REVIEW

What is at stake? Status and threats to South China Sea marine fisheries

Louise S. L. Teh, Allison Witter, William W. L. Cheung,
U. Rashid Sumaila, Xueying Yin

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Abstract Governance of South China Sea (SCS) fisheries remains weak despite acknowledgement of their widespread overexploitation for the past few decades. This review incorporates unreported fish catches to provide an improved baseline of the current status and societal contribution of SCS marine fisheries, so that the socio-economic and ecological consequences of continued fisheries unsustainability may be understood. Potential fisheries contribution to food and livelihoods include 11–17 million t in fisheries catch and USD $12\text{--}22 \times 10^9$ in fisheries landed value annually in the 2000s, and close to 3 million jobs. However, overfishing has resulted in biodiversity and habitat loss, and altered ecosystem trophic structures to a ‘fished down’ state. The present situation reiterates the urgency for fisheries policies that simultaneously address multiple political, social, economic, and biological dimensions at regional, national, and local scales. Importantly, improved cooperation between SCS nations, particularly in overcoming territorial disputes, is essential for effective regional fisheries governance.

Keywords Fisheries sustainability · Governance · Marine fisheries · South China Sea

INTRODUCTION

The South China Sea (SCS), including the Gulfs of Thailand and Tonkin, covers an area of about 3.8 million km² in the western Pacific Ocean (Ablan and Garces 2005). It borders the coastlines of China, Hong Kong, Macau, Taiwan, the Philippines, Malaysia, Brunei, Indonesia,

Singapore, Vietnam, Thailand, and Cambodia (Fig. 1), whose combined population totalled almost 2 billion in 2015, and is expected to grow by 6 % by 2045 (UN 2015). SCS countries are some of the fastest growing developing economies of the world (The World Bank 2015). As they industrialise, anthropogenic pressure on the natural environment inevitably rises, resulting in region wide concerns about food insecurity and biodiversity loss. Marine fisheries, which forms an important source of national revenue and a crucial component of regional food security (Pernetta and Bewers 2013), underscore the conflict between humans and the environment.

Fishing has, and continues to be, a core economic activity for coastal communities in the SCS, providing employment, livelihoods, and products for trade (Funge-Smith et al. 2012; SEAFDEC 2014). For example, around 30–60 % of households in coastal Philippine towns are dependent on fisheries for employment (Cruz-Trinidad et al. 2009). Fishing also generates indirect economic benefits from fish processing, boat building, ice manufacturing, and other fishing-related services (FAO 2005, 2010; AFCD 2015). Moreover, marine fish are an important source of animal protein, contributing from 15 to 56 % of meat-derived protein to SCS populations (Table S1). However, heavily populated coastal areas and high market demand for fishery products have put immense fishing pressure on coastal waters throughout the SCS. Consequently, fisheries in the region have been intensively exploited for decades, particularly in Thailand and Taiwan following the rapid expansion of their trawling sectors in the 1960s (Christensen et al. 2003; Huang and Chuang 2010). In other parts of the SCS, fishers in the Philippines reported that catch rates have been declining at least since the 1970s (Muallil et al. 2014), while in Malaysia declines were observed since the 2000s (Teh et al. 2008). Despite

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Fig. 1 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)

these trends, a prevailing lack of effective fisheries management means that overfishing remains a persistent societal and ecological concern in the SCS (Stobutzki et al. 2006a).

Against this backdrop, the objective of this study is to review the status of SCS fisheries in order to determine the societal and ecological consequences of continued fisheries unsustainability. We first provide an overview of SCS fisheries, including threats to their sustainability. Second, we summarise what is at risk of being lost if SCS fisheries continue on their present path of overexploitation. Specifically, we quantify current economic benefits from fisheries, and characterise the impact of overfishing on fisheries stocks. We then review whether and how prevailing governance systems can address current problems

such that fisheries in the SCS can be sustained into the future.

Two comprehensive reviews about the historical development of Southeast Asian fisheries (Butcher 2004; Christensen and Tull 2014) provide the context leading to the present socio-political and biological state of fisheries in the SCS. Recent escalation in SCS territorial disputes not only has regional political consequences, but has also impacted marine habitats, fisheries resources, and livelihoods (Fabinyi 2016). Consequently, this study is timely for drawing attention to the urgency for multilateral, regional cooperation in managing SCS fisheries, particularly since it has been more than a decade since the last thorough, multidisciplinary study of Southeast Asian fisheries was conducted by Silvestre et al. (2003). More

recently, Pernetta and Bowers (2013) compiled a series of studies about marine and coastal management in the SCS [the United Nations Environment Programme Global Environmental Facility (UNEP GEF) South China Sea Project], but did not focus solely on fisheries.

MATERIALS AND METHODS

Literature review

We conducted a desk top review of published and grey literature (reports, theses, newspaper and online articles) on the ecological, socio-economic, and governance aspects of fisheries in the SCS. We aimed to cover literature published after the study by Silvestre et al. in 2003. However, this was not possible for all SCS countries because of their small fishing sectors and thus limited fisheries related research and monitoring (e.g. Singapore and Macau). Our literature review was limited to English publications, and utilised web based search engines (Google and Google Scholar) and scientific databases [Aquatic Sciences and Fisheries Abstracts (ASFA), and Web of Science]. Some sample keywords utilised in our search included: ‘fisheries’ plus ‘sustainability’, ‘exploitation’, ‘stock assessments’, ‘economics’, ‘small-scale’, ‘food security’, and ‘livelihoods’. These search terms were systematically applied to ‘South China Sea’ as well as for each individual SCS country. We also perused the online publication archives of relevant research institutions involved in SCS fisheries and marine research, including the Southeast Asian Fisheries Development Center (SEAFDEC), WorldFish Center, Asia-Pacific Fishery Commission (APFIC), Fisheries and Agriculture Organisation of the United Nations (FAO), and the UNEP GEF South China Sea Project.

Fisheries data

Fish catch forms the basis for social and economic benefits to SCS countries. To obtain as comprehensive an estimate as possible of catch derived from SCS waters, we compared data from two sources:

- (i) The *Sea Around Us* (SAU) Project (www.seaaroundus.org) provides spatially refined fisheries catch and landed value data based on FAO (Fisheries and Agriculture Organisation of the United Nations) landings statistics (Pauly and Zeller 2015). These data are available by Exclusive Economic Zone (EEZ), or by Large Marine Ecosystem (LME),¹ covering the period 1950–2010. As

this study focuses on the SCS as a whole, we extracted data at the LME level. The geographical extent of the SCS used in this study included 2 LMEs—the SCS and Gulf of Thailand (Fig. 1).

- (ii) National statistics—Annual fisheries catch and landed value data were extracted from the annual fisheries statistical reports of each SCS country, where available, for the period 2005–2010. Five SCS countries (Malaysia, Indonesia, Philippines, China, and Thailand) have fishing grounds that fall within the SCS and other seas (Table S2), and their national fisheries statistics were segregated geographically in order to determine the quantity of catch originating from the SCS. Where national statistics were not available, fisheries landings statistics were extracted from the Annual Fisheries Bulletins published by SEAFDEC (South East Asia Fisheries Development Agency).

A common problem of national fisheries statistics, including those of SCS countries, is that they generally do not record the catches from all fishing sectors (Pauly and Zeller 2016). Catch reconstructions undertaken by the SAU Project incorporates these missing catch data e.g. from small-scale, recreational, and illegal fisheries, and discards. Reconstructed catch data for SCS countries are available on the SAU Project database, and were added to reported catches at the LME level to account for the full range of marine catches taken from SCS waters.

Indirect economic benefits of fisheries catch

Fisheries can generate indirect benefits through secondary and tertiary activities in the fisheries sector. To capture this effect, we used national level economic and income multipliers estimated by Dyck and Sumaila (2010). These multipliers reflect the impact that a change in fisheries output, as measured by fisheries landed value, will have on fisheries related economic activities and the household income of fishery workers, and were estimated for all maritime countries globally. We estimated the economic and household income effect associated with fisheries productivity for each SCS country as follows:

Economic output: $LV \times \text{economic multiplier}$;

Income output: $LV \times \text{income multiplier}$;

where LV is the total fisheries landed value in 2012 for each SCS country, and income and economic multipliers were taken from Dyck and Sumaila (2010).

Trade

Exports of fishery products generate foreign earnings for national economies. SCS export data were extracted from

¹ Large Marine Ecosystems (LMEs) are large, ecologically distinct regions of the world's oceans that were developed to allow for collaborative management of marine resources in transnational areas.

two online databases: (1) the FAO Fisheries Global Information System (FIGIS),² which provides country-level trade data on fishery commodities up to 2011, and (2) the International Trade Centre,³ which provides country-level trade data and information on trading partners up to 2011.⁴ It was not possible to segregate trade data geographically at the national level; thus, we reported trade data for the entire country, even for countries where only part of the coastline borders the SCS. While trade data was available in national statistics reports of some SCS countries, we only used data extracted from the above-mentioned international databases to maintain a consistent data set for analysis.

Mean maximum length of the catch (ML)

Each fish species has an associated maximum length (cm). The mean maximum length of the catch is provided for annual catch data extracted from the SAU Project database; this is an ecosystem and biodiversity indicator based on the assumption that an ecosystem becomes more unsustainable if its catch consists of increasingly smaller species (i.e. decreasing ML).

SOUTH CHINA SEA (SCS) FISHERIES

Overview

The overview of SCS fisheries covered in this section is summarised in Table S2.⁵ The northern extent of SCS fishing grounds border the southern Chinese provinces of Hainan, Guangdong, and Guangxi municipality, while the western coasts of Kalimantan and south-eastern Sumatra (Indonesia) form the southern bounds. The eastern boundary extends from the western coast of Taiwan in the north down to the Western Philippine Sea until the western coast of Sabah (Malaysia) in the south. SCS fisheries span subtropical and tropical zones, and can be broadly divided into a multi-gear small-scale sector, and a commercial sector dominated by trawlers and purse seines. China and Taiwan have significant distant water fleets which extend across the high seas of the Pacific, Atlantic, and Indian Oceans.

Small-scale fisheries are prevalent along coastal communities in all countries bordering the SCS, except in Singapore and Macau, where local fisheries are now very limited and diminishing (Canadian Trade Commissioner Service 2013; Panicker and Leong 2013). Inshore waters are subject to intense fishing pressure from heavily populated coastal areas (Cheung and Sadovy 2004; Pomeroy et al. 2009; Huang and Chuang 2010; Hughes et al. 2013; Muallil et al. 2014). For instance, a density of 16 fishers km⁻² was recorded in the Lingayen Gulf of the Philippines, which was four times higher than the threshold level of 4 fishers km⁻² required for sustaining catch levels that can meet poverty needs (Cruz-Trinidad et al. 2009). Small-scale fisheries target a wide variety of demersal and nearshore pelagic fish species from various shallow coastal ecosystems, including coral reefs, mangroves, and seagrass beds. Common gears used in small-scale fisheries include hook and line, gillnet, traps, long line, troll line, and cast net, among others. Gleaning on the intertidal zone for invertebrates is also an important subsistence activity.

Trawls are used extensively in SCS commercial fisheries, and accounted for almost 50 % of total fisheries production from Southeast Asian SCS countries in 2012. Trawls are also the dominant commercial fishing gears used in Thailand, Malaysia, Brunei, Vietnam, Hong Kong (FAO 2005; SEAFDEC 2014; AFCD 2015). Industrial trawling is most pervasive in the Gulf of Thailand, where open access led to overcapitalization and overfishing as far back as the 1970s (Stobutzki et al. 2006b). The subsequent unregulated expansion of Thai trawlers into new fishing grounds in the SCS heavily impacted fisheries resources and the livelihoods of small-scale fishers in the region, as the trawling sector in neighbouring countries such as Malaysia also followed Thailand's development pattern (Christensen and Tull 2014). A trawl ban was imposed in Indonesia in the early 1980s, but trawling continued to occur in some areas due to poor enforcement (Christensen and Tull 2014). Nevertheless, conflict between small-scale and commercial fishers remains an issue in many SCS countries due to the frequent intrusion of commercial vessels into small-scale fishing grounds (Pomeroy et al. 2007; Salayo et al. 2008; Perez et al. 2012).

Overcapitalisation is a persistent problem for SCS fisheries, particularly in China, Taiwan, Thailand, and the Philippines (Salayo et al. 2008; Yu and Yu 2008; Huang and Chuang 2010; Perez et al. 2012). Attempts to limit fishing capacity in China and Taiwan have not been considered successful (Yu and Yu 2008; Huang and Chuang 2010), and in many coastal areas, fisheries remain essentially open access (Stobutzki et al. 2006b; Teh et al. 2014). For instance, fishing effort in Hong Kong was largely unregulated until a trawl ban was imposed in 2012 (Cheung 2013). The open access problem is exacerbated by the huge

² FIGIS website: <http://www.fao.org/fishery/statistics/global-commodities-production/en>.

³ International Trade Centre website: www.intracenter.org.

⁴ Trade data may not consistently reflect the country of origin or final destination for given fish and fishery products.

⁵ Singapore and Macau are not included in this summary due to their small fishing sectors and lack of information on their respective fisheries.

number of rural, poor, fishing dependent communities along the coasts of SCS countries. Many of these communities have a long tradition of fishing, and despite declining catches, continue to exert strong fishing pressure on coastal marine resources due to the lack of alternative economic opportunities (e.g. Teh et al. 2008; Pomeroy et al. 2010; Fabinyi et al. 2014; Muallil et al. 2014).

Threats

Excessive fishing capacity is a primary threat to future fisheries sustainability in the SCS, and has continued to increase in both commercial and small-scale fisheries (Stobutzki et al. 2006b; Huang and Chuang 2010; Funge-Smith et al. 2012). Lack of strong fisheries governance has perpetuated this threat, which in turn spurs other problems such as the proliferation of illegal, unreported, and unregulated (IUU) fishing (APEC 2008; Pitcher et al. 2009) and destructive fishing practices (Wilkinson et al. 2005), both of which can damage marine habitat and biodiversity, as well as alter marine community structure.

Perverse economic incentives (e.g. fuel subsidies) can be a threat to sustainable fisheries by encouraging excessive fishing pressure. This is a concern in the SCS because the Philippines, Indonesia, Vietnam, and Thailand ranked 3rd, 4th, 5th, and 8th, respectively, among the top ten largest subsidy providing developing fishing countries in the world (Sumaila et al. 2013). Economic incentives from growing global demand for fish and fishery products can also have negative ramifications on marine resources and society if the underlying fisheries are not managed properly to support trade growth. For instance, it has been argued that Southeast Asian governments' drive to expand exports of fishery products comes at the expense of decreased domestic food security and economic opportunities for coastal communities (van Mulekom et al. 2006). The growing proportion of traded fishery products derived from aquaculture (FAO 2014) also raises environmental concerns (Rico et al. 2012). High international demand for luxury seafood provide fishers with financial incentives to intensely target vulnerable species for live reef fish, sharks fin, fish bladders, and sea cucumbers, thereby driving the serial depletion of these largely unregulated fisheries (Cheung and Sadovy 2004; Anderson et al. 2011; Sadovy de Mitcheson et al. 2013), which can in turn result in serious livelihood impacts on artisanal fishers (Fabinyi and Dalabajan 2011; Christensen and Tull 2014).

Indirect threats to fisheries also arise from the widespread destruction of vulnerable coastal habitats from land reclamation, pollution from shrimp farming, agricultural and coastal development, and charcoal production (Liu 2013; Vo et al. 2013). It was estimated that

from the mid 1990s to 2000s, the decadal rate of decline in total area of seagrass, coral reefs, and mangroves in the SCS was 30, 16, and 16 %, respectively (Vo et al. 2013). The loss of these critical habitats means a loss of important feeding, spawning, and nursery grounds that not only impact fisheries productivity, but also threatens the survival of endangered species populations. Environmental degradation that stresses fisheries resources can also lead to significant economic losses, as happened when harmful algal blooms caused mass mortality of wild and cultured fish and shellfish populations in the northern SCS (Liu 2013).

On top of anthropogenic pressures, climate change is expected to make fisheries management more challenging, as many commercially important fish stocks are likely to be affected by ocean warming. Fish species distribution is projected to shift in the future, resulting in higher diversity and fisheries potential in higher latitudes (Cheung et al. 2010). This will potentially result in food security and livelihood issues for countries located in the more tropical zones of the SCS. Moreover, shifts in species distribution can potentially lead to increased transboundary fisheries disputes (Miller et al. 2013), particularly given the highly contested territorial claims over parts of the SCS. Expected increases in atmospheric CO₂ levels are likely to exacerbate the impact of ocean acidification on shallow water marine life in the SCS (Liu et al. 2014). While the frequency of tropical cyclones is expected to decrease in the region, their intensity is projected to rise, resulting in increased damage to coastal habitats and severe human and economic costs (World Bank 2013).

WHAT IS AT STAKE?

If the prevailing pressures on fisheries, marine habitats, and ecosystems in the SCS are not addressed, countries will potentially stand to lose economic and social benefits, while fisheries induced changes to fish populations and habitat will potentially decrease the resilience and functionality of marine ecosystems in the SCS. These are documented in the following sections:

Economic and social benefits

Fisheries catch

Reported fisheries catch from the SCS and Gulf of Thailand Large Marine Ecosystems extracted from the *Sea Around Us* database totalled 10.5 million t in 2010, and have been maintained at this general level since the late 1990s (Fig. 2).

Fig. 2 Temporal trend in fisheries catch (solid line) and landed value (broken line) from the SCS and Gulf of Thailand Large Marine Ecosystems (1950–2010). Source *Sea Around Us* Project (2015) (www.seaaroundus.org)

National fisheries statistics from SCS countries provided similar catch levels,⁶ with an annual catch of around 10.5 million t from 2005 to 2010 (Fig. 3), accounting for approximately 13 % of annual global marine fish catch for the same period. China was the top country in terms of catch quantity, accounting for 30–34 % of total SCS catch per year. This was followed by Taiwan and Vietnam (range of 17–21 %), and Thailand (10–17 %) (Fig. 3). Unreported catches from the *Sea Around Us* database averaged about 8 million t annually from 2000 to 2010, and their inclusion resulted in catch levels that were 90 to 60 % higher than reported catches for the period 2000–2010. In 2010, the inclusion of unreported data resulted in 60 % higher catch—16.6 million t—aggregated at the LME level (Fig. S1).

Fisheries landed value

At the Large Marine Ecosystem level, reported fisheries landed value in the SCS and Gulf of Thailand totalled USD 12.3×10^9 in 2010. Since peaking in the early to mid 1990s, landed value stayed at this general level from the late 1990s onwards, albeit with annual fluctuations (Fig. 2). The inclusion of unreported data resulted in total fisheries landed values that ranged from 82 to 60 % higher than reported values over the period 2000–2010; in 2010, the landed value of reconstructed catches was USD 19.5×10^9 in 2010, which was 60 % higher than reported landed value of USD 12.5×10^9 (Fig. S2). Data from national statistics provided a landed value of USD 21.8×10^9 for SCS catches in 2012 (Table 1), of which China accounted for 45 %.

Economic impact of fisheries

Total economic activity in the broader economy that was supported by fishing amounted to an estimated USD 66.6×10^9 for all SCS countries based on 2012 levels of fisheries landed value. China accounted for half of this economic output, due to its proportionally higher fisheries landed value, as well as high economic multiplier (Table 1). This was followed by Vietnam, which accounted

⁶ National fisheries statistics can be found at the following websites: Malaysia (<http://www.dof.gov.my/en/fishery-statistics>); Indonesia (<http://statistik.kkp.go.id/>); Philippines (<http://countrystat.bas.gov.ph/>); Thailand (<http://www.fisheries.go.th/it-stat/yearbook/>); and Taiwan (<http://www.f.a.gov.tw/en/PublicationsYearbook/>). Statistics for China were extracted from the annual China Fisheries Yearbooks, but these are not publicly accessible online.

Fig. 3 Breakdown of SCS marine fisheries catch quantities (t) by country (2005–2010). *Source* National Fisheries Statistics of Malaysia, Indonesia, Taiwan, the Philippines, and Thailand⁶; data for Vietnam, Cambodia, Brunei, Hong Kong, and Singapore were extracted from SEAFDEC (2012)

Table 1 Landed value of catch from SCS countries (2012), and the economic activity and household income (000 USD) supported by reported levels of landed value *Source* of economic and income multipliers: Dyck and Sumaila (2010)

Country	Landed value (000 USD)	Economic multiplier	Income multiplier	Economic effect (000 USD)	Income effect (000 USD)
Brunei	18.42 ^a	2.16	0.62	39.75	11.39
Cambodia	110.73 ^a	1.73	0.54	191.94	59.60
China	9807.03 ^b	3.34	0.79	32 727.94	7752.11
Hong Kong	296.77 ^c	2.59	0.46	769.16	135.27
Indonesia	1084.99 ^b	1.66	0.52	1806.05	568.66
Malaysia	1219.13 ^b	2.58	0.70	3140.01	856.69
Philippines	817.34 ^b	1.19	0.34	972.91	275.36
Singapore	12.30 ^a	4.01	0.70	49.31	8.66
Taiwan	2731.29 ^b	3.28	0.97	8957.90	2645.49
Thailand	1286.63 ^b	2.12	0.24	2725.64	308.84
Vietnam	4384.18 ^a	3.47	0.77	15 201.03	3363.13
Total ^d	21 768 810			66 581 628	15 985 210

^a *Source* SEAFDEC (2012)

^b *Source* National fisheries statistics of respective countries

^c *Source* Agriculture, Fisheries, and Conservation Department Hong Kong (<http://www.gov.hk/en/about/abouthk/factsheets/docs/agriculture.pdf>)

^d *Note* Total does not include Macau, for which no data was available, but is likely to be minimal

for 23 % of total SCS economic output. The income multiplier reflects total household income supported throughout the economy by output in the fisheries sector. This totalled around USD 16.0×10^9 for all SCS countries, and

was highest in China, Vietnam, and Taiwan (Table 1). Together, total economic activity and household income supported by fisheries production amounted to USD 82.6×10^9 , which was around 3.8 times higher than the

direct landed value of SCS fisheries catch alone. Altogether, both direct and indirect values of fisheries totalled USD 104.3×10^9 in 2012. Within the context of national economies, this made up less than 1 % of the USD 13.7×10^{12} GDP from all SCS countries combined in 2014, although it is noted that it was not possible to attribute national GDP figures to the SCS portion of countries only.

Employment and vessels

Approximately 541 000 small-scale and commercial fishing vessels operate in SCS waters, although this is likely an underestimate given that the small-scale sector in many SCS countries remains unaccounted for in official statistics (Teh et al. 2009; Muallil et al. 2014). Therefore, while employment in SCS marine fisheries is estimated at around 2.7 million people, this likely does not account for the large number of fishers involved in IUU fishing (e.g. Teh et al. 2009). Indeed, it was estimated that the number of reef fishers in SCS countries alone was around 3 million (Teh et al. 2013). This indicates that the reported employment of 2.7 million people in SCS fisheries is substantially underestimated, since reef fishers should form a subset of marine fishers. Moreover, an increasingly serious issue is the use of human trafficking to supply an unknown number of labourers to work aboard fishing vessels in Southeast Asia (E.J.F. 2014). Table 2 summarises the best available vessel and employment figures for fisheries in selected SCS countries.

Export trade

SCS countries play a major role in global fish trade. China is the world's leading exporter of fishery products, while Thailand and Vietnam were the 3rd and 4th largest exporters in terms of value in 2012 (FAO 2014). Fishery product exports from SCS countries totalled USD 38.7×10^9 in 2011, and have been increasing since 2000 (Fig. 4a). China was the dominant exporter, accounting for 44 % (USD 16.9×10^9) of total exports. The value of exported products by the next leading country (Thailand) was much lower at USD 8.1×10^9 , and was followed by Vietnam (USD 6.2×10^9), Indonesia (USD 3.2×10^9), and Taiwan (USD 2.3×10^9). Similarly, the volume of exported fishery products from SCS countries increased temporally, doubling from 4.5 million t in 2000 to 9.2 million t in 2011. China was the largest exporter in terms of volume, accounting for 43 % (3.9 million t) of total exported volume from SCS countries in 2011 (9.2 million t). This was followed by Thailand and Vietnam, which accounted for 19 % (1.8 million t) and 14 % (1.3 million t) of total volume, respectively (Fig. 4b).

Total SCS fisheries export trade value in 2011 (USD 38.7×10^9) could have accounted for 30 % of global fish trade of USD 129.2×10^9 in 2014 (FAO 2014). Despite their importance in global fisheries trade, fishery products only made up around 1 % of total export value of all goods from SCS countries in 2011. It should be noted that it was not possible to separate national export figures according to the portion originating from the SCS. Thus, while fisheries products may make up slightly more than 1 % of total SCS export value, its contribution to total SCS export trade is still minor.

Sustainability of fisheries resources

Stock assessments

The status of fishery resources in SCS countries was assessed by national agencies and collated in two regional reports (FAO 2010; Funge-Smith et al. 2012); these national assessments were carried out using a variety of methods, including yield per recruit analysis, surplus production modelling, fishery independent surveys, and expert based evaluations. A noted problem for SCS countries was the lack of regular and consistent fish stock assessments (FAO 2010). An exception is Thailand, which has carried out regular trawl surveys since the 1960s to monitor the abundance of fisheries resources (Department of Fisheries Thailand 2015).

FAO (2010) found that the majority of assessed stocks were overfished or fully fished; the heaviest fishing occurred on the western, shallower shelf fisheries of Thailand, Vietnam, and China, while stocks around Sabah, Sarawak, and parts of the Philippines were in better condition (Funge-Smith et al. 2012). Specifically, the assessment found that fishery resources were in worst shape in the northern part of the SCS and the Gulf of Thailand, in which the proportion of overexploited⁷ species, especially demersals, was the highest. Most fisheries in Malaysia's SCS region fared better, and were either moderately or fully exploited. Similarly, based on national catch statistics, fish stocks in the Indonesian SCS were assessed to have a lower proportion of overexploited species, with 61 % (14 of 23 major fish species) being fully exploited (FAO 2010). However, trawl surveys conducted in the SCS part of Indonesian waters showed that standing stock densities had progressively declined over the past 30 years (Masriat 2012).

⁷ The FAO defines fish stock status as follows: Overexploited = the fishery is being exploited above the optimal yield, with no potential room for further expansion; Fully exploited = the fishery is operating at or close to its optimal yield, with no expected room for further expansion; Underexploited = undeveloped fishery with potential for expansion in total production.

Table 2 Summary of vessel and employment numbers in selected SCS fisheries. *Source* Funge-Smith et al. (2012), unless otherwise indicated

Fishery location	No. vessels	Data year	No. people employed	Data year
Brunei	2627 ^a	2012	3840 ^b	2006
Cambodia	6236 ^c	2006	74 572 ^c	2006
China (northern SCS)	92 312	2004–2008	648 799	2009
Hong Kong	4500 ^d	2014	9400 ^a	2014
Indonesia (FMA 711)	76 763	2010	320 017	2010
Macau	n/a		n/a	
Malaysia (Peninsular east coast, Sabah, Sarawak)	31 660 ^a	2012	56 113	2008
Philippines (Regions NCR, CAR, I, III, IV)	116 959 ^e	2012	627 000 ^f	2013
Singapore	4 ^a	2012	n/a	
Taiwan	23 159 ^g	2012	271 592 ^g	2012
Thailand (east coast)	58 119	2000	168 680	2000
Vietnam	129 519	2010	540 000 ^h	2000
Total	541 858		2 720 013	

^a *Source* SEAFDEC (2014)^b *Source* Abdul Rahim (2007)^c *Source* Puthy (2007)^d *Source* Agriculture, Fisheries and Conservation Department (AFCD) of Hong Kong. Retrieved 12 February, 2016, from www.hk-fish.net/eng/fisheries_info/fishing_fleet/index.htm^e This consists of 115 303 municipal boats and 1656 commercial vessels. Municipal boat count is based on 2000 data; commercial vessel numbers are based on 2007 data. *Source* BFAR (2012)^f This is the total number of fishers in fishery subzone A and B. Note that Zone B consists of one region (Region V) that does not fall within the SCS. *Source* Palomares and Pauly (2014)^g Number of fishers consists of coastal, offshore, and far sea fishermen. *Source* Taiwan Ministry of Fisheries (2015). Retrieved 12 February, 2016, from www.fish.gov.tw^h *Source* Pomeroy et al. (2009)

Assessment of the top 10 most important species in the Philippines found that the majority were moderately exploited, with the remaining fully exploited and none overexploited. However, this assessment may have contained high uncertainty because it was based on existing reports, publications, and expert judgement (FAO 2010), and appears inconsistent with prior stock status assessments which indicated that marine fisheries throughout the Philippines were growth overfished from the 1980s onwards (Palomares and Pauly 2014). Inshore fisheries in Vietnam were also considered to be severely overexploited (Pomeroy et al. 2009). Offshore fisheries showed a general decline nationwide, although deep water demersal and meso-pelagic resources in central and southern offshore waters were not considered to be overexploited (Anonymous 2005).

Throughout the SCS, increasing production trends in the past decades (Fig. 2) mask underlying depletion of higher level trophic groups, as the proportion of low value fishes in the catch has increased. In most cases, assessed fisheries in SCS countries show a similar trend of declining catches of large demersal and pelagic species, while catches of

smaller sized species have increased, suggesting that ‘fishing down the food web’ is occurring in some SCS regions (Christensen et al. 2003; Funge-Smith et al. 2012). This is reflected in the temporal trend of the mean maximum length of catch (ML) indicator (Fig. 5), which shows that the ML declined substantially in the mid-1960s as the region’s fisheries became increasingly overexploited following rapid expansion of the industrial fishing sector. The lowest level was reached in the mid-1970s for the Gulf of Thailand LME, and mid-1980s for the SCS LME, after which the mean maximum length remained fairly stable, with slight increases since 2000 in both LMEs. The loss of large predatory species can affect ecosystem structure, function, and resilience, with resulting socio-economic and management consequences (Baum and Worm 2009). Cascading effects, wherein the decrease in predator abundance leads to an explosion in their prey population, can shift the socio-economic dynamics of the fishery, and also increase variability and instability in the system, thereby posing substantial challenges for fisheries management.

The ‘fishing down’ phenomenon has also been shown in recent ecosystem models: (1) in the Central Visayas,

Fig. 4 (a) Export quantity (million t) and (b) value (10^9 USD) of fish and fishery products from SCS countries (2000–2011). *Source* FAO FIGIS database (2015)

Philippines, fish catch was dominated by lower trophic level fish and invertebrates, indicating that illegal and destructive fishing practices had impacted ecosystem structure and dynamics (Bacalso and Wolff 2014); (2) in the Gulf of Tonkin, current high levels of fishing mortality

resulted in the dominance of low trophic level species while the biomass of top predators declined by 80–90 % (Chen et al. 2011); (3) a trophic model of coral reefs in Nanwan Bay, Taiwan, suggested that overfishing had reduced the mean trophic level of the catch and also

Fig. 5 Mean maximum length of the catch for the South China Sea (solid line) and Gulf of Thailand (dashed line) LMEs for the period 1950–2010

affected the flow of organic matter through the food web (Liu et al. 2009); (4) projections from three sub-models of the SCS indicated that by 2045, overfishing, climate warming, ocean acidification, and changes in primary productivity would result in biomass decreases ranging from 9 to 59 % relative to 2015 for all fished species groups. In particular, vulnerable species such as groupers, large sharks, and large croakers were projected to decrease by 50 % or more over the simulation period (Witter et al. 2015).

Catch per unit effort (CPUE)

Qualitative accounts of temporal declines in catch rates are common in SCS small-scale fisheries (Teh et al. 2008; Pomeroy et al. 2009; Muallil et al. 2014). Similarly, the majority of assessed SCS fisheries showed a temporal decline in catch rates (Funge-Smith et al. 2012). This applied to all trawl and gillnet fisheries except Malaysia (Table 3). Detailed trends in CPUE by SCS country are provided in Funge-Smith et al. (2012), and summarised in Table 3.

CPUE in Indonesia, Taiwan, and Vietnam showed a general decreasing trend. In China, CPUE decreased until the 1990s, and has since stabilised, although there has been a shift of the fishery to smaller and faster recruiting species. Similarly, CPUE in Thailand is relatively stable, although at decreased rates compared to 20 years ago. This also suggests that the fishery is at a ‘fished down’ level. Gillnet and purse seine CPUE decreased in the east coast of Peninsular Malaysia from 2000 to 2010. In contrast, purse seine CPUE in two locations—west coast of Sabah (Malaysia) and the Moro Gulf in the Philippines—increased; the former was due mainly to an increase in the anchovy fishery, while the Philippines purse seine fishery

targets skipjack and yellowfin tuna (Funge-Smith et al. 2012).

GOVERNANCE OF SOUTH CHINA SEA MARINE FISHERIES RESOURCES

Reducing fishing capacity in a way that will not severely impact fisheries dependent livelihoods is a major challenge for SCS fisheries management, where a range of problems such as lack of enforcement, poor compliance, and poor coordination between different government bodies persist (Christie et al. 2005; Pomeroy et al. 2007; Ferrol-Schulte et al. 2015).

SCS countries generally have some degree of marine environment protection written into their national constitutions, and also have the legislative powers to limit fishing capacity (Morgan et al. 2007). A range of methods and tools have been used by SCS countries to manage their fisheries resources (Tables S3, S4). However, while there has been substantial progress in countries developing national plans of action to reduce fishing capacity since the early 2000s (Morgan et al. 2007), legislation is also often not supported by practical laws and tools for implementing effective compliance and enforcement measures (Basiron and Lexmond 2013). This not only affects countries’ fisheries resources, but also intensifies inter-sectoral conflict (e.g. Muawanah et al. 2012), and impedes SCS countries’ ability to protect marine ecosystems to meet international biodiversity goals, particularly in the face of climate change (Chircop 2010; Juffe-Bignoli et al. 2014).

Inadequate trade governance, especially for high-value fisheries, can exacerbate the pressure on already vulnerable fish and invertebrate populations (Purcell et al. 2013; Fabinyi et al. 2014). International regulations such as CITES⁸ may be able to control trade in certain species and benefit their long-term conservation, but these are generally too slow to react to the rapid expansion of boom and bust style fisheries (Anderson et al. 2011). At the national level, trade monitoring is complicated by the type and quality of data, and by undocumented trade in high-value seafood (Fabinyi et al. 2014; Eriksson and Clarke 2015). Moreover, the impact of trade on the social development goals of communities is often not considered, and this raises concerns when there is a misalignment in trade and social goals and policies (Fabinyi et al. 2014).

Regionally, cooperation on environmental and fisheries issues has generally been hindered by competing territorial claims and SCS states’ discontent over maritime boundary delimitations (Chen 2013), despite the existence of

⁸ All SCS countries are parties to CITES except for Taiwan, which implements CITES regulations through its domestic legislation.

Table 3 Percentage (%) change in CPUE by gear or by overall rate for selected SCS countries (*Source* Funge-Smith et al. 2012)

Country	Time period	Overall	Otter/pair trawl	Purse seine	Drift/gillnet	Hand line	Anchovy purse seine
China (Northern SCS)	1970–2008	−43	−21 to −58				
Vietnam	1985–2003	−68					
Philippines (Moro Gulf)	2003–2007	−		+21	−47	+48	
Thailand (East coast)	1997–2009	−	−48	−41			
Malaysia (Peninsular east coast)	2000–2010	−	+1	−25 to −36	−21		+15
Malaysia (Sabah west coast)	2000–2008	−		+4 to 18	+7		+40
Indonesia (FMA 711)	1990–2007	−	−43	−63	−36		
Taiwan ^a	2002–2008	Decline					

The study did not cover Taiwan, Hong Kong, Singapore, and Macau, while no data were available for Cambodia

^a *Source* Liu (2013). This study did not disaggregate CPUE by gear

multilateral instruments and intergovernmental bodies in the SCS (Table S5). Hence, in areas of overlapping national claims, effective regulation may not be possible unless sovereignty issues are resolved and there is multilateral collaboration in regulating fisheries. Yet, the absence of a legally binding regional fisheries agreement for managing SCS fisheries resources prevents major issues such as IUU fishing and transboundary fish stock management from being addressed adequately (George 2012; Basiron and Lexmond 2013). Another barrier to environmental cooperation in the SCS has been national governments' prioritisation of economic development over environmental protection (Chen 2013). On a positive note, there has been regional cooperation in protecting SCS marine and coastal systems since the 1980s (Kao et al. 2012), with recent multilateral attempts to shift SCS ocean management to an ecosystem-wide approach through regional cooperation in scientific research (Basiron and Lexmond 2013; Chen 2013).

Multilateral projects also contribute to human resource development, which is crucial for progressing towards improved governance capacity, particularly since SCS countries still lack adequate expertise in fundamental subject areas such as fisheries biology, laws and legislation, and social sciences (SEAFDEC 2012). Nevertheless, a weakness of multilateral, regional projects to date is that they would not have been possible without the assistance of global organisations (Kao et al. 2012).

DISCUSSION AND CONCLUSION

This review reiterates the general consensus that SCS fishing activities have been unsustainable for the past few decades (Silvestre et al. 2003; Butcher 2004), exemplifying the continued conflict between humans and the environment. Past assessments have demonstrated the overexploited state of SCS fisheries biologically (e.g. through fish

stock assessments, ecosystem models), and socio-economically (e.g. fisheries valuation, household surveys). Our results build upon these studies to present a more complete picture about the status of SCS fisheries through the incorporation of previously omitted fish catch data. We show that up to 60 % more catch is potentially being taken from SCS waters, and indirect economic benefits supported by fisheries output are potentially almost 4 times greater than the direct landed value of fisheries. Thus, SCS fisheries likely support greater socio-economic benefits than previously accounted for, even without considering unrecorded cross-border trade (Fabinyi et al. 2014), which was not quantified here. At the same time, the state of fisheries resources may be more overexploited than acknowledged by fisheries management agencies, putting the following socio-economic fisheries benefits at risk of being reduced if fisheries sustainability does not improve:

- 10.5–16.6 million t in annual fisheries catch, accounting for 13–21 % of global reported annual catch;
- USD 12–22 × 10⁹ in fisheries landed value annually;
- USD 67 × 10⁹ in fisheries associated economic output annually;
- USD 16 × 10⁹ in household income supported by fisheries annually;
- 2.7 million fisheries jobs in the 2000s; and
- USD 39 × 10⁹ in fishery product exports in 2011.

Reflecting the general trend in global reconstructed fish catch (Pauly and Zeller 2016), fisheries catch (reported + unreported) from the SCS Large Marine Ecosystem appears to have peaked in the mid-1990s, then stayed at a relatively stable level until dropping in the mid-2000s. The global decline in fish catch over the past decade was not due to improved fishing effort regulation (Pauly and Zeller 2016); therefore, the decreasing SCS catch trend is likewise likely due to declining fish populations rather than effective fishing regulations. This raises the concern about how much longer current SCS fisheries catch and its associated

economic benefits can persist under the prevailing state of weak fisheries and marine governance. Indeed, fisheries landed values have remained stagnant or shown slight annual decreases since 2000. Underlying this trend may be the shift of SCS fish catch composition towards a larger proportion of low value, small fish species (Funge-Smith et al. 2012). Moreover, the estimate that some SCS countries could have lost up to 1 million t of their potential fish catch due to overfishing over the period 1990–2004 (Srinivasan et al. 2012) highlights the severe impact the continuation of unsustainable fisheries will have on regional food security and livelihoods. This trend is reflected not only in the SCS, but also worldwide, where it appears that attaining the Aichi Target of global fisheries sustainability⁹ by 2020 will likely not be achieved (Leadley et al. 2014).

At the national level, the low priority accorded to fisheries may be due to the perception that fisheries make a relatively minute contribution (1 %) to the GDP and total export trade of SCS countries. This perspective however, masks the enormous importance fisheries play in supporting local livelihoods and food demand throughout the SCS (Butcher 2004; Perez et al. 2012). Fish is not only crucial for meeting basic dietary needs in rural communities (e.g. Cruz-Trinidad et al. 2009), but is also in high demand in the more affluent SCS markets of Hong Kong and Singapore, where social preference has led to an increasing trend in seafood consumption rates (Canadian Trade Commissioner Service 2013; Panicker and Leong 2013). In fact, the high societal and economic contribution of SCS fisheries may be an underlying reason inhibiting national governments from limiting fishing capacity.

Combined with climate driven uncertainty, marine ecosystems in the future may be less resilient and have reduced capacity to provide the same ecosystem services that we obtain today. This will also incur substantial economic loss, as it was estimated that the annual production value from SCS mangroves, coral reefs, and seagrasses was around USD 5×10^9 , USD 1×10^9 , and USD 87 million, respectively (Pernetta et al. 2013). Nevertheless, despite the undisputed importance of SCS fisheries, improvements in governance and management systems in the SCS have tended to remain frustratingly static (Pomeroy et al. 2007; Kao et al. 2012). Lack of political will is a major contributing factor (Carbonetti et al. 2014) to the perpetuation of unsustainable fisheries at all scales. At the regional level, addressing the ongoing SCS territorial dispute, which

impedes regional cooperation, is a major challenge that requires the involvement of intra-governmental and international bodies. Nationally, recommendations for reducing the chronic overcapacity in SCS fisheries span a range of input, spatial, and temporal restrictions, as well as the integration of broader, inter-sectoral environmental planning in conjunction with fisheries management (Pomeroy et al. 2009; Huang and Chuang 2010; Perez et al. 2012; Pomeroy 2012; Wu 2014). The huge dependence on small-scale coastal fisheries in the SCS also makes the integration of socio-economic policy within fisheries management imperative.

Thus, at national and local scales, effective solutions will involve multiple dimensions, including fisheries resource management, restoration and conservation, as well as livelihoods, social, economic and community development (Pomeroy 2012; Ratner et al. 2012) to address the underlying drivers of poverty and community marginalisation. In addition, there is a need to understand fishers' perceptions about regulatory measures in order to achieve compliance (Salayo et al. 2008); fishers' inter-temporal preferences can also play a role in influencing their attitudes towards marine resource management (Sumaila and Dominguez-Torreiro 2010; Teh et al. 2014). In particular, failure with top-down management in many SCS countries indicates the importance of incorporating bottom-up, community approaches in fisheries governance (Pomeroy 2012; Wu 2014). Co-management is now extensively applied in SCS countries (Ratner et al. 2012), and was found to lead to reduced resource conflict and increased civil order, which in turn improved food security in SCS communities (Pomeroy et al. 2007).

Our review indicates that there will be dire societal and ecological consequences if future SCS fisheries development and management follow past and current trajectories. Notwithstanding the myriad of potential fisheries management approaches and policies, to really effect change in fisheries governance will require action across all sectors of the community, including governments, regional organisations, academia, businesses, civil society, and individuals. To this extent, communications and knowledge dissemination form an important component of strategies for sustainable fisheries (e.g. Salo 2015). Framing fisheries management as part of national agenda priorities such as food security and national security is one way of elevating the message that continuing with the status quo of fisheries governance is not a good option for SCS countries.¹⁰

⁹ Aichi Target 6 states that “By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits”.

¹⁰ This suggestion was raised by participants at an expert workshop on South China Sea fisheries held in May 2015 in Hong Kong. The workshop was organised by the authors of this paper, and funded by ADM Capital Foundation.

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REFERENCES

- Abdul Rahim, K.R. 2007. Pembangunan perusahaan perikanan tangkapan di Negara Brunei Darussalam. Retrieved 16 February, 2016, from <http://jati.um.edu.my/iconsea2007/download/paper/pgb.pdf>.
- Ablan, C.A., and L.R. Garces. 2005. Exclusive Economic Zones and the management of fisheries in the South China Sea. In *A sea change: The Exclusive Economic Zone and governance institutions for living marine resources*, ed. S.A. Ebbin, A.H. Hoel, and A.K. Sydnese, 136–149. Dordrecht: Springer.
- Agriculture, Fisheries and Conservation Department Hong Kong (AFCD). 2015. Fisheries Overview. Retrieved 10 July, 2016, from http://www.afcd.gov.hk/english/fisheries/fish_cap/fish_cap_latest/fish_cap_latest.html.
- Anderson, S.C., J.M. Flemming, R. Watson, and H.K. Lotze. 2011. Serial exploitation of global sea cucumber fisheries. *Fish and Fisheries* 12: 317–339.
- Anonymous. 2015. Vietnam fisheries and aquaculture sector study. Final Report, Vietnam Ministry of Fisheries and The World Bank.
- APEC. 2008. *Assessment of impacts of illegal, unreported and unregulated (IUU) fishing in the Asia-Pacific*. Singapore: Asia-Pacific Economic Cooperation Secretariat.
- Bacalso, R.T.M., and M. Wolff. 2014. Trophic flow structure of the Danajon ecosystem (Central Philippines) and impacts of illegal and destructive fishing practices. *Journal of Marine Systems* 139: 103–118.
- Basiron, M.N., and S.M. Lexmond. 2013. Review of the legal aspects of environmental management in the South China Sea and Gulf of Thailand. *Ocean and Coastal Management* 85: 257–267.
- Baum, J.K., and B. Worm. 2009. Cascading top-down effects of changing oceanic predator abundances. *Journal of Animal Ecology* 78: 699–714.
- Bureau of Fisheries and Aquatic Resources (BFAR). 2012. Philippine Fisheries Profile 2012. Department of Agriculture, Quezon City, 70 pp.
- Butcher, J.G. 2004. *The closing of the frontier: A history of the marine fisheries of Southeast Asia 1850–2000*. Singapore: Institute of Southeast Asian Studies.
- Canadian Trade Commissioner Service. 2013. Fish and seafood profile—Hong Kong & Macao. Retrieved 20 July, 2016, from <http://www.tradecommissioner.gc.ca/eng/sector-info.jsp?nid=585>.
- Carbonetti, B., R. Pomeroy, and D.L. Richards. 2014. Overcoming the lack of political will in small-scale fisheries. *Marine Policy* 44: 295–301.
- Chen, S. 2013. Environmental cooperation in the South China Sea: Factors, actors and mechanisms. *Ocean and Coastal Management* 85: 131–140.
- Chen, Z., Y. Qiu, and S. Xu. 2011. Changes in trophic flows and ecosystem properties of the Beibu Gulf ecosystem before and after the collapse of fish stocks. *Ocean and Coastal Management* 54: 601–611.
- Cheung, C.F. 2013. Trawling ban means end of an era for Hong Kong's fishermen. *South China Morning Post Online Tuesday*, 1 January 2013. Retrieved 12 February, 2016, from <http://www.scmp.com/news/hong-kong/article/1116809/trawling-ban-means-end-era-hong-kongs-fishermen>.
- Cheung, W.W.L., and Y. Sadovy. 2004. Retrospective evaluation of data-limited fisheries: A case from Hong Kong. *Reviews in Fish Biology and Fisheries* 14: 181–206.
- Cheung, W.W.L., V.W.Y. Lam, J.L. Sarmiento, K. Kearney, R. Watson, D. Zeller, and D. Pauly. 2010. Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology* 16: 24–35.
- Chircop, A. 2010. Regional cooperation in marine environmental protection in the South China Sea: A reflection of new directions for marine conservation. *Ocean Development & International Law* 41: 334–356.
- Christensen, J., and M. Tull (eds.). 2014. *Historical perspectives of fisheries exploitation in the Indo-Pacific*. Dordrecht: Springer.
- Christensen, V.T., L.R. Garces, G.T. Silvestre, and D. Pauly. 2003. Fisheries impact on the South China Sea large marine ecosystem: A preliminary analysis using spatially-explicit methodology. In *Assessment, management and future directions for coastal fisheries in Asian countries*, WorldFish center conference proceedings 67, ed. G. Silvestre, L. Garces, I. Stobutzki, M. Ahmed, R.A. Valmonte-Santos, C. Luna, L. Lachica-Aliño, P. Munro, et al., 51–62. Penang: WorldFish Center.
- Christie, P., K. Lowry, A.T. White, E.G. Oracion, L. Sievanen, R.S. Pomeroy, R.B. Pollnac, J.M. Patlis, et al. 2005. Key findings from a multidisciplinary examination of integrated coastal management process sustainability. *Ocean and Coastal Management* 48: 468–483.
- Cruz-Trinidad, A., R.C. Geronimo, and P.M. Alino. 2009. Development trajectories and impacts on coral reef use in Lingayen Gulf, Philippines. *Ocean and Coastal Management* 52: 173–180.
- Department of Fisheries Thailand. 2015. Marine Fisheries Management Plan of Thailand. A National Policy for Marine Fisheries Management 2015–2019. Indian Ocean Tuna Commission Report IOTC-2015-WPDCS11-INF04.
- Dyck, A.J., and U.R. Sumaila. 2010. Economic impact of ocean fish populations in the global fishery. *Journal of Bioeconomics* 12: 227–243.
- E.J.F. 2014. *Slavery at sea: The continued plight of trafficked migrants in Thailand's fishing industry*. London: Environmental Justice Foundation. 39 pp.
- Eriksson, H., and S. Clarke. 2015. Chinese market responses to overexploitation of sharks and sea cucumbers. *Biological Conservation* 184: 163–173.
- Fabinyi, M. 2016. New dynamic for South China Sea fisheries. Australian Institute of International Affairs. Retrieved 10 July, 2016, from http://www.internationalaffairs.org.au/australian_outlook/new-dynamic-for-south-china-sea-fisheries/.
- Fabinyi, M., and D. Dalabajan. 2011. Policy and practice in the live reef fish for food study from Palawan, Philippines. *Marine Policy* 35: 371–378.
- Fabinyi, M., M. Pido, E.M. Ponce de Leon, M.A. De las Alas, J. Buenconsejo, A. Uyami-Bitara, B. Harani, and J. Caceres. 2014. Fisheries trade and social development in the Philippine-Malaysia maritime border zone. *Development and Policy Review* 32: 715–732.
- FAO. 2005. FAO Fishery Country Profile—The Socialist Republic of Viet Nam. Retrieved 10 July, 2016, from <http://www.fao.org/fi/oldsite/FCP/en/VNM/profile.htm>.
- FAO. 2010. Report of the second workshop on the assessment of fishery stock status in South and Southeast Asia, Bangkok, 5–9 October 2009. FAO Fisheries and Aquaculture Report No. 940 (FIR/R940). FAO, Rome.
- FAO. 2014. *The state of world fisheries and aquaculture*. Rome: FAO.
- Ferrol-Schulte, D., P. Gorris, W. Baitoningsih, D.S. Adhuri, and S.C.A. Ferse. 2015. Coastal livelihood vulnerability to marine

- resource degradation: A review of the Indonesia national coastal and marine policy framework. *Marine Policy* 52: 163–171.
- Funge-Smith, S., M. Briggs, and W. Miao. 2012. Regional overview of fisheries and aquaculture in Asia and the Pacific 2012. RAP Publication 2012/26. Asia-Pacific Fishery Commission, FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.
- George, M. 2012. Fisheries protections in the context of the geopolitical tensions in the South China Sea. *Journal of Maritime Law & Commerce* 43: 85–128.
- Huang, H.W., and C.T. Chuang. 2010. Fishing capacity management in Taiwan: Experiences and prospects. *Marine Policy* 34: 70–76.
- Hughes, T.P., H. Huang, and M.A. Young. 2013. The wicked problem of China's disappearing coral reefs. *Conservation Biology* 27: 261–269.
- Juffe-Bignoli, D., S. Bhatt, S. Park, A. Eassom, E.M.S. Belle, R. Murti, C. Buyck, A. Raza Rizvi, et al. 2014. *Asia Protected Planet 2014*. Cambridge: UNEP-WCMC, 67 pp.
- Kao, S.M., N.S. Pearre, and J. Firestone. 2012. Regional cooperation in the South China Sea: Analysis of existing practices and prospects. *Ocean Development and International Law* 43: 283–295.
- Leadley, P.W., C.B. Krug, R. Alkemade, H.M. Pereira, U.R. Sumaila, M. Walpole, A. Marques, T. Newbold, et al. 2014. Progress towards the Aichi Biodiversity Targets: An assessment of biodiversity trends, policy scenarios and key actions. Technical Series 78, Secretariat of the Convention on Biological Diversity, Montreal, Canada.
- Liu, J.Y. 2013. Status of marine biodiversity of the China Seas. *PLoS ONE* 8: e50719. doi:10.1371/journal.pone.0050719.
- Liu, P.J., K.T. Shao, R.Q. Jan, T.Y. Fan, S.L. Wong, J.S. Hwang, J.P. Chen, C.C. Chen, et al. 2009. A trophic model of fringing coral reefs in Nanwan Bay, southern Taiwan suggests overfishing. *Marine Environmental Research* 68: 106–117.
- Liu, Y., Z. Peng, R. Zhou, S. Song, W. Liu, C.F. You, Y.P. Lin, K. Yu, et al. 2014. Acceleration of modern acidification in the South China Sea driven by anthropogenic CO₂. *Scientific Reports* 4: 5148. doi:10.1038/srep05148.
- Masriat, J.A.N. 2012. Standing stock of demersal fish assessment in southern part of South China Sea. *Journal of Coastal Development* 14: 276–281.
- Miller, K.A., G.R. Munro, U.R. Sumaila, and W.W.L. Cheung. 2013. Governing marine fisheries in a changing climate: A game-theoretic perspective. *Canadian Journal of Agricultural Economics* 61: 309–334.
- Morgan, G., D. Staples, and S. Funge-Smith. 2007. Fishing capacity management and IUU fishing in Asia. RAP Publication 2007/16, FAO, Bangkok.
- Muallil, R.N., S.S. Mamaug, J.T. Cababaro, H.O. Arceo, and P.M. Alino. 2014. Catch trends in Philippine small-scale fisheries over the last five decades: The fishers' perspectives. *Marine Policy* 47: 110–117.
- Muawanah, U., R.S. Pomeroy, and C. Marlesy. 2012. Revisiting fish wars: Conflict and collaboration over fisheries in Indonesia. *Coastal Management* 40: 279–288.
- Palomares, M.L.D., and D. Pauly, eds. 2014. Philippine marine fisheries catches: A bottom-up reconstruction, 1950 to 2010. Fisheries Centre Research Reports 22 (1), University of British Columbia, Vancouver, Canada.
- Panicker, V., and Leong, A. 2013. Sea fish industry authority. UK Trade & Investment Overseas Market Introduction Service. Retrieved 20 July, 2016, from <http://seafoodsingapore.org/files/8414/0786/6886/singapore.pdf>.
- Pauly, D., and D. Zeller, eds. 2015. Sea Around Us concepts, design and data. www.seaaroundus.org.
- Pauly, D., and D. Zeller. 2016. Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nature Communications* 7: 10244. doi:10.1038/ncomms10244.
- Perez, M.L., M.D. Pido, L.R. Garces, and N.D. Salayo. 2012. Towards sustainable development of small-scale fisheries in the Philippines: Experiences and lessons learned from eight regional sites. Lessons Learned Brief 2012–10, WorldFish Center Report, Penang, Malaysia.
- Pernetta, J.C., and J.M. Bowers. 2013. Introduction to the special issue of coastal and ocean management entitled the South China Sea Project: A multilateral marine and coastal area management initiative. *Ocean & Coastal Management* 85(B): 127–130.
- Pernetta, J.C., J.E. Ong, N.E.O. Padilla, K.A. Rahim, and N.T. Chinh. 2013. Determining regionally applicable economic values for coastal habitats and their use in evaluating the cost effectiveness of regional conservation actions: The example of mangroves in the South China Sea. *Ocean & Coastal Management* 85(B): 177–185.
- Pitcher, T., D. Kalikoski, G. Pramod, and K. Short. 2009. Not honouring the code. *Nature* 457: 658–659.
- Pomeroy, R.S. 2012. Managing overcapacity in small-scale fisheries in Southeast Asia. *Marine Policy* 36: 520–527.
- Pomeroy, R., J. Parks, R. Pollnac, T. Campson, E. Genio, C. Marlesy, E. Holle, M. Pido, et al. 2007. Fish wars: Conflict and collaboration in fisheries management in Southeast Asia. *Marine Policy* 31: 645–656.
- Pomeroy, R., K.A.T. Nguyen, and H.X. Thong. 2009. Small-scale marine fisheries policy in Vietnam. *Marine Policy* 33: 419–428.
- Pomeroy, R., L. Garces, M. Pido, and G. Silvestre. 2010. Ecosystem-based fisheries management in small-scale tropical marine fisheries: Emerging models of governance arrangements in the Philippines. *Marine Policy* 34: 298–308.
- Purcell, S.W., A. Mercier, C. Conand, J.F. Hamel, M.V. Toral-Granda, A. Lovatelli, and S. Uthicke. 2013. Sea cucumber fisheries: Global analysis of stocks, management measures and drivers of overfishing. *Fish and Fisheries* 14: 34–59.
- Puthy, E.M. 2007. *Marine fisheries resource management potential for mackerel fisheries of Cambodia*. Reykjavik: The United Nations University, 65 pp.
- Ratner, B.D., E.J.V. Oh, and R.S. Pomeroy. 2012. Navigating change: Second-generation challenges of small-scale fisheries co-management in the Philippines and Vietnam. *Journal of Environmental Management* 107: 131–139.
- Rico, A., K. Satapornvanit, M.M. Haque, J. Min, P.T. Nguyen, T.C. Telfer, and P.J. van den Brink. 2012. Use of chemicals and biological products in Asian aquaculture and their potential environmental risks: A critical review. *Reviews in Aquaculture* 4: 75–93.
- Sadovy de Mitcheson, Y., M.T. Craig, A.A. Bertoncini, K.E. Carpenter, W.W.L. Cheung, J.H. Choat, A.S. Cornish, S.T. Fennessy, et al. 2013. Fishing groupers towards extinction: A global assessment of threats and extinction risks in a billion dollar fishery. *Fish and Fisheries* 14: 119–136.
- Salayo, N., L. Garces, M. Pido, K. Viswanathan, R. Pomeroy, M. Ahmed, I. Siason, K. Seng, and A. Masae. 2008. Managing excess capacity in small-scale fisheries. Perspectives from stakeholders in three Southeast Asian countries. *Marine Policy* 32: 692–700.
- Salo, J. 2015. South China Sea dispute: Fish are on the brink of extinction due to conflict, experts say. *International Business Times Online*, 3 November 2015. Retrieved 10 February, 2016, from <http://www.ibtimes.com/south-china-sea-dispute-fish-are-brink-extinction-due-conflict-experts-say-2167730>.
- SEAFDEC. 2012. *The Southeast Asian state of fisheries and aquaculture 2012*. Bangkok: Southeast Asian Fisheries Development Center, 130 pp.

- SEAFDEC. 2014. *Fishery statistical bulletin of Southeast Asia 2012. SEC/ST/46*. Bangkok: Southeast Asian Fisheries Development Center, 135 pp.
- Silvestre, G., L. Garces, I. Stobutzki, C. Luna, L. Lachica-Alino, P. Munro, V. Christensen, and D. Pauly (eds.). 2003. *Assessment, management and future directions for coastal fisheries in Asian countries. WorldFish Center conference proceedings 67*. Penang: Worldfish Center.
- Srinivasan, U.T., R. Watson, and U.R. Sumaila. 2012. Global fisheries losses at the exclusive economic zone level, 1950 to present. *Marine Policy* 36: 544–549.
- Stobutzki, I.C., G.T. Silvestre, A. Abu Talib, A. Krongprom, M. Supongpan, P. Khemakorn, N. Armada, and L.R. Garces. 2006a. Decline of demersal coastal fisheries resources in three developing Asian countries. *Fisheries Research* 78: 130–142.
- Stobutzki, I.C., G.T. Silvestre, and L.R. Garces. 2006b. Key issues in coastal fisheries in South and Southeast Asia, outcomes of a regional initiative. *Fisheries Research* 77: 109–118.
- Sumaila, U.R., V. Lam, F. Le Manach, W. Swartz, and D. Pauly. 2013. Global fisheries subsidies. Report prepared for the European Parliament's Committee on Fisheries. Policy Department Structural and Cohesion Policies. Retrieved 10 February, 2016, from http://www.europarl.europa.eu/RegData/etudes/note/join/2013/513978/IPOL-PECH_NT%282013%29513978_EN.pdf.
- Sumaila, U.R., and M. Dominguez-Torreiro. 2010. Discount factors and the performance of alternative fisheries governance systems. *Fish and Fisheries* 11: 278–287.
- Taiwan Ministry of Fisheries. 2015. 2012 Taiwan Fisheries Yearbook. Retrieved 12 February, 2016, from www.fish.gov.tw/en/PublicationsYearbook/.
- Teh, L., L. Teh, D. Zeller, and A. Cabanban. 2009. Historical perspective of Sabah's marine fisheries. In *Fisheries catch reconstructions: Islands, Part I*, eds. D. Zeller and S. Harper, 77–98. Fisheries Centre Research Reports 17(5). Vancouver: University of British Columbia.
- Teh, L., W.W.L. Cheung, A. Cornish, C. Chu, and U.R. Sumaila. 2008. A survey of alternative livelihood options for Hong Kong's fishers. *International Journal of Social Economics* 35: 380–395.
- Teh, L.S.L., L.C.L. Teh, and U.R. Sumaila. 2013. A global estimate of the number of coral reef fishers. *PLoS ONE* 8: e65397. doi:10.1371/journal.pone.0065397.
- Teh, L.S.L., L.C.L. Teh, and U.R. Sumaila. 2014. Time preference of small-scale fishers in open access and traditionally managed reef fisheries. *Marine Policy* 44: 222–231.
- The World Bank. 2015. GDP growth (annual %). Retrieved 10 February, 2016, from <http://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG>.
- UN. 2015. World Population Prospects: The 2015 Revision, Key findings and Advance Tables. United Nations Department of Economic and Social Affairs/Population Division. Retrieved 10 February, from http://esa.un.org/unpd/wpp/publications/files/key_findings_wpp_2015.pdf.
- U.S. Energy Information. 2013. South China Sea. Retrieved 15 September, 2016, from <http://www.eia.gov/beta/international/regions-topics.cfm?RegionTopicID=SCS>.
- van Mulekom, L., A. Axelsson, E.P. Batungbacal, D. Baxter, R. Siregar, and I. de la Torre. 2006. Trade and export orientation of fisheries in Southeast Asia: Under-priced export at the expense of domestic food security and local economies. *Ocean and Coastal Management* 49: 546–561.
- Vo, S.T., J.C. Pernetta, and C.J. Paterson. 2013. Status and trends in coastal habitats of the South China Sea. *Ocean & Coastal Management* 85(B): 153–163.
- Wilkinson, C., L. DeVantier, L. Talaue-McManus, D. Lawrence, and D. Souter. 2005. South China Sea, Global International Waters Assessment 54, UNEP/University of Kalmar, Kalmar, Sweden, 104 pp.
- Witter, A., L. Teh, X. Yin, W. Cheung, and U.R. Sumaila. 2015. Taking stock and projecting the future of South China Sea fisheries. Fisheries Centre Working Paper #2015-99, University of British Columbia, Vancouver, Canada, 91 pp.
- Wu, C.C. 2014. Cross-scale and multi-level mismatch in marine natural resources management in the Penghu Archipelago, Taiwan. *Regional Environmental Change* 14: 2079–2087.
- World Bank. 2013. Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience. A report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics. Washington, DC: World Bank.
- Yu, H., and Y. Yu. 2008. Fishing capacity management in China: Theoretic and practical perspectives. *Marine Policy* 32: 351–359.

AUTHOR BIOGRAPHIES

Louise S. L. Teh (✉) is a Research Associate at the Institute for the Oceans and Fisheries, University of British Columbia. Her research focuses on how interactions between humans and marine ecosystems impact fisheries sustainability.

Address: Fisheries Economics Research Unit, Institute for the Oceans and Fisheries, University of British Columbia, AERL 2202 Main Mall, Vancouver, BC V6T 1Z4, Canada.
e-mail: l.teh@oceans.ubc.ca

Allison Witter is a Doctoral Student at the Institute for the Oceans and Fisheries, University of British Columbia. Her research interest is on the economics of community supported fisheries.

Address: Fisheries Economics Research Unit, Institute for the Oceans and Fisheries, University of British Columbia, AERL 2202 Main Mall, Vancouver, BC V6T 1Z4, Canada.

William W. L. Cheung is an Associate Professor at the Institute for the Oceans and Fisheries, University of British Columbia. His research focuses on the impact of climate and global change on fisheries sustainability.

Address: Changing Oceans Research Unit, Institute for the Oceans and Fisheries, University of British Columbia, AERL 2202 Main Mall, Vancouver, BC V6T 1Z4, Canada.

U. Rashid Sumaila is a Professor at the Institute for the Oceans and Fisheries, University of British Columbia. His research centres on the role economics plays in affecting the sustainability of fisheries and marine ecosystems.

Address: Fisheries Economics Research Unit, Institute for the Oceans and Fisheries, University of British Columbia, AERL 2202 Main Mall, Vancouver, BC V6T 1Z4, Canada.

Xueying Yin is a Doctoral Student at the Institute for the Oceans and Fisheries, University of British Columbia. Her research interest is using ecosystem modelling to study the resilience of marine ecosystems.

Address: Changing Oceans Research Unit, Institute for the Oceans and Fisheries, University of British Columbia, AERL 2202 Main Mall, Vancouver, BC V6T 1Z4, Canada.