite the reduction in fishing boats, net monetary returns have not increased due to an increase in costs (Liu 2013b). In addition, a prevailing social issue is the decline in Taiwan's local fishing labour force, which has seen a subsequent rise in the number of mainland Chinese crew (Liu 2013b).

Catch Statistics

In this section we compare landings data from two sources: the *Sea Around Us* Project (www.searounds.org), and from national fisheries statistics. Data from the *Sea Around Us* Project is aggregated at the Large Marine Ecosystem level. Catches in the *Sea Around Us* database are spatially allocated to $\frac{1}{2} \times \frac{1}{2}$ degree cells that cover the world oceans. Catch data are pre-assigned to a country or territory's EEZ according to fish taxa caught, fishing sectors, biological distributions of fish, and fishing access agreements.⁹ Through this process, the reported catch includes all catches, including those caught by foreign vessels, allocated to a spatial entity, in this case the East China Sea LME.

Sea Around Us data show that catches from the East China Sea LME are growing temporally, increasing from 972,000 t in 1950 to 6.2 million t in 2014. The largest increases occurred during the 1970s through to the early 1990s. Despite some slight fluctuations, annual catches have been maintained at close to 5.5 million t since the

⁸ Data extracted from Taiwan Fisheries Agency: <http://www.fa.gov.tw/en/PublicationsYearbook/>.

⁹ See http://www.searounds.org/catch-reconstruction-and-allocation-methods/#_Toc421534365 for details about the method of spatially allocating catch data.

mid-1990s. For the most recent years 2011-2014, reported catches have been at historically high levels, at close to, or reaching 6 million t (Fig. 8).

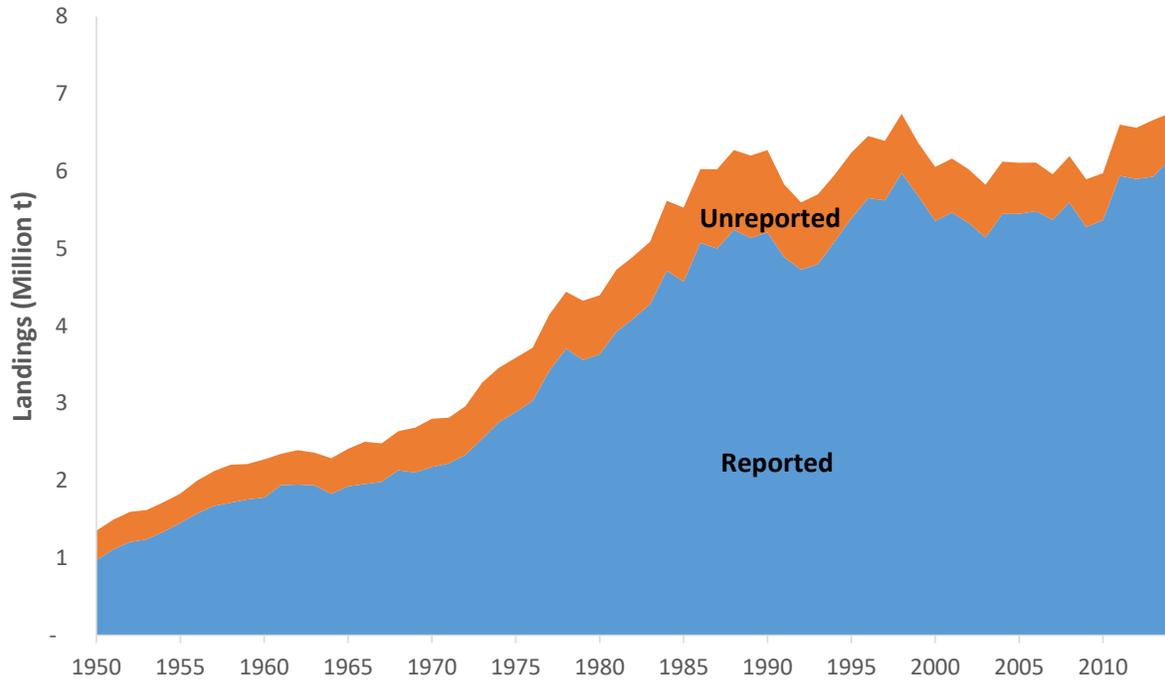


Fig. 8. Reported and Unreported landings for the East China Sea Large Marine Ecosystem 1950-2014. Source: *Sea Around Us*.

For the period 2000-2014, China was the major fishing country within the ECS LME, accounting for on average 70% of total fish catches (Fig. 9) and followed by Japan and Korea, at 16% and 10%, respectively. For the period 1950-2014, 60% and 37% of total catches were from commercial and small-scale artisanal fisheries, respectively, while subsistence and recreational fisheries accounted for the remaining 3% and 1%, respectively (Fig. 10). Since 1990, the importance of commercial industrial fisheries has grown, as it contributed to 73% of total catches, while artisanal fisheries accounted for 26%.

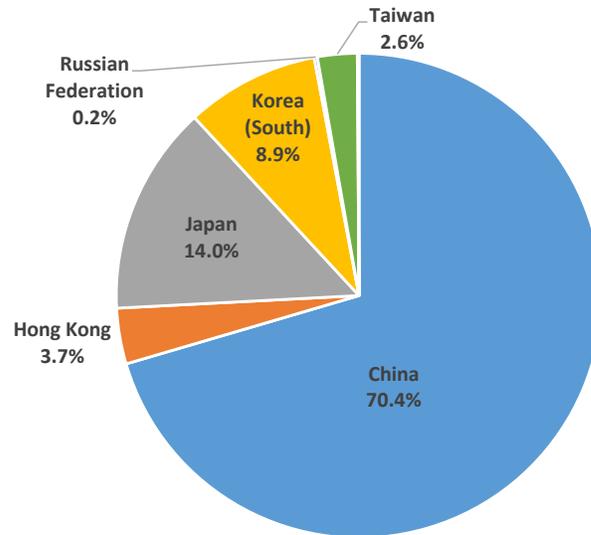


Fig. 9. Percentage of cumulative catch taken by fishing countries within the East China Sea Large Marine Ecosystem for the period 2000-2014. Source: *Sea Around Us* database.

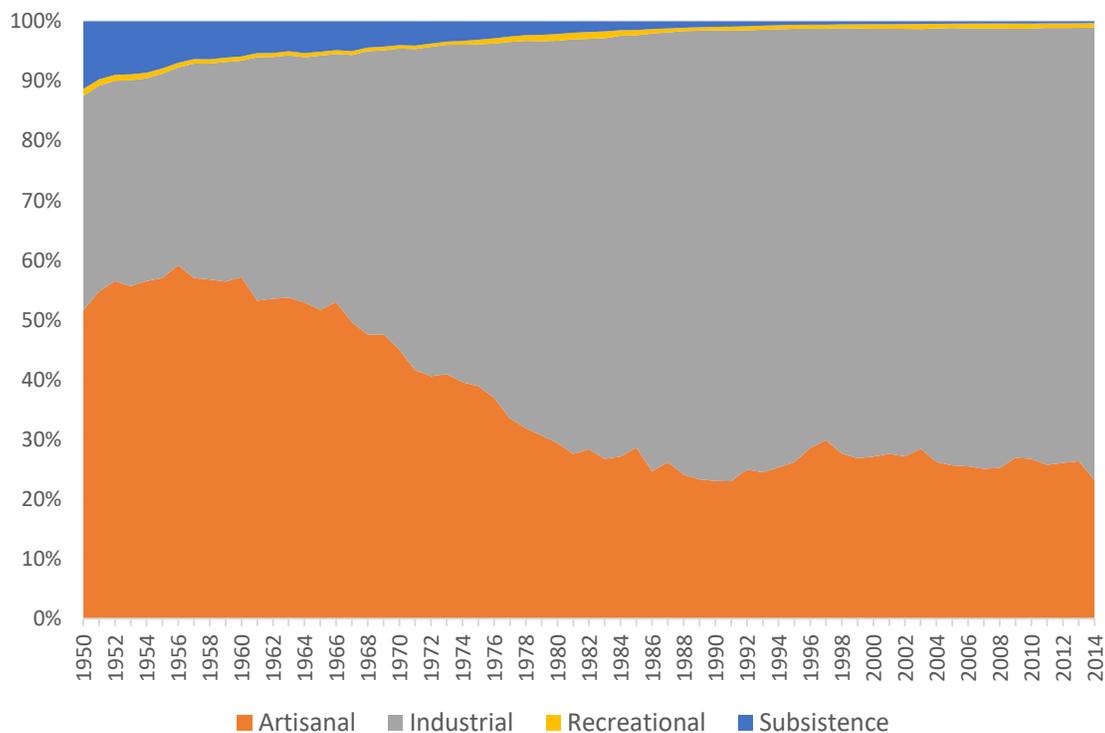


Fig. 10. Contribution of fishing sectors to total catch, 1950-2014. Source: *Sea Around Us* database.

We were able to obtain national fisheries catch data segregated by sea regions for the 4 ECS countries for 2004-2015 (Fig. 11). Annual fisheries statistics for China and Japan reported fisheries catches taken from the East China Sea, although this was not available for China for 2004-2006. For these years, catches from Fujian, Zhejiang, Jiang Su, and Shanghai were summed to obtain ECS catches. It should be noted that domestic capture fisheries are probably less than 70% of that reported in official Chinese national fishery statistics (pers. comm. from Chinese fisheries scholar provided to T. Mallory). For Korea, catches from Busan, Gyeongsangnam-do,

Jeollanam-do, and Jeju Island were extracted to represent Korean ECS catches, while for Taiwan catches from the northern districts of Taoyuan, Ilan, Keelung, and new Taipei City were used. Fisheries production is reported by fishing sector in the Taiwan Fisheries Statistics; for this report, we summed production from the offshore and coastal sectors. For the 2004-2015 period, total ECS catches reported by national statistics showed a fairly stable trend at an average of around 6.2 million t a year. A dip occurred in the late 2000s, falling to about 5.8 million t in 2008, but subsequently increased to 6.5 million t by 2012 and thereafter was maintained at around 6.2 million t (Fig. 11).

National data are fairly consistent with reported catches from the *Sea Around Us* Project, although in the most recent years SAUP data tend to be slightly higher. It is now widely acknowledged that national statistics generally do not fully capture all fishing sectors (Pauly and Zeller 2016). For instance, the activities of rural small-scale fisheries often go unrecorded. Thus, it is important to recognise that national fisheries data can benefit from careful adjustment, i.e., reconstruction, based on local knowledge about a range of issues that can affect the accuracy of reported landings data (Pauly and Zeller 2016).

Reconstruction of fisheries catch for all coastal countries from 1950 to 2010 has been undertaken based on the premise that fishing, where it occurs, throws a shadow on society. This ‘shadow’ enables one to estimate the amount of fish caught from a fishery that is known to exist, even if national statistics state that there is zero catch, or no data available, for that particular fishery (Pauly and Zeller 2016). Catch reconstruction follows 6 general steps (Zeller et al. 2007):

1. For each EEZ, identify and compare baseline catch time series that are reported by FAO, national or regional bodies, according to area, fish taxon, and year.
2. Identify ‘missing’ fishing sectors that are not covered in baseline catch statistics.
3. Conduct literature searches and consult with local experts to obtain alternative information sources on missing sectors identified in (2).
4. For each missing data item (e.g., subsistence catch), develop data ‘anchor points’ in time. Anchor points are catch estimates for a single year, sector, and area – anchor point data can be used to expand to country-wide catch estimates based on raising factors such as population density, fisher population, or shelf area.
5. Interpolate for time periods between data anchor points, e.g., linear interpolation or following non-linear trends such as human population growth trends.
6. Combine estimated catch time series derived from (2) to (5) to obtain total reconstructed total catch time series.

Incorporating reconstructed catches for ECS countries (Shon et al. 2014; Swartz and Ishimura 2014; Pauly and Le Manach 2015; Divovich et al. 2015) showed that unreported catches averaged about 653,000 t, or around 12% of reported catches annually from 2000-2014 for the East China Sea LME. This is substantially lower than the quantity of unreported catches for the South China Sea LME, which averaged 8.1 million t for the 2000-2010 period (Teh et al. 2016).

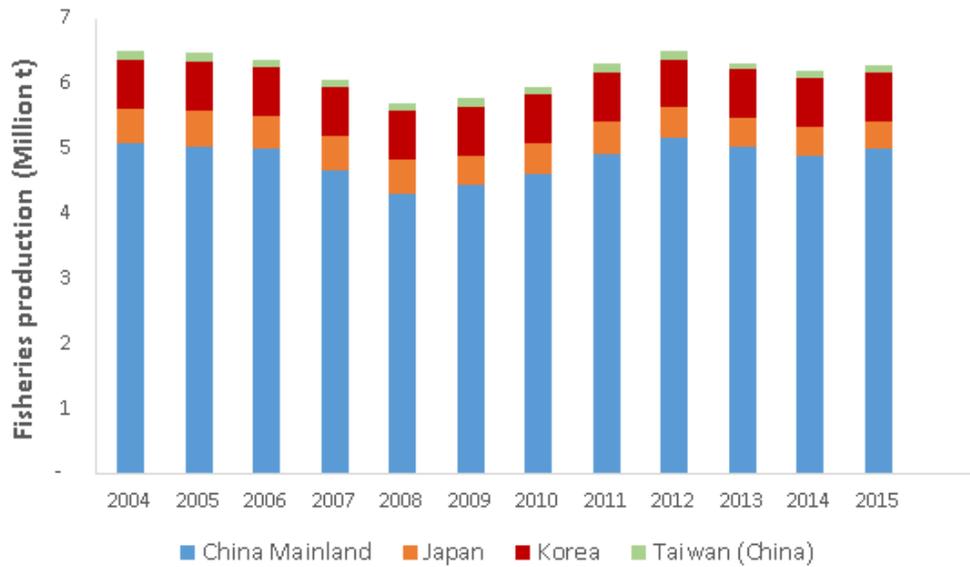


Fig. 11. Fisheries production for the East China Sea by country for the period 2004-2013. Data source: Compiled from national fisheries statistics of China, Japan, Korea, and Taiwan.

The temporal trend in landed value at the LME level was fairly similar to landings, although with more fluctuations throughout the 1980s-2000s. In particular, a steep increase in total reported and unreported landed value occurred in the late 2000s, rising from around USD 7 billion in 2007 to USD 13 billion in 2013 (Fig. 12). Data compiled from national statistics showed higher landed value of USD 16.4 billion in 2013, compared to reported landed value of USD 11.2 billion from the *Sea Around Us* database. Similar to the pattern in fisheries catch, China accounted for the bulk (84%) of landed value from ECS countries (Fig. 13).

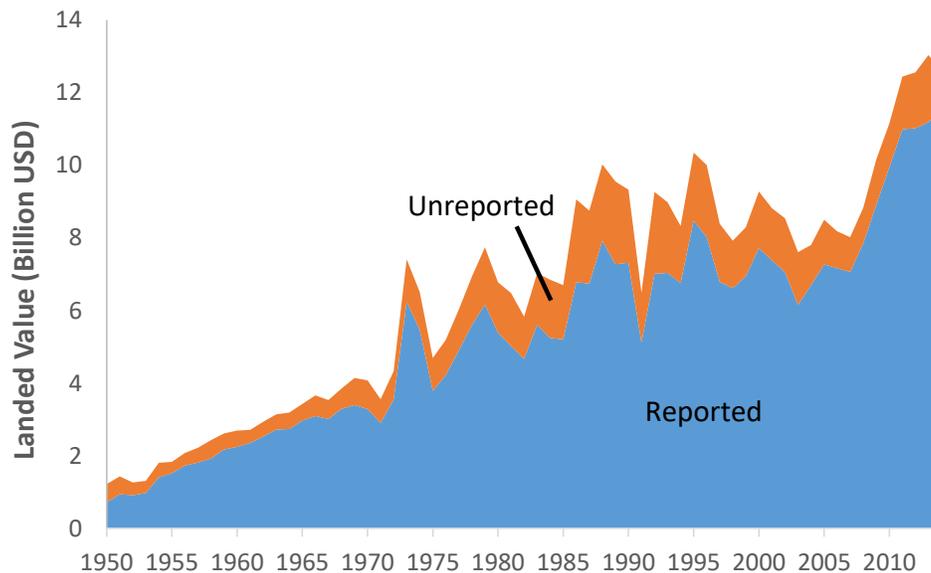


Fig. 12. Reported and Unreported landed value for the East China Sea Large Marine Ecosystem 1950-2014. Source: *Sea Around Us*.

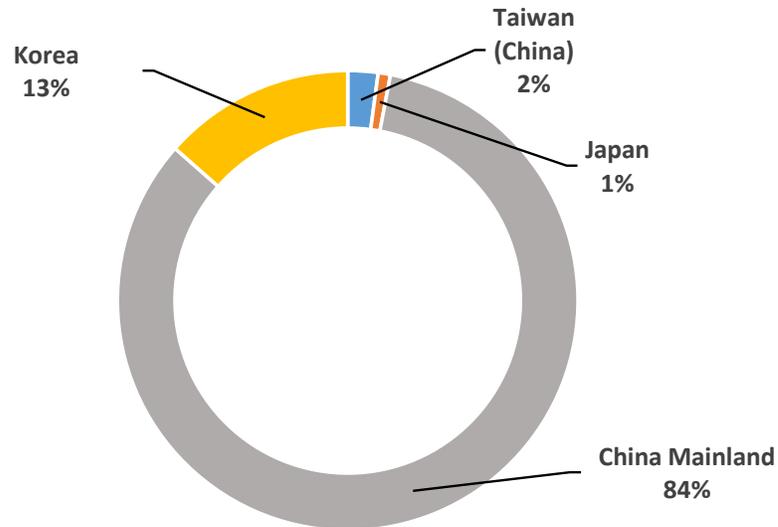


Fig. 13. Breakdown of 2013 landed value compiled from national statistics. Total ECS landed value was USD 16.4 billion. Percentages show contribution to total ECS landed value.

Catch composition

According to the *Sea Around Us* database, medium pelagics (e.g., chub mackerel, horse mackerel, Japanese halfbeak) and medium demersals (e.g., drums, croakers, threadfin breems) accounted for the biggest proportion of 2014 LME catch (Table 2). In contrast, the biggest contributors to landed value were jellyfish and shrimps, followed by other demersal invertebrates such as abalone, clams, mussels, and scallops (Table 2). A different picture also emerges for the composition of unreported catches. While medium demersals and pelagics were again the top 2 contributors, medium demersals accounted for over half (54%) of total catch, much larger than when looking at the overall reported and unreported catches (Table 3). In terms of unreported landed value, medium demersals again accounted for the largest proportion, at almost a third (31%) of total landed value. This was followed by other demersal invertebrates, at 17% (Table 3).

Table 2: Species composition of reported and unreported LME catch and landed value, 2014. Source: *Sea Around Us*.

Functional group	% catch	Functional group	% landed value
Medium pelagics	16.4	Jellyfish	14.4
Medium demersals	15.0	Shrimps	13.6
Shrimps	9.2	Other demersal invertebrates	9.9
Medium benthopelagics	9.0	Medium pelagics	9.8
Large benthopelagics	8.8	Medium demersals	8.4
Small pelagics	6.9	Large benthopelagics	7.2
Cephalopods	6.5	Large demersals	6.9
Jellyfish	5.2	Medium benthopelagics	5.8
Lobsters, crabs	4.9	Medium reef associated fish	5.1
Others	18.3	Others	18.9

Table 3: Species composition of unreported LME catch and landed value, 2014. Source: *Sea Around Us*.

Functional group	% catch	Functional group	% landed value
Medium demersals	53.9	Medium demersals	30.8
Medium pelagics	10.1	Other demersal invertebrates	17.4
Other demersal invertebrates	7.3	Medium pelagics	9.0
Cephalopods	3.9	Large demersals	7.7
Medium benthopelagics	3.4	Medium reef associated fish	5.9
Others	17.7	Small reef associated fish	5.1
		Large benthopelagics	5.1
		Cephalopods	4.7
		Others	14.4

Fish consumption

Fish is an integral part of the diet in ECS countries, where annual fish consumption rates are higher than the global average of 20.5 kg per capita per year (FAO 2018) (Table 4).¹⁰ In particular, China is the world's largest fish consuming country; excluding China results in a global average apparent fish consumption rate of 15.5 kg per capita per year. It is noted however, that fish consumption trends differ within the ECS – for instance, consumption has been increasing in China but decreasing (although remains high by global standards) in Japan.

Table 4: Annual fish consumption (kg/capita/year) in East China Sea countries.

Country	Kg/capita/year	Data year	Source
China	42.0	2016	OECD (2017)
Japan	27.3	2014	MAFF (2015)
Korea	53.8	2013	Yoo (2016)
Taiwan	42.4	2001	Li et al. (2001)
	28.5	2013	FAO Stat (2017)

Number of people and vessels engaged in fisheries

The number of people engaged in fisheries is reported in national statistics of ECS countries, although it is noted that this category may be defined differently in each country. In Japan and Taiwan, the number of persons actively engaged in fisheries is provided, whereas in Korea reported figures refer to fishery household workers and Chinese statistics report the number of traditional marine fishers. As such, the data presented in Table 5 does not represent the number of marine fishers only. To estimate the number of people engaged in ECS fisheries, we extracted data for the provinces, prefectures, or administrative divisions bordering the ECS in each country. In total, approximately 1.38 million people are engaged in fisheries across the 4 ECS countries. The vast majority of these fishery workers are from the Chinese ECS, which accounts for 88% of the total. Taiwan has the next highest, albeit comparatively much lower, population of fishery workers, accounting for about 5% of the total (Table 5).

¹⁰ Consumption rates provided by FAO refer to fish supply per capita, rather than actual consumption.

Table 5: Number of people engaged in ECS fisheries.

ECS Country	Number of people	Reporting year	Source
China	1,209,164	2016	China Fisheries Yearbook 2017
Taiwan	72,782	2015	Taiwan Fisheries Yearbook
Japan	40,490	2014	Ministry of Agriculture, Forestry and Fisheries Japan
Korea ¹	57,345	2017	Korea Statistical Information Service
Low	55,091		
High	59,598		
Total ECS	1,379,781		

¹There were 4,507 registered traditional dive fisherwomen recorded in Jeju Island in 2014 (Hilty 2015). However, the Korean Statistical Information Service reported a total of only 4,762 fishery workers for Jeju Island in 2017. As we cannot ascertain what proportion of traditional divers were included in the number reported by the Korean Statistical Information Service, or whether they were included at all, the number of people engaged in Korea's ECS fisheries could potentially range from approximately 55,000 (i.e., all traditional fisherwomen included) to 59,600 (none included). We use the average of this range (57,345) to represent the number of people engaged in Korea's ECS fisheries.

The number of fishing vessels reported in annual national fishery statistics were extracted for the relevant ECS provinces/prefectures. In total, there were an estimated 315,821 fishing vessels in the ECS, with China accounting for the biggest proportion (71%). However, it is noted that the number of fishing vessels recorded in Chinese statistics is inclusive of both marine and inland vessels used for capture fisheries as well as fish farming. At the national level, around 18% of total reported fishing vessels in 2015 were classified as marine capture fishing vessels. Applying this to the provincial data results in approximately 112,048 vessels used for marine capture fisheries. In comparison, there were 75,865 fishing vessels in China's ECS fisheries in 2005 (Guo et al. 2008).

The majority of ECS fishing vessels can be considered to be small-scale vessels. In Taiwan, Japan, and Korea, 65-96% of vessels are 10 GRT or less (Table 6), which is considered to be a defining characteristic of small-scale fisheries (Jentoft and Eide 2011). While provincial level data did not report the number of fishing vessels by gross tonnage categories in China, at the national level, 67% of China's total fishing vessels were categorized as below 12 m in length, which is another common designation for small-scale fisheries (Jentoft and Eide 2011).

Table 6: Number of fishing vessels in ECS countries

ECS Country	Number of vessels	Reporting year	10 GRT or less
China	224,097	2015	N/A
Taiwan ¹	4,245	2015	2,750 (65%)
Japan	56,616	2014	54,409 (96%)
Korea	30,863	2010	1,089 (81%)
Total ECS	315,821		

¹ The total number of fishing vessels includes powered vessels only.

Fishing power in the ECS has generally increased (Popescu and Ogushi 2013, Cao et al. 2017). For instance, total engine power in Japan's fishing fleet has increased, even though there has been a net decrease in total number of vessels and gross tonnage (Popescu and Ogushi 2013). This is similar to the trend in Taiwan's ECS districts, where total tonnage of fishing vessels decreased since 2010, while engine horsepower increased (Fig. 14a). In Chinese ECS provinces, both unit power (kW/vessel) and capacity (ton/vessel) of fishing vessels increased over the period 2010-2014 (Fig. 14). Comparable data (number of vessels by administrative divisions) for Korea was

available for 2010 only - total tonnage of powered fishing vessels in Korean ECS areas (Busan, Jeollanam-do, Gyeongsannam-do, Jeju) was 108,940 tons. The tonnage of powered vessels in Korea is considerably lower than Taiwan and China - Overall average tonnage was 5.9 t/vessel across Korean ECS areas, ranging from 3.6 t/vessel in Jeollanam-do to 8.9 t/vessel in Jeju (Korean Statistical Information 2018).

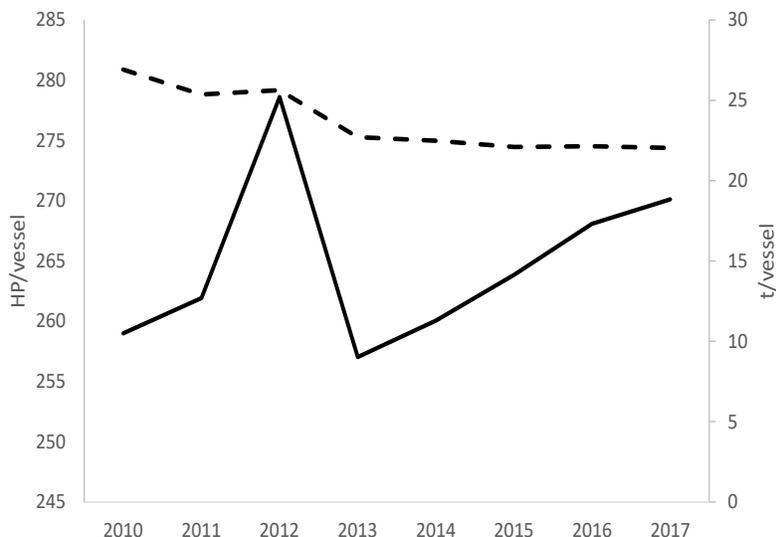


Fig. 14a. Horsepower/vessel (solid line) and t/vessel (broken line) of fishing vessels in Taiwanese ECS districts (New Taipei City, Ilan, Taoyuan, Keelung City), 2010-2017. Source: Taiwan Fishery Yearbooks.

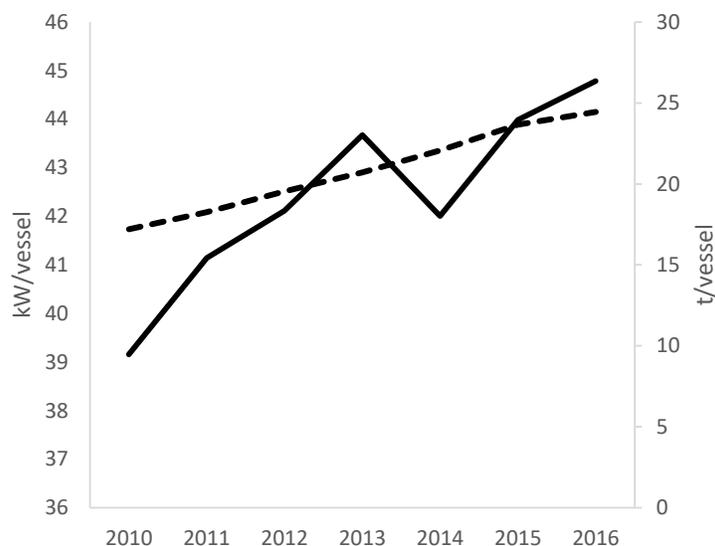


Fig. 14b. kW/vessel (solid line) and t/vessel (broken line) of fishing vessels in Chinese ECS provinces (Jiangsu, Zhejiang, Fujian, Shanghai), 2010-2016. Source: China Fishery Yearbooks.

Status of ECS fisheries

Fisheries resources in the ECS are generally considered to be overexploited. Indications of overfishing include declines in catch quantity and fishing effort, changes in catch species composition, life history traits of exploited species, and change in marine trophic food webs. These are detailed in the following sections:

Catch levels, Catch Per Unit Effort (CPUE)

Stock assessments carried out in the 1990s already suggested that catch rates of most targeted fish stocks in the ECS had decreased substantially since the early 1980s, and that fishing effort had to be reduced (Hiyama et al. 2002; Kim et al. 2007). In the Chinese ECS, initial depletion of targeted species' biomass occurred before 1980 (Liang and Pauly 2017). Catch per unit effort (measured in kg per kW) dropped by a factor of around 3 between the 1960s and 1990s, declining from around 2,300 kg/kW in the 1960s to below 1,000 kg/kW in the 1980s and 1990s (Chen 1999). While the number and power of fishing fleets in the 1990s was 26 and 13 times higher, respectively than the 1960s, catches only increased by a factor of 3.7 (Chen 1999). Likewise, it was found that total fishing power increased by a factor of 7.6 between 1960s and 1990s, while CPUE declined by a factor of 3 (Kang 2006).

Intense fishing pressure has resulted in overfishing of numerous commercial species. For instance, chub mackerel (*Scomber japonicus*) is targeted by the light-purse seine fisheries of all ECS countries and is considered to be overexploited in the Chinese ECS, where commercial fishing for it first started in the 1960s and rapidly increased after the 1970s (Wang et al. 2014). It was estimated that fishing effort for chub mackerel was about 80% higher than that required to achieve the target reference point of $F=0.4$ (Wang et al. 2014). Similarly, Japan's annual catches of chub mackerel had already experienced substantial decline in the 20-year period from 1975-1999 (Hiyama et al. 2002).

Meanwhile, despite limited knowledge about the status of many commercially caught species, fish stocks in Korea's fisheries are generally considered to be overexploited due to intense fishing pressure in Korean waters since the 1970s (Kim et al. 2008; Lee and Midani 2014; Zhang et al. 2014). Catches in the Korean ECS rapidly grew from less than 200,000 t in the early 1960s to over 800,000 t by the mid-1970s, but started to decrease after peaking at around 1.2 million t in the mid-1980s (Kim and Zhang 2016) (Fig. 14). At the same time, catch per unit effort in the 1980s and 1990s decreased substantially across Korean fisheries (Kim et al. 2009).

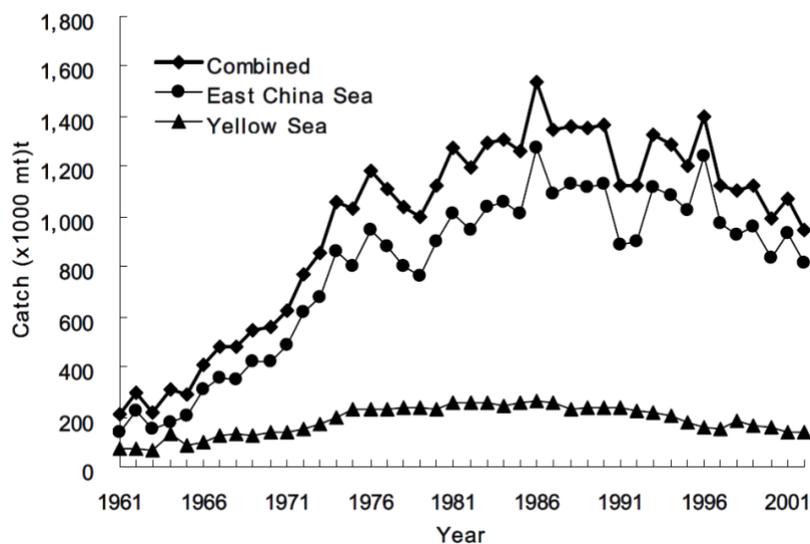


Fig. 15. Historical catches from Korean portion of the ECS 1961-2001. Source: Kim et al. (undated)

Size

Throughout the ECS, the size of exploited fish species such as chub mackerels, small yellow croakers, and hairtails have been getting smaller (Yan et al. 2004; Kim et al. 2007; Chang et al. 2012; Liang and Pauly 2017;

Ma et al. 2017). In the case of chub mackerel, it was estimated that if fishing effort levels prevailing in 2009-2010 were maintained and not reduced, the proportion of small individuals would increase and only 8% of the catch would be larger than recruitment size of 300 mm (Wang et al. 2014).

Increases in smaller sized and younger fish in the Chinese ECS catch were apparent by the 1990s, indicating heavy overfishing (Chao et al. 2005). For example, the minimum size of maturity for small yellow croaker decreased from 14-15 cm Total Length (TL) in the 1970s to around 11-12 cm TL in the 1990s (Chen et al. 1997). Spring spawning small yellow croakers shrunk in size from 220 mm in 1956 to 160 mm in 1994, while their body weight fell from 193 g to 49 g during the same period (Chao et al. 2005). Further, the age structure for most fished populations in the ECS consist mainly of one-year olds (Lin et al. 2006). In the Korean ECS, fishery and biological data over a period of 30 years (1969-2002) showed that since the 1970s biomass of small yellow croaker had decreased; moreover, the average size of harvested small yellow croaker had decreased while the proportion of less mature fish in the catch increased (Yeon et al. 2010).

Trophic levels

It has been widely documented that the mean trophic levels of ECS catches have declined. Liang and Pauly (2017) used time series of ECS catch data to show that the mean trophic level of catch declined from over 4.0 in 1979 to below 3.8 in 2014. Taking body size into account, the mean trophic level for the period declined by 0.15 TL per decade - one of the highest declines in the world. Another study used Ecopath with Ecosim ecosystem modelling approach to show that the mean trophic level of the ECS ecosystem had declined from a mean of 3.5 in 1965 to 3.01 in 2000 (Li et al. 2009). This was attributed mainly to the collapse of traditional fisheries that targeted high TL demersal species and the consequent expansion of new fisheries targeting lower TL species (Li et al. 2009). This was consistent with another study which estimated that average trophic level of the catch declined from 3.5 in 1965 to 2.8 in the 1990s (Chao et al. 2005). Trophic levels also dropped substantially in the Korean and Japanese ECS throughout the 1980s and 1990s (Zhang et al. 2009; Makino 2011).

Changes in trophic levels reflect the marked shift in the species composition of ECS catch from demersal to pelagic dominated. Before the 1980s, dominant species were large sized, commercially good quality and high value fish such as hairtail (*Trichiurus haumela*), small yellow croakers (*Pseudosciaena polyactis*) and silver pomfret (*Pampus argenteus*). However, since the 1970s, high fishing pressure and resulting overexploitation of the 4 traditionally targeted “old” species led to a substantial change in catch composition, wherein “new” lower value species started to dominate the catch (see Fig. 2). In the 1990s these “old” species declined to less than 50% of 1980s levels (Chen et al. 1997). In fact, five species - large and small yellow croaker, cuttlefish, jellyfish, and green filefish were fished to commercial extinction by 1990 (Chen et al. 1997). Further, benthic surveys showed that these areas were instead dominated by low economic value and low trophic level fishes such as bentooth (*C. snyderi*), grenadier (*C. multispinosus*) and dragonet (*R. virgis*) (Chang et al. 2012). In contrast, acoustic surveys showed that the biomass of non-commercial species such as lanternfish (*Diaphus chrysorhynchus*), and pearlside (*Maurolicus japonicus*) were about 2 – 19 times higher that of commercially important pelagic fish in the Japanese ECS (Ohshimo et al. 2012).

In Korea, demersal fish used to dominate the catch in the 1960s, but present-day fisheries are dominated by pelagic species instead (Kim et al. 2007). Due to fishermen pursuing migratory species from their overwintering, spawning and feeding areas in the ECS, both recruitment and growth overfishing became common for small yellow croaker and hairtail, two of the most important fisheries in the Korean ECS (Kim et al. 2007). Overfishing is also thought to be a main driver of the dramatic increases in jellyfish populations observed in the ECS since the end of the 1990s (Jiang et al. 2008; Uye 2008). For instance, CPUE of jellyfish in the ECS increased from

963 kg/hr in 2000 to 43,000 kg/hr in 2003 at the same time that CPUE of commercial species such as yellow croakers and hairtail kept decreasing (Yan et al. 2004).

Fisheries impacts on the ECS ecosystem has also been demonstrated through ecosystem models. For instance, Li et al. (2009) showed that fishing activities removed much of the fishable production from China's ECS shelf ecosystem. In another Ecopath with Ecosim model of the ECS shelf ecosystem, a decrease in mean trophic level of the community and Kempton's biodiversity index suggested degradation of ecosystem structure and function over time (Li and Zhang 2012). Further, another Ecopath with Ecosim study indicated that fisheries exploitation could have initiated mutual competition and predation between large jellyfish and Stromateoidae (butterfishes), which led to the development of large jellyfish blooms observed in the ECS (Jiang et al. 2008).

Studies which have estimated the biomass and Maximum Sustainable Yield (MSY) of commercial species in the ECS indicate that catches were above MSY levels for important commercial species such as small yellow croaker, silvery pomfret, and chub mackerel (Table 7). It is important to note that even in certain fisheries where catches are below MSY, it may still be necessary to reduce fishing effort if the objective is to achieve economic efficiency. For instance, Kim et al. (2008) estimated that 2006 yield for the Korean common octopus trap fishery, whose main fishing grounds are around the ECS off southern Korea, were below MSY. However, if trap usage increased to the MSY level, fishing profit would become negative. Consequently, trap usage per trip had to be reduced by 13% in order to increase profit.

Table 7: Examples of estimated biomass, Maximum Sustainable Yield (MSY), and catch for commercial species in the Chinese ECS.

Species	Biomass (10 ⁴ t)	MSY (10 ⁴ t)	Catch (10 ⁴ t)	Year	Source
Silvery Pomfret (<i>Pampus argenteus</i>)	19.38	14.4	18	2005-2006	Zhou et al. 2012
Small yellow croaker (<i>Pseudosciaena polyactis</i>)	-	13.4	12	1996-2009	Zhou et al. 2012
Chub mackerel	45.3	18.8	20	2009-2010	Wang et al. 2014
Hairtail (<i>Trichiurus japonicus</i>)	-	71.2	81.2	1990-2003	Wang and Liu 2013

Assessments of the status of other important commercial species in the Chinese ECS are summarised in Table 8.

Table 8: Status of fish species caught in the Chinese ECS. Source: Greenpeace East Asia (2017)

Common name	Scientific name	Status in ECS
Shark	<i>Scoliodon macrorhynchos</i>	Resource decline
Conger pike	<i>Muraenesox cinereus</i>	Catch and size decline
Chinese herring	<i>Ilisha elongate</i>	Overexploited, resource decline to almost depleted
Commerson's anchovy	<i>Stolephorus commersoni</i>	Overexploited
Japanese anchovy	<i>Engraulis japonicus</i>	Overfished, resource declining
Slender lizardfish	<i>Saurida elongate</i>	Overexploited
Japanese scad	<i>Decapterus maruadsi</i>	Resource is fine but need to avoid exploiting immature fish
Jack mackerel	<i>Trachurus japonicus</i>	Resource decline
Large yellow croaker	<i>Larimichthys crocea</i>	Resource seriously declined
Small yellow croaker	<i>Larimichthys polyactis</i>	Overfished, resource decline
Japanese Spanish mackerel	<i>Scomberomorus niphonius</i>	Overfished

Largehead hairtail	Trichiurus lepturus	Overfished, resource seriously declined
Silver pomfret	Pampus argenteus	Overfished
Filefishes	Thamnaconus hypargyreus	Overfished, overexploited
Bombay duck	Harpadon nehereus	Moderately fully exploited

Stock assessments by Japan’s Ministry of Fisheries and Marine Affairs are reported for the entire Japan fishery and not broken down by sea region; nevertheless, the results are likely applicable to the ECS because the majority of assessed stocks are caught in the ECS. In 2015, stock assessment for 84 stocks showed that 19% of stocks had a high status, 31% were moderate, and 50% were low. Recent trends are generally that 40-50% of total assessed stocks are low, about 20% high, and the rest in moderate condition.

Box 1: Collapse of the large yellow croaker (*Larimichthys crocea*) in the East China Sea (Liu and Sadovy de Mitcheson (2008))

The trajectory of the large yellow croaker is illustrative of the intense fishing pressure and subsequent decline of commercially valuable fisheries in the East China Sea. The large yellow croaker was one of the 4 traditionally targeted fish species from the Chinese East China Sea, and was once among the top three commercial marine fisheries of China. Between the 1950s and early 1980s, China accounted for about 90% of the world’s large yellow croaker catch; almost all (98%) of this catch was from the East China Sea. However, by the late 1980s catches of large yellow croaker were depleted, and between 1974 and 1990 China’s catches declined by 99%. The estimated biomass of the croaker dropped from 430,000 t between the late 1950s-early 1970s to about 36,000 t in the early 1980s, a decline of over 90%. The collapse of wild stocks was attributed to overfishing of spawning and over-wintering aggregation grounds by drag seine-nets and trawlers throughout the 1950s to 1970s, as well as lack of timely and effective management measures. In fact, since the 1980s no spawning or over-wintering aggregations of croakers were observed within its geographic range. Despite subsequent management efforts, including mariculture and restocking programmes, wild stocks of large yellow croaker in the East China Sea have not recovered.

Key Concerns for ECS Fisheries

The East China Sea is a globally significant fishing ground because it supports the fisheries of the world’s leading fishing nations. In particular, the largest proportion of China’s marine fisheries catch comes from the ECS. Given China’s dominant role in global fishery production and trade, ensuring the sustainability of ECS fisheries is thus of global interest. However, overfishing remains a key problem for the future sustainability of the region’s marine resources, as the ECS has been intensely exploited since the 1960s. Major concerns affecting the state of ECS marine ecosystems include IUU fishing, fleet overcapacity, destructive fishing, coastal pollution, and habitat destruction and loss. Driving these issues are broader, interacting factors such as inefficient governance, climate change, and socio-economic development trajectories.

One of the most important points to emphasise is that despite ECS countries being the most developed and rapidly industrializing countries in Asia, fisheries in all ECS countries are predominantly small-scale and coastal. Thus, continued decline of ECS inshore fisheries resources will have detrimental impacts on fishing communities. Fishing households are already facing lower income and rising costs (Liu and Gao 2009; Makino 2011; Popescu and Ogushi 2013; Liu et al. 2013b; Mallory 2016). In Japan and Korea, demographic patterns put the future of community fisheries at risk, as the fishing population in both countries is getting older and not being replaced by new entrants. Taiwan is also struggling with a declining fishing labour force, which is being replaced by crew members from mainland China – this has given rise to safety concerns due to language and communication barriers (Liu et al. 2013b). China is the only ECS country with an increasing fisher population, as

fishing continues to attract peasants from inland provinces (Zhang 2015b). Nevertheless, small-scale fishers face increasing livelihood difficulties due to increasing competition for shrinking inshore resources (Liu and Gao 2009). Thus, it is clear that the continuation of present unsustainable trajectories will not only affect global fishery production, but ultimately hurt some of the most vulnerable coastal communities in the ECS.

One of the largest barriers to effective ECS fisheries management is the ongoing territorial disputes over overlapping national boundaries after ECS States began to declare their 200 nautical mile EEZs following the adoption of the United Nations Convention on the Law of the Sea (Ou and Tseng 2010). There are further sovereignty disputes over 8 uninhabited islands in the southern ECS. In the northern ECS, progress in joint fisheries management between China, Japan, and Korea has been made through bilateral Fishery Agreements (Sino-Japanese, Sino-Korean, and Korean-Japanese) (Xue 2005). Further, Korea, Japan, and China have engaged in non-government trilateral fisheries negotiations since 2011¹¹. These 3 countries also collaborate on research for sustainable fishery resource use, and jointly adjust fishing quotas annually (Ou and Tseng 2010). Nevertheless, illegal fishing by ECS countries in each other's EEZ continues to occur, with some of these cases escalating into violence and diplomatic disputes (Mallory 2013; Zhang 2016a).

While there is some degree of cooperative fisheries management in the northern ECS, this is not present in other parts of the ECS due to the political relationship between Taiwan and the other 3 ECS countries (Xue 2004; Yeh et al. 2015). Consequently, there lacks a multilateral fisheries agreement for the entire ECS. This has serious repercussions for the region's commercially important fish stocks, the majority of which are migratory and thus require cooperative management from all 4 countries (Ou and Tseng 2010; Tseng and Ou 2010). For instance, a game theory model showed that non-cooperation between China and Taiwan in managing the valuable grey mullet fishery would ultimately hurt the fish stock (Hung and Shaw 2006).

Nationally, fisheries management within each ECS country have not proven to be fully effective in addressing overcapacity or restoring fisheries and marine ecosystems (Ou and Tseng 2010; Liu 2013b; Lee and Midani 2014; Shen and Heino 2014; Lee and Midani 2015; Cao et al. 2017a, 2017b; Liang and Pauly 2017). For instance, despite the Chinese government imposing a summer fishing moratorium in the ECS since 1998, consequent surveys indicated that the moratorium had no effect on fish community structure and ecological function (Jiang et al. 2009). In particular, the Chinese government's provision of fuel subsidies to commercial fisheries largely undermines management measures (Mallory 2016; Yang et al. 2017). The fisheries industries in Japan, Korea, and Taiwan also receive fuel subsidies (EU 2016), thus bringing up the importance of eliminating harmful subsidies in the ECS.

The deteriorating state of ECS countries' coastal and ocean environment further stress the region's fisheries. Anthropogenic activities and population growth around China's Yangtze River area, in particular, have resulted in pollutant levels that threaten the health and well-being of human populations and marine ecosystems (Li and Daler 2004; Chen et al. 2007; Chang et al. 2012; Zhang 2016b). Environmental conditions may also be inhibiting fisheries management measures. For instance, Chang et al. (2012) found that eutrophication was the primary cause behind the failure of fish stock recovery on the ECS inner shelf where China's fishing moratorium was applied. On top of habitat and ecosystem degradation, climate effects are projected to affect marine species and ecosystem resilience, thereby exacerbating stress on ECS marine resources. These complex interactions will ultimately affect the state of future fisheries and its associated social-cultural and economic systems.

Overall, this review reiterates prior findings that East China Sea fisheries have been unsustainable for the past few decades. As in the neighbouring South China Sea (Teh et al. 2017), this implies that there will be dire

¹¹ Source: <http://www.cinon.com.au/item/509188.aspx>

consequences for ECS societies and ecosystems if future development and management follow past and current trajectories. Hence, our review emphasizes the urgency of taking action at national and multinational scales to mitigate human and climate pressures on the ECS marine ecosystem. To understand the ECS management and governance context, the next section outlines the current status and challenges associated with managing East China Sea fisheries and marine ecosystems.

Management and Governance of East China Sea Fisheries

The East China Sea is completely claimed by the surrounding countries, and no area is in the high seas. However, the health of the ecosystem is challenged by competing area claims, pollution, and competition over fisheries resources. While each government has in place legislation to manage their fisheries resources, the historic lack of coordination between nations limits successful management.

Each nation here has their own fisheries management organization and supporting fisheries legislation (Table 9). All of these countries have updated their fisheries acts since the year 2000 to reflect changing conditions.

Table 9: Fisheries management authorities and legislation for each ECS nation

Country	Responsible government authority	Original fisheries act	Last updated
China	Bureau of Fishery Administration and Fishing Port Superintendence, Ministry of Agriculture, Coast Guard	The Fishery Act of the People's Republic of China (1986)	2004
Taiwan	Fisheries Agency, Council of Agriculture	Fisheries Act (1929)	2016
Korea	Ministry of Oceans and Fisheries	Fishery Resources Protection Act (1953), replaced by Fisheries Act (2009)	2014
Japan	Fisheries Agency of the Ministry of Agriculture, Forestry and Fisheries	Fishery Act (1949)	2007

In addition, it can be useful to view these countries' previous evaluations from a management perspective. The Marine Resource Management (MRM) score and the Fisheries Management Index (FMI) are both indicators developed to evaluate a country's management and status of fisheries resources and biodiversity in their waters (Alder et al. 2010; Melnychuk et al. 2017) (Table 10). The MRM score is a scale from 1-5 while the FMI is from 0-1 with a higher score indicating superior management on both scales. The MRM score evaluates 11 different indicators including MPA coverage¹², compliance with the FAO code of conduct, and the quality of fisheries statistics.

The FMI is based on survey responses from country experts on levels of research, management, enforcement, socioeconomics, and fish stock status. Taiwan was excluded from the FMI analysis because they are not a member of many international organizations used as input data. While the MRM score and FMI are set at different levels, Korea and Japan perform better than China and Taiwan (where evaluated) on both metrics showing overlapping areas of concern. These can broadly show that the level of fisheries management and other ecological indicators are performing better in Korea and Japan than in Taiwan and China.

¹² The study represented Marine Protected Area (MPA) coverage as the area of officially designated MPAs relative to the area of that country's claimed EEZ. MPA data was from MPA Global (www.mpaglobal.org), EEZ area was from the *Sea Around Us* Project (www.seaaroundus.org)

Table 10: Marine management indices of ECS nations

Country	Marine Resource Management Score (Scale of 1-5) ¹	Fisheries Management Index (scale of 0-1) ²
China	3.7	0.35
Korea	4.2	0.68
Taiwan	3.6	N/A
Japan	4.5	0.63

1. 1 indicates the lowest score and 5 indicates the best score (Alder et al., 2010)
2. Unweighted and not adjusted FMI from (Melnychuk et al., 2017)

Country Overviews

China

China's fisheries are managed by three organizations (Table 9), and by their *Fisheries Law*. Many Chinese fisheries management regulations do not distinguish between the small and large-scale sectors. One exception is the importance placed by government on further developing the large-scale and offshore fishery sectors (Standing Committee of the National People's Congress, 2004).

China's fisheries management relies strongly on input control and technical measures such as closed seasons and minimum mesh sizes, in addition to controls on the number of vessels and their total engine power (Shen and Heino 2014). In the ECS, the annual summer seasonal closure begins on May 1st and lasts three months, in line with China's moratorium on fishing activity in its coastal seas.¹³ The summer fishing moratorium occurs in all of China's coastal seas with the length varying year by year, but generally extends for 2-3 months. In addition, China has implemented a program to reduce the number of vessels they have, although it has resulted in the average and total power of their fishing fleet increasing at the same time (Shen and Heino 2014). While China has tried many input control mechanisms, the outcome has not been promising; consequently, there has been a recent increase in wild stocking programmes as another means to address fisheries decline (Shen and Heino, 2014).

China's fisheries management mainly suffers from a lack of enforcement. Although there are many regulations in place, most of these are not properly implemented or enforced due to a lack of staff and equipment (Shen & Heino, 2014). This may be exacerbated by having many divisions responsible for different areas of ocean management (Chang, 2017). Thus, China likely needs a more comprehensive reform of the management of their fisheries sector to achieve the benefits they want from their current efforts to manage their fisheries (Cao et al., 2017).

Japan

Japan's fisheries are managed by the Fishery Agency of the Ministry of Agriculture, Forestry and Fisheries. Under this management, Japan's fisheries are officially divided into three segments: coastal, offshore, and distant-water fisheries. Coastal fisheries are governed by Territorial Use Rights in Fisheries (TURFs). In this case, coastal fisher communities form Fisheries Cooperative Associations that are responsible for the sustainability of their resources (Yagi et al. 2012). Offshore and distant-water vessels are managed centrally through licenses from the national government. Some have argued that the current TURF system does not support economic efficiency, and that the Fisheries Cooperative Associations promote social equity rather than maximizing fishery output or economic gain (Yagi et al. 2012). Nevertheless, the Japan's system of allowing bottom-up interventions and management through fishing rights and cooperative associations is beneficial to

¹³ <http://chinaseafoodexpo.com/china-begins-annual-summer-fishing-ban-areas>

small-scale coastal fishers (Makino and Matsuda 2005). Overall, Japan's fisheries management performs well on both the MRM and FMI external indices included in this report (Alder et al. 2010; Melnychuk et al. 2016).

Japan's aquaculture is regulated by the 'Law to Ensure Sustainable Aquaculture Production (1999)'. The law focuses on three areas: water quality, sediment impact on the bottom, and health of the cultured fish (Takeda, 2010). Food safety is a very important aspect of aquaculture legislation, which has a main focus on reducing the spread of disease on farms. There have already been successes in the reduction of volatile compounds released from farms, and a switch from fresh fish feed to dry-pelleted feeds is aiding in this progress (Takeda, 2010).

Korea

In 1996, Korea established a government agency focused on the oceans and this has benefited their management of their maritime sector (Cho 2006). Korea's fisheries and aquaculture operations are now managed by the Ministry of Maritime Affairs and Fisheries. Korea's fisheries policy was formerly highly production-oriented which led to overexploitation of their resources (FAO 2003). This was partially driven by a country with a small land-mass and relatively large accessible coastal waters (Hong 1995). The national level policies often led to overexploitation of the surrounding stocks and overcapacity of Korea's fisheries (Hong 1995). This position became increasingly difficult to continue due to greater restrictions on distant water fishing and national and international demands to rebuild fisheries, and decrease their impact on non-target organisms (e.g., marine mammals and turtles) (Hong 1995).

In 2005, the national government started a fish stock rebuilding plan due to declining biomass and the resulting decline in national fisheries catches. This stock rebuilding plan focused on reducing total allowable catches for a period until stocks could be rebuilt. The plans involved close cooperation with community-based fisheries associations which received technical assistance from the national government for implementing catch reduction targets and rebuilding targets into the future (Lee and Rahimi 2014). So far, these rebuilding plans have increased catches for almost all stocks with a plan in place, and increased revenues by 200 million USD for the period 2004 - 2008 (Lee and Rahimi 2014). While Korea is well placed to benefit from improved fisheries management, many fish stocks in the ECS are shared and thus need cooperation from the other fishing nations. This has occurred to some extent, as Korea has benefited from increased cooperation with its neighbours over shared management areas and quotas (Cho 2006) (see Fishing Access and EEZ Disputes sections). This progress is needed to rebuild the fisheries resources of the East China Sea from their depleted state.

Taiwan

Taiwan implemented a program of rapid development for their fisheries sector, and then later for their aquaculture sector, since the 1950s. This was supported by government and intergovernmental programs, including subsidies to develop their fleet capacity. In this period, they developed a strong distant water fleet which still operates one of the largest tuna fisheries in the world. Their fisheries moved from being coastal to distant-water focused operations, although they still catch nearly 200,000 t of fish in the ECS. As CPUE began to decline for the coastal Taiwanese fleet, the government began a vessel-buyback program to reduce fisheries capacity (Huang and Chuang 2010).

The coastal buyback program did not improve production for the coastal fleet, but has reduced the number of coastal craft substantially (Huang and Chuang 2010). The lack of production gains may be attributed to a lack of knowledge on how much effort needs to be reduced, which is difficult to ascertain given the current lack of stock assessments performed for Taiwan (Huang and Chuang 2010). Taiwan has a single body responsible for their marine enforcement, and recently established an Ocean Committee with power from the federal government to manage, plan, and control marine resource use (Chang 2017). There is some evidence that a single body for

marine issues can aid in management and enforcement of regulations (Chang 2017). Taiwan should use this body to push for the reforms it needs for its coastal fisheries. Therefore, Taiwan’s fisheries management organization may be well positioned to improve their management in the future, if they can supplement the current information on the state of their fish stocks and their fisheries. This management is hindered by over-exploitation from other countries in the ECS, as well as incursions of illegal fishers into Taiwanese waters (Tseng and Ou 2010).

EEZ Disputes

There are three major disputed areas in the ECS, excluding the dispute over sovereignty between the People’s Republic of China and the Republic of China (Tseng and Ou 2010). This disagreement affects the multilateral agreements formed in the ECS, but is not considered directly here. Dokdo/Takeshima is disputed between Korea and Japan. Japan argues that it is within their EEZ, but Korea has placed a research station on the island in part to strengthen their claim over the area. The Senkaku Islands (aka Diaoyutai islands or Diayu islands), a chain of eight islands, are disputed by China, Japan, and Taiwan. They have been under Japanese control since 1971, but this is disputed by the other two powers in the area. Another formal dispute is Taiwan’s claim over islands off the coast of mainland China. In addition, China and Japan are engaged in an ongoing dispute over the development of the Chunxiao/Shirakaba gas field. The area that is disputed in the ECS is so large, it would take an area 1.3 times larger than the ECS for all claims to be satisfied (Table 11). These EEZ disputes create challenges to long term fisheries management because of the resulting tension and lack of clarity over jurisdiction and management of the ECS’ many transboundary fish stocks.

Table 11: National claims to waters in the East China Sea.

Nation	Area Claimed (km ²)	Proportion Claimed
China	326,385	42%
Japan	386,660	50%
Korea	169,785	22%
Taiwan	115,632	15%
Actual Size	768,281	130%

Fishing Access

Despite many disagreements over extent of EEZs (Table 11), and territorial claims in the ECS, many fishing agreements have been made between these nations (Lee et al. 2017) (Table 12). Functionally, many of these agreements are made solely on the basis of ignoring the disputed islands for the time-being (Yagi et al. 2012). Currently, there are fishing agreements between China and Korea, Japan and China, and Japan and Taiwan (Ou and Tseng 2010). These agreements largely function on each country being allowed to use the area they currently fish in (e.g., their Current Fishing Pattern Zone) (Lee et al. 2017). An agreement signed in 2000 limits China and Korea to exercise control over their own respective vessels when fishing in the Provisional Measure Zone which extends from the Yellow Sea in the ECS (Seokwoo Lee et al. 2017). Japan and Taiwan formed an agreement to jointly manage the fisheries in the disputed Pinnacle Islands.¹⁴ The agreements between China and Japan, China and Korea, and Japan and Korea created joint management over areas of overlapping EEZs between these countries in the northern ECS. Japan and Korea’s agreement was for a catch quota of 60,000 t assigned to each country to fish in each other’s EEZ waters. However, this has failed as the negotiations for the past two years have been tense and will likely not happen in time for this fishing season.¹⁵

¹⁴ http://www.canon-igs.org/en/column/security/20130530_1938.html

¹⁵ <http://english.yonhapnews.co.kr/news/2016/06/29/15/0200000000AEN20160629005500320F.html>

Japan's fishing agreement with Taiwan began with the formation of a temporary enforcement line. While the waters are claimed by both nations, Japan often exerts its force by detaining Taiwanese boats fishing past a certain point. However, Japan started to enforce the law less if they were to the east (or Taiwanese side) of the temporary enforcement line (Yeh et al. 2015). Illegal fishing, or deemed illegal fishing, appears to be common in the ECS (Xue 2004; Ou and Tseng 2010). This can be partially explained by different territorial claims where one country views the waters as their own, but another country has a claim over the waters. China has been observed fishing in Korean waters for many years, and Korea blames part of their stock declines on this exploitation.¹⁶ China also allegedly fishes in Japan's waters or just on the edge of their EEZ, separate from their agreements.¹⁷ Due to the tenuous nature of these agreements, a more formal multilateral agreement that additionally includes Taiwan to a greater degree would benefit the health of the fisheries resources in the ECS.

Table 12: Formal Fishing Access Agreements in the ECS

Agreement/Partner countries	Area	Year entered into force	Active?
Taiwan & Japan ¹	Pinnacle Islands	2013?	Y
China & Korea ²	Provisional Measure Zone	2001	Y
China & Japan ²	Provisional Measure Zone	2000	Y
Korea & Japan ^{2,3}	Provisional waters zone	1999	N

¹ Ou and Tseng (2010)

² Source: http://www.canon-igs.org/en/column/security/20130530_1938.html

³ Source: <http://english.yonhapnews.co.kr/news/2016/06/29/15/0200000000AEN20160629005500320F.html>

Marine Protected Areas (MPAs)

Only 0.1% of the ECS falls within Marine Protected Areas (Table 13). In addition, an even smaller portion of this is in no-take fisheries zones, as most MPAs in the ECS allow fishing. Korea accounts for 70 of the 72.47 km² of no-take area in the ECS. Japan has a large area within the ECS designated as MPAs, but fishing is allowed in over 99% of this area. China and Taiwan have almost no MPAs within the ECS, although they both have some MPAs outside of the ECS (Table 13). The efficacy of MPAs is dependent on many factors but those with adequate budget and staffing are those that deliver the most (Gill et al. 2017). However, these benefits within the ECS are likely to be minimal at present as well over 90% of the areas designated as MPAs allow fishing activity.

Table 13: Marine protected area coverage in the ECS (Atlas of Marine Protection, 2017)

Country	No take area (km²)	Reported marine area (km²)
Japan	2	3668
Korea	70	2453
Taiwan	0.47	0.6
China	0	0
Total	72.47	6121.6

¹⁶ <http://www.maritime-executive.com/article/chinese-poaching-damages-south-korean-fisheries>

¹⁷ <http://time.com/4463943/japan-china-fishing-marine-iuu-environment-google-skytruth/>

Table 14: Marine protected areas (% of territorial waters) of ECS countries (World Bank, 2017)

Country	1990	2014
China	0.4	2.3
Japan	5	5.1
Korea	3.3	4.3
Taiwan ¹	N/A	N/A

¹The World Bank does not report MPA data on behalf of Taiwan (World Bank, 2017).

International Agreements

East China Sea fisheries management is influenced by many international agreements pertaining to the management of fisheries and its impact on the marine environment (Table 15), as ECS countries have commitments to many of these agreements. However, no Regional Fisheries Management Organization currently manages fisheries within the ECS. One potential avenue that can be used to address this in the near future is through the issue of fisheries subsidies. The World Trade Organization is one of the organizations where all four nations of the ECS are members, and all four nations have substantial fisheries subsidies (Sumaila et al. 2010; Sumaila et al. 2016). The restriction of fisheries subsidies on overfished stocks could reduce fishing pressure in the ECS as the economic benefits and incentives to fish overfished stocks would likely be reduced. However, this cannot be confirmed until a final agreement is made and enters into force.

Table 15: Participation of ECS countries in multilateral instruments and regional bodies

Agreement/ Organization	China	Japan	Korea	Taiwan
United Nations Convention on the Law of the Sea (UNCLOS)	✓	✓	✓	
Convention on Biological Diversity (CBD)	✓	✓	✓	
International Convention for the Prevention of Pollution from Ships (MARPOL)	✓	✓	✓	
Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES Convention)	✓	✓	✓	
FAO Code of Conduct for Responsible Fisheries	N/A	N/A	N/A	N/A
International Maritime Organization (IMO)	✓	✓	✓	
Coordinating Body on the Seas of East Asia	✓		✓	
Asia-Pacific Fishery Commission (APFIC)	✓	✓	✓	
Western Central Pacific Fisheries Commission (WCPFC)	✓	✓	✓	✓
Food and Agriculture Organization (FAO)	✓	✓	✓	
North Pacific Fisheries Commission (NPFC)	✓	✓	✓	✓
World Trade Organization	✓	✓	✓	✓
Paris Agreement	✓	✓	✓	
Coordinating Body on the Seas of East Asia (COBSEA)	✓		✓	
Partnerships in Environmental Management for the Seas of East Asia (PEMSEA)	✓	✓	✓	
Northwest Pacific Action Plan (NOWPAP)	✓	✓	✓	
FAO International Plan of Action to prevent, deter and eliminate IUU Fishing (IPOA-IUU)	✓	✓	✓	✓
Agreement on Port State Measures (PSMA)		✓	✓	

Sources: (CITES, 2017; COBSEA, 2005; Convention on Biological Diversity Secretariat, 2017; FAO, 2017a, 2017b, International Maritime Organization, 2017, 2018; NPFC, 2015; UNFCCC, 2016; United Nations, 2017; WCPFC, 2015; Witter et al. 2015; WTO, 2016)

Key Concerns

Taiwan is excluded from many international agreements and organizations due to the enforcement of China's 'One China Policy'. Therefore, any organizations and agreements that may pertain to the ECS are less effective when it comes to their force over Taiwan. This is challenging as many international agreements can have positive impacts on the management of Taiwanese fisheries and the conservation of marine biodiversity.

The disputes over ocean area within the ECS hinder other formal agreements and management of the resources. Despite this, some agreements have been made on how certain disputed areas and quotas can be used and shared (Keyuan, 2003). While many agreements have been made for fishing access in 'shared' areas, a central multilateral agreement to govern fisheries resources in the ECS is still lacking (Lee et al. 2017). As many ECS stocks are overexploited, the rebuilding efforts of some nations may go to waste if not all actors are participating in the attempts to rebuild fish stocks.

In addition to these challenges, and partially to blame for the lack of success of countries' regulatory measures, is the continued provision of fuel subsidies to the ECS fishing fleet (Mallory 2016; Sumaila et al. 2016) (Table 16). Fuel subsidies are often harmful to fisheries resources as they allow fisheries to continue to operate past what would be profitable when resources are depleted by subsidizing both the searching for, and the catching of fish. The potential for fuel subsidies in the ECS to exacerbate fisheries overexploitation is augmented by the fact that almost all of it goes to the large-scale sector - All fuel subsidies in China and Japan are provided to large-scale fisheries, while in Korea and Taiwan, only 3% and <1 % of fuel subsidies go the small-scale sector, respectively (Schuhbauer 2017). The World Trade Organization (WTO) has considered passing agreements limiting fisheries subsidies, or the fishery recipients of fisheries subsidies, but the most recent meeting failed to achieve any agreement with all members.

Table 16: Estimated fuel subsidies provided to ECS countries (000 USD) in 2003 and 2009, and the amount provided to the small-scale fishing sector (SSF). Sources: Sumaila et al (2010) and Schuhbauer (2017).

Country	2003	2009	SSF
China	1,814,000	1,986,520	0
Japan	1,115,000	180,065	0
Korea	331,000	407,831	417
Taiwan	120,000	130,183	4085

Mariculture in the East China Sea

Mariculture in the East China Sea produces around 3 million t annually (Fig.16 and 17). China, as the largest aquaculture producer in the world, is obviously important here, but Korea and Japan also farm a significant amount. It is important to note that while inland aquaculture plays an important role in many of these countries, we focus here exclusively on mariculture, i.e., sea cage culture or shallow sea culture. The top five animal species which account for 70% of production are all bivalves (oysters, clams, and mussels).

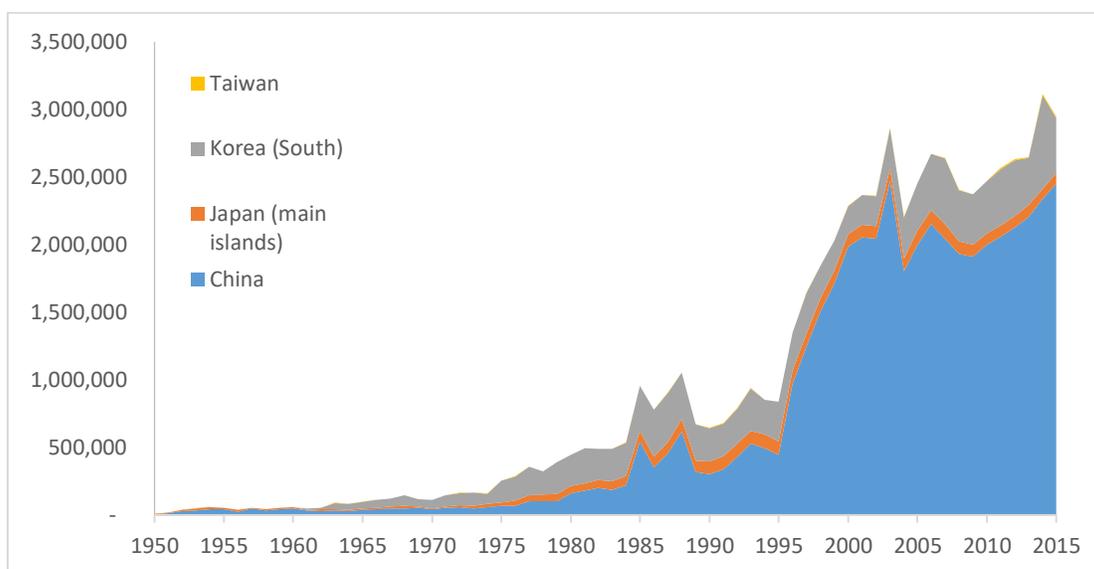


Fig. 16. Mariculture production (t) by country

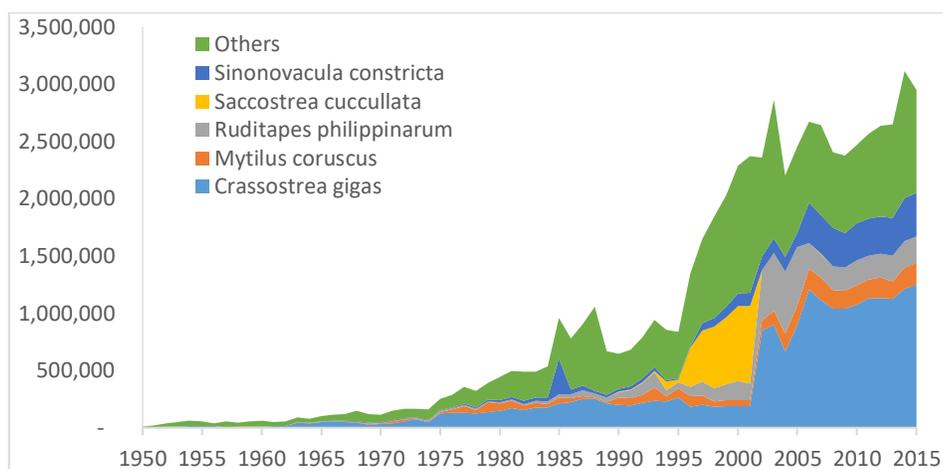


Fig.17. Mariculture production (t) by species (animals only)

The three major groups of mariculture occurring in the ECS can be grouped as aquatic plants, bivalves, and high-value carnivorous finfish. Aquatic plants likely make up the bulk of mariculture production in the ECS, although this cannot be fully confirmed due to current data availability.¹⁸ Environmentally, bivalves are almost completely innocuous, as they neither require feed inputs nor produce significant wastes. High-value carnivorous fish are farmed in fairly large quantities in the ECS. As the four countries in the ECS are industrialised economies, they all have large middle-classes with high demand for these types of fish, which include croakers, groupers, halibut, and amberjack (Godfray et al. 2010). The culture of these fish also creates a large demand for feed inputs from the ECS as well as from external systems (Cao et al. 2015) (Box 2).

Mariculture production area was reported in the fisheries statistics of China, Korea, and Taiwan (Table 17). For each country, we extracted mariculture area occurring in districts bordering the ECS for 2010-2017. China has, by far, the largest mariculture area, whereas there is minimal mariculture production in the ECS districts of Taiwan. The amount of mariculture area decreased substantially in Korea after 2010 – this is because

¹⁸ At present, we only have animal mariculture broken down into sub-national units at a finer scale than the country level.

mariculture area for Busan administrative division was not reported after 2011; however, the reason for this is not known.

Table 17: Mariculture production area (ha) in districts or provinces bordering the East China Sea. Mariculture in Korea refers to sea cage culture, and in Taiwan refers to shallow sea culture.

Year	Korea	China ¹	Taiwan ²
2010	133.02	423,967	-
2011	96.04	434,227	12.23
2012	90.04	434,585	15.46
2013	86.05	437,618	16.96
2014	83.47	438,253	16.96
2015	87.97	433,785	37.4
2016	89.08	488,650	33.92
2017	92.26	-	16.95

¹ Data for China is only available up to 2016.

² Data for Taiwan in 2010 was not broken down by district.

The mariculture sector as a whole is a significant employer in the ECS region, although it does not contribute substantially to the GDP of ECS economies. In Taiwan's ECS area, 1,474 individuals are employed in the mariculture sector, while about one third of households in Korean ECS areas are involved in aquaculture. In Japan, there are 3,618 farm sites located in the ECS with over 2,000 of these being for nori farming and another 300 being other forms of aquatic plant farming.

Country Overviews

China

China is the largest mariculture producer in the world, and unsurprisingly the largest producer in the ECS (Campbell and Pauly 2013; FAO 2017b). Since 2000, China's mariculture in the ECS has accounted for ~80% of all mariculture production in the ECS. Based on a recent analysis, China is one of the few countries in the world that farms more fish than its sea area would be expected to produce at maximum output (Gentry et al. 2017). This is either attributed to over-reporting in their production statistics, as they have previously done for fisheries statistics (Watson and Pauly 2001), or due to the intensiveness of their production methods. In fact, it is noted that aquaculture production is probably less than 70% of that reported in Fisheries Statistics Yearbooks (pers comm. From Chinese fisheries scholar provided to T. Mallory).

China's intensive mariculture is dependent on large amounts of fish inputs in the form of fishmeal and direct feed derived from 'trash fish'. China is the world's largest importer of fishmeal (FAO 2016), and also imports or catches (from its distant water fisheries) substantial amounts of marine fishes for this purpose (Cao et al. 2015). There is also a discrepancy in the amount of fishmeal China is estimated to consume, compared to their reported production and imports (Greenpeace East-Asia 2017).

In addition to their finfish culture, China also produces large amounts of seaweed annually, which has been proposed as a solution for the eutrophication problem in Chinese waters (Liu et al. 2009; Wu et al. 2015). However, as some of these farmed algae break off from the farmed site, it can aggregate and lead to large macroalgal blooms itself, a different marine challenge for these ecosystems. The intensiveness of China's algal farming is partially to blame for the large macroalgal bloom noticed during the 2008 summer Olympics in Beijing (Liu et al. 2009).

Japan

Japan's aquaculture is focused on high value species and seaweed (nori) production. While Japan produces a total of 1.3 million t through aquaculture, only ~13% of this is in the ECS. Japan's main farmed species in the ECS are Japanese amberjack (*Seriola quinqueradiata*) and silver seabream (*Pagrus auratus*), which together account for over 90% of total farmed production in the ECS. In addition, Japan has started increasing their farming of Pacific Bluefin tuna in the ECS to make up for falling supply from wild capture (Metian et al. 2014; ISSF 2017). These three species are all high-value species which contribute to Japan's aquaculture production being a high-value sector. Japan's farming of carnivorous species makes it highly dependent on fish-based feed inputs including direct feed, fishmeal, and fish oils.

Japan's aquaculture is regulated by the 'Law to Ensure Sustainable Aquaculture Production (1999)'. The law focuses on three areas: water quality, sediment impact on the bottom, and health of cultured fish (Takeda 2010). Food safety is very important in this regard, and aquaculture legislation focuses on reducing the spread of disease on farms. There have already been successes in the reduction of volatile compounds released from farms, and a switch from fresh fish feed to dry-pelleted feeds is aiding in this progress (Takeda 2010).

Korea

Korea has the second largest mariculture in the ECS, and their production in this ecosystem makes up over 80% of their aquaculture production. Apart from Korea's seaweed production which makes up half of their aquaculture by weight (FAO 2006), a large portion of their animal mariculture is from bivalves, specifically Pacific cupped oyster (*Crassostrea gigas*) and Korean mussel (*Mytilus coruscus*). They also have significant production of bastard halibut (*Paralichthys olivaceus*) and Korean rockfish (*Sebastes schlegeli*).

Korea's mariculture now produces more fish than their fisheries (FAO 2017c,d). The aquaculture industry employs over 60,000 people which is equivalent to a third of those employed in the fishery sector (FAO 2006). Most farming of finfish occurs in cage farms as is common in the region.

The Korean government issues licenses for aquaculture farms and has issued over 13,000 to date. They limit the size of these farms in hopes to encourage small scale businesses. In addition, there are controls on the use of antibiotics and on the water quality surrounding the sites (World Fishing & Aquaculture 2013). Along with these regulations, the Korean government has a policy in place to grow their finfish mariculture sector due to its high value. In addition, the government has taken actions such as the Ground Management Act to improve aquaculture operations and reduce their impact on the environment (FAO 2003).

Taiwan

The majority of Taiwan's aquaculture occurs inland or not within the ECS (Campbell and Pauly 2013; FAO 2017c). Overall, Taiwan has about 22,000 people working in the mariculture sector (FAO 2014; Witter et al. 2015). While the sector is important to the country as a whole, it appears that most of this production is focused outside of the ECS and is thus less likely to be influenced by environmental changes within the ECS.

Taiwan's major mariculture species are Japanese hard clam (*Meretrix lusoria*) and milkfish (*Chanos chanos*). These two species form the bulk of Taiwan's mariculture production in the ECS which is between 3,000 to 5,000 t annually. Therefore, Taiwan's total contribution to mariculture in the ECS is only a fraction of a percent (~0.15%). However, it is acknowledged that many farms operate without a license and these may not be reported in total national production (Chen and Qiu 2014). Taiwan's aquaculture sector grew rapidly in the 1970s and 1980s which led to negative environmental impacts (Chen and Qiu 2014). In addition, disease outbreaks were quite common during this time period (Chen and Qiu 2014). Taiwan adopted firm reforms to the sector that has

substantially benefitted the sector since then. Currently, Taiwan's aquaculture sector is facing a challenge for space. This comes from many existing and future development aiming to use the same space as the farms are using, with potentially negative effects on the farms. This has been seen with heavy metal (copper and zinc) polluting the area and turning oysters green (Chen and Qiu 2014).

Key Concerns

Feed Sources

For many trawl fisheries in East Asia, former target species have become depleted, resulting in the current situation wherein the majority of catches are composed of low-value fish. However, these low-value fish have a new market possibility with the growth in demand for fishmeal and fish feed for the growing aquaculture sector (Funge-Smith *et al.* 2005) (Box 2). The new form of fishing which solely targets the biomass of fish to be used as feed inputs is called biomass fishing, which is a major concern in the ECS. However, this topic has not been studied thoroughly to date. It is believed biomass fishing is attributable to lower populations of the former high-value target species (e.g., shrimps, groupers, etc.), and to the increase in price paid for 'trash fish' that is used for direct feed or fishmeal production.

Based on a recent global study, ~26% of landings from the ECS are likely used as feed inputs into aquaculture (Cashion *et al.* 2017). One million t of this are converted into fishmeal, and another 600,000 t are used for other non-direct human consumption uses, which is likely used for direct feed for aquaculture. While not all of the landings sourced from the ECS are used for mariculture within the ECS, it is likely a high proportion. In addition, China sources fishmeal from many other countries and waters that are likely used for feed in the ECS.

Japan and China are much more dependent on feeds for their mariculture sector than Korea and Taiwan, which farm more bivalves, for which feed is not required. The aquaculture industry has made large gains with regard to the efficiency of feed conversion ratios (the amount of feed inputs required to yield a certain biomass of cultured fish), as well as reductions in the amount of fish in the average feed (Tacon and Metian 2008). Nevertheless, the ecological implications arising from the sheer quantity of 'trash fish' being taken to supply the growing aquaculture industry remains a large management concern.

Box 2: Situation analysis of trash fish fisheries in the East and South China Seas (Sadovy de Mitcheson, Leadbitter, and Law 2018).

The status of the trash fish industry in China is largely unknown. This is a concern given the rise in demand for trash fish to supply base materials for China's huge and growing aquaculture industry, and also as feed for other animals. To investigate the present status of trash fish fisheries, a recent field study was conducted in Chinese provinces bordering the East and South China Sea (Sadovy de Mitcheson, Leadbitter, and Law 2018). Two of the three field survey sites were in the ECS provinces of Zhejiang and Fujian.

Trawling is the main source of trash fish for fish feed and fishmeal, with other sources coming from purse seine, set net, and remains from fish processing. Mean annual production from trawlers in Zhejiang and Fujian was 2,103,225 and 778,343 t, respectively. Of this, interviews with fishermen indicated that trash fish on average accounted for 50% and 37% of total trawler catch in Zhejiang and Fujian, respectively. Trash fish samples collected from trawlers found 62 families of fish, 3 families of cephalopods, and 16 families of crustaceans. The top 5 fish species/groups, which made up 26% of total fish samples by weight, consisted of anchovies (*Setipinna* spp., *Engraulis japonicus*), mackerels (*Rastrelliger* spp.), lanternbellies (*Acropoma hanedai*), and yellow goosfish (*Lophius litulon*). In terms of abundance, the top five species/groups were *Acropoma hanedai*,

Bregmaceros spp. (codlets), *Rastrelliger* spp., *Setipinna* spp., and *Trachurus japonicus* (hairtail). Collectively, these species accounted for 29% of fish samples analysed by abundance.

The majority of trash fish in ECS provinces (62% and 67% in Fujian and Zhejiang, respectively) is utilized for fish feed. Besides direct fish feed, most processing plants in northern China are also involved in fishmeal production, with Zhejiang being one of two highest fishmeal production provinces in China, the other being Shandong. To a much lesser extent, some trash fish is also used for human consumption (Fig. 18) (Greenpeace 2017). Fishermen in Zhejiang reported that they sometimes sold trash fish to large yellow croaker aquaculture facilities in Fujian, or to fur farms in northern China. This trading of trash fish between provinces makes it difficult to link the volume of trash fish utilized in a province to the production of trash fish in the province. Overall, this study indicates that a substantial portion of trawler catches, which constitute the highest contribution to China’s annual marine fish catch, is used for animal feed and fishmeal production. The prevalence of trash fish in China’s fisheries emphasizes that continued aquaculture growth and overfishing has serious environmental and food security consequences for marine and human systems in the ECS.

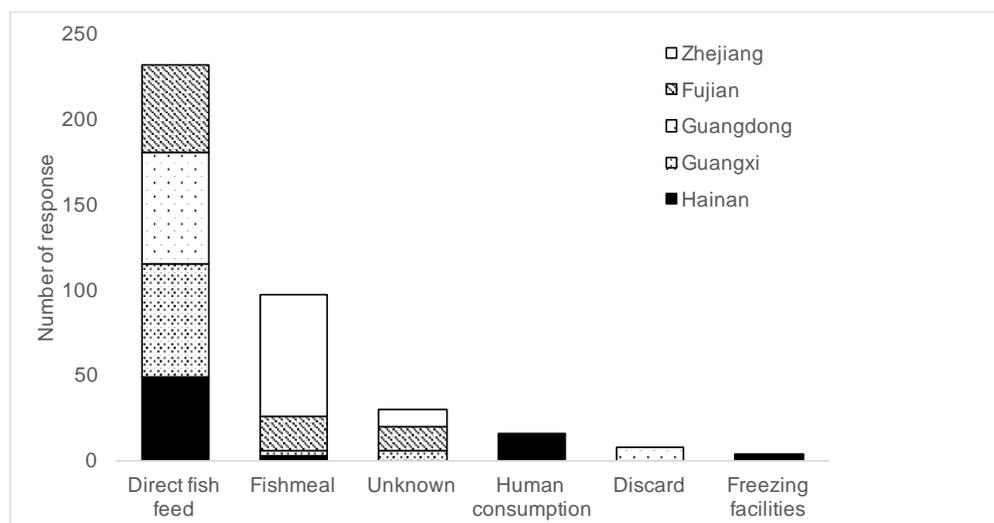


Fig. 18. Range and frequency of responses to the different utilization of “trash fish/low-valued fish” by interviewees (n=386). Note that some interviewees provided more than one answer. Source: Greenpeace (2017)

Aquatic Diseases and Disease Management

Many aquatic diseases are common in shrimp mariculture in the ECS and surrounding waters. China is believed to be the source of white spot syndrome virus (WSSV), which spread to many other shrimp farming nations in the region. White spot syndrome can cause massive mortalities on farms when not protected against. Another virus which affects crustaceans, called taura syndrome virus (TSV), was first reported in Taiwan. As seafood trade is common, and many countries source live organisms for grow-out from others, these diseases can spread quickly and negatively impact farmed organisms and their surrounding ecosystems. Further, the proliferation of these diseases increases the need and desire for antibiotic use.

Commercial aquaculture feeds often have antibiotics incorporated into them, or antibiotics are given to the fish in their environment. Depending on the delivery mechanism, this can lead to a lot of leaching into the aquatic environment. These antibiotics can affect non-cultured organisms and their potential survival, changing the functioning of the ecosystems, and can also lead to large-scale antibiotic resistance (Zou et al. 2011). A high

proportion of anti-biotic resistant genes has been detected in the effluent of South Korean mariculture sites (Jang et al. 2018).

Pollution and Habitat Effects

Excess nutrients from mariculture effluents are often a challenge of fed mariculture (Wang et al. 2016). This problem is exacerbated by excessive feeding, or using feeds that break apart easily (Cao et al. 2007). The use of commercially made feeds is likely at an all-time high, but for smaller-scale mariculture, farm-made feeds are still common (Hasan and Halwart 2009; Tacon and Metian 2015). Excessive nutrients have been linked to hypoxia in the ECS, with detrimental impacts on the ecosystems (Wang et al. 2016). While not studied as much at the LME level, excessive nutrient loading and the negative impacts it has on the seabed ecosystems has been studied in Japan (Pawar et al. 2001; Zhang and Kitazawa 2015). This issue is of less direct importance in mariculture for Korea and Taiwan as their industry is not focused on those that cause these high levels of pollution - Korea is focused mainly on bivalve culture and Taiwan's industry is mainly inland.

Mariculture of bivalves and aquatic plants are often seen as potential solutions to excessive nutrient supply as they can utilize the nutrients to increase production (Wu et al. 2015). However, these can be the cause of other challenges including habitat modification and excessive activity due to harvesting techniques (see China Section, (Liu et al. 2009). While not necessarily pollution, the habitat alteration caused by mariculture development can have negative consequences. The first is the destruction of habitat formerly used as fish spawning grounds. Further, mariculture development can lead to creation of hard substrate, such as that found on shellfish farming grounds, and this can provide increased habitat for jellyfish polyps (Dong et al. 2010).

Conclusion

The East China Sea LME is a globally important fishing ground which supports the fisheries of the world's leading fishing nations. Total fisheries catch from the ECS LME have in recent years reached 6 million t per year, with a value of up to USD 13 billion. As well, these fisheries provide employment for up to an estimated 1.4 million fishers. While the number of people involved in ECS fisheries may not be high compared to the population of ECS countries, it is important to recognize that ECS fisheries are predominantly small-scale and coastal. Thus, they remain crucial for supporting coastal communities' food security, livelihoods, income and welfare, even though ECS countries are some of the most developed or rapidly industrializing countries in Asia. However, the capacity for ECS fisheries to provide socio-economic benefits is challenged by continued overexploitation and depletion of coastal marine resources. Major concerns affecting the state of ECS marine ecosystems include IUU fishing, fleet overcapacity, destructive fishing, coastal pollution, and habitat destruction and loss. Rapid growth in aquaculture and the resulting need for fish feed has also fueled biomass fishing, which is a big concern in ECS fisheries. Driving these issues are broader, interacting factors such as inefficient governance, climate change, and socio-economic development trajectories.

One of the largest barriers to effective ECS fisheries management is the ongoing territorial disputes over overlapping national boundaries, which hinder other formal agreements and management of marine resources. While there are bi-lateral agreements for fishing access in 'shared' areas between ECS countries, there lacks a multilateral fisheries agreement for the entire ECS. This has serious repercussions for the region's commercially important fish stocks, the majority of which are migratory and thus require cooperative management from all 4 countries. Another challenge to fisheries regulatory measures is the continued provision of fuel subsidies to the ECS fishing fleet, almost all of which goes to the large-scale sector, thereby exacerbating the overexploitation of fisheries resources.

In conclusion, it is clear that the continuation of present unsustainable trajectories in ECS fisheries will not only affect global fishery production, but also hurt the social, economic, and human well-being of coastal communities. As such, our review emphasizes the urgency for overcoming the stalemate in ECS territorial disputes, and to take action at national and multinational (LME wide) scale to mitigate human and climate pressures on the ECS marine ecosystem.

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Appendix

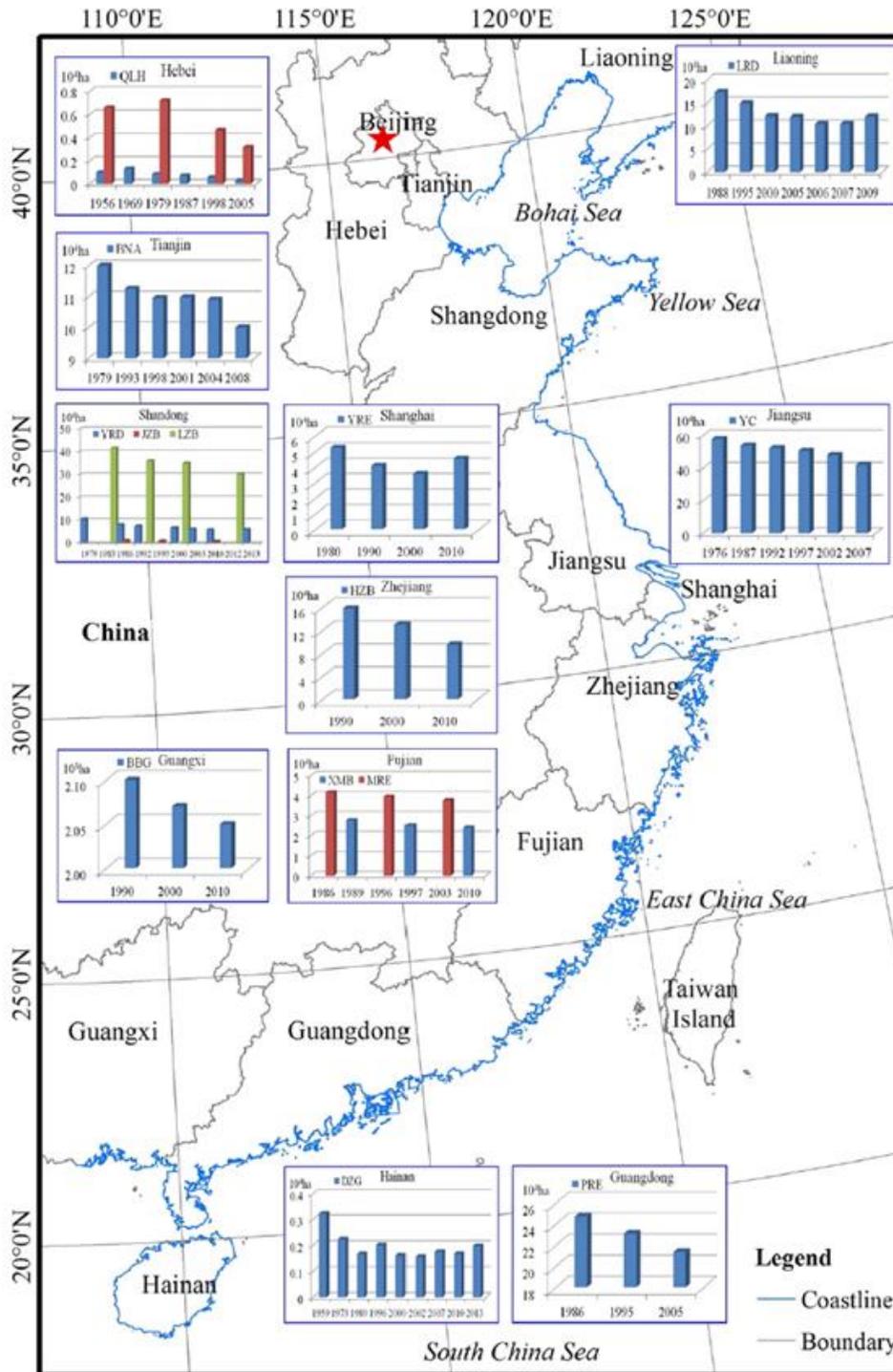


Fig. A1. Areas of main natural coastal wetlands in China's coastal provinces. Bar charts represent the area (ha) of natural coastal wetlands in coastal provinces over the past decades. ECS provinces are Jiangsu, Zhejiang, Fujian, and Shanghai. Source: Sun et al. (2015)

Table A1: Fisheries Management Index (unweighted and not adjusted)

Country	FMI	Research	Management	Enforcement	Socioeconomics	Stock Status
China	0.35	0.47	0.31	0.31	0.31	0.17
Japan	0.63	0.84	0.57	0.44	0.65	0.74
Korea	0.68	0.83	0.66	0.57	0.65	0.54

Source: (Melnychuk et al., 2016)

Table A2: Fisheries Management Index (weighted and adjusted)

Country	FMI	Research	Management	Enforcement	Socioeconomics	Stock Status
China	0.37	0.48	0.33	0.34	0.32	0.17
Japan	0.61	0.83	0.55	0.43	0.64	0.74
Korea	0.67	0.83	0.64	0.55	0.66	0.52

Source: (Melnychuk et al., 2016)

Table A3: Marine Resource Management Score with 14 indicators¹. Source: Alder et al. (2010)

Indicator	China	Korea	Taiwan	Japan
MPA _{area}	0	1	0	0
MPA _{inv}	0	0	1	1
EEZ _{trawl}	4	4	4	4
MSI _{ecol}	5.2	7.1	5	7.5
BIRD _{prot}	3.7	2.8	1.6	3.5
MAM _{prot}	5.1	5.3	6	4.4
LV _{GDP}	3	5	4	5
MEAL _{mar}	10	10	8	8
CODE _{FAO}	4.7	5.5	4	6.3
STAT _{rep}	15.1	39.8	27.5	36.8
SUB _{good}	0	0	0	6
CATCH _{fuel}	0	0	0	0
SUB _{LV}	8	8	8	7
MSI _{soc}	6.1	6.4	5.7	6.5
Aggregate	3.7	4.2	3.6	4.5

¹MPA_{area} : marine protected area coverage, MPA_{INV} : investment to marine protected areas, EEZ_{Trawl} : change in EEZ area trawled, MSI_{ECOL} : ecological components of mariculture sustainability, BIRD_{prot} : seabird protection index, MAM_{prot} : marine mammal protection index, LV_{GDP} : landed value relative to GDP, MEAL_{MAR} : fishmeal consumption by mariculture, CODE_{FAO} : compliance with the FAO code of conduct, STAT_{REP} : context-adjusted fisheries statistics indicator, SUB_{GOOD} : 'Good' to 'Good + Bad' subsidies ratio. For full details of each indicator, and how it was calculated, see (Alder et al., 2010).

Chapter 3. Global Change and the Fate of the East and South China Seas

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Abstract

Overfishing and climate change are two of the major anthropogenic stressors impacting marine ecosystems today. To understand how these related impacts will affect ecosystems and the fisheries that depend on them, we used two existing Ecopath with Ecosim models of the East China Sea and the South China Sea. To these models, we applied a matrix of three different climate change scenarios and four different fishing scenarios for a total of twelve scenarios. The results show potential benefits of climate change in the East China Sea, whereas there are large-scale declines in biomass and the fisheries of the South China Sea. With reductions in fishing effort and greenhouse gas emissions, many functional groups can remain in these seas. In contrast, under baseline fishing and a high emissions scenario, our results predict a 99% decline in biomass compared to 2000 levels of 17 functional groups in the South China Sea and 8 functional groups in the East China Sea. Overall, these two Seas will be heavily impacted by climate change, but the fisheries can remain if proper reductions in fisheries effort and greenhouse gas emissions are undertaken.

Introduction

Overfishing and climate change are two of the major anthropogenic stressors impacting marine ecosystems today. To understand how these related impacts will affect ecosystems and the fisheries that depend on them, we used two existing Ecopath with Ecosim (EwE) models of the East China Sea and the South China Sea. To these ecosystem models, we applied an experimental design and approach in matrices consisting of two different climate change scenarios and six different fisheries management scenarios for a total of twelve different management-climate scenarios. The climate change scenarios are: RCP 2.6 and RCP 8.5 (defined below), and the management scenarios, defined below, consist of (i) status quo; (ii) increasing effort; (iii-v) decreasing effort by various amounts; and (vi) reducing feed fisheries, respectively.

Methods

East China Sea EwE model

We adapt and apply the EwE model of Li and Zhang (2012) for the East China Sea shelf ecosystem for 1970. This model had several advantages over a model with a more recent 'base year' of 2000 (Li et al., 2009) because it enables us to take advantage of longer time-series data for improved fitting of the model. This EwE model has 38 functional groups, including all major fisheries resources and important groups in the ecosystem, such as marine mammals and seabirds. In addition, some of the same authors developed an ECS model with the same functional groups for the year 2000, giving us a reference case to compare our trajectory of the 1970 model trends (Li et al., 2009).

Biomass data for two functional groups in the East China Sea and Tsushima Strait were used from the RAM legacy database (Ricard et al., 2012). In addition, anchor points were derived for 25 functional groups where independent estimates were used as inputs into the 1970 and 2000 version of the existing ecosystem models (Li et al., 2009; Li & Zhang, 2012). Landings and discards data by functional group and fleet were obtained from the *Sea Around Us* (Pauly & Zeller, 2015). Catches destined for fishmeal and fish oil, and for direct feed often yield a lower price (Tai et al., 2017), and the relative prices per fleet and functional group for the year 2000 were used. The original Ecopath model was fit to these time series data to minimize the differences (i.e., residuals) between the observed biomass data and the model outputs. The vulnerability (v) estimates derived by Li and Zhang

(2012) were adopted here, but were capped at a maximum value of 10 (i.e., avoiding the assumption predator-prey interactions being purely driven by random encounters) to prevent unrealistic population growth in our projections and scenario analysis.

Northern South China Sea EwE model

Here, we apply the adapted EwE model of Cheung (2007) of the northern portion of the South China Sea. As this model is composed of most of the diverse habitats that make up the South China Sea, we use it as a representative model of the whole SCS. Cheung developed two balanced models of the SCS for the 1970s and 2000s and thus the 2000s model benefits from the time series fitting of the 1970s model. Thus, there was no need to fit this model to further data, except to manage the growth of fisheries in the region from 2000 to present.

Landings and discards data by functional group and fleet were obtained from the *Sea Around Us* database (Pauly & Zeller, 2015). The fleets were not updated to be the same fleets as the ECS. Instead, pair trawls and shrimp trawls were assumed to correspond to bottom trawls, hook and line to small-scale lines, and others was assumed to be other small-scale gears. Gillnets and purse seines are fleet segments in each original model and thus no assumptions were needed to apply catch and effort data to these fleets.

Fishing effort data

The original ECS EwE model was fit to a forcing function of the relative fishing effort in the ECS from 1970 to 2000 (Li & Zhang, 2012). In addition to this, we extracted another fishing effort time series based on data presented in Cao et al., (2017) of the Chinese fleet vessels numbers and average horsepower from 1995-2014. The data was extracted using DataThief3 (Tummers, 2006). The number of vessels was multiplied by the horsepower per vessel (kW/vessel) to give a measure of fleet capacity over this period expressed in kW. The growth rate of the fleet was calculated as 0.65% year⁻¹ from 2000 to 2014. This growth rate was used to inform the development of our future scenarios. The Chinese fleet is subject to seasonal closures in both the ECS and SCS and fishing fleet effort was reduced by the Chinese proportion of catches for the summer months (here defined as May, June, and July) starting in 1995 for the ECS and 2000 for the SCS (Shen & Heino, 2014). This seasonal closure was assumed to be in place for the remainder of the scenarios.

Climate change scenarios

To predict changes of the four climate change factors used to drive the EwE models, we used climate change simulation outputs from the Earth System Model ESM2M developed by the NOAA- Geophysical Fluid Dynamics Laboratory (Dunne et al., 2012) under two greenhouse gas emission scenarios: Representative Concentration Pathway (RCP) 2.6 as an “strong mitigation” low CO₂ emissions, and RCP 8.5 as the “business-as-usual” high emission scenario. For the ECS, we used climate change data predicted for the ECS LME, while for the northern South China Sea (NSCS) data for the entire LME was used as there are no downscaled predictions for the northern part of the SCS. Thus, time-series projections for changes in sea surface temperature (SST), pH, oxygen (surface) and net primary production were obtained from ESM2M (over the period 1950-2100 for RCP 2.6 and RCP 8.5), and time series data from 1996 to 2099 was used for the modelling work, as shown in Appendices I and II. For full details on forcing functions of climate variables (i.e. time series of relative change according to the climate predictions) used in these models, please see the supplementary materials.

Management scenarios

To model changes to the ecosystem and fisheries due to fishing pressure and climate change we developed six alternative fishing scenarios to be applied in tandem with the climate change scenarios. Thus, we present six alternative scenarios: status quo scenario, increased fishing effort scenario (hereafter, ‘Increase50’), three

version of a decreased fishing effort scenario (hereafter, ‘Decrease2’, ‘Decrease25’, and ‘Decrease50’), and a reduction of fisheries for feed into aquaculture and livestock by 50% (hereafter, ‘Reduced Feed Fisheries’). Given that current global fishing capacity is likely between 1.5 to 2.5 times the level required to maximize sustainable catch (Porter, 1998; Sumaila et al., 2012), fishing effort likely needs to be reduced by 40 to 60% (World Bank, 2017). All scenarios were modelled until 2099 given climate change scenarios extending to the end of the century, and all fishing scenario modifications were done through adjusting relative fishing effort of the fleets in each LME (Figs 1 and 2).

Status quo: The status quo scenario continued the current level of fishing effort to 2099.

Increased Effort: The increased effort scenario was developed to determine the effects of an increase of effort by 50% over the first 10 years and then a constant level of effort to 2099.

Reduced Effort: Three scenarios were modeled with a reduction in fishing effort. In these scenarios, fishing effort was decreased for all fleets by 2, 25, or 50% over the first 10 years and then maintained at constant levels to 2099.

Reduced Feed Fisheries: A fourth scenario was modeled where fishing effort was reduced for those fleets responsible for generating feed for the aquaculture and livestock sectors. The relative effort in these fleets was reduced by half of the proportion of their landings that are destined for fishmeal, fish oil, or direct feed based on Cashion *et al.* (2017) (Fig 2). When combined, there are twelve scenarios total with each fishing scenario applied to each climate change scenario (RCP2.6 and RCP8.5).

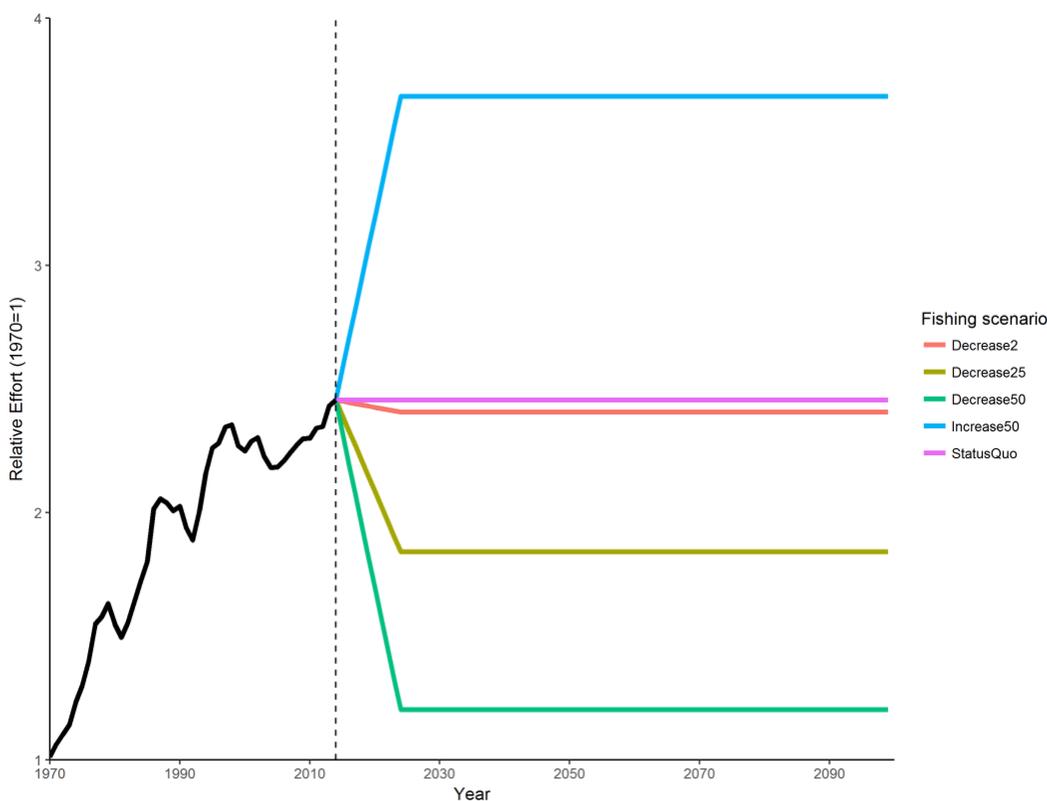


Fig. 1. Relative fishing effort for the fishing scenarios (excluding reduced feed fish scenarios, see Fig. 2.)

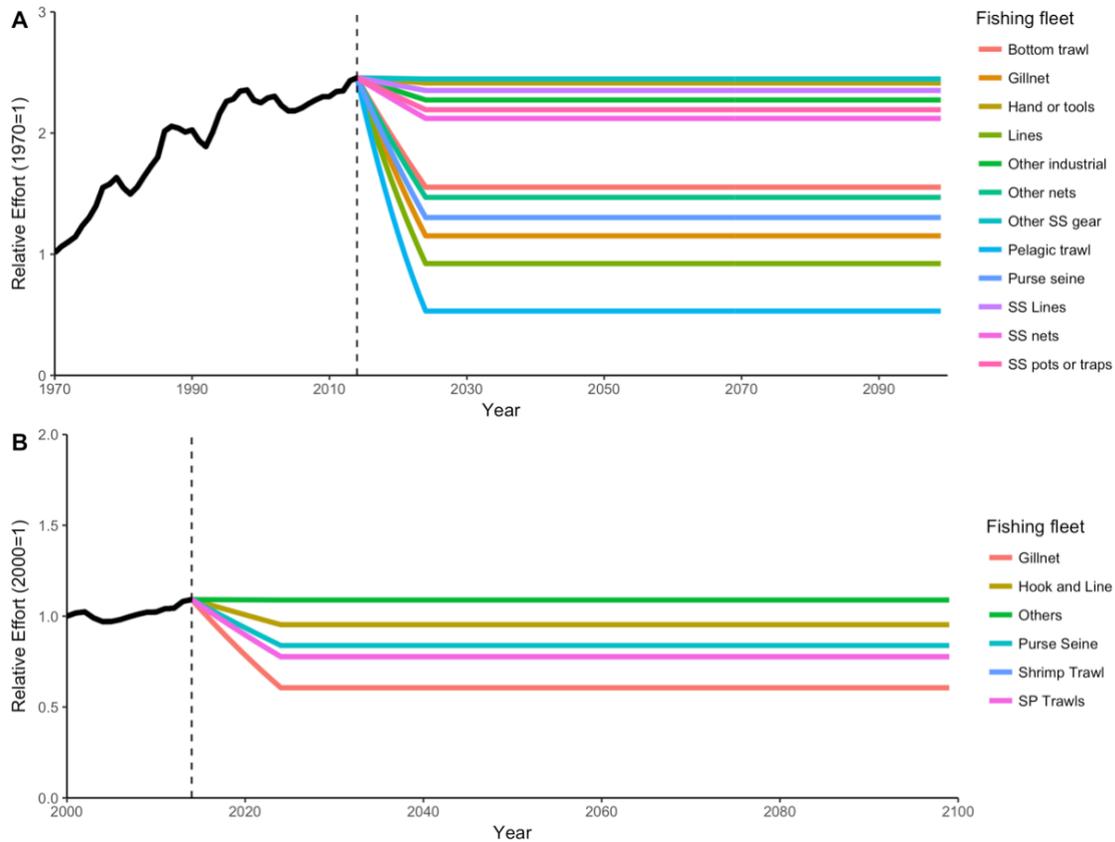


Fig. 2. Relative fishing effort for the reduced feed fish fishing scenarios for the ECS (A) and SCS(B)

Price flexibilities

Prices were adjusted for the scenarios going forward based on a literature review of how species groups respond to increased landings. In general, prices increase (decrease) as supply decreases (increases), and this has been shown to be true for fisheries, especially as the output of the stock is partially dependent on exogenous factors. A previous review of the literature for price flexibilities for fish estimated price flexibilities for the FAO functional groups (Sumaila et al., 2019). We applied these to the relevant functional groups in this study to adjust the price depending on the catch each year using the price and quantity landed in 2014 as the base year. Here, we assume all other factors affecting the new price are constant into the future to adjust prices relative to their supply (i.e., only affected by scarcity). Therefore, the price (P) in year (t) for a specific functional group (f) is a function of the change in landings (ΔL), the functional group price flexibility, and the 2014 price. This was calculated following the equations below:

$$\Delta L \% = ((L_t / L_{2014}) - 1) * 100 \quad (1)$$

$$\text{Value Change \%} = \Delta L \% * -\psi \quad (2)$$

$$P_{ft} = P_{f, t=2014} * ((100\% + \text{Value Change \%}) / 100) \quad (3)$$

Feed Fisheries Analysis

We quantified the effect of these different scenarios on expected fish for feed (processed into fishmeal and fish, and used for direct feeding in livestock and aquaculture). We used the proportion of different functional groups used by different fishing fleets in 2014 in the ECS and SCS to see how the catches of these functional groups would in turn effect availability of currently commonly used feed fish. For the ‘Reduced Feed Fisheries’ scenario, we reflected the reduction in fishing effort as resulting in a reduction in use for feed for those fleets and assumed the proportion that would have been used for feed would be redirected towards direct human consumption.

Results

East China Sea

Overall biomass in ECS

The biomass of species functional groups exhibited marked differences for either RCP 2.6 or RCP 8.5 as shown in Table 1. Relative to the 2000s, the percent change in biomass are respectively 14% and 52% for the fishing status quo under RCP 2.6 and RCP 8.5, while for the increased effort scenario, the percent changes are 14% and 54%, respectively. The fishing scenarios perform very similar to each other within each RCP scenario but the RCP scenarios are markedly different from each other. Considering the mean temperature (thermal) tolerance of fish species in the region, the higher increases in biomass for these scenarios under RCP 8.5 in the subtropical ECS may be plausibly explained by the incidence of tropicalization due to the northward re-distribution of fish species from southern tropical regions in the face of ocean warming (Cheung et al. 2013; Cheung et al. 2016).

Table 1: Biomass scenarios (mean \pm SD) in tonnes km⁻² for different fishing scenarios under two climate change treatments (RCP 2.6 and RCP 8.5). Biomass values for the status quo scenario are also reported here as reference for comparison purposes.

Climate change treatment	Status Quo (tonnes km ⁻²)	Increase 50% (tonnes km ⁻²)	Decrease 2% (tonnes km ⁻²)	Decrease 25% (tonnes km ⁻²)	Decrease 50% (tonnes km ⁻²)	50% feed fisheries (tonnes km ⁻²)
RCP 2.6	93.2 (2.03)	92.6 (2.26)	93.2 (2.03)	93.5 (2.11)	94 (2.2)	93.3 (2.11)
RCP 8.5	125.2 (13.32)	126.7 (12.91)	125.1 (13.32)	125.1 (13.23)	127.5 (13.35)	124.8 (13.37)

Overall catch in ECS

Similar to the scenarios for biomass changes, the overall marine catches were projected to increase for fishing status quo, increased effort scenario, decreased effort scenarios and reduced feed fisheries regimes under high CO₂ emissions, i.e. RCP 8.5 (Table 2). The percent increases ranged from 58.7% (RCP 2.6) to 157.6% (RCP 8.5) in the status quo and from ~96.6% (RCP 2.6) to close to 223.9% (RCP 8.5) in the increased fishing effort, respectively. Within them decreased fishing effort scenarios, the percent increase in marine catches was between -5.14% under Decrease50 while up to 57.3% under RCP 2.6, and 115.2% to 154.4% under RCP 8.5, respectively. The Reduced Feed Fisheries scenario had increased catches of 30.7% under RCP 2.6, and 114% under RCP 8.5. These outcomes can be explained by the mean temperature of the catch (MTC), which has been projected to increase in the ECS, where a strong relationship between MTC and SST was observed from 1950 to 2010 (Liang et al., 2018).

Table 2: Marine catches (mean \pm SD) in tonnes km⁻² for different fishing scenarios under two climate change treatments (RCP 2.6 and RCP 8.5). Catch values for the status quo scenario are also reported here as reference for comparison purposes.

Climate change treatment	Status Quo (tonnes km ⁻²)	Increase 50% (tonnes km ⁻²)	Decrease 2% (tonnes km ⁻²)	Decrease 25% (tonnes km ⁻²)	Decrease 50% (tonnes km ⁻²)	50% feed fisheries (tonnes km ⁻²)
RCP 2.6	7.9 (1.09)	9.7 (0.76)	7.8 (1.1)	6.6 (1.01)	4.7 (0.75)	6.5 (0.96)
RCP 8.5	12.8 (0.94)	16.1 (1.73)	12.7 (0.92)	10.4 (0.76)	10.7 (0.71)	10.7 (1.41)

Overall revenue in ECS

The total revenues of marine catches in the ECS shows contrasting values between RCP 2.6 and RCP 8.5 relative to the present under all scenarios (Table 3). Percentage decreases in revenues, ranging from -1.34% for Decrease25 to -25.30% for Decrease50 are projected under RCP 2.6. For RCP 8.5 all scenarios had an increase in revenues ranging from a low of 13.18% for Decrease50 scenario to a high of 109.76% under increased fishing effort. The Reduced Feed Fisheries scenario shows a decrease in revenues by -1.45% under the RCP 2.6, but a percent increase of 27.29% under RCP 8.5. The positive impact for overall revenues under RCP 8.5 is consistent with the plausible increases in biomass and marine catches (Tables 3 and 4).

Table 3: Overall revenues (mean \pm SD) in \$ km⁻² different fishing scenarios under two climate change treatments (RCP 2.6 and RCP 8.5). The value of the marine catches for the status quo scenario are also reported here as reference for comparison purposes.

Climate change treatment	Status Quo (\$ km ⁻²)	Increase 50% (\$ km ⁻²)	Decrease 2% (\$ km ⁻²)	Decrease 25% (\$ km ⁻²)	Decrease 50% (\$ km ⁻²)	50% feed fisheries (\$ km ⁻²)
RCP 2.6	6671.9 (380.18)	7636.2 (588.42)	6658.3 (363.73)	6280.8 (253.76)	4755.8 (326.73)	6273.9 (290.93)
RCP 8.5	9596.2 (1024.29)	13263.2 (1499.01)	9449.8 (1001.41)	7803.5 (705.62)	7156.3 (365.6)	8048.2 (911.54)

Species/Functional group level in ECS

The difference in the biomass of the different functional groups explains this result as many high value species populations decrease dramatically under heavy fishing pressure and climate change (Fig. 5), contrasting with the growth of molluscs accounting for a large portion of the biomass in the ecosystem (Figs. 3 and 4). However, their catches, and values can be increased dramatically with increased fishing pressure (Figs. 5 and 6).

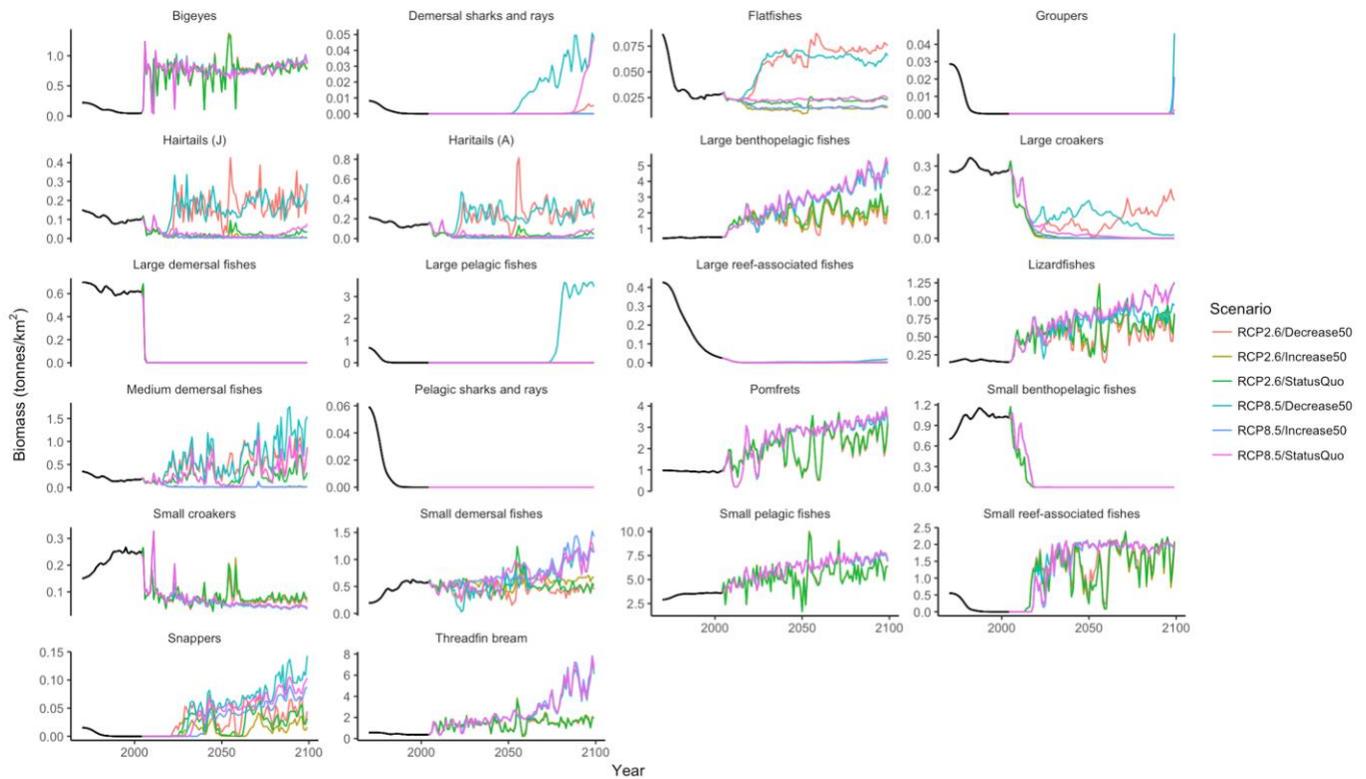


Fig. 3. Biomass ($t\ km^{-2}$) in the ECS of finfish functional groups under RCP 2.6 and RCP 8.5 for the Decrease50, Increase and Status Quo fishing scenarios.

The amount and value of catches remain concentrated in a small number of functional groups in the ECS over the time period (Tables 4 and 5). However, some groups of notable fisheries and conservation interest disappear from being a mainstay of the fisheries such as both large and small yellow croakers. In addition, the catches are more concentrated at the end of the period in fewer functional groups than at the beginning of the period. In terms of fisheries revenues, the top three functional groups account for 62% of the total in the 2090s compared to 44% in the 2000s.

Table 4: Average catch (t km⁻²) of from top 10 functional groups in the 2000s and 2090s in the ECS under the Status Quo RCP 8.5 scenario.

Functional group	Average catch in the 2000s (t km ⁻²)	Cumulative Percentage (%)	Functional group	Average catch in the 2090s (t km ⁻²)	Cumulative Percentage (%)
Demersal fishes1	0.87	17	Large benthopelagic fishes	2.46	19
Small pelagic fishes	0.80	33	Demersal fishes2	2.40	37
Cephalopods	0.53	44	Molluscs	2.16	54
Demersal fishes2	0.49	54	Demersal fishes1	1.83	68
Molluscs	0.49	64	Small pelagic fishes	1.71	81
Other invertebrates	0.34	70	Small reef-associated fishes	0.58	85
Large benthopelagic fishes	0.29	76	Threadfin bream	0.44	89
Haritails (A)	0.18	80	Other invertebrates	0.32	91
Large croakers	0.13	83	Lizardfishes	0.27	93
Small croakers	0.11	85	Cephalopods	0.15	94
All others	0.76	100	Others	0.73	100

Table 5. Average value (\$) of from top 10 functional groups in the 2000s and 2090s in the ECS under the Status Quo RCP 8.5 scenario

Functional group	Average value in the 2000s (\$)	Cumulative Percentage (%)	Functional group	Average value in the 2090s (\$)	Cumulative Percentage (%)
Benthic crustaceans	1171.23	19	Large benthopelagic fishes	2845.79	29
Demersal fishes1	930.75	33	Molluscs	1938.38	49
Cephalopods	678.49	44	Demersal fishes1	1305.73	62
Other invertebrates	670.89	55	Other invertebrates	665.48	69
Molluscs	608.28	64	Small pelagic fishes	662.09	76
Large benthopelagic fishes	552.17	73	Demersal fishes2	456.79	81
Small pelagic fishes	458.82	80	Cephalopods	330.87	84
Zooplankton	178.83	83	Small reef-associated fishes	319.70	87
Haritails	165.32	86	Threadfin bream	221.35	90
Large croakers	143.83	88	Zooplankton	177.87	91
All others	764.38	100	All others	834.73	100

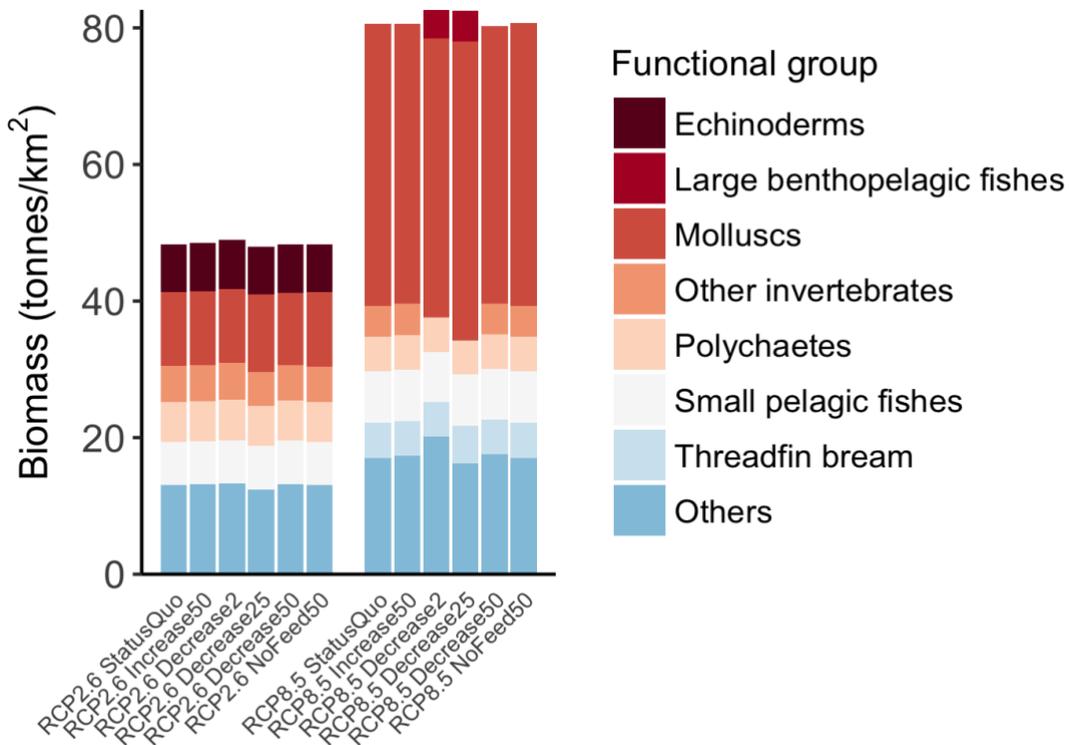


Fig. 4. Average biomass from 2090-2098 of major functional groups under different scenarios in the ECS. Note: only the top 5 groups by biomass are displayed in each bar with all others aggregated under ‘Others’.

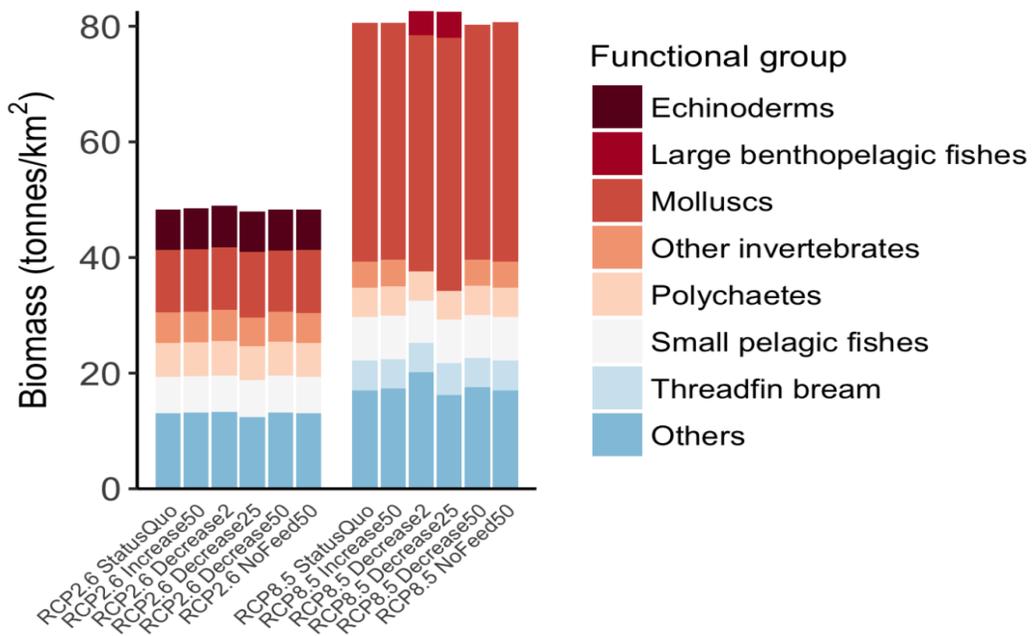


Fig. 5. Average biomass from 2090-2098 of major functional groups under different scenarios in the ECS excluding detritus, phytoplankton, zooplankton, and benthic producers. Note: only the top 5 groups by biomass are displayed in each bar with all others aggregated under ‘Others’.

Many marine invertebrates will prosper under climate change, while most marine fish groups will decline substantially (Fig. 5). Overall, eight functional groups biomass declines by 99% or greater under the high emission scenario with status quo fishing (Table 6). For instance, while the biomass of jellyfish substantially declines in the ECS due to greater predation by pomfrets (Stromateids) and increased fishing effort for jellyfish, snappers and small-reef associated fish benefit in the ECS under most high emission scenarios.

Table 6: Functional groups that decline by >99% in the high emissions (RCP 8.5) status quo scenario for the ECS and SCS

ECS	SCS
Benthic crustaceans	Adult demersal fish (>30cm)
Small demersal fishes	Benthic crustaceans
Jellyfish	Benthopelagic fish
Large croakers	Bigeyes (Priacanthids)
Large pelagic fishes	Cephalopods
Pelagic sharks and rays	Croakers (≥ 30 cm)
Small benthopelagic fishes	Demersal fish (<30 cm)
	Juvenile demersal fish (≥ 30 cm)
	Juvenile large croakers
	Juvenile large pelagic fish
	Melon seed
	Other marine mammals
	Pelagic fish (≥ 30 cm)
	Pelagic fish (<30cm)
	Pelagic sharks and rays
	Pomfret (Stromateids)
	Threadfin bream (Nemipterids)

Fleet results in ECS

In the ECS, most fleets can increase their catches and value under many of the modeled scenarios (Figs. 6 and 7). Due to the reductions in fishing effort, industrial fleets and those that use a large amount of their catches for fish feed do not maintain as high catches or value under these fishing scenarios compared to status quo and increased fishing effort scenarios. Many small-scale gears have increased catches and value under climate change scenarios RCP2.6 and RCP 8.5.

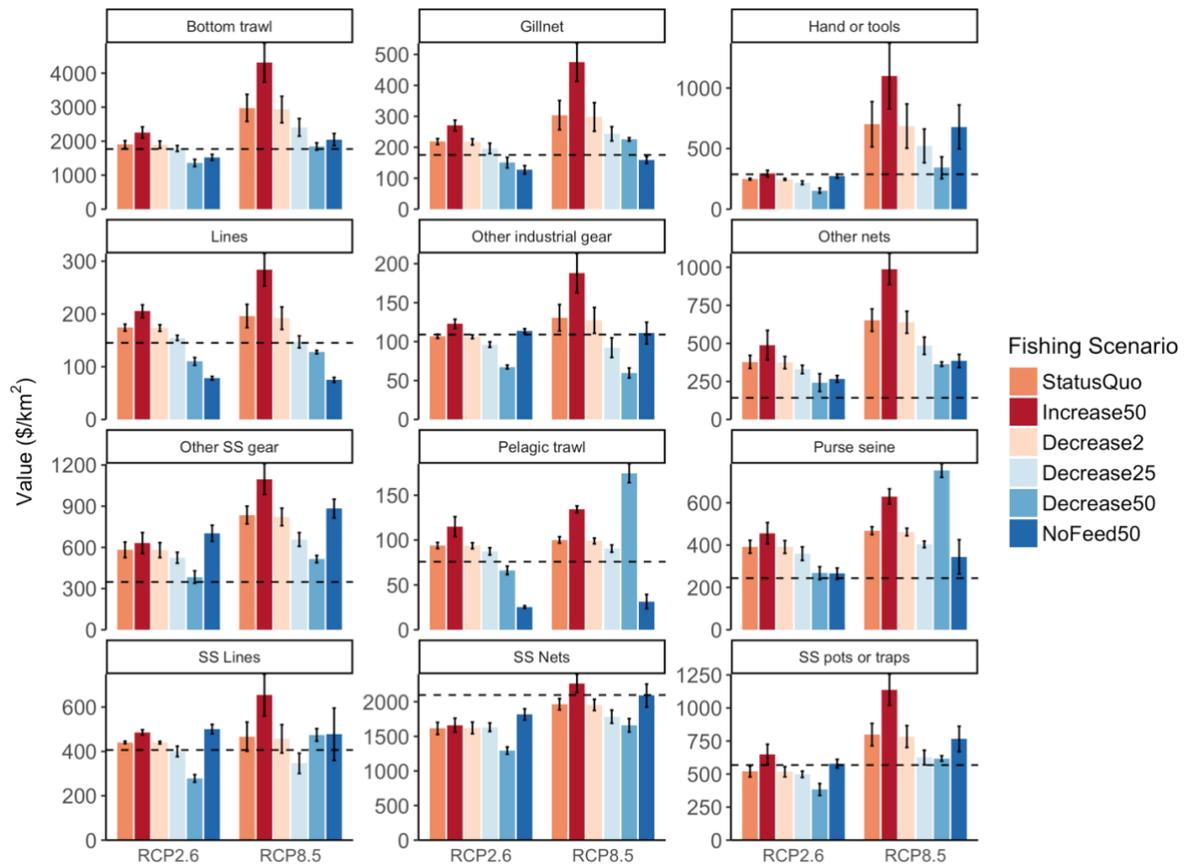


Fig. 6. Average value by fishing fleet in the ECS in the 2090s under different fishing and climate scenarios. Horizontal dashed line shows average value in the 2000s under RCP2.6 and status quo fishing scenarios.

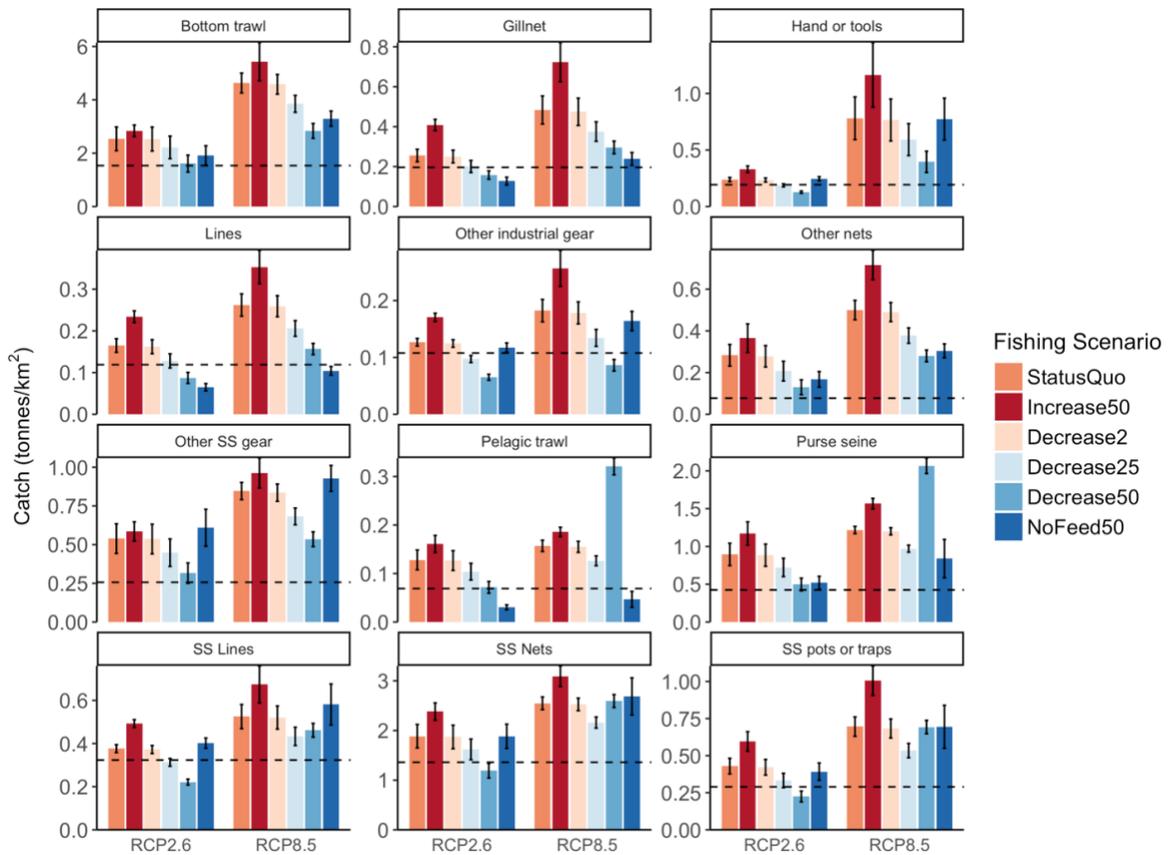


Fig. 7. Average catch by fishing fleet in the ECS in the 2090s under different fishing and climate scenarios. Horizontal dashed line shows average value in the 2000s under RCP2.6 and status quo fishing scenarios.

South China Sea

Overall biomass in the South China Sea

In contrast to the positive increases in biomass under RCP 2.6 and RCP 8.5 in the ECS, the overall biomass in the SCS is almost identical under all fishing scenarios under RCP 2.6 (Table 7). High CO₂ emissions (RCP 8.5) causes a decrease of -13% for all scenarios (Table 7).

Table 7: Biomass scenarios (mean ±SD) in tonnes km⁻² for different fishing scenarios under two climate change treatments (RCP 2.6 and RCP 8.5). Biomass values for the status quo scenario are also reported here as reference for comparison purposes.

Climate change treatment	Status Quo (tonnes km ⁻²)	Increase 50% (tonnes km ⁻²)	Decrease 2% (tonnes km ⁻²)	Decrease 25% (tonnes km ⁻²)	Decrease 50% (tonnes km ⁻²)	50% feed fisheries (tonnes km ⁻²)
RCP 2.6	597.4 (17.44)	597.6 (17.4)	597.3 (17.44)	596.9 (17.32)	596.6 (17.3)	596.8 (17.3)
RCP 8.5	514.1 (38.14)	514.1 (38.25)	514.1 (38.14)	514.2 (38.07)	514.6 (38.07)	514.2 (38.04)

Overall catch in the South China Sea

Similar to the projections for biomass in the SCS, the marine catches show a decrease under RCP 2.6 and RCP 8.5 in all scenarios relative to the present (Table 8). The percent decrease in catches is -9% for either status quo

and decrease (2%) in fishing effort, while reduced feed fisheries and decrease 25% scenarios show decreases of around 20%. The scenario with increased fishing effort keeps catches the highest at a decrease of only 1%. These projections are consistent with the lack of increase in the MTC for the SCS, where the MTC is not expected to increase as marine fish cannot be replaced by other species adapted to this tropical region as temperature increases (Liang *et al.* 2018).

Table 8: Marine catches (mean \pm SD) in tonnes km⁻² for different fishing scenarios under two climate change treatments (RCP 2.6 and RCP 8.5). Catch values for the status quo scenario are also reported here as reference for comparison purposes.

Climate change treatment	Status Quo (tonnes km ⁻²)	Increase 50% (tonnes km ⁻²)	Decrease 2% (tonnes km ⁻²)	Decrease 25% (tonnes km ⁻²)	Decrease 50% (tonnes km ⁻²)	50% feed fisheries (tonnes km ⁻²)
RCP 2.6	5.7 (1.02)	6.2 (1.12)	5.7 (1.02)	4.9 (0.89)	3.6 (0.6)	5.0 (0.91)
RCP 8.5	1.9 (0.31)	2.4 (0.52)	1.9 (0.3)	1.6 (0.21)	1.2 (0.14)	1.6 (0.2)

Overall revenue in the South China Sea

The economic value of the marine catches (\$ km⁻²) in the SCS show positive changes for some of the fishing scenarios in both RCP 2.6 or RCP 8.5 (Table 9) despite the aforementioned decrease in biomass and catches in this region. Under RCP 2.6, the overall revenue is the highest when fishing effort is increased (i.e. increase of 33.94%), while the lowest value for revenue is -19.18% for decrease 50% when compared to the present. Conversely, subject to the influence of RCP 8.5, the revenue increases 20.45% for the status quo scenario and 26.09 % for the increased effort (Table 9). Most fishing scenarios show a minor to moderate influence on total revenues for both climate scenarios, except for decrease 50 which is negative for both RCP 2.6 and RCP 8.5. The percent increase in revenue in reduced feed fisheries is 1.44% and 4.01% for RCP 2.6 and RCP 8.5, respectively.

Table 9: Overall revenues (mean \pm SD) in \$ km⁻² different fishing scenarios under two climate change treatments (RCP 2.6 and RCP 8.5). The value of the marine catches for the status quo scenario are also reported here as reference for comparison purposes.

Climate change treatment	Status Quo (\$ km ⁻²)	Increase 50% (\$ km ⁻²)	Decrease 2% (\$ km ⁻²)	Decrease 25% (\$ km ⁻²)	Decrease 50% (\$ km ⁻²)	50% feed fisheries (\$ km ⁻²)
RCP 2.6	181.1 (13.71)	208 (15.87)	179.6 (12.96)	160.6 (6.83)	125.5 (6.88)	157.5 (6.13)
RCP 8.5	187.6 (21.64)	196.3 (34.62)	186.4 (21.36)	167.6 (18.84)	132.4 (17.38)	162 (18.10)

Species functional group level in the South China Sea

In the SCS, a large change in overall biomass can be observed to be driven by decreased phytoplankton biomass (Fig. 8). However, this is partially compensated for by a growth in crabs (Fig. 9). The SCS undergoes a large-scale simplification and concentration of its catches and revenues into two functional groups: crabs and shrimps (Tables 10 and 11). By the end of the 2090s under RCP 8.5, these two groups account for 87% of the catches and 99% of fisheries revenues. In contrast, small and large pelagic fishes which form a large part of the catch at the beginning of the century, are nearly absent in terms of catches by the end of the century (Table 10). The decline in biomass of many important fishes is apparent (Fig. 10) and translates into declines in the catches and revenues attributed to these functional groups.

Table 10: Average catch (t km⁻²) of from top 10 functional groups in the 2000s and 2090s in the SCS under the Status Quo RCP 8.5 scenario

Functional group	Average catch in the 2000s (t km⁻²)	Cumulative Percentage (%)	Functional group	Average catch in the 2090s (t km⁻²)	Cumulative Percentage (%)
Pelagic fish (less than 30cm)	1.82	31	Crabs	1.23	63
Juvenile large pelagic fish	0.67	42	Shrimps	0.47	87
Shrimps	0.58	52	Non-cephalopod molluscs	0.19	97
Threadfin breams	0.53	61	Zooplanktons	0.04	98
Benthopelagic fish	0.42	68	Croakers (less than 30cm)	0.01	99
Non-cephalopod molluscs	0.32	73	Benthic producers	0.01	99
Pomfrets	0.30	78	Jellyfish	0.00	99
Juvenile demersal fish (30+cm)	0.23	82	Lizard fish	0.00	100
Cephalopods	0.19	85	Juvenile hairtails	0.00	100
Crabs	0.19	88	Sessile/other invertebrates	0.00	100
All others	0.68	100	All others	0.00	100

Table 11: Average value (\$) of from top 10 functional groups in the 2000s and 2090s in the SCS under the Status Quo RCP 8.5 scenario

Functional group	Average value in the 2000s (\$)	Cumulative Percentage	Functional group	Average value in the 2090s (\$)	Cumulative Percentage (%)
Shrimps	96.90	62	Crabs	102.86	55
Crabs	24.62	78	Shrimps	84.40	99
Pelagic fish (less than 30cm)	9.89	84	Non-cephalopod molluscs	0.68	100
Pomfrets	4.13	87	Adult groupers	0.26	100
Juvenile large pelagic fish	3.96	90	Croakers (less than 30cm)	0.12	100
Threadfin breams	2.66	91	Juvenile hairtails	0.04	100
Benthopelagic fish	2.66	93	Sessile/other invertebrates	0.03	100
Cephalopods	2.01	94	Lizard fish	0.03	100
Melon seed Juvenile demersal fish (30+cm)	1.27	95	Adult hairtail	0.01	100
Juvenile demersal fish (30+cm)	1.19	96	Cephalopods	0.01	100
All others	6.43	100	All others	0.01	100

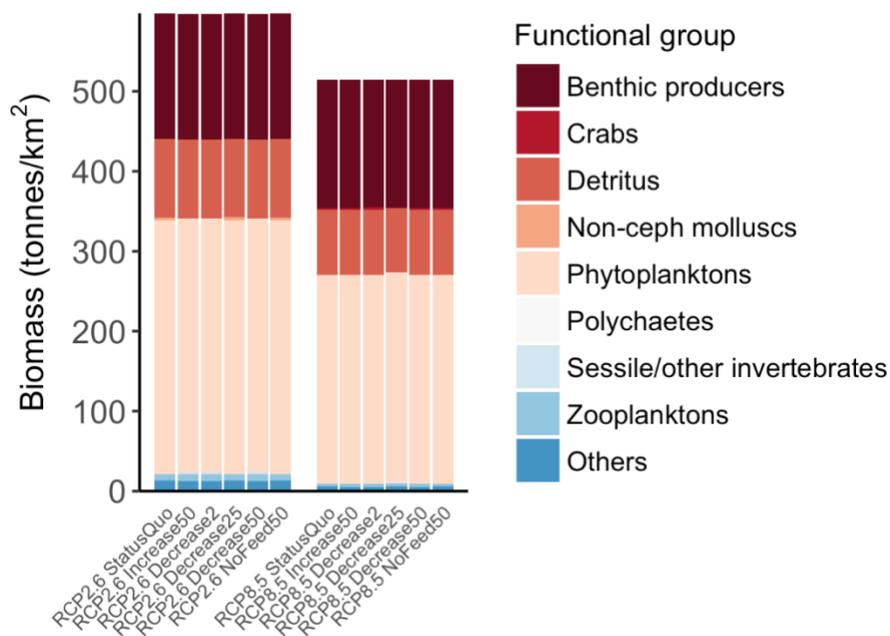


Fig. 8. Biomass of major functional groups under different scenarios in the SCS. Note: only the top 5 groups by biomass are displayed in each bar with all others aggregated under ‘Others’.

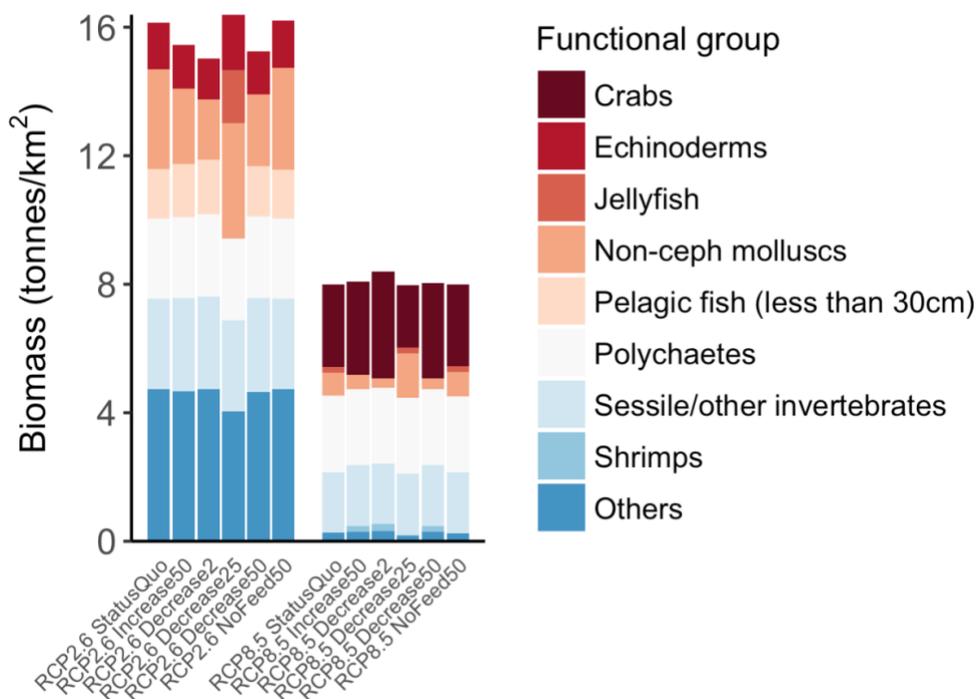


Fig. 9. Biomass of major functional groups under different scenarios in the SCS excluding detritus, phytoplankton, zooplankton, and benthic producers. Note: only the top 5 groups by biomass are displayed in each bar with all others aggregated under ‘Others’.

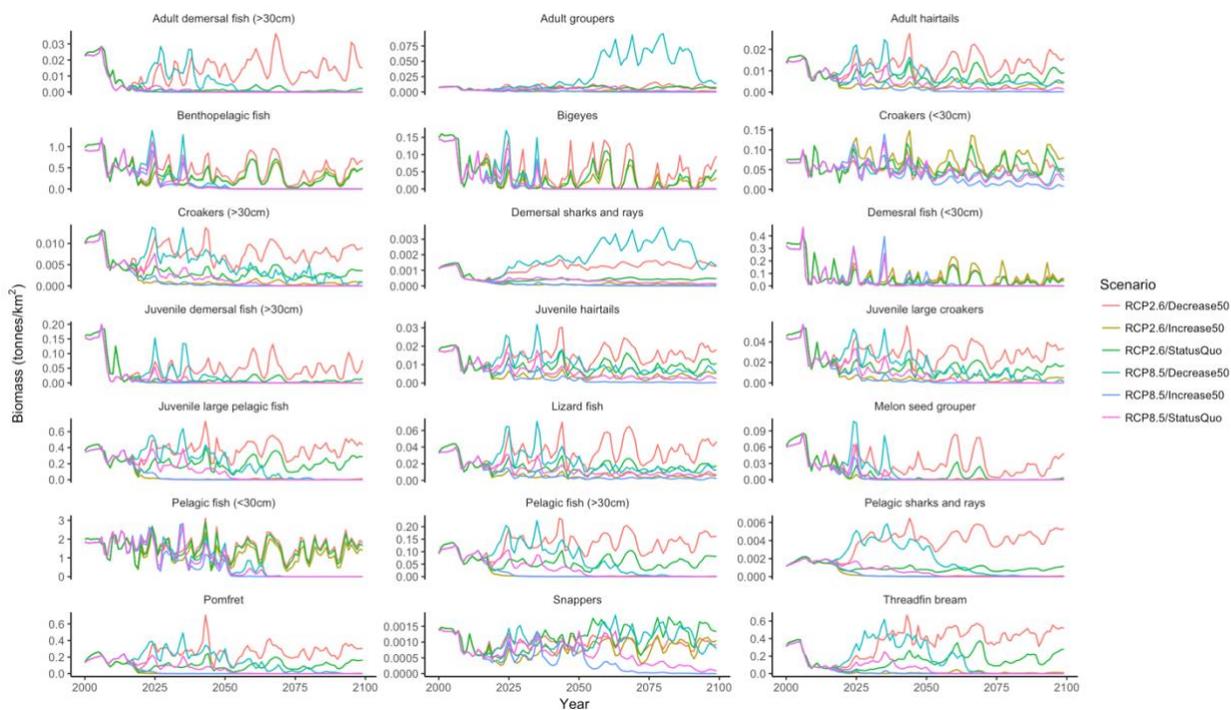


Fig. 10. Biomass ($t\ km^{-2}$) in the SCS of finfish functional groups under RCP 2.6 and RCP 8.5 for the Decrease50, Increase and Status Quo fishing scenarios.

Fleet results in the South China Sea

In the SCS, many fleets' catches and values fall over the time period due to the overall biomass decline in the ecosystem (Figs. 11-12). Hook and line and gillnet fisheries fare the worst in all scenarios for their catches, although the gillnet fishery is compensated by catches of higher valued species such as crabs, juvenile large pelagic fish, and pomfrets (Figs. 11 and 12.). While the purse seine fishery performs well under multiple fishing scenarios under RCP 2.6, it is essentially non-existent under RCP 8.5. In contrast, the shrimp trawl fishery has similar catches in terms of tonnage, but of much higher value leading to benefits for this fleet.

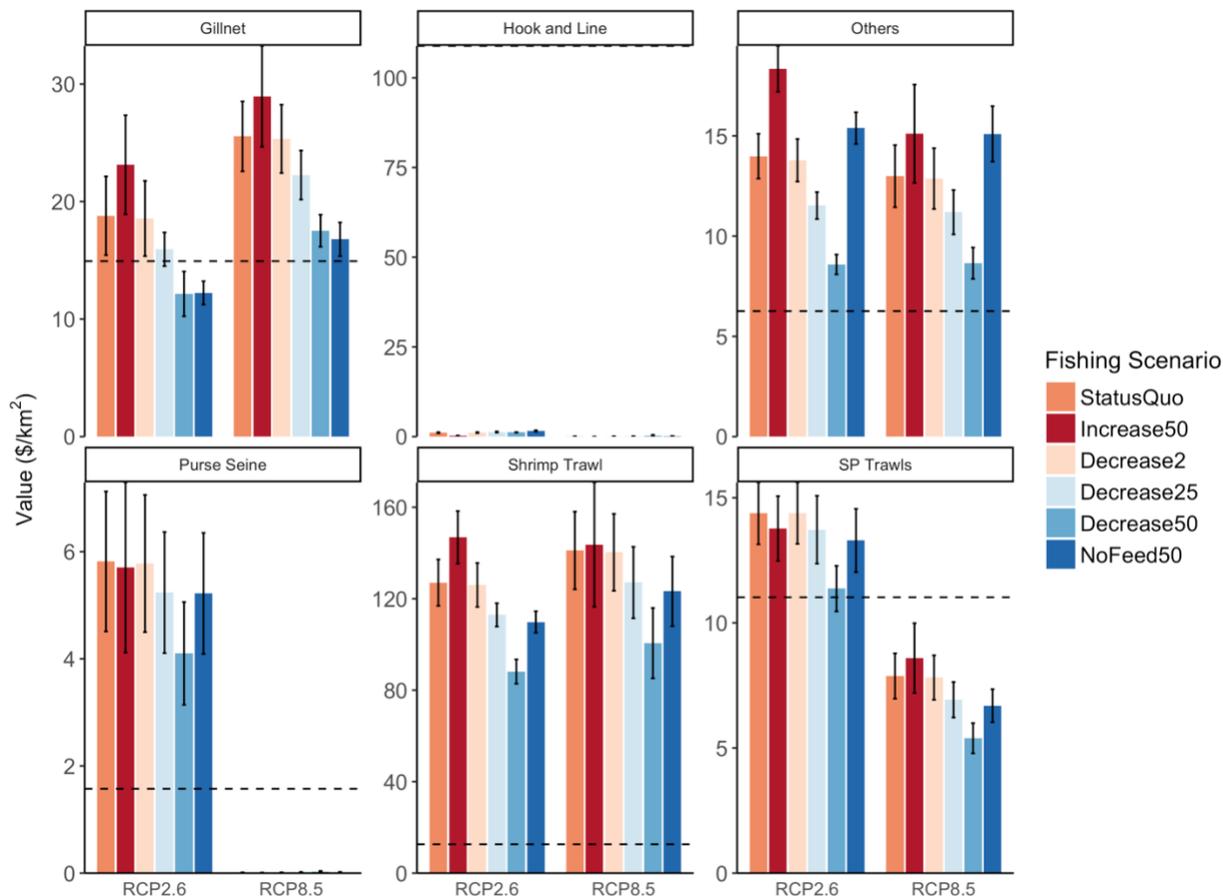
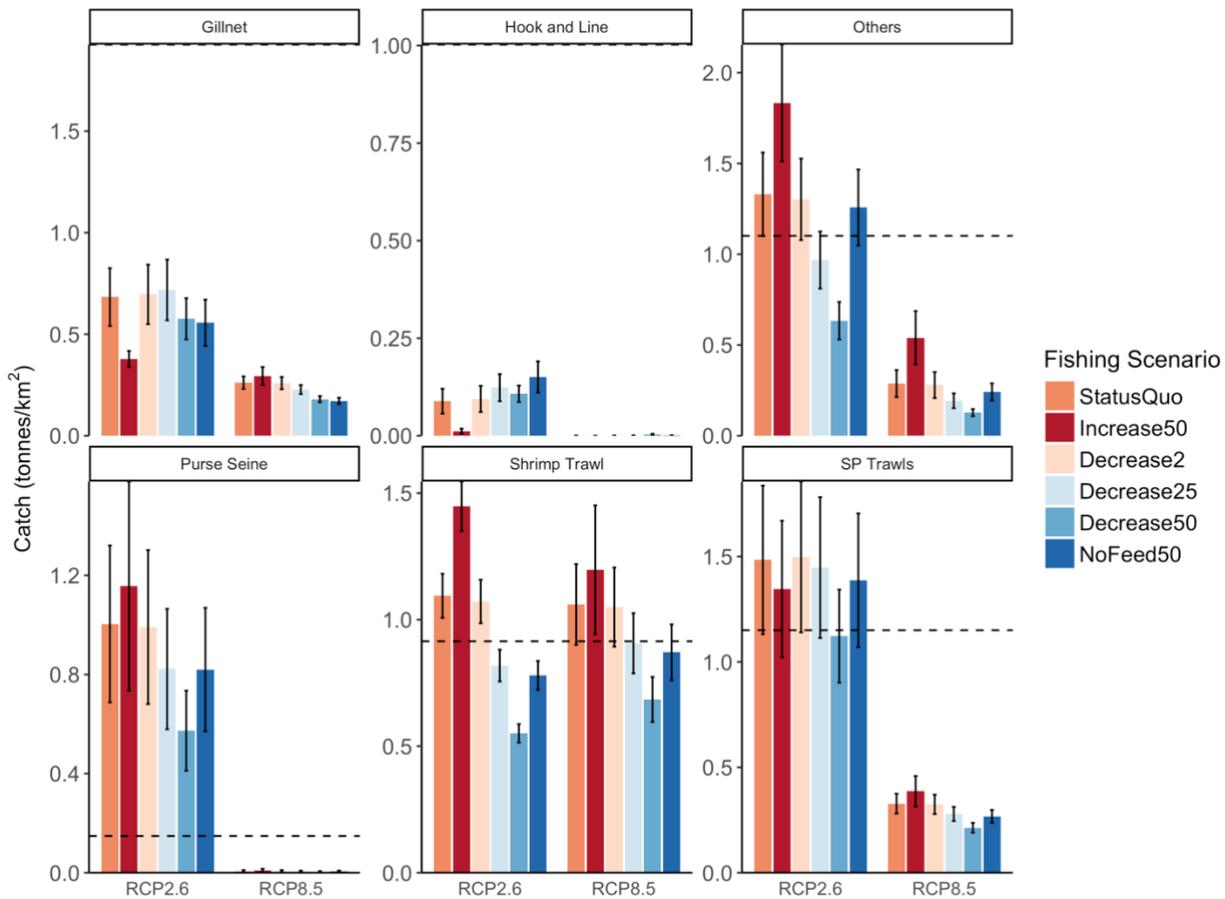


Fig. 11. Average value by fishing fleet in the ECS in the 2090s under different fishing and climate scenarios. Horizontal dashed line shows average value in the 2000s under the RCP 2.6 climate scenario with status quo fishing.


Fig.

12. Average catch by fishing fleet in the SCS in the 2090s under different fishing and climate scenarios. Horizontal dashed line shows average value in the 2000s under RCP2.6 and baseline fishing.

Discussion

The modeled scenarios show relative increases for biomass, and thus fisheries catches and value in the ECS compared to the SCS. The differences between these effects may be attributed to shifts from the base state and climate change-specific impacts for each LME. Although these two marginal seas border each other, the SCS is a tropical ecosystem and has a present average SST that is 7 to 9°C warmer than the ECS. Liang *et al.* (2018) found lack of change of the mean temperature of the catch (MTC) in marine fishes from the SCS, where this was attributed to the relatively small increase in SST over the period 2050-2010. However, the MTC in marine catches from the SCS LME is not expected to increase as their marine fauna, which is already adapted to this tropical region exhibiting higher temperatures, cannot be replaced by other species with less capacity to adjust their thermal tolerance (Liang *et al.*, 2018). One possible explanation is that many species there are already at their maximum thermal tolerance and thus the substantial warming projection (especially under RCP8.5) will have devastating consequences. Alternatively, the climate change driven warming in the ECS appears to increase primary production and thus secondary production, although the other effects of climate change lead to a simplifying of the ecosystem over time.

Major shifts in fish assemblage structure have been already observed in Ieodo (Korea), a marine location in the ECS, where the dominant species was filefish (*Thamnaconus modestus*) during 1981-1992, but chub mackerel (*Scomber japonicus*) dominated during 1992-2007 (Hwang and Jung, 2012). Moreover, projected shifts in marine catch distribution of 12 commercially-important and exploited species in the Korean waters showed that

the mean latitude of five of the 12 species (i.e. horse mackerel, *Trachurus japonicus*; Pacific sardine, *Sardinops sagax*; common squid, *Todarodes pacificus*; Spanish mackerel, *Scomberomorus niphonius*; and, yellow tail, *Seriola quinqueradiata*) displayed significant positive associations with respect to water temperature in the Korea Strait, indicating a northward shift from the 2000s to the 2030s, while anchovies (*Engraulis japonicus*), showed a significantly negative association as an indication of southward shift (Jung et al. 2014). Subsequently, Jung et al. (2016), projected the decrease in larval anchovy biomass in the Yellow Sea with a concomitant increase of biomass in the Korea Strait (within the ECS) and the East Sea of Japan by 2030.

The reduction of fisheries for feed present an opportunity here, according to our analysis. The benefits to biomass, catches, and value nearly mimic those of a stronger rebuilding scenario. This is not overly surprising due to both scenarios being modelled based on reduction in fishing effort of some large fleets, such as bottom trawls and purse seines. Although not explicitly modeled here, reductions in these fisheries could have a disproportionate effect due to their high catches of juveniles (Funge-Smith et al., 2005). Therefore, the benefits of reducing catches of juveniles in these fisheries for feed is likely to be higher than modeled here. However, the importance of these inputs for the aquaculture and livestock sectors should not be understated. This is especially true as this region is a major current, and future consumer of fish for feed into livestock and aquaculture (Cao et al., 2015; Froehlich et al., 2018). The reduction of these feed fisheries would come with additional costs that would be distributed differently depending on how fishing effort is reduced during fisheries rebuilding.

The results for the SCS here are similar to those provided in an earlier analysis of climate change and fisheries impacts on the SCS, although this only extended to 2045 (Sumaila & Cheung, 2015). The longer time horizon shows more dramatic declines over the remainder of the century, as well as the upside of reducing greenhouse gas emissions and thus the effects of climate change, and reducing overfishing. In addition, climate change will lead to large temporal scale variability in catches and value. This can have serious negative consequences for fishers (and the fish processing sector) and coastal communities that rely on these fisheries. The greater variability could lead to boom and bust periods for the fishery. This is particularly important given the value of fisheries in the region, with the ECS generating annual ex-vessel values of USD 3.7 billion to USD 8 billion in 2010 (UNEP, 2016), and USD 19.5 billion in the SCS (Teh et al., 2017).

The fleet level results show how some fleet segments will be highly negatively impacted by climate change and fishing scenarios over time. In the SCS, this means there are major winners and losers under the modeled scenarios where shrimp trawling and other gears can continue and even prosper under all scenarios, whereas purse seine fisheries would be eliminated by high emission scenarios regardless of the fishing effort pursued. In the ECS, although biomass is higher on average, some groups (e.g., small-scale nets and small-scale lines) perform similar to the present while some are able to yield much higher catches and values (e.g., other small-scale gear and bottom trawls). The changes in ability for these fleets will have additional effects for employment and livelihoods in the region, especially for small-scale fleets that contribute more to jobs and value of fisheries per tonne than large-scale fleets and are already negatively affected by dwindling marine resources (Liu & Gao, 2009).

It should be noted that the scenarios were created to demonstrate how alternative fishing scenarios would combine with climate change to drive the ecosystem into different states and what the repercussions would be for ecosystem biomass, fish catch, and ex-vessel values. The scenarios do demonstrate differences in catches and values, although changes in biomass appear to be more strongly driven by climate change. Changes in future fishing effort is only one way fisheries could be curtailed in the future but easily manipulated in the EwE environment. In addition, the changes to fishing effort may not be completely realistic at times. It was important to model increases in fishing effort as fishing effort has continued to increase over the past 15 years, even though

the area has experienced severe overfishing so potential future increases in fishing effort are not out of the question. Future research could use these models to optimize for societal or ecological goals, whereas this research focused on a variety of choices to alter or maintain our current trajectory of climate change and fishing pressure in these ecosystems. In this context, alternative climate change scenarios for reduction and mitigation of CO₂ emissions and climate change should be considered as nations around the ECS have envisioned plans and strategies for reducing carbon emissions. Particularly, China, the first top country contributing to greenhouse emissions in the world, has enacted policies, strategies and actions for addressing climate change (National Development and Reform Commission of the People's Republic of China, 2009, 2011; He, 2016; Yun, 2016). Following the Paris Agreement (UNFCCC, 2015), China has responded by pledging to reduce the emissions of CO₂ per unit of GDP by 60%–65% from the 2005 level by 2030, increase the share of non-fossil fuels in primary energy consumption to approximately 20%, and increase forest stock by approximately 4.5 billion m³ against the 2005 level (Yun, 2016).

Finally, while the ecosystems demonstrate different trends in their impact in terms of biomass, catches, and fisheries revenues, both ecosystems undergo a strong trend in ecosystem simplification. Many functional groups are eliminated from each ecosystem, thereby reducing the overall diversity. While average biomass and catch values were increased in the ECS, there is substantial variability within these averages that may be attributable to a lack of redundancies in the ecosystem leading to potentially unstable dynamics.

Conclusion

In both the ECS and SCS, many functional groups are threatened by fishing pressure and the effects of climate change. However, the effects on fisheries catches are not likely to be overly negative, but involve a major change in the types of species being caught shifting from mainly fish to almost all invertebrates. The negative effects on the ecosystem and fisheries can be curtailed by reducing greenhouse gas emissions at a global level, and by reducing fishing effort at a local level.

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Chapter 4. The impact of biomass fishing for feed on catch and revenues from the East and South China Seas

Tim Cashion & U. Rashid Sumaila

Abstract

The combined high demand of fish inputs for aquaculture and livestock and decline in high-value species has led fishers to fish for large amounts of miscellaneous fishes irrespective of species or life stage. While this will likely affect the long-term sustainability of the resource, we investigate the loss in economic returns of the fishery from exploiting high levels of juveniles for a low-value product. We compare this given an alternative scenario of waiting to catch these fishes as adults when they are larger and likely receive a higher price, especially if used for human consumption instead of feed. The catches of the fishery are lower in the first year only under the modeled alternative scenario, and generate substantially higher catches and revenues for the fishers into the future.

Introduction

Currently, over 70% of global aquaculture is fed aquaculture (FAO 2016), and a large portion of the feed comes from wild capture fisheries. An estimated 20 million tonnes of capture fisheries is destined for fishmeal and fish oil or other non-human consumption uses in aquaculture, livestock, as bait, and for industrial purposes (Cashion et al. 2017). The production and use of fish for fishmeal has grown especially important in China (Cao et al. 2015), and East Asia in general, which now accounts for ~62% of global aquaculture production (FAO 2018). As formerly high-value species were depleted, and to maintain a supply of low-cost fish inputs for aquaculture and livestock, the fisheries in the region turned to catching larger quantities of ‘miscellaneous’ fish for feed (Pauly and Chuenpagdee 2003). Here, as others have done before us (e.g., Sadovy et al. 2018), we call this development, ‘biomass fishing’.

Biomass fisheries are herein defined as consisting of non-selective fishing gears used to catch large amounts of marine fishes and invertebrates for the purpose of supplying feed to the aquaculture sector. These fisheries are not selective for a particular species, and their landings are used (almost) exclusively for the production of fishmeal or as direct feed in aquaculture (i.e., trash fish). Due to the indiscriminate nature of their catch, and the lack of reporting and assessment of the underlying fish stocks, this fishing is suspected to be detrimental to current and future fish populations, and the predators that depend on them. In addition to the negative ecosystem consequences of these fisheries, they may also have detrimental consequences for fishers and those that depend on fish protein. The catches of these fisheries produce are of low-value and receive a low price in the market compared to fish caught for human consumption. Therefore, these fishers and fisheries may not be maximizing their potential when we consider the future value of these fish. In addition, as they produce a lower quality product that is often used for feed, it may reduce the amount of fish directly destined for human consumption, and are often used in aquaculture production systems that are net consumers of calories and fish protein (Tacon and Metian 2008).

Based on an existing dataset (Cashion et al. 2017) combined with the *Sea Around Us* catch database, we provide preliminary estimates of feed fisheries and biomass fisheries in the South and East China Seas. The first dataset is the global use of fisheries landings for direct human consumption (DHC), fishmeal and fish oil, and other uses (Cashion et al. 2017). Other uses explicitly include bait use, industrial uses, and, importantly for this area, direct feeds. The second dataset is the newly updated *Sea Around Us* catch database with gear assigned for all fisheries catches (Cashion et al. 2018, Pauly and Zeller (2015)). We use the catch data from these regions combined with their end use to provide estimates of the major feed fisheries in these regions (Cashion et al. 2017; Pauly and Zeller 2015).

Our preliminary estimate of biomass fisheries is limited to fisheries using trawl gears (including pelagic trawls and bottom trawl gears like shrimp trawls, otter trawls, and beam trawls), that catch a portion of their catches for non-DHC uses. DHC fisheries are generally assigned as those that deliver nearly all of their landings for human consumption and these were excluded. The estimate is further limited to catches not taxonomically known to the species rank. Based on the current study, this estimate was limited to fisheries within the South and East China Sea Large Marine Ecosystems (LMEs). These estimates can be improved over time through improvements of the underlying datasets of the kinds of fish and fisheries (in terms of taxa caught, gear, sector, reporting status, etc.) are characterized by being used for fishmeal and direct feed.

The ECS went from being dominated by Japan in the 1980s to being dominated by China for the remainder of the period (Fig. 1). As China catches the most from ECS for all purposes, this is unsurprising. China currently catches an average of 1.48 million tonnes for feed from the ECS annually. In comparison, the remainder of the bordering countries and other countries that fish in these waters occasionally caught 29 thousand tonnes. The feed fisheries in the ECS use a diversity of gear types with large amounts from bottom and pelagic trawls, gillnets, and small-scale fisheries gears (Fig. 2).

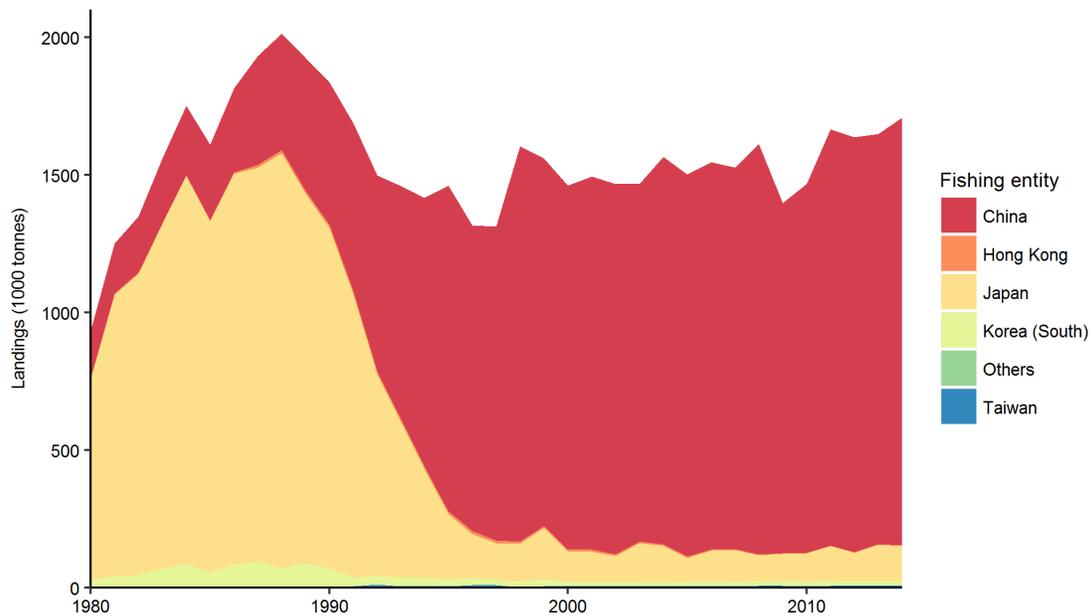


Fig. 1. Fish used for feed by country in the ECS

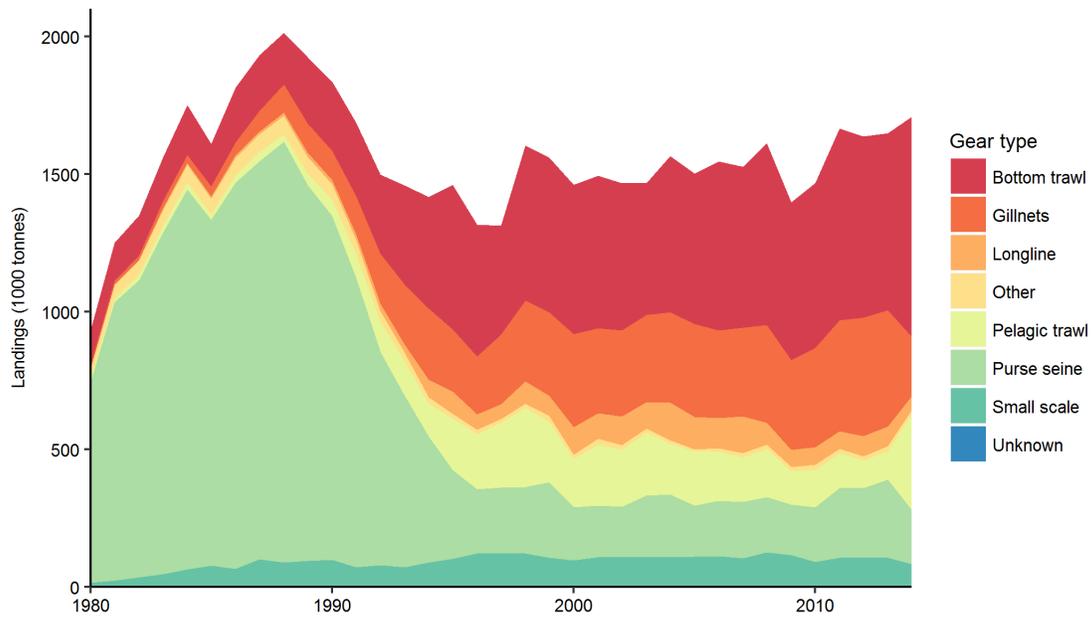


Fig. 2. Fish used for feed by gear type in the ECS

Fish for feed in the SCS is dominated by China, Viet Nam, and Thailand (Fig. 3), where these three countries account for 56.9%, 10.4%, and 27.5%, respectively. The remaining countries thus account for only 5.2% or 81 thousand tonnes. Similar to the ECS, the SCS has many gears contributing to feed fisheries in its waters (Fig. 4). The main gears include bottom trawls, gillnets, and small-scale fisheries gears like in the ECS. However, there is a larger catch from purse seine fisheries here, and a much smaller amount from pelagic trawl fisheries.

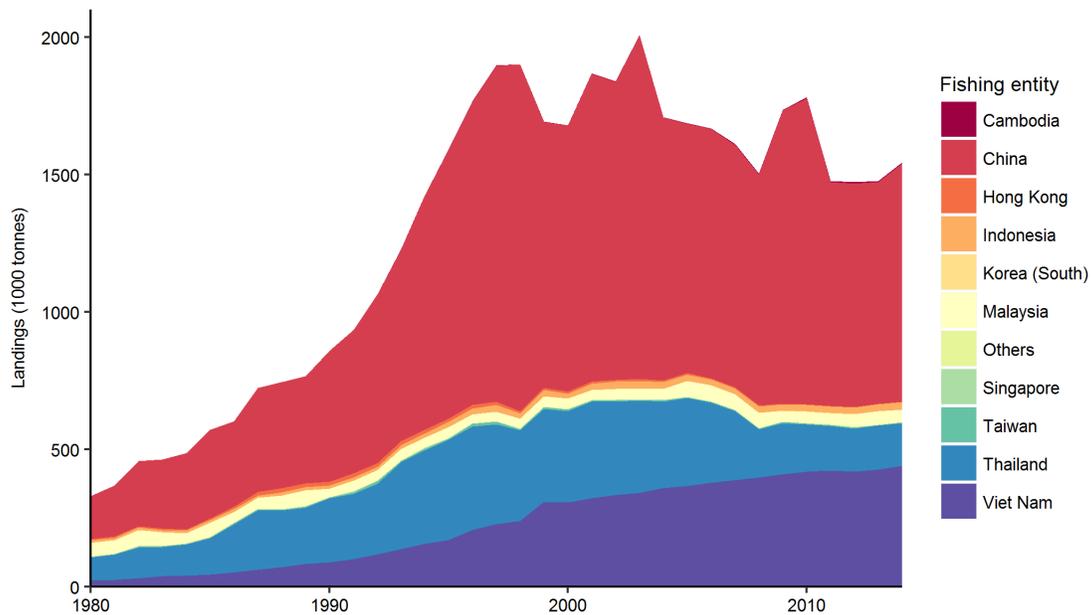


Fig. 3. Fish used for feed by country in the SCS

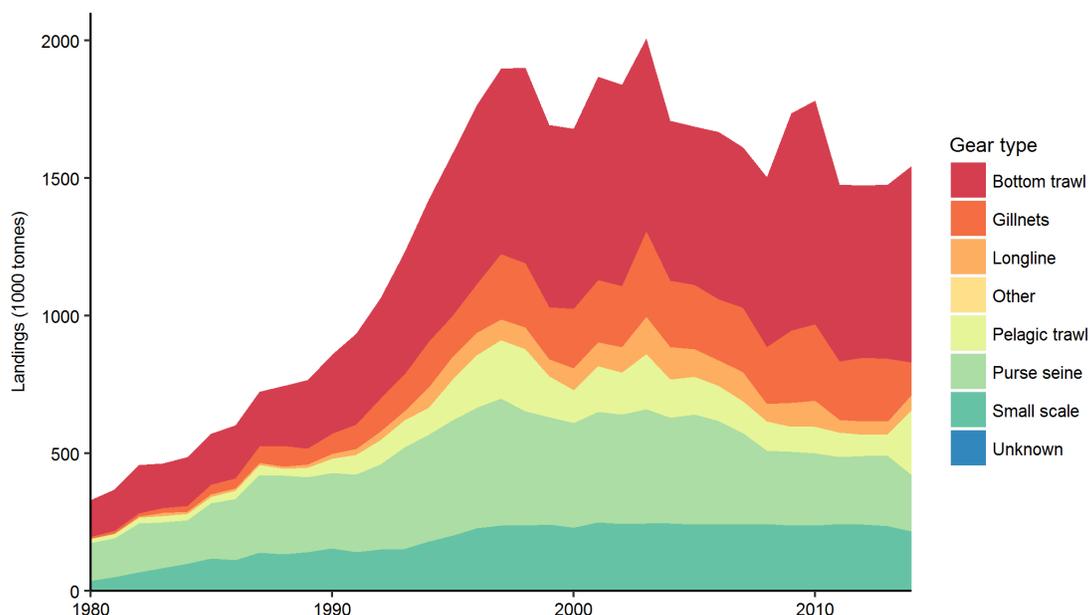


Fig. 4. Fish used for feed by gear type in the ECS

Many of the same taxonomic groups are caught for feed in both the ECS (Fig. 5) and SCS (Fig. 6). However, of the top taxa identified in the data, only five are identified as species (Chub mackerel, Japanese anchovy, Largehead hairtail, Silver croaker, and yellow croaker). Most of the tonnage is accounted for at taxonomic ranks below the species level.

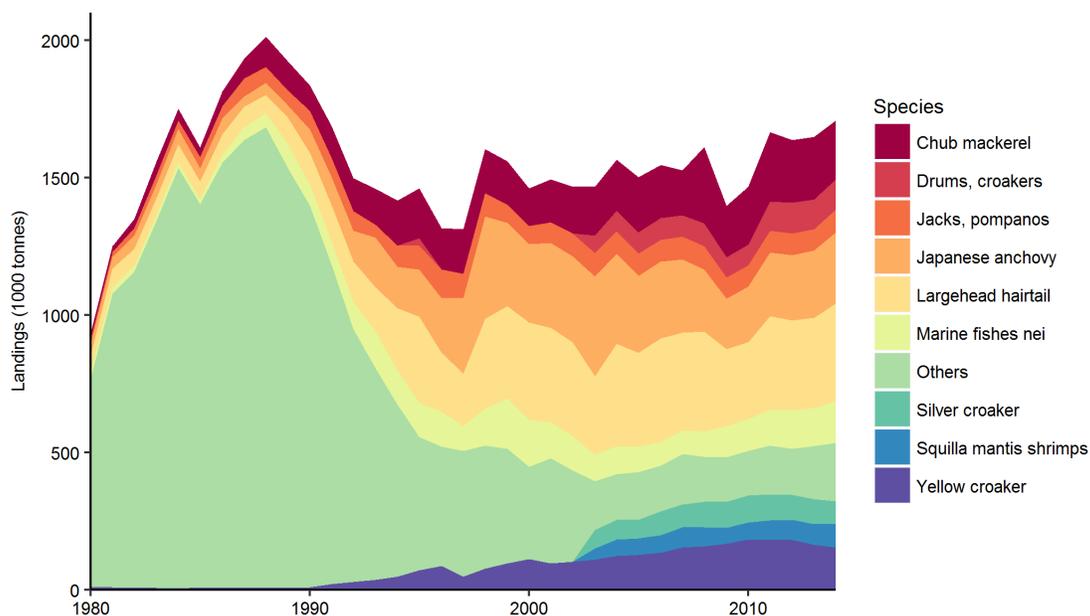


Fig. 5. Fish used for feed by main taxa and others in the ECS. (Others includes 203 other taxa groups)

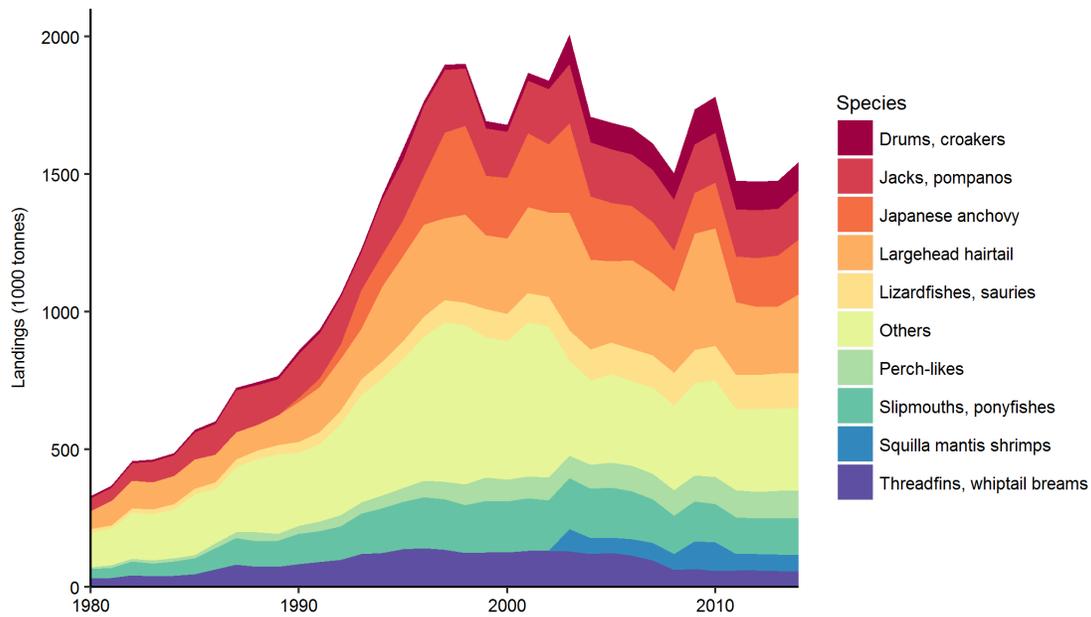


Fig. 6. Fish used for feed by main taxa and others in the SCS. (Others includes 278 other taxa groups)

In addition to the trends seen above, we classified landings for feed by their type of source fishery: biomass fishing, other gear feed fishing, and species level feed sources. In the SCS, roughly two thirds of landings destined for feed are not identified at the species rank, while in the ECS most landings are identified to the species rank (Fig. 7). Both LMEs have seen a growth in biomass fishing and other miscellaneous feed fishing over the past 35 years.



Fig. 7. Landings for feed by different types of feed fisheries in the SCS (above) and ECS (below)

Methods

We estimate the loss in net present value of revenue from these fisheries based on the large amount of individuals that are caught as juveniles (Table 1) and/or not preserved for higher value uses. Thus, there is an unrealized value of the difference between the value that the fish are sold for, and their potential value if they had been caught as adults and preserved properly for human consumption. We evaluated the two scenarios using the present value (i.e., sum of present and discounted future revenues) of these catches if they had been caught as adults and used for direct human consumption. Here, we focus on five provinces in China that border the ECS and SCS based on the importance of China’s fishing for feed in both these large marine ecosystems and data availability.

We used two recent studies covering fisheries landings of five Chinese provinces destined for reduction into fishmeal and use as direct feed in aquaculture and livestock (Greenpeace East-Asia 2017; Sadovy, Leadbitter, and

Law 2018). The studies undertook port-side sampling and identified (where possible) the number of individuals, mass, and proportion of juveniles. We used this information to model the potential growth of these individuals into adults and their capture at this stage rather than as juveniles. We exclude all recorded marine invertebrates (e.g., cephalopods and crustaceans) that are used for feed (Table 1) due to a lack of information on the numbers caught as juveniles.

Table 1: Percentage of fish and percent of juvenile individuals in fish samples of ‘trash fish’ fisheries (Sadovy et al. 2018, Greenpeace 2017)

Province	Fish (% by weight) (Greenpeace)	Fish (% by weight) (Sadovy)	Juveniles (% by number) (Greenpeace)	Juveniles (% by number) (Sadovy)
Zhejiang	93.0	91.5	30.0	23.5
Fujian	83.7	89.4	39.8	60.6
Hainan	76.4	94.8	25.8	43.8
Guangdong	90.2		40.4	
Guangxi	85.5		60.2	

The proportion of juveniles in the catch by province ranged from 23% to 60% (Table 1). As we did not have refined values to the taxa level of the proportion of juveniles, we adjusted the proportion of juveniles for each taxon within a province using a Bayesian distribution. The prior distribution was defined as the percent of juveniles in the province, and the likelihood values used to update the distribution was the percentage difference of the weight at capture from the weight at maturity. We then used the median value of the posterior distribution as the percent of juveniles for that taxon in that province.

These juveniles were assumed to be caught as adults in the alternative scenario and this was determined by the length and age at first sexual maturity. We used the median life history traits for each taxon for the time it would take them to achieve this state obtained from FishBase (Froese and Pauly 2012). For the life history traits, we used minimum length ($min(L)$), maximum length ($max(L)$), length at maturity (L_M), length-infinity (L_∞), instantaneous natural mortality (M), theoretical age where length is equal to 0 (t_0), and growth rate values (K, a, b). We used these values with the von Bertalanffy growth equation (Bertalanffy 1938) to derive estimated ages and weights for the fishes at the different life stages of juvenile capture and maturity. Where taxon specific values were not available or the individuals were not identified to the species level, genus values were used or family level values from within those species and genus reported in the samples.

We estimate the change in weight and time to achieve this growth for each taxon based on the following equations:

$$L_C = \frac{W_C^{1/b}}{a} \quad (1)$$

$$\Delta W_s = a_s * L_{M_s}^b - a_s * L_{C_s}^b \quad (2)$$

$$\Delta A = ((1/-K) * \log(1 - (L_M / L_\infty)) + t_0) - ((1/-K) * \log(1 - (L_C / L_\infty)) + t_0) \quad (3)$$

where L_C is the length (L) at capture, ΔW is the change in weight from that at capture to maturity, and ΔA is the time in years to achieve this change in age. We combined this change in each individuals weight with knowledge on the natural mortality (M) of the fish to assume a portion of these fishes would not make it to maturity if not captured by the fishery. Therefore, the increase in weight at a given time ($t = t + \Delta A$) for $Species_x$ is given by:

$$\Delta W_{st} = Individuals_s * \Delta W_s * \Delta A_s * M_s \quad (4)$$

We used the reported range of prices for the fish destined for feed (Greenpeace East-Asia 2017). To compare prices for direct human consumption and for non-human consumption (fishmeal, fish oil, and direct feed), we

used the ratio of the average values of fish for DHC to the average value for non-DHC in China in 2010 (\$2360 per tonne and \$406 per tonne, respectively or 5.81:1) from the newest global ex-vessel price database disaggregated for this purpose (Tai et al. 2017). To quantify the difference here, we used the ex-vessel prices of fish caught for fishmeal and fish oil or direct feed multiplied by their respective catches to estimate the current revenues they generate. We calculated the current potential landed values generated by the fishery as the landings multiplied by their respective prices under these two scenarios and compare them using a discounted net present value.

All analysis was performed in R statistical software (R Core Team 2017), and using the rMarkdown, tidyverse, RColorBrewer, gridExtra, and LearnBayes packages (Wickham 2016; Albert 2015; Neuwirth 2005; Auguie 2017; Baumer and Udwin 2015).

Scenarios

We conduct our analysis under two scenarios. The first scenario is based on current fishing and use of ‘trash fish’ for feed where the present fishing pattern is carried forward. The second scenario assumes the adult fish are caught today, and the juveniles of each stock are caught once they reach age of maturity. We assume that if the juvenile individuals were not caught today, a certain proportion would not be available to be caught in the future due to natural mortality. In some cases, this would deliver results where the increase in weight per individual of the juveniles to maturity would lead to higher catches (Fig. 8). The initially lower catches under scenario 2 are from catching solely adults, while the catches increase after the expected time for these juveniles to grow to maturity. In contrast, the catches for *Rastrelliger spp.* in Zhejiang are not expected to increase due to mortality rates that are large enough to counteract the increased weight of individuals leading to net lower catches (Fig. 9). The major difference between these two example species is that the expected adult size that could be caught were much higher adult weight for *Trachurus japonicus* counteracts the natural mortality while the modest increase in weight for *Rastrelliger spp.* does not (Table 2).

Table 2: Life history characteristics for modeling growth of *Trachurus japonicus* and *Rastrelliger spp.*

	<i>Rastrelliger spp.</i>	<i>Trachurus japonicus</i>
Province	Zhejiang	Fujian
Family	Scombridae	Carangidae
Juveniles (%)	0	100
Age Difference (months)	1.00	17.37
Weight at capture (g/individual)	84.80	3.13
Weight at maturity (g/individual)	68.60	92.98
Survival Rate (%)	0.20	23.85

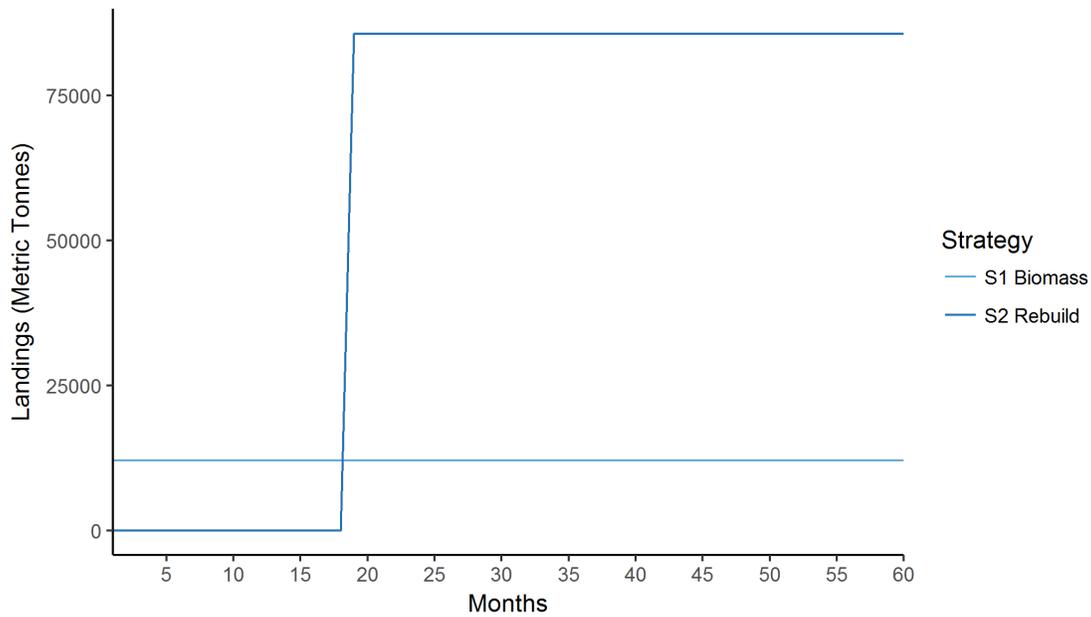


Fig. 8. Catch of *Trachurus japonicus* under alternative scenarios.

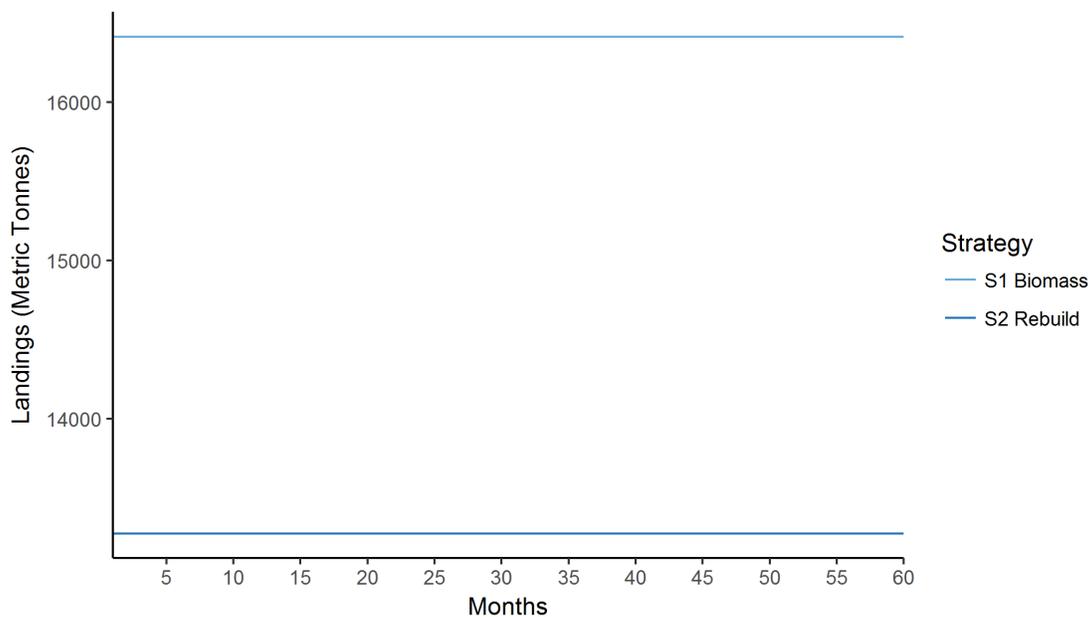


Fig. 9. Catch of *Rastrelliger* spp. under alternative scenarios.

It is important to note that our scenarios do not take into account the current or future population status of these stocks. This is explicitly done as the stock status for many of these stocks are unknown, but likely still used suboptimally with regards to the fish size and value.

Computing present value of revenues

The present value revenue (PVR) was calculated as sum of the PVR for each species over time as expressed in the equation below:

$$PVR = \sum_{s,t=0} V_{s,t} / (1 + \hat{r})^t \quad (5)$$

where V is the fisheries revenue generated in time period t for species s , and \hat{I} is the discount rate assumed to be 4%. In addition, it can be important to model fisheries with intergenerational discounting as the shortened time horizons give unrealistic preferences that do not consider that future generations may value fisheries catches equally as we do now. Therefore, the intergenerational NPV was calculated using the following (Sumaila 2004, Sumaila and Walters (2005)):

$$PVR = \sum_{s,t=t_{L-1}+1}^{t_L=T} V_{s,t} / (1 + \hat{I})^{t-t_{L-1}} \quad (6)$$

where L is the generation. Practically, this was calculated as in (Sumaila and Walters 2005) with the same discount rate applied for the present generation as the future generation (4%), for an assumed generation time of 20 years.

Sensitivity Analysis

We performed sensitivity analyses to parameters we used for price and for the discount rate. For price, we estimated the PVR with no price premium as compared to the empirical value used in this study (Tai et al. 2017). We also tested the results of our model to variable discount rates with a sequence of 0% to 30% with a step value of 5%.

Results

Present value of revenues generated under two scenarios

We found non-trivial benefits under the alternative scenarios of fishing after a modest period of allowing the population to reach maturity (Table 3). The revenues of the fishery are higher under the modeled alternative scenarios across all years due to the higher prices expected to be received for the catch. The PVR continues to rise for the first few years because of higher catches in tandem with the increased prices being received. After three to five years, the catches peak for both scenarios and the PVR begins to decline as the increased catches and value are counteracted by discounting over this period. The PVR of the current fishing scenario is expected to decline linearly and produce a total value at least 10 times less than either of the alternative scenarios.

Table 3: Average annual catch and value by province under our two scenarios

Province	Average annual catch (000 tonnes)		Average annual revenue (million USD)	
	Biomass	Rebuild	Biomass	Rebuild
Fujian	206	910	53	1363
Guangdong	137	446	17	319
Guangxi	166	279	33	326
Hainan	41	85	10	125
Zhejiang	541	1275	167	2284

In addition to the higher revenues achieved, the fisheries would yield substantially higher catches (Table 3). Similar to the revenues, the catches are lower initially for the first year under scenario 2, but higher for the remainder of the period. As scenario 2 assumes the adults can be caught while the juveniles remain in the water to grow, the catches are actually higher for the first year of scenario 2 as some of these juveniles would reach adult size by the end of the year. Therefore, a minor delay in fishing could show large gains in catches especially close to the three to five-year mark.

When we incorporate intergenerational discounting, we see a gradual decline over the 100-year period (Table 4). There is still a large difference between the two scenarios in the first 20 years, but the size of the difference decreases as we approach the end the modeled period.

Table 4: Average annual present value of revenue (PVR) of biomass fishing under two scenarios with standard and intergenerational discounting

Strategy	Average annual PVR (million USD)	
	Standard discounting	Intergenerational discounting
S1 Biomass	71.5	151.2
S2 Rebuild	1,069.5	2,342.4

Sensitivity Analysis

Even with a variety of discount rates (0-30%), the benefits are clear for catching these individuals as adults and using them for DHC (Fig. 10). Unsurprisingly, higher discount rates produce lower expected PVR over the whole time period and especially in the future (Table 4). As discount rates get higher (e.g. 25%), the benefits in the future shrink and become nearly equal to any of the fishing strategies at the end of the time horizon modeled here (20 years).

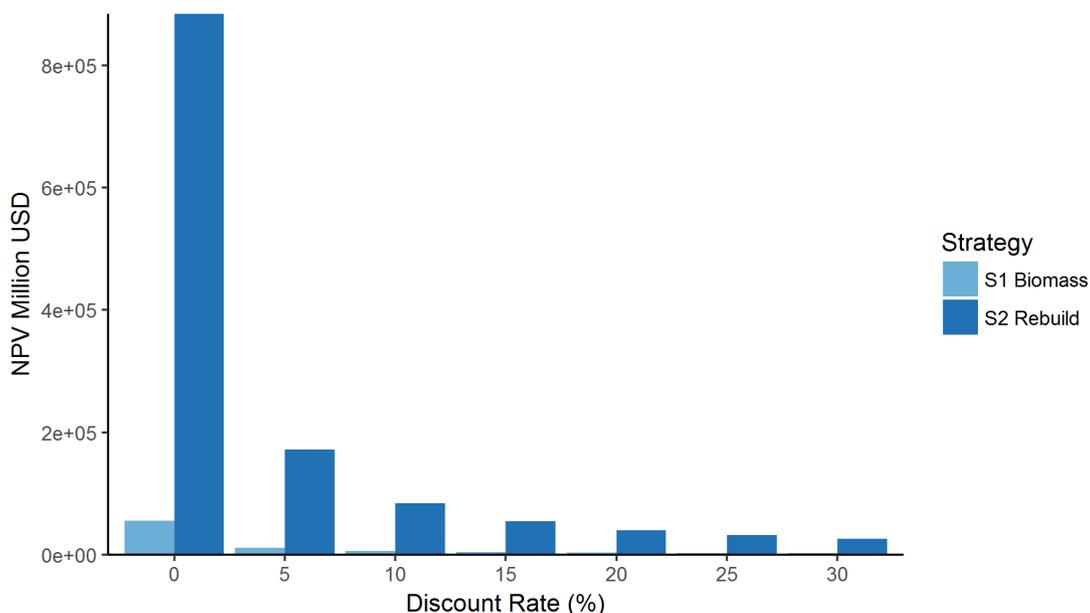


Fig. 10. Total present value of revenue (PVR) under our two scenarios with variable discount rates (0%-30%)

The results were insensitive to the multiplier used for the expected increase in prices due to use for DHC (Fig. 11). Our default value was derived from a previous study on prices of fish used for DHC versus non-DHC. However, even with no price premium, the NPV is higher under our alternative scenario due to the higher catches generated in that case.

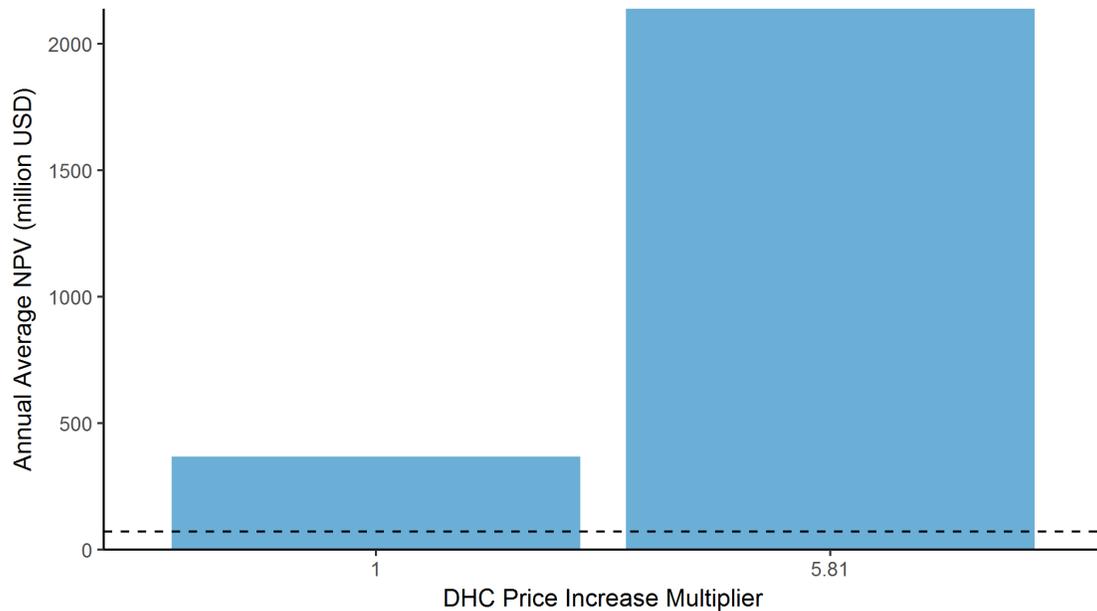


Fig. 11. Total present value of revenue (PVR) under our two scenarios with variable DHC price multipliers. Dashed line indicates annual average PVR generated when biomass fishing is allowed.

Discussion

We describe the major feed fisheries in the region broken down by country, gear type, taxonomic group (where possible), and type of fishery. Our initial classification of these fisheries is inherently coarse, as the data for these fisheries is generally poor. This builds on previous research in the region (Funge-Smith, Lindebo, and Staples 2005), but also works to advance our understanding of this type of fishery including its magnitude and the potential for alternative uses.

Our results demonstrate that there are clear economic gains to be made for stopping biomass fishing and allowing juvenile fish to grow to maturity before they are fished and used for direct human consumption. This result appears to be driven by growth overfishing where fishing continues even though the size of the fish is not socially optimal (Diekert 2012). From a game theory perspective, this is perhaps unsurprising as uncooperative agents will act to maximize their gains from an open access resource and dissipate the rents of the fishery (Diekert 2012; Sumaila 2013). This may have additional consequences for the sustainability of the stock if this enters into recruitment overfishing. While not explicitly considered here, there could be large benefits to the population of increasing the number of fish that are allowed to spawn. It is likely that this would benefit the fisheries here as many stocks in these waters are considered to be overfished (Greenpeace East-Asia 2017; Chao et al. 2005; Sumaila and Cheung 2015).

There are some similarities to these fishing practices and the recently advocated for approach of balanced harvesting (Leeuwen, Ament, and Roos 2012). Due to the increased natural mortality with allowing juveniles to mature, the catches modeled here are lower than under the unselective fishing strategy. However, the use of these fish at present is generally restricted because they are undersized. Therefore, the argument that this unselective fishing would increase food from fish is unlikely in this scenario as these undersized fish are used for feed whereas the adults are more likely to be used for food (Greenpeace East-Asia 2017).

Conclusion

Under the modeled conditions, there are large revenue gains to be made from delaying fishing in biomass fisheries until individuals can be caught as adults and sold for human consumption. This provides an important economic rationale for modifying the fishing strategies to maximize potential economic returns of these fisheries, while providing a product that will more directly feed the people of the region.

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Summary of the Present and Future of East China Sea Fisheries

This report reiterates prior findings that East China Sea fisheries have been unsustainable for the past few decades. As in the neighbouring South China Sea (Teh et al. 2017), this implies that there will be dire consequences for ECS societies and ecosystems if future development and management follow past and current trajectories. Given that small-scale fisheries predominate in the ECS, the continued depletion of fisheries resources will have a particularly negative impact on coastal livelihoods and well-being, especially for the estimated 1.38 million fishers in ECS countries. At the same time, the continued deterioration of ECS marine ecosystems from human and environmental threats continue to exacerbate the ability for fish stocks to recover. Our review thus emphasizes the urgency of taking action at national and multinational scales to mitigate human and climate pressures on the ECS marine ecosystem.

However, a major challenge towards formal cooperation and management of ECS fisheries resources is the ongoing disputes over ocean areas within the ECS. While many bi-lateral agreements have been made for fishing access in 'shared' areas, a central multilateral agreement to govern fisheries resources in the entire ECS is still lacking. Adding to this challenge is Taiwan's political status, which excludes it from many international agreements and organisations. As such, the rebuilding efforts of some nations may go to waste if not all actors are participating in the attempts to rebuild fish stocks.

Future trajectories from ecosystem modelling suggest that many marine functional groups in both the East and South China Seas are threatened by fishing pressure and the effects of climate change. An encouraging finding is that the effects on fisheries catch do not appear to be overly negative. However, there is likely a major change in the types of species being caught, with a shift from current fish dominated catches to catch which will consist almost entirely of invertebrates. In addition, the biomass fishing analysis shows that large revenue gains can be made if the current practice of catching juveniles is changed, i.e., wait until the fish mature and can be caught as adults for human consumption. Doing so can maximize potential economic returns of these fisheries, while also meeting food security needs by providing a product that will more directly provide food for the region's population. Overall, the main message from the ecosystem modelling component is that negative effects on ECS and SCS marine ecosystems and fisheries can be minimized by reducing greenhouse gas emissions at a global level, and by reducing fishing effort at a local level.

In summary, the various analyses in this report demonstrate that the continuation of current trends in fishing practices and management, anthropogenic activities, and environmental conditions is not sustainable for ECS marine fisheries, ecosystems and society. There is hence a clear need to address these threats and improve governance of ECS fisheries and marine ecosystems in order to support present and future social and economic benefits. Doing so requires a concerted and cooperative effort from governance institutions at both national and international levels.

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