The Fisheries of the Arabian Sea Large Marine Ecosystem

M. L. D. Palomares, M. Khalfallah, D. Zeller, and D. Pauly

Abstract The fisheries of the Arabian Sea Large Marine Ecosystem, which includes the northern part of the western Indian Ocean, from the Horn of Africa to India's Malabar Coast are described, along with some of the physical parameters impacting on their productivity. The bulk of fishing and thus the majority of catches in the Arabian Sea occur within the exclusive economic zones of the bordering countries, which allow national governments to control and manage the exploitation of marine resources, allowing for potentially better control compared to most fishing in the high seas waters. Some progressive and forward-looking actions seem to have been taken on some issues plaguing fisheries, but most countries around this LME struggle with massive overcapacity, often enhanced by poor policy choices made in the past, especially with regards to the ill-advised preference given to industrial fisheries development at the expense of small-scale, food-security and livelihood fisheries. Serious considerations ought to be given by all these countries to reducing and tightly controlling industrial fishing, both domestic and foreign, with particular emphasis on reducing or banning wasteful bottom trawl fisheries and assisting and empowering well-managed small-scale fisheries.

1 Introduction

The Arabian Sea Large Marine Ecosystem (LME) is located in the northwestern part of the Indian Ocean and ranges from Djibouti at the Horn of Africa in the west to the Malabar Coast and the tip of India in the East (Fig. 1). Although the Persian Gulf belongs to the Arabian Sea LME (Sherman and Hempel 2008), it is here given less

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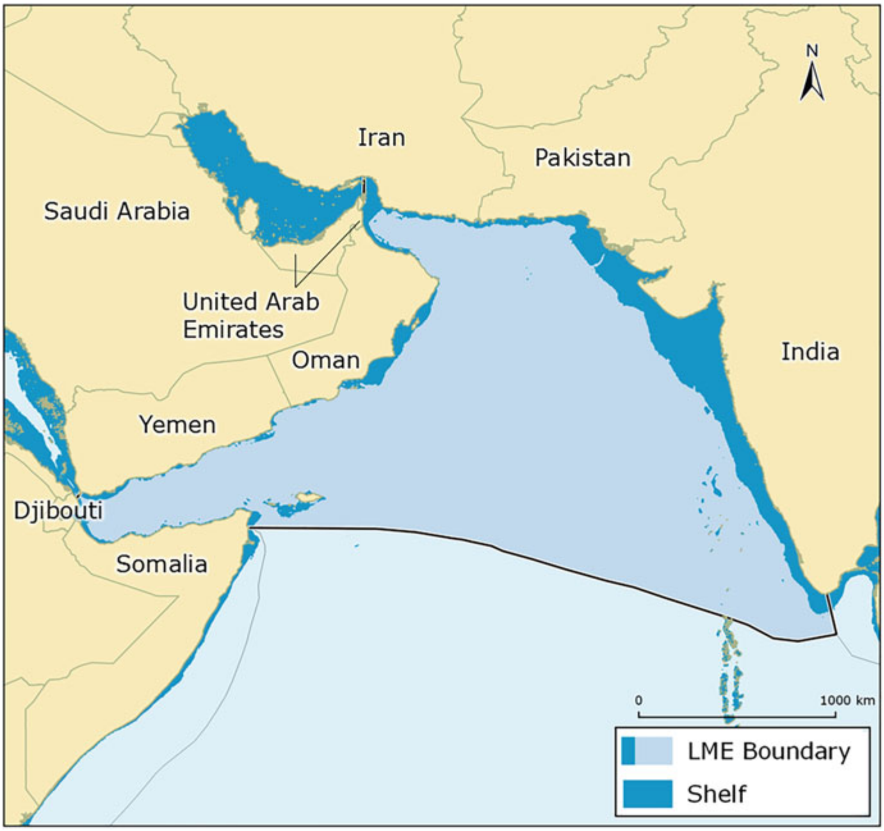

Fig. 1 The Arabian Sea Large Marine Ecosystem (LME) covers 3,950,420 km^2 as defined here, i.e. excluding the Persian Gulf (349,550 km^2)

emphasis, due to its peculiar characteristics (high temperature and salinity, shallowness), covered in recent accounts of its ecology (Wabnitz et al. 2018) and fisheries (Al-Abdulrazzak et al. 2015). Thus, the Arabian Sea LME as defined here mainly covers, from West to East, all or part of the coast of Djibouti, Somalia, Yemen, Oman, the UAE, Iran, Pakistan and India (Fig. 1).

The Arabian Sea LME has a high primary productivity, notably due to various fronts (Belkin et al. 2008) and upwelling areas off Somalia, Oman, Pakistan, and India (Heileman et al. 2008). The overall climate of the Arabian Sea, however, is shaped by the alternating of the monsoons, i.e. the southwest monsoon (June–September) and the northeast monsoon (November–April). Belkin et al. (2008) identified several front structures in the Arabian Sea LME, notably across the Gulf of Aden, off the Omani coast, in the Gulf of Oman and along the coast of India.

The high upwelling-induced primary productivity led to abundant fish populations in the Arabian Sea LME, now strongly exploited in all but a few cases (notably Djibouti, see Colléter et al. 2015). However, the Arabian Sea is also characterized by deoxygenated subsurface waters, which make the development of deep bottom trawling impossible in many areas and which can even reach onto the shelf, where it causes fish kills (e.g. along India's Malabar Coast; Banse 1968).

A description of the fisheries in the Arabian Sea LME (minus the Persian Gulf, see Al-Abdulrazzak et al. 2015) is given below which emphasizes the roles of their different sectors, i.e. industrial, artisanal, etc., usually ignored when regional analyses are performed. This is because such analyses usually rely on fisheries landing statistics compiled by the Food and Agriculture Organization of the United Nations (FAO) from submissions by member countries and which do not distinguish between fisheries sectors, besides being biased downward (Pauly and Zeller 2016a, b).

Instead, here, the analysis is performed using 'reconstructed catches', (Zeller et al. 2016) which complement the official reported data with best estimates of unreported catches (which may be legal or illegal) and unreported discards and which assign all reported and unreported catches to one of four fishing sectors (industrial, artisanal, subsistence and recreational). Reconstructed catches are furthermore allocated to individual exclusive economic zone (EEZ) waters of each country or high seas areas.

2 Material and Methods

The contributions in Pauly and Zeller (2016a) give details on the decade-long international project, which led to the reconstruction of catch data for every country in the world, as well as describing the assumptions and methods used for their national implementations. Further details are available from Table 1; see also the *Sea Around Us* (www.seaaroundus.org), and Pauly and Zeller (2016b), Le Manach et al. (2016), Zeller et al. (2016), and Coulter et al. (2020).

Essentially, catch reconstructions consist of examining the annual marine fisheries catches reported by a given country (especially to the FAO) since 1950 and complementing them with time series of the estimated catch for fisheries components that were not considered in the official reports or are underreported in official data. These can include subsistence fisheries (see Zeller et al. 2015) or neglected artisanal fisheries (see Pauly and Charles 2015), catches by vessels operating illegally in a given EEZ (see Miller et al. 2016) or estimates of discarded fish (see Zeller et al. 2018) that are not included in the data submitted to and reported by the FAO. Thus, FAO data are actually landings data (Pauly et al. 2005; Pauly and Zeller 2016a, b) and do not account for discarded catch (Zeller et al. 2018). The definitions of the four fishing sectors we distinguish are available from the *Sea Around Us* website[1] (see also Pauly and Zeller 2016b and Zeller et al. 2016) and are summarized as follows:

[1] http://www.seaaroundus.org/catch-reconstruction-and-allocation-methods/#_Toc421534357

Table 1 Main features of the domestic fisheries of countries with coastlines along the Arabian Sea LME in the 2000–2015 time period, moving clock-wise from the Horn of Africa

Country	Main findings (sources)
Somalia (Puntland)	The fisheries along the north coast of Somalia are, since 2000, exclusively small-scale, and their catch is increasing (Cashion et al. 2018)
Djibouti	The domestic fisheries within the EEZ of Djibouti are mainly artisanal. Catches in Djibouti decreased in the mid-1990s due to civil war, but increased thereafter due to development initiatives during the 2000s. Between 2000 and 2015, Djibouti's fishing industry caught mostly Carangidae, Lethrinidae, *Scomberomorus* spp., *Epinephelus* spp. and Lutjanidae (Colléter et al. 2015)
Yemen (Gulf of Aden)	The Yemeni fishing industry in the Gulf of Aden is mostly artisanal, but industrial fishing, mainly shrimp trawling occurs. Fisheries are characterized by an important subsistence sector, whose catches have been increasing. Main taxa between 2000 and 2015 are *Thunnus albacares*, *T. tonggol*, *Euthynnus affinis*, *Scomberomorus commersoni* by large scombrids and shark and rays (Tesfamichael et al. 2012)
Oman (including Musandam)	Omani catches have been steadily increasing between 2000 and 2015, most of which were artisanal. Industrial trawl fishing existing until 2011, when it was banned by the government to reduce the pressure on fish stocks. Main taxa are *Sardinella longiceps*, Carangidae, *Thunnus albacares*, Clupeidae and *Lethrinus nebulosus* (Khalfallah et al. 2016)
UAE (Fujairah)	Fisheries in Fujairah are entirely artisanal and gradually have been gaining in importance since 2000. The main taxa for the 2000–2015 period were *Sardinella longiceps*, *Alectis ciliaris*, *Rastrelliger kanagurta*, Lethrinidae and *Sphyraena* spp. (Khalfallah et al. 2015)
Iran (Sistan and Baluchestan)	The Iranian marine fishery in 2000–2015 was mostly artisanal but some industrial fishing took place. Catches were relatively stable between 2000 and 2009. Starting in 2010, catches began increasing. The main taxa caught in Sistan and Baluchestan for the 2000–2015 time period were *Sardinella longiceps*, *Scomberomorus commerson*, *Scomberoides commersonnianus*, Elasmobranchii, *Caranx ignobilis* and *Carcharhinus sorrah* (Roshan Moniri et al. 2013)
Pakistan	Pakistani marine fisheries for the 2000–2015 time period are characterized by almost equivalent catch of the artisanal and industrial sectors and an important subsistence fishery. Main taxa are *Sardinella longiceps*, *Rastrelliger kanagurta*, Ariidae, Sciaenidae, and *Trichiurus lepturus* (Hornby et al. 2014)
India (Malabar Coast)	The industrial and artisanal sectors between 2000 and 2015 were equally important in India. The main taxa for this period are *Sardinella longiceps*, Sciaenidae, Carangidae, and Trichiuridae (Hornby et al. 2015)

Industrial sector: this consists of larger fishing vessels whose acquisition and deployment requires sizable investments and which operate either in their domestic waters, or in the EEZ of other countries, and/or beyond, i.e. in the high seas. The landings of industrial vessels are always sold, and thus industrial fisheries are often called 'commercial' fisheries; however, this is a misnomer, because artisanal fisheries (see below) also sell (most of) the catch they land.

By definition, motorized vessels deploying fishing gear that are towed or dragged on the bottom of the sea, or higher in the water column (typically bottom- and midwater trawls), are considered industrial, whatever their size (Martín 2012); this includes the 'baby trawlers' operating in the Philippines (Palomares and Pauly 2014). Also, all fleets that may be deemed 'artisanal' by national definitions, but actually fish in the EEZ waters of neighbouring countries (i.e. long distance fishing) are here deemed industrial, i.e. large-scale commercial operations (which they are). This includes, for example, the large pirogues equipped for long-range operations in Senegal and which may reach deep into Guinea-Bissau (Belhabib et al. 2014).

Artisanal sector: this consists of operations involving the deployment of small-scale gears such as hand lines, gillnets, etc. and/or the use of traps or weirs to catch fish and invertebrates which are then sold (except for a small fraction which may be consumed directly by, or given away to the crew). The *Sea Around Us* definition of artisanal fisheries also pertains to adjacency: they are assumed to limit themselves to domestic operation (i.e. within their country's EEZ). Within their EEZ, they are further constrained to shelves (i.e. to depths not deeper of 200 m) or a coastal band of 50 km from the coast, whichever comes first. This is what we call the Inshore Fishing Area (IFA; Chuenpagdee et al. 2006). The definition of the IFA includes that the coastline is populated; thus unpopulated islands have no IFA, but they can be visited by artisanal fishers from within the same EEZ, while unpopulated islands surrounded by the own EEZ cannot be visited by artisanal fisheries, which are limited to the own EEZ (see above). The artisanal sector is defined as small-scale and commercial.

Subsistence sector: this consists of fishing by persons (often women and children) who collect small fish and invertebrates for consumption by themselves and their families, usually in shallow waters. The *Sea Around Us* also considers as 'subsistence' the fraction of artisanal catches that is given to crew for their and their families' (see, e.g. Tesfamichael et al. 2012). Subsistence fisheries are here defined as non-commercial and small-scale.

Recreational sector: this consists of operations usually performed by private individuals fishing for pleasure or by commercial operators providing operational platforms for groups of individuals fishing for pleasure. While the sale of fish caught recreationally is usually forbidden by the licensing authorities, a small fraction of recreational catches is in fact being sold, while the rest is consumed by the fishers, their friends and families (Cisneros-Montemayor and Sumaila 2010). Recreational fisheries are here defined as non-commercial and small-scale.

In addition to reconstructing the catches within the EEZ waters of each country (e.g. Somalia, Cashion et al. 2018; Oman, Khalfallah et al. 2016), we also reconstructed the worldwide catches of large pelagic taxa (mainly tuna, billfishes and sharks) by complementing the official reported data of all RFMOs (Regional Fisheries Management Organizations), which are taken in either high seas waters or within countries' EEZs (Coulter et al. 2020). We harmonized the various pelagic data with individual country-EEZ reconstructions to avoid double counting.

The time series of all reconstructed fisheries catches are spatially allocated to half degree latitude/longitude geographic grid cells (Zeller et al. 2016), using a series of rules that incorporate both biological probability distributions of occurrence of each taxon (Palomares et al. 2016) and foreign fishing access data (Zeller et al. 2016). There are 180,000 half-degree ocean cells in the world, of which 1380 are in the Arabian Sea LME, exclusive of the Persian Gulf, which consists of 129 cells.

The catch reconstructions for the various EEZs in the Arabian Sea LME (Table 1) plus the Arabian Sea LME portion of the global reconstruction of large pelagic taxa (Coulter et al. 2020) derived catch data for 269 species (out of a total of 318 taxa) that are either reported as caught or which showed up as unreported catches in catch reconstructions. For each species, the mean trophic level of the catch was determined (Pauly et al. 1998; Kleisner et al. 2014), which were on trophic level data estimated from diet composition details in FishBase (www.fishbase.org) for fishes and SeaLifeBase (www.sealifebase.org) for non-fish marine life.

To assess if the Arabian Sea LME fisheries are fishing down the marine food webs, i.e. are increasingly exploiting species with decreasing trophic levels, we first used the Fishing in Balance index (FiB; Bhathal and Pauly 2008; Pauly and Palomares 2000, 2005) to verify if an offshore expansion of the fisheries is taking place. The FiB index is based on trophic levels and catches of all taxa in an ecosystem, along with the efficiency of energy transfer between trophic levels. Then we used the Regional Marine Trophic Index (RMTI; see Kleisner et al. 2014), which can correct for the effect of expansion. The RMTI is based on a reformulation of the FiB index, and decomposes trends in the mean trophic level of catches into inshore, mid-shore and offshore.

Furthermore, to assess the effects of climate change on the Arabian Sea fisheries, the preferred temperature (i.e. temperature preferendum or TP) by each species was estimated by overlapping the biological probability distributions for each species derived via FishBase and SeaLifeBase (Palomares et al. 2016; Zeller et al. 2016) with an atlas of mean sea surface temperatures (Belkin 2009). The TP of each species was used to estimate trends in the mean temperature of the catch (MTC) for the Arabian Sea, as suggested by Cheung et al. (2013).

3 Results and Discussion

Overall, the catches of the fisheries sectors of the Arabian Sea LME (excluding the Persian Gulf) increased over the 65 year period covered here, with total extractions reaching 187 Mt (Fig. 2). Of this, 44.4% were made by the industrial, 39.3% by the artisanal, and 16.2% by the subsistence fisheries (Fig. 2). Recreational fisheries accounted for only 0.005% of total catches and therefore were included in the subsistence sector for the present study. Small-scale fisheries, i.e. the artisanal and subsistence sectors, grew steadily from 1950 to 2014, reaching combined small-scale catch levels of 21.3 Mt in the 2010s. Industrial fisheries, on the other hand, initially increased near exponentially, peaking in 1997, then declining and stabilizing at around 2.3 Mt per year in the 2000s. These general trends are similar to those reported by Pauly and Zeller (2016b) for the global fisheries catches of all maritime countries of the world. Notably, however, the present study differs in the relative

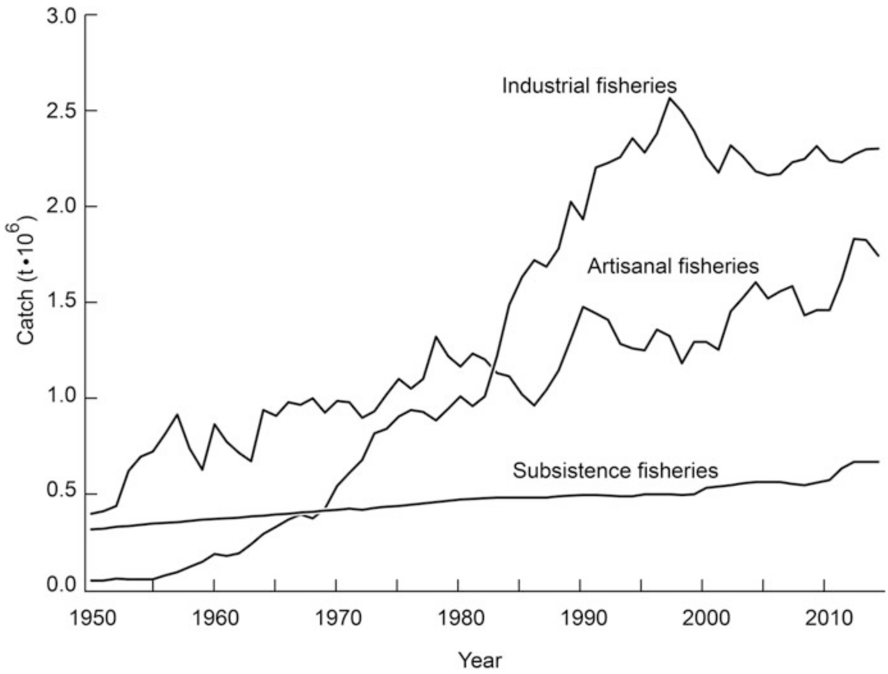

Fig. 2 Time series of reconstructed total catches by fisheries sectors in the Arabian Sea Large Marine Ecosystem (excluding the Persian Gulf). The small-scale subsistence (incorporating very minor recreational catches) and artisanal sectors grew steadily from 1950 to 2014, while industrial fisheries increased exponentially until the late 1990s, then declined and stabilized. These trends are similar to those of global fisheries (Pauly and Zeller 2016b), but the combined small-scale sectors provide more total catches than the industrial fisheries, which is specific to this LME

importance of small-scale versus large-scale (industrial) fisheries. While on a global basis, small-scale fisheries account for around 24% and industrial fisheries for 76% of catches (Pauly and Zeller 2016a, b), the fisheries in the Arabian Sea have a far higher prevalence of small-scale (~56%) compared to industrial fisheries catches (44%), making small-scale fisheries a far more important fisheries component in this region.

The geographical distribution of catches in the Arabian Sea LME (excluding the Persian Gulf; see Fig. 3) was dominated by the 56% of total catches caught in India’s EEZ off the Malabar Coast, followed by catches in Pakistan’s EEZ at 21%, Yemen at 5%, Somalia at 3.08%, Iran at 2%, and the United Arab Emirates and Djibouti together at 0.4%. The catches in high seas waters in Fig. 3, i.e. areas outside of any EEZ, contributed only 8.3% of the total catch, which is also similar to global fisheries (www.seaaroundus.org/data/#/global?). Note that the catches in each of these EEZs do include catches taken by foreign fleets fishing in each of these EEZs, which can be legal or illegal (the latter applies when the foreign fleet operates within an EEZ without an explicit permission).

Considering who (i.e., which flag-states) fish in the Arabian Sea LME waters (either within EEZs or in High Seas waters), we find that, in 2014, India (48%), Pakistan (16%)

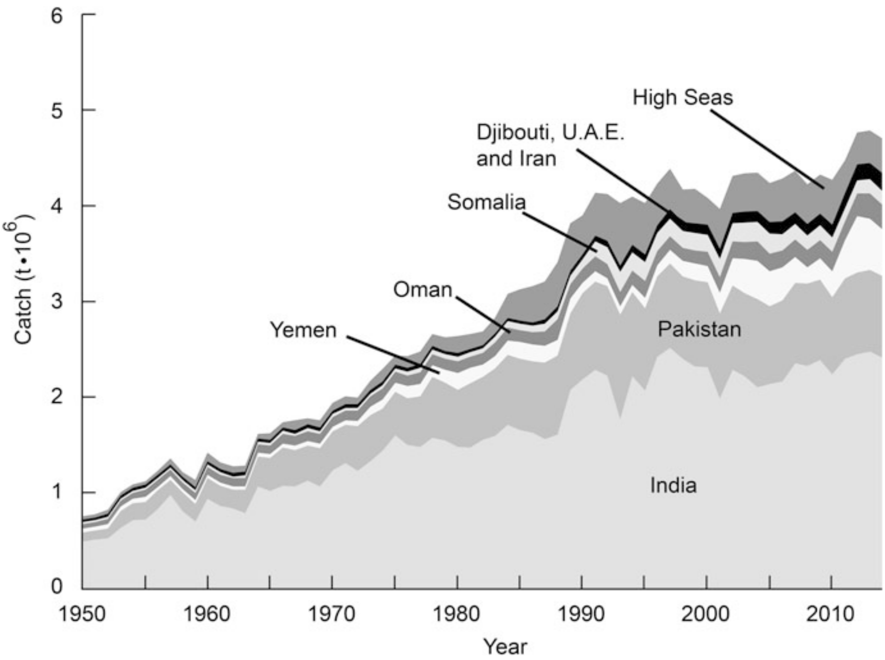

Fig. 3 Reconstructed catches in the Arabian Sea Large Marine Ecosystem (excluding the Persian Gulf), by EEZ within which these catches were taken, and for the High Sea waters of this LME. As expected, catches in India's Malabar (West) Coast dominate, followed by those in Pakistani and Yemeni waters (see also www.seaaroundus.org). Note that our spatial assignments include catches taken by foreign vessels within each country's waters

and Iran (11%) are the major fishing countries, followed by Yemen (9%) and Oman (5%, Fig. 3). Distant water fleet fishing (i.e., countries with no EEZs in these waters) in the waters of the Arabian Sea LME accounted for around 3% of total catches from these waters. Among the distant water fleet countries, China dominates in recent years (China is now the largest distant water fishing country in the world, Pauly et al. 2014), followed by a category called 'unknown fishing country', which reflects the poor quality of data reporting with regard to flag states for many reported data sets and reconstruction data sources. South Korea, Thailand and Egypt are also important fishing countries in these waters in recent years, while in earlier periods Taiwan, Russia, and Ukraine were also prominent (see www.seaaroundus.org).

The contribution of the 318 taxa caught in the Arabian Sea LME (excluding the Persian Gulf; see Fig. 4) is dominated by bony fishes making up 65% of the total extractions, much more than crabs, lobsters and shrimps at 8%, sharks and rays at 5%, cephalopod molluscs (squids and cuttlefishes) at 2.3%, bivalve and gastropod molluscs at 1.2% and jellyfishes at 0.6%. The 'miscellaneous' category, making up 18.0% of the total catch, includes unsorted juvenile and other small fish and various invertebrates. The highest catch of bony fish is of the Indian oil sardine (*Sardinella*

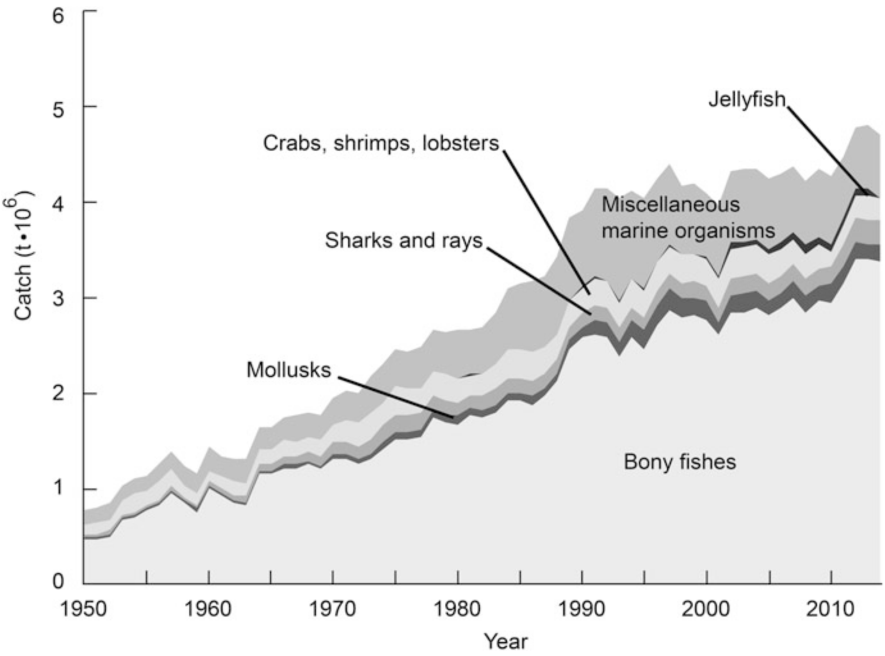

Fig. 4 Taxonomic composition of the reconstructed catch from the Arabian Sea (excluding the Persian Gulf). Note the dominance of bony fish, followed at a distance by crustaceans, sharks & rays, and mollusks (mainly cephalopods such a squids and cuttlefish, but also gastropods and bivalves). The 'miscellaneous' category includes unsorted juvenile and other small fish and various invertebrates

longiceps), which makes up 9.7% of the catch, while Bombay duck (*Harpadon nehereus*), sciaenids and carangids are also major contributors.

Indian oil sardine, Indian mackerel (*Rastrelliger kanagurta*) and yellowfin tuna (*Thunnus albacares*) were recently assessed in a workshop held in Kochi, India (see Palomares and Froese 2017), given the importance of these pelagic species in the fisheries of the Arabian Sea. Results of these preliminary analyses indicate that, at least for the three stocks mentioned here, continued fishing at high levels of fishing effort is driving catchable biomass below their sustainability levels (see Ganga et al. 2017; Sathianandan et al. 2017; Vivekanandan et al. 2017).

Over the last 20+ years, an increasing number of stocks in the Arabian Sea LME can be considered overexploited, or to a smaller extent collapsed (Fig. 5). The majority of stocks seems to be fully exploited, with few if any stocks with potential for fisheries growth. Importantly, the trend over time is one of increasingly more overexploited, collapsed and fully exploited stocks, while stock rebuilding seems to be poor (Fig. 5).

The spatial expansion of fisheries in the Arabian Sea LME (including those of the Gulf) is evidenced through the increasing FiB Index and the splitting and declining RMTI (Fig. 6). Catches over time in the fisheries in this ecosystem have increasingly

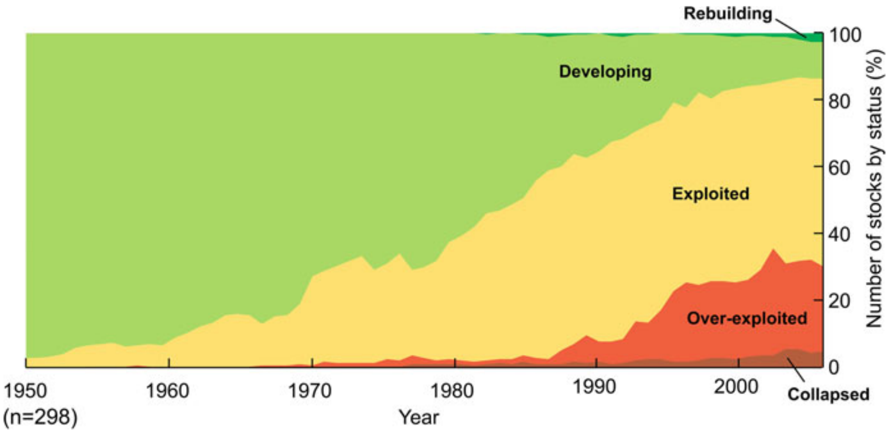

Fig. 5 Stock status plot (SSP) for the fisheries catches from the Arabian Sea LME (excluding the Persian Gulf) as defined in Pauly et al. (2008) and Kleisner et al. (2013), showing the number of stocks by status (in %), which illustrates the typically increasing number of stocks that are considered overfished or collapsed. Note the very small, but gradually increasing number of 'rebuilding' stocks in the upper right corner of the graph

consisted of taxa lower in the food web, with mean trophic level declining consistently in all three 'zones' (inshore to offshore) as estimated by the RMTI (Fig. 6). Declining mean trophic levels generally imply that increasingly smaller organisms contribute to the catches. This confirms that the 'fishing down the food web' phenomenon of Pauly et al. (1998) and Pauly and Palomares (2005) is already evident in the Arabian Sea. Fishing down and coastal spatial expansion have previously also been demonstrated for Indian waters (Bhathal and Pauly 2008).

Finally, the impact of climate change on the fisheries of the Arabian Sea LME (excluding the Persian Gulf; see Fig. 7) using the TPs of 269 species shows an increase in MTC from 1960 to 1990s, followed by stagnating values. The stagnation in MTC after 1990 is likely due to a lower contribution to the catch of subtropical (lower TP) species with respect to that of tropical (higher TP) species. These results resemble those of Cheung et al. (2013) and Liang et al. (2018) for tropical LMEs: the MTC of the fisheries of the Arabian Sea LME runs at first (1960–1990) more or less parallel to the trend in SST (because of the relative decline of subtropical species), but the MTC then stagnates, once only tropical species dominate the catches. In general, an increasing MTC from fisheries in the same ecosystem over time is a clear indicator of ocean warming-induced changes in the spatial distribution of organisms being reflected in the fisheries catches taken by the fleets in this area.

As we have shown here, the majority of fishing, in this LME and thus the majority of catches occur within national EEZ waters. This ensures that national governments can control and manage the exploitation of marine resources, allowing for potentially better control compared to most fishing in the high seas waters. Some progressive and forward looking actions seem to have been taken on some issues plaguing fisheries, such as the 2011 trawl ban in Oman (Khalfallah et al. 2016) and the ban

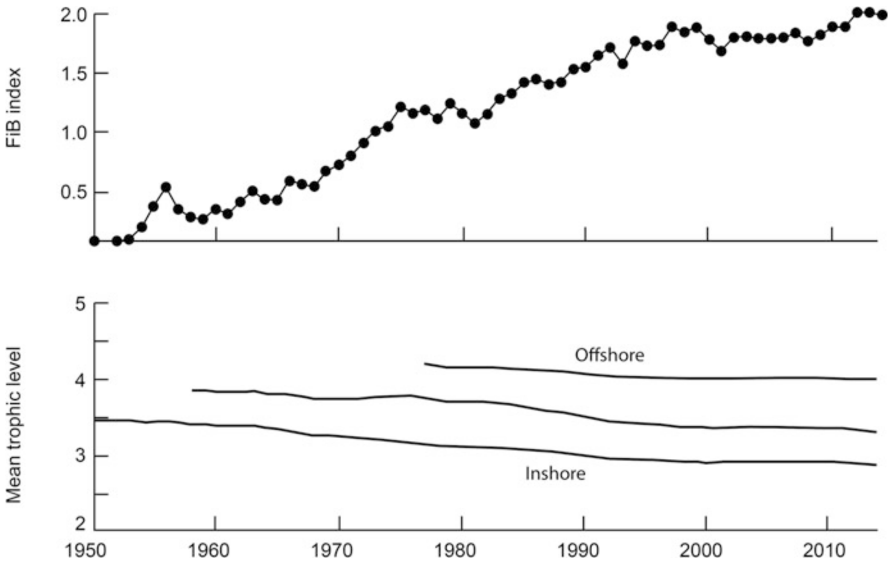

Fig. 6 The steady spatial expansion of fisheries in the Arabian Sea LME (including those of the Gulf) documented through the FiB index (top panel; see also Bhathal and Pauly 2008) and through the Region-based Marine Trophic Index, or RMTI (bottom panel; see also Liang et al. (2017) and Kleisner et al. 2014). The RMTI, using a reformulation of the FiB index uses the trophic levels and catches of all taxa in an ecosystem, along with the efficiency of transfer between trophic levels to decompose trends in the mean trophic level of catches into inshore, mid-shore and offshore. Here, the RMTI shows that the fisheries of the Arabian Sea LME, like most fisheries in the world, increasingly rely on catches lower in the food web (generally smaller organisms), i.e. that they are 'fishing down the food web' (Pauly et al. 1998)

on trawl and driftnets in the UAE (Al-Abdulrazzak 2013). However, in both countries, as elsewhere in the region, poor fisheries regulations and often lack of control and enforcement continue. Other countries struggle with massive overcapacity, often enhanced by poor policy choices made in the past, especially with regard to ill-advised preferences given to industrial fisheries development at the expense of small-scale, food-security and livelihood fisheries (Bhathal and Pauly 2008; Hornby et al. 2015). On the positive side, Somalia, gradually emerging from decades of civil war and failed state status, with the associated national policy, management and enforcement vacuum which contributed to the rise of piracy, is increasingly trying to develop coherent fisheries policies that balance national food security needs with the potential for generating foreign exchange earnings via licensing foreign access to national marine resources (Cashion et al. 2018). Thus, a wide variety of management approaches (and utter absence thereof), and associated successes and failures in fisheries policy and management exist in this region. All countries would do well to look beyond their borders, and try and learn more from their regional and global neighbours as to which direction their national fisheries policies ought to take. Serious considerations ought to be given by all countries (and not only in this region) that have not implemented such policies yet, to (1) reducing

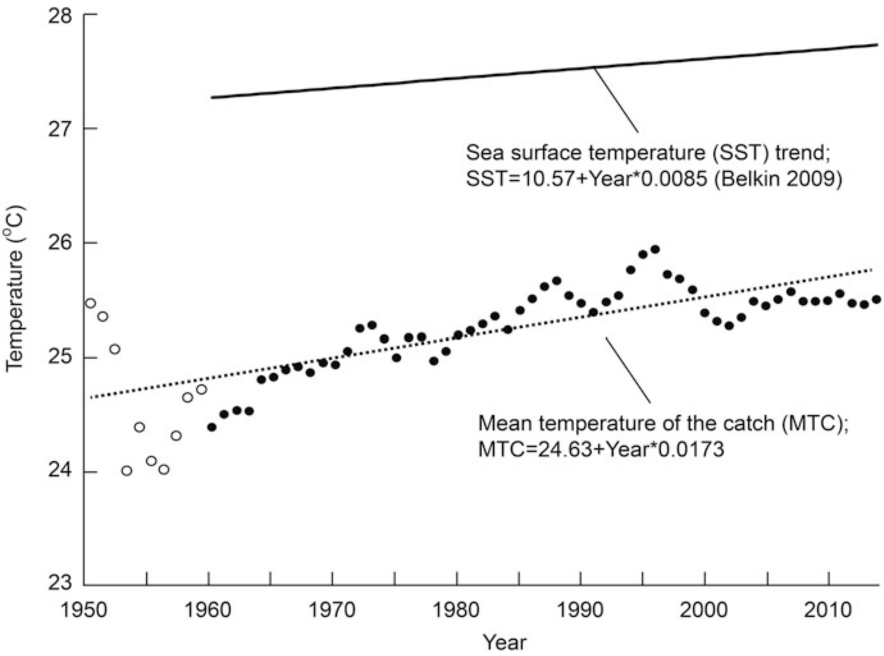

Fig. 7 The increasing 'Mean Temperature of the Catch' (MTC) from the Arabian Sea LME (excluding the Persian Gulf), based on the mean temperature preferenda (TP) of 269 exploited species, weighted by their catch. The observed increase of the MTC, from 1960 to the 1990s, followed by stagnating values is likely due to a lower contribution to the catches of subtropical (lower TP) species vis-à-vis tropical (high TP) species, as also shown in Cheung et al. (2013) for tropical LMEs. This is different for SSTs (solid line) which show a linear increase in that ecosystem (Belkin 2009)

and tightly controlling industrial fishing, both domestic and foreign, with particular emphasis on reducing or banning bottom trawl fisheries which are known to be highly wasteful (Cashion et al. 2017) and damaging to ecosystem structures that underlie most stock production (Watling and Norse 1998), and (2) assisting and empowering well-managed small-scale fisheries for both national consumption (food- and nutritional security, Golden et al. 2016) and carefully controlled and monitored export fisheries. This is the direction in which all fisheries around the world need to be heading (Zeller and Pauly 2019), to ensure the survival of a blue economy (Pauly 2018).

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References

Al-Abdulrazzak D (2013) Estimating total fish extractions in the United Arab Emirates: 1950-2010. pp. 53–59 *In:* Al-Abdulrazzak D and Pauly D (eds.), From dhows to trawlers: a recent history of fisheries in the Gulf countries, 1950 to 2010. Fisheries Centre Research Reports 21(2), Fisheries Centre, University of British Columbia, Vancouver

Al-Abdulrazzak D, Zeller D, Belhabib D, Tesfamichael D, Pauly D (2015) Total marine fisheries catches in the Persian/Arabian Gulf from 1950 to 2010. Reg Stud Mar Sci 2:28–34

Banse K (1968) Hydrography of the Arabian Sea Shelf of India and Pakistan and effects on demersal fishes. Deep-Sea Res 15:45–79

Belhabib D, Koutob V, Sall A, Lam V, Pauly D (2014) Fisheries catch misreporting and its implications: the case of Senegal. Fish Res 151:1–11

Belkin IM (2009) Rapid warming of large marine ecosystems. Prog Oceanogr 81:207–213

Belkin IM, Cornillon PC, Sherman K (2008) Fronts in large marine ecosystems. Prog Oceanogr 81:223–236

Bhathal B, Pauly D (2008) 'Fishing down marine food webs' and spatial expansion of coastal fisheries in India, 1950-2000. Fish Res 91:26–34

Cashion T, Le Manach F, Zeller D, Pauly D (2017) Most fish destined for fishmeal production are food-grade fish. Fish Fish 18(5):837–844. https://doi.org/10.1111/faf.12209

Cashion T, Glaser SM, Persson L, Roberts PM, Zeller D (2018) Fisheries in Somali waters: reconstruction of domestic and foreign catches for 1950–2015. Mar Policy 87:275–283

Cheung WWL, Watson R, Pauly D (2013) Signature of ocean warming in global fisheries catch. Nature 497:365–368

Chuenpagdee R, Liguori L, Palomares MLD, Pauly D (2006) Bottom-up, global estimates of small-scale marine fisheries catches. Fisheries Centre Research Reports 14(8), University of British Columbia, Vancouver, 112p

Cisneros-Montemayor AM, Sumaila UR (2010) A global estimate of benefits from ecosystem-based marine recreation: potential impacts and implications for management. J Bioecon 12:245–268

Colléter M, Darar Djibril A, Hosch G, Labrosse P, Yvergniaux Y, Le Manach F, Pauly D (2015) Le développement soutenu des pêcheries artisanales: reconstruction des captures marines à Djibouti de 1950 à 2010 [with an extended English abstract]. In: Le Manach F, Pauly D (eds) Fisheries catch reconstructions in the Western Indian Ocean, 1950–2010. Fisheries Centre Research Reports 23(2), pp 13–25

Coulter A, Cashion T, Cisneros-Montemayor AM, Popov S, Tsui G, Sy E, Le Manach F, Palomares MLD, Zeller D, Pauly D (2020) Using harmonized historical catch data to infer the expansion of global tuna fisheries. Fish Res 221:105379

Ganga U, Rajesh KM, Vivekanand B (2017) CMSY for stock assessment of the Indian oil sardine. In: Palomares MLD, Froese R (eds) Training on the use of CMSY for the assessment of fish stocks in data-poor environments, pp 27–30. Workshop report submitted to the GIZ by Quantitative Aquatics, Inc. Q-quatics Technical Report No. 2, 58p

Golden CD, Allison E, Cheung WWL, Dey M, Halpern B, McCauley DJ, Smith M, Vaitla B, Zeller D, Myers SS (2016) Nutrition: fall in fish catch threatens human health. Nature 534:317–320

Heileman S, Eghtesadi P, Mistafa N (2008) Arabian Sea LME. In: Sherman K, Hempel G (eds) The UNEP large marine ecosystem report: a perspective on changing conditions in LMEs of the World's Regional Seas. Nairobi, UNEP Regional Seas Reports and Studies No. 182, pp 221–223

Hornby C, Moazzam M, Zylich K, Zeller D (2014) Reconstruction of Pakistan's marine fisheries catches (1950–2010). Fisheries Centre Working Paper #2014-28. University of British Columbia, Vancouver, 54p

Hornby C, Bhathal B, Pauly D, Zeller D (2015) Reconstruction of India's marine fish catch from 1950–2010. Fisheries Centre Working Paper #2015-77. University of British Columbia, Vancouver, 42p
Khalfallah M, Zeller D, Pauly D (2015) Reconstruction of marine fisheries catches for Fujairah (UAE) (1950–2010). Fisheries Centre Working Paper #2015-57. University of British Columbia, Vancouver, 12p
Khalfallah M, Zylich K, Zeller D, Pauly D (2016) Reconstruction of domestic marine fisheries catches for Oman (1950-2015). Front Mar Sci 3:152. https://doi.org/10.3389/fmars.2016.00152
Kleisner K, Zeller D, Froese R, Pauly D (2013) Using global catch data for inferences on the world's marine fisheries. Fish Fish 14(3):293–311
Kleisner K, Mansour H, Pauly D (2014) Region-based MTI: resolving geographic expansion in the Marine Trophic Index. Mar Ecol Prog Ser 512:185–199
Le Manach F, Chavance P, Cisneros-Montemayor AM, Lindop A, Padilla A, Schiller L, Zeller D, Pauly D (2016) Global catches of large pelagic fishes, with emphasis on the High Seas. In: Pauly D, Zeller D (eds) Global Atlas of Marine Fisheries: a critical appraisal of catches and ecosystem impacts. Island Press, Washington, DC, pp 34–45
Liang C, Pauly D (2017) Fisheries impacts on China's coastal ecosystems: unmasking a pervasive 'Fishing Down' effect. PloS ONE 12(3):e0173296. https://doi.org/10.1371/journal.pone.0173296
Liang C, Xian W, Pauly D (2018) Impacts of ocean warming on China's fisheries catch: application of the 'Mean Temperature of the Catch'. Front Mar Sci 5:26. https://doi.org/10.3389/fmars.2018.00026
Martín JI (2012) The small-scale coastal fleet in the reform of the common fisheries policy. Directorate-general for internal policies of the Union. Policy Department B: Structural and Cohesion Policies. European Parliament. IP/B/PECH/NT/2012_08, Brussels. www.europarl.europa.eu/studies, 44p
Miller D, Sumaila UR, Copeland D, Zeller D, Soyer B, Nikaki T, Leloudas G, Fjellberg ST, Singleton R, Pauly D (2016) Cutting a lifeline to maritime crime: marine insurance and IUU fishing. Front Ecol Environ 14(7):357–362
Palomares MLD, Froese R (eds) (2017) Training on the use of CMSY for the assessment of fish stocks in data-poor environments. Workshop report submitted to the GIZ by Quantitative Aquatics, Inc. Q-quatics Technical Report No. 2, 58 p
Palomares MLD and Pauly D (2014) Reconstructed marine fisheries catches of the Philippines, 1950-2010. pp. 137–146 In: Palomares MLD and Pauly D (eds.), Philippine marine fisheries catches: a bottom-up reconstruction, 1950 to 2010. Fisheries Centre Research Reports 22(1), University of British Columbia, Vancouver
Palomares MLD, Cheung WWL, Lam WWL, Pauly D (2016) The distribution of exploited marine biodiversity. In: Pauly D, Zeller D (eds) Global Atlas of Marine Fisheries: ecosystem impacts and analysis. Island Press, Washington, DC, pp 46–58
Pauly D (2018) A vision for marine fisheries in a global blue economy. Mar Policy 87:371–374. https://doi.org/10.1016/j.marpol.2017.11.010
Pauly D, Charles T (2015) Counting on small-scale fisheries. Science 347:242–243
Pauly D, Palomares MLD (2000) Approaches to dealing with three sources of bias when studying the fishing down marine food webs phenomenon. In: Durand F (ed) Fishing down the Mediterranean food webs? Proceedings of a CIESM workshop, Kerkyra. CIESM Workshop Series No 12, pp 61–66
Pauly D, Palomares MLD (2005) Fishing down marine food web: it is far more pervasive than we thought. Bull Mar Sci 76(2):197–211
Pauly D, Zeller D (eds) (2016a) Global Atlas of Marine Fisheries: a critical appraisal of catches and ecosystem impacts. Island Press, Washington, DC, xii +497 p
Pauly D, Zeller D (2016b) Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. Nat Commun 7:10244, doi:https://doi.org/10.1038/ncomms10244, 9p

Pauly D, Christensen V, Dalsgaard J, Froese R, Torres FC (1998) Fishing down marine food webs. Science 279:860–863

Pauly D, Watson R, Alder J (2005) Global trends in world fisheries: impacts on marine ecosystems and food security. Philos Trans R Soc Lond B Biol Sci 360(1453):5–12

Pauly D, Alder J, Booth S, Cheung WWL, Christensen V, Close C, Sumaila UR, Swartz W, Tavakolie A, Watson R, Wood L, Zeller D (2008) Fisheries in large marine ecosystems: descriptions and diagnoses. pp 23–40. In: Sherman K, Hempel G (eds) The UNEP large marine ecosystem report: a perspective on changing conditions in LMEs of the World's Regional Seas. Nairobi, Kenya, UNEP Regional Seas Reports and Studies No. 182

Pauly D, Belhabib D, Blomeyer R, Cheung WWL, Cisneros-Montemayor A, Copeland D, Harper S, Lam V, Mai Y, Le Manach F, Österblom H, Mok KM, van der Meer L, Sanz A, Shon S, Sumaila UR, Swartz W, Watson R, Zhai Y, Zeller D (2014) China's distant water fisheries in the 21st century. Fish Fish 15:474–488

Roshan Moniri N, Roshan Moniri N, Zeller D, Al-Abdulrazzak D, Zylich K and Belhabib D (2013) Fisheries catch reconstruction for Iran, 1950-2010. pp. 9–18 In Al-Abdulrazzak D and Pauly D (eds.), From dhows to trawlers: a recent history of fisheries in the Gulf countries, 1950–2010. Fisheries Centre Research Reports 21(2), Fisheries Centre, University of British Columbia, Vancouver

Sathianandan TV, Kuriakose S, Mini KG, Varghese E (2017) Use of CMSY and BSM for the assessment of Indian mackerel, *Rastrelliger kanagurta* along the South Kerala coast. In: Palomares MLD, Froese R (eds) Training on the use of CMSY for the assessment of fish stocks in data-poor environments, pp 24–26. Workshop report submitted to the GIZ by Quantitative Aquatics, Inc. Q-quatics Technical Report No. 2. 58 p

Sherman K, Hempel G (eds) (2008) The UNEP large marine ecosystem report: a perspective on changing conditions in LMEs of the world's Regional Seas. UNEP Regional Seas Reports and Studies No. 182, United Nations Environment Programme, Nairobi, 852 p

Tesfamichael D, Rossing P and Saeed H (2012) Reconstruction of Yemen's catches in the Gulf of Aden, 1950-2010. pp. 135–152 *In:* Tesfamichael D and Pauly D (eds.), Catch reconstruction for the Red Sea large marine ecosystem by countries (1950–2010). Fisheries Centre Research Reports 20(1), Fisheries Centre, University of British Columbia, Vancouver

Vivekanandan E, Jayasankar J, Pillai SL (2017) CMSY estimate for yellow fin tuna of Indian Ocean. In: Palomares MLD, Froese R (eds) Training on the use of CMSY for the assessment of fish stocks in data-poor environments, pp 39–42. Workshop report submitted to the GIZ by Quantitative Aquatics, Inc. Q-quatics Technical Report No. 2, 58 p

Wabnitz CC, Lam VWY, Reygondeau G, Teh L, Al-Abdulrazzak D, Khalfallah M, Pauly D, Palomares MLD, Zeller D, Cheung WWL (2018) Climate change impacts on marine biodiversity, fisheries and society in the Arabian Gulf. PLoS One, in review

Watling L, Norse EA (1998) Disturbance of the seabed by mobile fishing gear: a comparison to forest clearcutting. Conserv Biol 12(6):1180–1197

Zeller D, Pauly D (2019) Viewpoint: back to the future for fisheries, where will we choose to go? Glob Sustain 2, e11:1–8

Zeller D, Harper S, Zylich K, Pauly D (2015) Synthesis of under-reported small-scale fisheries catch in Pacific-island waters. Coral Reefs 34(1):25–39

Zeller D, Palomares MLD, Tavakolie A, Ang M, Belhabib D, Cheung WWL, Lam VWY, Sy E, Tsui G, Zylich K, Pauly D (2016) Still catching attention: Sea Around Us reconstructed global catch data, their spatial expression and public accessibility. Mar Policy 70:145–152

Zeller D, Cashion T, Palomares MLD, Pauly D (2018) Global marine fisheries discards: a synthesis of reconstructed data. Fish Fish 19:30–39. https://doi.org/10.1111/faf.12233