The fisheries of the South China Sea: Major trends since 1950

Daniel Paulya,∗, Cui Liangb,c

a Sea Around Us, Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, B.C., V6T 1Z4, Canada
b CAS Key Laboratory of Marine Ecology and Environmental Sciences, Institute of Oceanology, Chinese Academy of Sciences, Qingdao, 266071, PR China
c Laboratory for Marine Ecology and Environmental Science, Qingdao National Laboratory for Marine Science and Technology, Qingdao, 266237, PR China

ABSTRACT

The catches taken from the South China Sea (SCS) by the bordering countries and others are presented for the period from 1950 to 2014, with emphasis on catches that were ‘reconstructed’, i.e., corrected for completeness. Following a rapid increase in the 1980s and early 1990s, catches from the SCS reached about 10 million tonnes per year, then stagnated despite increasing fishing effort. Some details are provided by (i) functional groups containing hundreds of species, (ii) fishing gears, of which trawls and purse seines are dominant, (iii) fishing sectors, with artisanal fisheries currently taking ¾ and industrial fisheries nearly ⅔ of the catches, and (iv) by ex-vessel value, i.e., about 16 billion USD per year. It is also shown that the 10 million tonnes level was achieved by ‘fishing down,’ i.e., catching smaller fish lower in the food web, and through a demand- and subsidy-driven offshore expansion that ended engulfing the entire SCS. Finally, we introduce global warming and its effects on the SCS, and the need to mitigate its impacts, along with the other impacts (acidification, plastics) that will add to the pressures on the SCS ecosystem. Cooperation between the countries bordering the SCS, even if fraught with difficulties, is seen as the only avenue to mitigating these impacts.

1. Introduction

The South China Sea (SCS), which ranges from 104 to 122° east and from 25° north to 3° South (Fig. 1), is near the world centre of marine biodiversity [1]. Thus, although it covers 3.1 million km² and represents only 8.6% of the ocean’s surface, it harbours 3790 fish species, i.e., 22% of the 17,200 reported from the world’s oceans [2].

For millennia, the shores of the SCS were the sites where members of multiple cultures met, and from which they drew their sustenance [3]. Japan [4] and various colonial powers (France in Vietnam, the U.K in Malaysia, The Netherlands in what is now Indonesia) made unsuccessful attempts prior to WWII to introduce industrial fishing, notably trawling, into Southeast Asia [5–7]. However, it was the post-WWII rebuilding in the Philippines that saw the first massive motorization of marine fisheries in the SCS region, mainly via engines salvaged from abandoned US military vehicles [8].

This development was monitored by a German fishery development expert, who helped transfer the concept to Thailand, where trawling took off in the mid-1960s. Then, the Manila-based Asian Development Bank, “commencing with its first fisheries loans in 1969 [...] made loans of US$ 1055 million to a total of 51 fisheries projects in 17 [countries]” [9]. This enabled trawling to burst out of the Gulf of Thailand into the SCS and to become adopted by Malaysia, Singapore, Indonesia, Brunei-Darussalam and Vietnam. Similar developments occurred in southern China, where coastal trawling became the main tool of fisheries industrialisation [10].

This expansion of trawling led to intense competitions with the hundreds of thousands of traditional artisanal fishers operating along Southeast Asian coastlines [3,11], generating conflicts [12] that remain unresolved to this day.

The SCS was described as a Large Marine Ecosystem (LME [in Ref. [13]]) based mainly on physical oceanographic data [14,15], and fisheries catch data [16] consisting of a spatialized version of the marine catch data from 1950 to 2004 assembled and disseminated by the Food and Agriculture Organization of the United Nations, or FAO [17,18].

The catch data presented here cover the years 1950–2014, and they are more complete than the FAO statistics, which do not include discard and omit the bulk of small-scale fisheries catches (see below). Thus, we first present the catch reconstruction approach used by the Sea Around Us to improve in the generally deficient catch statistics of the countries surrounding the SCS. Then, we discuss the primary trends in these catch statistics, along with some associated issues, notably the effects of global warming, and our thoughts about their mitigation.

2. Materials and methods

Regional studies of fisheries are usually based on the catch statistics submitted annually by member countries to the FAO [17]. These data, however, do not include catches that are discarded at sea, rarely include full coverage of artisanal (= small-scale commercial) catches, and, even more rarely, subsistence and recreational catches, not to mention illegal...
industrial catches. Moreover, several countries bordering the SCS have statistics that are often aspirational, i.e., that reflect hoped for, rather than observed catches (see details in the references cited in Table 1). Thus, the FAO data cannot be used ‘as is’. Moreover, the FAO statistics are not georeferenced beyond being assigned to giant ‘FAO Major Fishing Areas’. Thus, the catches taken in the SCS proper could not be distinguished from the catches taken in FAO areas 61 (Northwest Pacific) and 71 (Western Central Pacific), with which the SCS overlaps.

The Sea Around Us has developed ‘catch reconstructions’ procedures to (partly) mitigate for these deficiencies and they are described in general terms in Zeller et al. [19], and in the contribution cited in Table 1 for the countries bordering the SCS. The catch time series thus obtained, which all start in 1950, are documented in detail on the website of the Sea Around Us (www.seaaroundus.org). Therein, catches are presented by the Exclusive Economic Zones (EEZ) claimed by the maritime countries of the world, including those bordering the SCS. These catches are also assigned to cells of ½ degree latitude and longitude, of which there are about 150,000 in the ice-free world’s ocean and 1185 in the SCS. Thus, it is straightforward to re-express catches by an LME, here for the SCS.

Once catches are available for a given LME, they can be combined with specific traits of the taxa in catch reports. Here, they were combined with the mean trophic level of each taxon, as obtained from FishBase (www.fishbase.org) for finfishes and from SeaLifeBase (www.sealifebase.org) for marine invertebrates such as to be able to check for the occurrence of the ‘fishing down’ phenomenon [30]. Also, these

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**Fig. 1.** Map of the South China Sea (SCS), with all the countries surrounding it. As defined, the SCS covers an area of 3.1 million km², of which 1.9 km² are shelf (< 200 m deep). The SCS contains about 7% of the coral reef area and 1% of the seamounts of the world (see www.seaaroundus.org).
trophic levels were used to infer the primary production required by the fisheries of the SCS using the method of Pauly and Christensen [31]. This method also relied on the reconstructed catches and a world map of average primary production data produced by averaging ten years of SeaWIFS satellite data [32].

Finally, we present estimates of the mean temperature of the catch (MTC, [33]) for the SCS as a tropical LME (based on the preferred temperature of 221 species; [34]). This allowed contrasting the response of the MTC in the SCS to increase in Sea Surface Temperature (SST; [14]) with the response of the MTC to SST increase in temperate and subtropical LMEs [33].

3. Results and discussion

Fig. 2 summarises the reported (black line) and reconstructs catches (stacked grey surfaces) from the SCS. Following a rapid growth in the 1980s and early 1990s, this catch stabilized at about 10 million tonnes per year since the mid-1990s, despite an increasing demand due to the increased incomes and populations in the surrounding countries. Another cause is the tendency to increase the size of national fleets as long as economically feasible and beyond, as enabled by massive subsidisation [37].

Fig. 2A illustrates the catch trend in terms of functional groups because of the national statistical systems of the countries bordering the SCS report most of their catch by higher taxa (genus, families ...). This is due to the taxonomic diversity of the catch, especially from trawlers, which is so great that reporting at the level of species is largely impractical. Obviously, this also has implications for single-species stock assessments, which are hampered by lack of species-specific data. On the other hand, single-species assessments are not very useful to trawl fisheries that simultaneously exploit hundreds of species [38]. The situation is different for pelagic fisheries, which tend to be reported at the species level, and for which stock assessments using the CMSY method [39] have been performed for a number of SCS stocks (see www.seaaroundus.org).

Fig. 2B shows that since the 1980s, bottom trawls are the dominant fishing gear (in terms of catch) in the SCS, followed by purse seines (to catch small pelagic fish) and a variety of small-scale gears. Fig. 2C shows that China has the greatest catch in the SCS, followed by Vietnam. Other countries, both from around the SCS and further away, contribute the rest of the SCS catch. Fig. 2D shows that the ex-vessel value of catches from the SCS from 2010 on, reached 16 billion USD, of which about 25% is contributed by artisanal fisheries (see also [40]).

More detail and updates on these various catch-related metrics can be found on the website of the Sea Around Us (www.seaaroundus.org).

Fisheries in the SCS impact all components of the ecosystem, from its inshore communities to its oceanic areas [41,42]. Fig. 3 illustrates these impacts on the fish and invertebrate community in the form of two panels. The upper one consists of the trend of mean trophic level of the catch (i.e., the MTI or ‘Marine Trophic Index’ [43]), while the lower one displays the results of an analysis using the Regional Marine Trophic Index (i.e., RMTI; [44]). The latter analysis accounts for offshore fleet movements as inshore catches decline, which has the effect of making the decline of mean trophic level in inshore stocks [44]. The RMTI analysis confirms the signal conveyed by the insert in Fig. 3A, i.e., the Fishing-in-Balance index (FIB), which expresses the tendency for fisheries to expand offshore [44,45].

As might be seen, the RMTI analysis suggests that there was, following the depletion of nearshore waters in the SCS [45–47], a clear shift toward offshore, deeper waters, as indeed occurred in the entire world [48].

This offshore expansion is also illustrated in Fig. 4, which shows the primary production required (PPR) by the fisheries in 1950 (left) and 2014 (right). PPR, which relates the primary production (PP) embodied in fish catches relative to locally observed primary production, allows comparisons of the impact of fisheries of coastal areas (with high PP) to their impact offshore (where PP is low). Here, the PPR maps of the SCS show that the offshore impact of fisheries is currently almost as significant as the impact inshore.

In absolute terms, the computed PPR for the SCS as a whole, since the mid-1990s, has exceeded observed PP in that body of water (see www.seaaroundus.org), which cannot occur in reality. This suggests that a combination of two biasing factors may be affecting this result:

1) The parameters of the PPR method of Pauly and Christensen [31] and/or the SeaWIFS primary production estimates for the SCS are biased;
2) The catch estimates from the SCS are biased upward, despite efforts (documented in the contribution listed in Table 1) to minimise over-reporting.

While we cannot exclude a bias originating from (1), notably because primary production in the SCS has changed [49], we believe that (2) has the stronger effect, given the demonstrated occurrence of over-reporting the countries surrounding the SCS. Over-reporting, in the SCS region, tends to occur because of administrative or political incentives, as described for several SCS countries in the contributions cited in Table 1, which document catch reconstructions that could only partly correct for demonstrable over-reporting. Another contributing factor is landing in the SCS ports of fish caught outside of the SCS; this second factor is most likely to affect Chinese catches [50].

Finally, Fig. 5 shows that the Mean Temperature of the Catch (MTC; [33]) does not increase in the SCS, despite temperature itself increasing (Fig. 5A). Indeed, the MTC is the SCS in decreasing, which may be due to a relative increase of catches in its northern part, whose exploited fish and invertebrates will tend to have a lower preferred temperature (as suggested by an anonymous reviewer). This decrease is in contrast to the temperate and subtropical LMEs (Fig. 5B), where the increase of the MTC is almost parallel to that of SST. This is because the (tropical) species that inhabit in the SCS (including the 13 SCS species reported from the Taiwan Strait [51]) are not being replaced by species with affinities to higher temperature [33,34]. In contrast, in the East China Sea, the influx of species from the SCS compensate, to a certain extent, for the species lost to the Yellow Sea, and the MTC trend thus follows the SST trend [33,34]. This suggests that if ocean warming continues

<table>
<thead>
<tr>
<th>Country or part thereof*</th>
<th>Domestic catch % in the SCS^</th>
<th>Sources’</th>
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<tbody>
<tr>
<td>Brunei Darussalam</td>
<td>100</td>
<td>[20]</td>
</tr>
<tr>
<td>China (Mainland)</td>
<td>41</td>
<td>[21]</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>100</td>
<td>[22]</td>
</tr>
<tr>
<td>Indonesia</td>
<td>15</td>
<td>[23]</td>
</tr>
<tr>
<td>Sabah/Sarawak (Malaysia)</td>
<td>85</td>
<td>[24]</td>
</tr>
<tr>
<td>Philippines</td>
<td>27</td>
<td>[25]</td>
</tr>
<tr>
<td>Taiwan</td>
<td>45</td>
<td>[26]</td>
</tr>
<tr>
<td>Singapore</td>
<td>100</td>
<td>[27]</td>
</tr>
<tr>
<td>Vietnam</td>
<td>79</td>
<td>[28]</td>
</tr>
</tbody>
</table>

* Thailand’s domestic catches are not included because Thai waters are not part of the SCS (see Fig. 1); however, Thai distant-water catches in the SCS are included in the catches taken from the EEZs of countries bordering the SCS, as are the catches of all other countries with distant-water fleets operating in the SCS.
^ Cumulative catches from 2000 to 2014.
’ All of these documents can be downloaded from www.seaaroundus.org. One-page summaries of each of them may be found in the ‘Global Atlas of Marine Fisheries’ [29].

Table 1
Catch reconstructions directly relevant to the South China Sea (SCS) as defined in Fig. 1 (available at www.seaaroundus.org).
(and there is, unfortunately, no reason to think that it won’t), the SCS will see a gradual temperature-induced erosion of its biodiversity [52].

Mitigating the impact of global warming onto the SCS would require, however, rebuilding some of its previous abundances, since large fish populations are more resilient [53]. The reason is that they will contain more variant genotypes, including some that may be resistant to higher temperature [54].

Unfortunately, the SCS is surrounded by countries with overlapping
claims to its waters and natural resources. Rather than their being turned into marine parks, as proposed in a less challenging time [55], its fishing grounds have become the prizes of a zero-sum game where the win of one country is the loss of another [56]. In this context, the tragedy of the commons [57] is exacerbated, and fish populations that once migrated from the waters of one country to the next are now facing the “double jeopardy” of unsustainable, competitive harvesting [58].

Still, there some reasons for hope, as several of the countries bordering the SCS have realized the importance of protecting their region’s fishery resources [59]. Thus, China, Vietnam and other countries have established marine protected areas covering approximately 15,600 square miles in the coastal waters of the SCS. This is not much if compared to some of the giant marine reserves that have been created in recent years, e.g., in the Chagos Archipelagos [60], but it is a positive signal.

However, to make a dent in tackling the issues mentioned above, the countries surrounding the SCS should cease viewing “increased production” as the primary objective of their fisheries. Rather, sustaining the annual catch of 10 million tonnes presently being taken will be enough of a challenge (see also [61]). Achieving sustainability would be much advanced by reducing and eventually getting rid of the government subsidies [37] which have allowed fishing effort to increase to the extent that catches are now stagnating, or even declining in some areas (see contributions in Table 1).

Moreover, a slightly reduced catch caught by unsubsidized fleets

[Fig. 3. Illustrating the impact of fishing in the SCS through the reduction of the mean trophic level of catches. A) Trend in mean trophic level for all SCS catch, i.e., the MTI (insert: Fishing-in-Balance index); B) trends in the Region-based Mean Trophic Level of the Catch, or RMTI, which account for the fisheries’ offshore migration (see text).]

[Fig. 4. Primary production required by the fisheries of the SCS (left: in 1950; right: in 2014).]
would generate far more societal benefits [58], especially if the fraction of fish suitable for direct human consumption were to be increased through policies encouraging the use of larger meshes in trawl nets [62].

There are numerous challenges to the SCS LME; we addressed fisheries resource depletion and global warming, whose effects are intensified by ocean acidification and deoxygenation, not to mention the deleterious effect of plastic debris. It is clear that cooperation between the countries bordering the SCS will be crucial in addressing these challenges. Such cooperation could use other semi-enclosed seas for reference (e.g., the Baltic Sea; [63]), and cooperate first on topics that are less sensitive, for example, environmental protection and scientific research [64]. This will strengthen mutual trust and the ties between the countries; eventually, this may help mitigate disputes over access to fishing grounds. We cannot definitely say that it will work, but we know for sure that non-cooperation would make things worse.

Declarations of interest

None.

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