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## Abstract

The Red Sea, characterized by a number of unique oceanographic and biological features, is a hotspot for coral reef ecology. It also provided humans for millennia, from the earliest record of human consumption of seafood to its current role as an important fishing ground for the seven countries along its shores. Contemporary fisheries need monitoring and management, and catch data are crucial to both. However, reliable time-series of catch data are lacking for most Red Sea fisheries. Here, the catches of Red Sea fisheries are ‘reconstructed’ from 1950 to 2010 by country (i.e., Egypt, Sudan, Eritrea, Yemen, Saudi Arabia, Jordan and Israel) and sector (artisanal, subsistence, industrial and recreational), and in terms of their species composition. Historical documents, published and unpublished reports and other grey literature, databases, field surveys, anecdotal information, interviews, and information on processed seafood products were used as sources.

When reliable data were available for a number of years, they were used as anchor points, and missing years were interpolated, based on assumptions of continuity, and given the best knowledge of the fisheries available. The reconstructed catches (which also include discards) were compared to the statistics submitted by the above-mentioned countries to the Food and Agricultural Organization (FAO) of the United Nations. Overall, the total Red Sea catch was low (around 50,000 t·year<sup>-1</sup>) until 1960, increased to a peak (around 177,000 t) in 1993, and is declining since. Overall, it was 1.5 times higher than the catch officially submitted to FAO by the countries bordering the Red Sea. Artisanal fisheries generally contributed about half of the total Red Sea catch, while the composition of the catch was extremely varied, with no single species or even family dominating. In addition to the national catch reconstructions, the local (Arabic) names of common commercial fishes, an ecosystem model and a time series of the effort are also presented. The resulting catch trends provide crucial historical records and important guidance for the development of future fisheries management policies aiming at resource conservation and sustaining the livelihoods of the coastal communities. Extra material for this chapter is available from <http://extras.springer.com/>.

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## Keywords

Catch time series • Mis-reported catch • Catch composition • Ecosystem based management • Red Sea

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## Introduction

The Red Sea is an elongated narrow sea between Northeastern Africa and the Arabian Peninsula, ranging from 30°N to 12°30'N and from 32°E to 43°E with a straight length of about 2,000 km and an average width of 208 km (Fig. 1.1). The maximum width is 354 km in the southern part (Morcos 1970), and the total area is  $4.51 \times 10^5$  km<sup>2</sup>. The Red Sea is connected to the Indian Ocean in the south through the narrow strait of Bab al Mandab, the door of fortune. Bal al Mandab, which is only 29 km wide, has a sill 137 m below sea level, which limits the circulation of water between the Red Sea and the Gulf of Aden. The Red Sea is also connected to the Mediterranean Sea through the Suez Canal since its opening in 1869. The average depth of the Red Sea is 491 m, with a maximum of 2,850 m. In the north, the Red Sea is divided into the Gulfs of Suez and Aqaba. The Gulf of Suez

is generally wide, shallow and muddy, while the Gulf of Aqaba is narrow and deep.

## Geological Evolution

The Red Sea was formed by plate tectonics, i.e., by the African and Arabian plates drifting apart, and is part of a larger tear that includes the Dead Sea and the East African rift systems. Geologically, the Red Sea is a young ocean that is still growing or spreading (Braithwaite 1987). The zone was already structurally weak during the Pan-African orogeny 600 Ma. The separation of the Arabian and African plates is believed to have started in the Tertiary period, between the Eocene and Oligocene periods; it accelerated during the late Oligocene, with intense magmatic activity and the development of a continental rift (Makris and Rihm 1991). The Red



**Fig. 1.1** The Red Sea (17,640 km<sup>2</sup>) and the surrounding countries, including their Exclusive Economic Zones (EEZs) and shelf areas

Sea depression is believed to have been flooded by the Mediterranean as a result of extensive sinking in the early Miocene (Girdler and Southren 1987). Since its inception, the Red Sea went through a series of connections and disconnections with the Mediterranean in the North and the Indian Ocean in the south. At the end of Miocene, upheaval of land occurred and the Red Sea was disconnected from the Mediterranean to become a separated salty lake. At the beginning of the Pliocene, the Red Sea was reconnected with the Mediterranean, and for the first time, it was also connected with the Indian Ocean, but at the end of the Pliocene, the northern connection with the Mediterranean was closed off due to crustal plate movement. The connection with the Indian Ocean was closed off during the Pleistocene, when the Red Sea again became an isolated sea. At the end of the Pleistocene, a glacial period, its connection with the Indian Ocean was re-established, whereas the connection with the Mediterranean remained closed until it was artificially opened via the Suez Canal in 1869 (Goren 1986; Getahun 1998). The Red Sea being young and still expanding is used as a case study to understand and explain plate tectonics, mid ocean ridges and formation of oceans.

## Physical Oceanography

The Red Sea area is generally arid, rainfall is very sparse with annual average ranging from 1 to 180 mm (Edwards 1987). Evaporation, with an annual average of 2 m (Morcos 1970), largely exceeds precipitation, and the deficiency is made up by the flow of water from the Indian Ocean through Bab al Mandab. In winter, warmer and less saline water flows into the Red Sea in the surface layer, while cooler and saltier water flows into the Gulf of Aden in the lower layer. In summer, there are three layers of water flow in the strait. In addition to the two winter flows, warm water flows on the surface from the Red Sea to the Gulf of Aden (Smeed 2004). The exchange with the Gulf of Aden is a major driving mechanism of the Red Sea ecosystem functioning (Triantafyllou et al. 2014). Sea and air temperatures are high in the Red Sea with mean annual sea surface temperature of 28 °C. Additionally, the Red Sea is undergoing an intense and rapid increase in temperature, which is attributed to climate change. The average temperature for the period 1994–2007 was 0.7 °C higher than the period 1985–1993. The increase in 1994 was the strongest shift in the last 160 years (Raitso et al. 2011).

Another remarkable characteristic of the Red Sea is its high salinity, about 35 psu on average at the surface; readings as high as 40.5 psu are also reported. The high salinity of the Red Sea is due to the combination of its geological history and its location in dry and hot environment. Though originally the Red Sea depression was flooded with

Mediterranean water, it soon started to become more saline due to high evaporation. Later during the glacial period, the Red Sea was an isolated salty lake with salinity higher than the present by 10 psu. The highly saline water was diluted by water from Indian Ocean when the Red Sea was reconnected with the Indian Ocean (Thunell et al. 1988; Rohling 1994). However, it is still more saline than the Indian Ocean water due to high evaporation (Morcos 1970). The salinity in the Red Sea increases from south to north. In the south (12.5°N), through which water from the Indian Ocean flows to the Red Sea, the salinity is around 36.5 psu, similar to the Gulf of Aden. It increases to 38 psu at 17°N, 39 psu at 22°N and 40 psu at 26°N, the gulfs of Suez and Aqaba (Edwards 1987).

## Biological Oceanography and Origin of the Biota

The Red Sea is not very productive, mainly due to lack of nutrient-rich terrestrial run off; also, there is almost no upwelling to lift nutrient-rich deep water to the surface where photosynthesis can occur. Moreover, for most of the year, the vertical mixing of water is prevented by a permanent thermocline as the temperature of the sub-surface water is always lower than the warm surface temperature. The thermocline is deeper in winter than summer (Edwards 1987). In the northern part, the deep waters are renewed by cold dense water from the surface which is cooled by cold winds (Sofianos and Johns 2015). The deep waters have higher nutrient contents causing the flourishing of green algae especially in the Gulf of Aqaba. Generally, the southern part of the Red Sea is more productive than the northern part due to the flow of nutrient rich water from the Indian Ocean, the main nutrient input, and the re-suspension of nutrients from the bottom sediments by turbulent mixing over shelf areas (Sheppard et al. 1992). The average primary productivity for the Red Sea large marine ecosystem (LME) based on SeaWiFS database was calculated to be 150–300 gC·m<sup>-2</sup>·year<sup>-1</sup>, which is considered moderately productive at a global scale (McGinley 2008). The shallow Gulf of Suez is also productive and supports many exploited fish populations. The Red Sea receive about 6 t of dust per year (Jish Prakash et al. 2015); the dust particles bring nutrients to the Red Sea; however, this contribution has never been quantified.

The connections of the Red Sea with the Mediterranean in the north and the Indian Ocean in the south account for the species that colonized it at different times. Though the Red Sea was first populated by Mediterranean species, its current biota resembles that of the Indian Ocean. When the Red Sea was disconnected from Mediterranean and for the first time connected with the Indian Ocean in the beginning of the Pliocene period (about 5–6 million years ago), it was populated by Indian Ocean fauna. Later during the glacial period

of the Pleistocene, the level of the world's oceans was low. The Red Sea was isolated with high level of salinity (about 50 psu at the surface) and low temperature (about 2 °C lower than the present) (Thunell et al. 1988). This resulted in the extinction of many species. Later, when the Red Sea was reconnected with the Indian Ocean at the end of the glacial period, 10,000–12,000 years ago, an opportunity was created for Indian Ocean species to re-populate it (Goren 1986). After the opening of the Suez Canal in 1869, organisms migrated from the Red Sea to the Mediterranean Sea, less in the other direction. These 'Lessepsian migrations' (Por 2012) are now becoming more frequent, due to rapid warming of the Eastern Mediterranean (Keskin and Pauly 2014).

As a result of its connection to the speciose Indo-Pacific fauna, the Red Sea currently has very high fish diversity, with more than 1,400 species of fishes reported in FishBase ([www.fishbase.org](http://www.fishbase.org)). It is also characterized by high degree of endemism, due to the closures alluded to above, with estimates of endemic fish species reaching 10–17 % (Ormond and Edwards 1987). Because the Red Sea has very low nutrient input, as explained above, species that can survive its extreme environments have very good chance to dominate, as there are fewer competitors. One example is the phytoplankton *Trichodesmium erythraeum*, a blue-green alga (cyanobacterium) that can overcome nitrate depletion by fixing atmospheric nitrogen dissolved in the water. In calm waters, its filaments float to the sea surface of the Red Sea and form a rather reddish scum, the likely origin of the name 'Red Sea' (and incidentally, of Eritrea's as well).

On the shores of coastal lagoons and sheltered bays mangroves are common. The most common species is *Avicennia marina*. *Bruguiera gymnorhiza* and *Ceriops tagal* also occur, though they are less common. The shallow waters of the lagoons and bays are home to seagrass beds. About 500 species of algae are reported from the Red Sea. Most algae in the north and central part are macroscopic, non-calcareous, brown, green and red algae. In the south, large brown algae such as *Sargassum* dominate (Walker 1987).

Five sea turtle species are reported from the Red Sea: hawksbill, green, olive ridley, loggerhead and leatherback. Hawksbill and green turtles are the most common, and are reported to nest along Red Sea beaches (Frazier et al. 1987). There is no active hunting for sea turtles in the Red Sea at the moment, but they are accidentally caught in fishing nets. The rich seagrass beds support dugongs, which are reported from Gulf of Suez in the north to Eritrea's Dahlak Archipelago in the south (Preen 1989). There used to be active fishing for turtles and dugongs. The reports of cetaceans from the Red Sea are sparse. Seven species of dolphins are commonly reported, as well as occasional spotting of killer whale and false killer whale. Frazier et al. (1987) suggested that the narrow strait of Bab al Mandab and the low productivity in the Red Sea as reasons for the scarcity of cetaceans. As far as seabirds are concerned, the enclosed nature of the Red Sea

acts as a barrier for pelagic fishes on which many seabirds feed. As a result pelagic seabirds, such as shearwaters and petrels, are poorly represented. Because of its elongated shape, the Red Sea has high coast to sea area ratio and its seabird fauna is dominated by coastal species (Evans 1987).

## Human Settlements

According to archeological evidence, human settlement on the Red Sea coast started millennia ago (Horton 1987) and the Red Sea has the oldest records of early Middle Stone Age artefacts (about 125 kyr ago) of human use of marine resources, in the form of giant clam and other shell middens (Walter et al. 2000). The Red Sea was also used as an important trade route between the Indian Ocean and the Mediterranean. However, in contrast with the rest of the world, where most of the population lives in a narrow strip of land along the coast (Edgren 1993), the population density on the Red Sea coast is still very low, except for very few major ports and cities. This is mainly due to the arid and hot climate, which resulted in most of the settlements being farther inland, in milder climate and where freshwater is less scarce. Until recently, this greatly limited the degree of coastal shoreline alteration, pollution and resource extraction. Thus, many Red Sea communities still depend on harvesting marine resources for subsistence using traditional methods of shell collection and fishing (Fig. 1.2).

However, in the last few decades, the wider availability of technology coupled with cheap oil, at least for the oil producing countries, is changing the demography of the Red Sea coast. The major port cities are metropolitan hubs, with diverse economic activities. For some countries, e.g., Saudi Arabia, fishing has become less important compared to other economic activities, resulting in the importation of foreign workers to do the fishing activities as most Saudis left the trade (see the Saudi Arabia chapter). Egypt has a strong recreational and tourism industry, and its coast is quite populated, creating pressure on the coastal ecosystems. Air conditioners and desalination plants are making life easier. A typical example is the Saudi Arabia coast where vibrant cities, such as Jeddah, have grown fast and new cities (e.g., Yanbu) are developing. In such cities, coastal reclamation and dredging are becoming common for residential, commercial and industrial purposes. Pollution is prevalent around urban areas and ports, and lack of sewage treatment is a serious problem throughout the Red Sea, as is the pollution from oil refineries. Overall the impact of human activities is growing (Frihy et al. 1996).

## Research Expeditions

One of the earliest scientific expeditions to the Red Sea is the Danish *Arabia Felix* of 1761–1767, which spent October



**Fig. 1.2** Fishing boats in the Red Sea; (left): *huris* in Eritrea (Photo: Steffan Howe); (right): *sambuk* in Saudi Arabia (Photo: Julia Spaet)

1762–August 1763 in the Red Sea area. It included the Swedish naturalist Peter Forsskål, a student of Linnaeus, who made an extensive collection of plants and animals, and particularly fish. His report was published posthumously by Carsten Niebuhr, the sole survivor (Forsskål 1775). There were many fragmented accounts of expeditions, most of them unsuccessful, to the Red Sea in the eighteenth and nineteenth centuries. One important and outstanding work in describing the Red Sea ecosystem and its organisms is that of Carl Benjamin Klunzinger, a German medical doctor who worked as a quarantine inspector in the Egyptian Red Sea port of Quseir from 1863 to 1869 and 1872 to 1875. His descriptions include coral fauna, fish, crustaceans, hemichordates and also meteorological (Klunzinger 1870, 1872), and cultural observations (Klunzinger 1878). An Austrian research vessel, the *Pola*, conducted an expedition in 1895–1896 to the northern Red Sea (Luksch 1898) and 1897–1898 to the south (Luksch 1900), including the first oceanographic studies and sampling of deep sea life down to 2,000 m (Head 1987a). The specimens from the expedition are kept in the Natural History Museum in Vienna (Stagl et al. 1996).

More recent expeditions include the *John Murray* expedition carried out using the Egyptian research vessel *Mabahiss* 1933–1934 (Rice 1986; Tesfamichael 2005), which collected oceanographic and biological samples throughout the Red Sea and the Arabian Sea (Norman 1939). From 1959 to 1964, the International Indian Ocean Expedition brought some vessels to sample the Red Sea, whose oceanography was compiled by Morcos (1970). An Israeli expedition to the southern Red Sea in 1962 and 1965 (Ben-Tuvia 1968), and the Israeli Marine Biological Station at Eilat, which was opened in 1968, also contributed to the knowledge of the Red Sea. At present, a lot of initiatives are taken by the countries bordering the Red Sea and new information is collected.

## Coral Reef Ecosystems

The Red Sea is one of the hotspots for coral reef ecology in the world (Roberts et al. 2002). Although it covers only 0.12 % of the global ocean, it accounts for 6.2 % of global coral reefs (Wilkinson 2008) (Fig. 1.3). In coral bio-geography, the Red Sea is considered part of the Indo-Pacific region and contains the highest diversity of reef communities outside of the Southeast Asian ‘coral triangle’ (DeVantier et al. 2000). There are 333 reported coral species (Dubinsky and Stambler 2011), of which many are found in other Indo-Pacific locations. The Red Sea also has high level of endemism, estimated at about 10 % (DeVantier et al. 2000; Sheppard 2000).

The high and relatively stable temperature of the Red Sea favours the formation of coral reefs, which are well developed in its northern part, starting from the tip of Sinai Peninsula (Sheppard et al. 1992). The longest continuous fringing reef in the Red Sea extends from Gubal, at the mouth of the Gulf of Suez, to Halaib, at the Egyptian border with Sudan (Pilcher and Alsuhaibany 2000). In the south, the reefs are more patchy, as the turbid waters of the shallow shelf prevent the formation of extensive reefs. Saudi Arabia, at 6,660 km<sup>2</sup>, has the largest area of coral reefs in the Red Sea (Bruckner et al. 2011b). There are diverse coral reef structures along the Red Sea coast: fringing (both along the mainland and around islands), platform patch, barrier and ridge reefs (Bruckner et al. 2011a; Al-Sofyani et al. 2014). The ridge reefs are characteristics of the Red Sea. Sanganeb Atoll, located in Sudan near the border with Egypt, is the only atoll in the Red Sea; it surges from a depth of 800 m to form a structure that has been recognized as regionally important for conservation, and proposed to UNESCO as a World Heritage Site in the 1980s (Pilcher and Alsuhaibany 2000). Some bays, locally called *sharms*, create conducive



**Fig. 1.3** Distribution of coral reefs in the Red Sea (Image base layer credits: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS user community)

environment for coral development and are unique to the Red Sea (Bruckner et al. 2011a). However, some *sharms* near river mouths are turbid and do not have coral reefs. The reefs in the Gulf of Suez are some of the northernmost reefs in the western Indo-Pacific and have a different community and geographical structures compared to other reefs in the Red Sea (Riegl et al. 2012). The Red Sea also has deep water corals found down to 760 m (Qurban et al. 2014).

The coral reefs of the Red Sea were some of the earliest to be described by researchers from Europe, i.e., Peter Forsskål, Christian Gottfried Ehrenberg, Eduard Rüppell and Carl Benjamin Klunzinger starting in the 1700s, but contemporary information is scarce. Moreover, more than 50 % of the published research on coral reefs of the Red Sea is from the Gulf of Aqaba, which accounts for less than 2 % of the total Red Sea area (Berumen et al. 2013). However, even for the Gulf of Aqaba, there are a lot of issues not well studied and which need attention (Loya et al. 2014). The quality and

detail of coral reef research in the Red Sea need to improve. In the international coral reef monitoring standard, the quality of data used for monitoring the Red Sea coral reefs is at the ‘low’ level (Wilkinson 2008).

The coral reefs of the Red Sea are important habitats for fish and invertebrates (Fig. 1.4). Generally, the populations of invertebrates are healthy except for localized depletions of giant clams in Egypt, other molluscs in Sudan, and lobsters and sea cucumbers throughout most of the Red Sea (Kotb et al. 2008). As far as fish abundance and distribution are concerned, diverse types of fishes inhabit the coral reefs of the Red Sea and there are still areas where large predators, which are the main targets of fishers, are available (Kotb et al. 2008). Sharks are one of the most heavily exploited groups (Tesfamichael and Pitcher 2006; Tesfamichael et al. 2014; Spaet and Berumen 2015). Environmental gradients affect the distribution of fish populations in the Red Sea (Nanninga et al. 2014). In a study conducted in Saudi coast, the density of herbivorous fishes was found to be higher in areas with less live coral cover, due to bleaching, than in reefs with higher live cover (Khalil et al. 2013). In another study from Saudi Arabia, top predators such as jacks, snappers and groupers dominated off shore reef communities resulting in an inverted (top-heavy) biomass pyramids, while in shore communities were dominated by lower trophic-level fish (bottom-heavy) pyramid, which is an evidence of trophic cascade (Kattan 2014). Spawning aggregations have been observed in the Red Sea coral reefs (Gladstone 1996).

Coral reefs recycle their nutrients, which enables them to maintain a high productivity, much like an oasis in a desert. They attract fishers mainly subsistence and small-scale artisanal operators. Globally, coral reefs support small scale fishing activities that provide basic needs to about 500 million people (Wilkinson 2008). In the Red Sea, almost all the commercially important fishes for the handline fishery are found in the reef areas (Barrania 1979; Vine and Vine 1980). Fishing pressure is increasing in the Red Sea and is affecting the coral reef ecosystem, especially spawning and nursery sites (Gladstone 1996; Kotb et al. 2008). In addition to fishing for consumption, ornamental fish are collected in most of the Red Sea countries. Another important economic activity based on the coral reefs of the Red Sea is tourism, mainly diving and snorkeling (Hawkins and Roberts 1994; Kotb et al. 2008). The diverse coral reef ecosystems coupled with clear and warm waters attract many tourists. At present, tourism is developed mainly in the north: in Egypt and Israel. At 250,000 dives per year, the coral reefs off Eilat, Israel, are among the most frequently visited places by recreational divers in the world (Zakai and Chadwick-Furman 2002). Tourism has not developed well in other countries of the Red Sea, mainly because of political instability, but also local customs, which do not encourage tourism activities.

**Fig. 1.4** A coral reef ecosystem in Eritrea (Photo: Yohannes Tecklemariam)



The current status of the coral reefs of the Red Sea is debatable. Some, relative to other areas, claim it is in good condition with live coral cover of 30–50 % (Kotb et al. 2008), while others assert that the coral cover showed significant decline and suggest that the claim the Red Sea reefs are healthy suffer from shifting environmental baselines (Price et al. 2014). Using data from more than two decades, Riegl et al. (2012) showed that dividing the Red Sea into three latitudinal faunistic zones, as sometimes done by researchers, was not apparent and coral size had decreased, recruitment had remained stable, and size distribution had not changed significantly, but mean coral size had decreased, due to a decline of large corals. The richest spots were found in Farasan Islands (18–23 spp.) and the Northern Islands of Egypt at Gubal Saghir. Overall, the health and coral cover increases significantly towards the north (Price et al. 2014).

There are multiple threats to the coral reefs of the Red Sea. The main damage has been due to coastal developments for urban and industrial centers, which include land-filling, dredging, port activities, oil spill, sewage and pollution (Kotb et al. 2008). The magnitude of the impacts of coastal construction has increased significantly in the last 30 years, beach oil has declined, but shore debris have increased (Price et al. 2014). The impacts are higher in areas where population size has increased, e.g., Jeddah and Yanbu in Saudi Arabia (Kotb et al. 2008). Other direct human activity affecting coral reefs in the Red Sea are diving and snorkeling, which raise sediments and also break reef structures. This is especially true along the Egyptian and Israeli coasts where there is high intensity of diving (Hawkins and Roberts 1994; Zakai and Chadwick-Furman 2002). In the shallow reefs of Eilat, Israel, where reef degradation has occurred, algal cover was up to 72 %, an indication of damage to the reef, while in the nearby areas in Aqaba, the turf cover was only 6 % (Bahartan et al. 2010). Reefs dominated by algae had higher densities of herbivorous fish (Khalil et al. 2013).

The Red Sea coral reefs suffered from coral bleaching in 1998. The damage was worse in the southern part, but some signs of recovery were seen especially in the central and northern Red Sea. In addition, extreme low tides in 2007 caused coral bleaching and mortality (Kotb et al. 2008). Outbreaks of crown-of-thorns starfish devastating coral reefs have been reported at different places and times along the Red Sea (Wilkinson 2008). The impact of climate change has also been observed in the region (Baker et al. 2004; Raitso et al. 2011; Riegl et al. 2012). The steady increase in sea surface temperature (SST) has been the key factor in coral reef skeletal growth by 30 % since 1998, rather than the increased acidity of the water (Cantin et al. 2010). Moreover, when and where temperatures decreased, there were signs of recovery indicating the resilience of Red Sea coral reef to changing temperatures (Baker et al. 2004). Using satellite derived sea surface and ground based air temperature, Raitso et al. (2011) showed that the Red Sea is going through an intense warming period starting the mid-1990s, with an abrupt increase of 0.7 °C since 1994. The Red Sea reef dwellers are adapted to very warm environments; however, they can be vulnerable to further and rapid warming. Thus, understanding abrupt temperature change becomes an important issue, as ecosystems have a better chance to adapt in a slowly rather than in a rapidly changing environment (Raitso et al. 2011). On the other hand, the adaptation of the Red Sea coral reefs to high temperature causes them to have high bleaching threshold and thus the Red Sea may become a refuge for corals exposed to climate change (Riegl and Piller 2003; Fine et al. 2013).

Considerable progress has been made in the understanding and management of the coral reefs of the Red Sea both by the individual countries and the Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden (PERSGA) (Kotb et al. 2008). PERSGA has been actively involved in assessing the status of Red Sea

resources, current issues, needs for additional actions and constraints. Every country bordering the Red Sea has either proposed or approved some form of Marine Protected Areas (MPAs). Some of the important coral reef ecosystems in the Red Sea could be good candidates for MPAs and conservation including the Farasan Islands, Dhalak Islands and Sanganeb Atoll (Gladstone 2000).

## Fisheries

The Red Sea has multiple uses, the major one being a shipping route from the Indian Ocean to Europe. Recently, interest in the tourism industry has been increasing, notably in Egypt, which has undergone extraordinarily rapid expansion from a handful of hotels in the 1980s to many hundreds today. As far as resource extraction is concerned, however, fishing is still the most important sector in Red Sea. The Red Sea has a long history (and prehistory) of resource exploitation by humans. Archaeological studies of middle stone age middens from the Eritrean Red Sea coast indicate that humans were eating giant clams and other molluscs about 125,000 years ago, possibly the most ancient such practice on record in the world (Walter et al. 2000). The artisanal fisheries have traditionally operated in relative harmony with the ecosystem because of low population; non-destructive traditional fishing technology; and poor communication and infrastructure. However, depletion of resources have been observed in areas frequently visited by fishers (Tesfamichael 2001) or resources that are specifically targeted by fishers such as sea cucumbers (Tewelde and Woldai 2007; Kotb et al. 2008) and sharks (Tesfamichael 2012; Spaet and Berumen 2015). Recently, more advanced and destructive methods are being used. Currently, fishing operations in the Red Sea range from foot

fishers catching fish mainly for their own consumption, to very large trawlers with freezing facilities.

The fisheries in the Red Sea are typical tropical fisheries, multi-gear and multi-species. Most fishing is performed from wooden boats ranging from 5 to 18 meters, locally called ‘Sambuk’ and ‘Huris’. Sambuks are larger, and have inboard engines; Huris are smaller and use outboard engines. Both Sambuks and Huris use similar fishing gears, mostly handlining and gillnet (Fig. 1.5). The main difference in the operation of Sambuk and Huri are length of the fishing trip, crew size and capacity (Tesfamichael and Pitcher 2006). Most of the countries do not have fisheries regulations (e.g., quota, total allowable catch) or if they have they are ineffectively enforced, thus the fisheries are practically open-access fisheries. Currently there is no regional fisheries management organization (RFMO) for the Red Sea. An initiative is underway to establish one under the umbrella of FAO.

Total annual potential landings from the Red Sea were once estimated at 360,000 t·year<sup>-1</sup> (Gulland 1971), but this value needs further scrutiny. Though the Red Sea accounts for 0.12 % of the total world ocean area, its contribution to the world catch is only 0.07 % (Head 1987b). Nevertheless, it is important to the countries in the region. Fishing produces a cheap source of animal protein and provides livelihood for the communities on the coast. Since the countries on the Red Sea coast are generally less industrialized, fisheries can provide multiple livelihoods.

Of the seven countries that border the Red Sea, Jordan and Israel have too small coastlines to support any major fishery. Of the other countries, Egypt and Yemen have well established fisheries and have been utilizing their resources for a long time. Egyptian and Yemen fishermen also fish in other countries’ waters. Sudan is the country which utilize its fishery resources the least, besides Jordan and Israel. Saudi



**Fig. 1.5** Fishing activities in the Red Sea, Saudi Arabia; (left): handlining (Photo: Julia Spaet); (right): gillnetting (Photo: Mohamed Gabr)

Arabia has recently established an industrial fishery, in addition to the artisanal fishery that has been active for many years. Eritrea had a strong small pelagic fishery in the past, then the fishery was dormant until it resumed after the country's independence in 1991.

## Fishery Data and Assessment

A key part of documenting a fishery is reporting its catches. Given the catch level of a fishery, inferences can be drawn on the intensity of the pressure it exerts, and the approximate number of people involved in, and/or dependant on that fishery. Also, from additional information on the catch composition, inferences can be drawn on the technology that is deployed, the trade linkages that a fishing community has with its neighbours, its income from fishing, etc. In fact, reliable catch data are the most straightforward source of information for a variety of disciplines, ranging from history and maritime anthropology to fisheries economics (Pauly 2006).

For fisheries scientists, the value of catch data is even greater. Indeed, catch data are crucial to their main task, which is to perform fish stock assessments in support of fisheries management. Herein, the key feature of stock assessments is to evaluate the status or level of fishing activity in relation to the productivity of the ecosystem, so that fish from a given stock can be caught in such a manner that the various components of the ecosystem and its regeneration potential are not compromised. If these conditions are met, the ecosystem will sustain fishing for a long time. To accomplish this task, there are two different subtasks to be considered: first establishing the potential of the ecosystem and second establishing where the fishery is relative to that potential. Many assessment tools have been developed to estimate the biological potential of a fishery system and use them as benchmarks for the level of exploitation. Maximum sustainable yield (MSY), and the ratio between the estimated original (un-fished) biomass and the current biomass are two of the many metrics used globally to establish levels beyond which extraction is advised not to go (Beverton and Holt 1993; Hilborn and Walters 1992). Of course, there are criticisms of those approaches, the assumptions they use and their applicability to different ecosystems, and they even share part of the blame for the decline of many fisheries (Larkin 1977; Punt and Smith 2001). However, until better alternatives are available to replace the traditional stock assessment tools, they will be used, despite their limitations. Moreover, while new approaches are being developed, many fisheries in the world do not even have estimates of those metrics and/or are not managed at all.

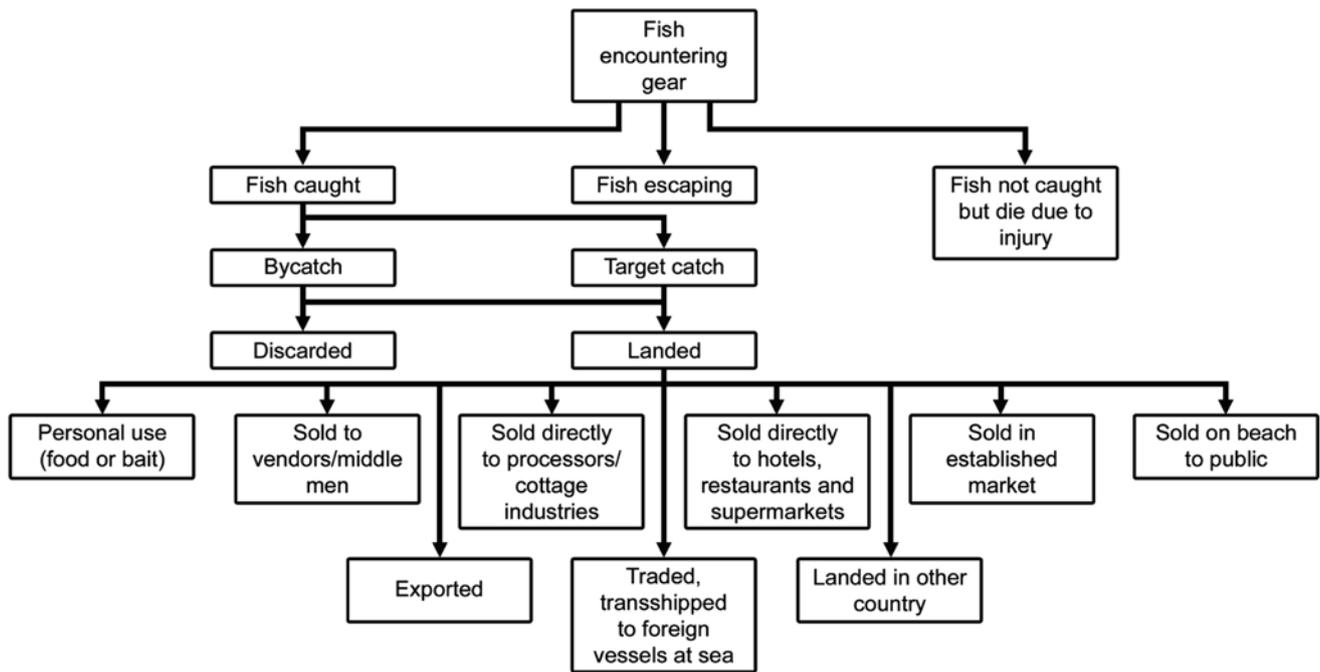
Overall, reliable catch data, jointly with the methods to estimate the biomass of fish and their productivity, are crucial components of effective assessment and management of

fisheries. Time series of total catch, preferably by species, is thus the most basic and important information that can be gathered about a fishery (Caddy and Gulland 1983; Pauly and Zeller 2003). It is even more useful when coupled with fishing effort data. Notably, catch and effort data can help with preliminary assessment of the status of populations upon which fisheries depend. However, this should be done with caution (Harley et al. 2001), because catch per unit of effort (CPUE), although an indicator of fish biomass, is not always proportional to abundance. CPUE can remain more or less stable while abundance is declining, a phenomenon called 'hyperstability', observed on schooling pelagic fish and spawning aggregations (Hilborn and Walters 1992; Pitcher 1995; Sadovy and Domeier 2005). On the other hand, CPUE can decline more than the actual decline of abundance, which is called 'hyperdepletion' (Hilborn and Walters 1992). This can occur, for example, when only a portion of the population is vulnerable to the fishery (Walters and Bonfil 1999; Kleiber and Maunder 2008). However, for many fisheries, CPUE is the best type of information available for assessment, and not using it is short-sighted.

## The Rationale for Catch Reconstructions

There are many ways catch data can be collected. The most common are log books filled in by fishers, the records of observers onboard fishing vessels and data collection at the landing sites and on markets (e.g., auction and exports). For Red Sea countries, many of these methods are very difficult to implement. Most of the local (artisanal) fishers are illiterate. The communities are predominantly based on oral traditions, thus logbooks are out of question. The majority of the boats are small, and on-board observers are impractical to deploy. Data recording at landing sites, although still arduous, is the most practical for routine catch and effort data collection. The challenge here is that the number of landing sites along the coast is quite large, and some of them are not even known to the fisheries administrations. Setting up proper data collection systems is thus not straightforward, given the complexity of fisheries and fish marketing.

There are many possible fates of a fish following its encounter with fishing gear (Fig. 1.6). The actual effect of a fishery in an ecosystem should be measured by the amount of fish killed (rather than fish landed). The actual measure of fishing mortality can be concealed by lack of data on the mortality of the fish at the different parts of Fig. 1.6. For example, for some Red Sea countries, more than half of the fish catch does not go through fish markets, where official recording occurs (Chakraborty 1983). If only the data from landing sites is used to calculate the fishing mortality, this will underestimate its actual magnitude. Thus, proper planning and systematic collection procedures are needed



**Fig. 1.6** Possible fates of fish following an encounter with a fishing gear, based on Mohammed (2003)

(Gulland 1975; Sparre 2000) and for the Red Sea, it is urgent (Tesfamichael 2012). Systematic data collection requires resources, and thus developed countries usually have better catch and related statistics than developing countries (Alder et al. 2010), while the latter also have to contend with a generally higher biodiversity, which makes the catch highly diverse, and hence comprehensive catch statistics difficult to produce (Pauly and Watson 2008). Note, however that even in developed countries with better statistics, overfishing is rampant, e.g., in the North Atlantic (see e.g., Christensen et al. 2003).

The Food and Agricultural Organization (FAO) of the United Nations assembles annual catch data submitted by member countries and harmonizes and disseminates them since 1950 (Garibaldi 2012; Pauly and Froese 2012), and Garibaldi (2012) gives a comprehensive description of the FAO database and its evolution. Because it consists of continuous, long time series and is easy to access, the FAO database is used extensively for research and policy at regional or international scales. Thus, 600 articles in peer-reviewed journals cited the FAO database in the last 15 years, notably because its standardized data makes comparisons straightforward (Garibaldi 2012).

FAO's mandate is very broad, and when it comes to fishery data, it can only compile and distribute what is submitted to it. This is the main bottleneck to the quality of the data. Countries do not necessarily have the incentive to submit reliable data, except as a moral obligation to contribute to a global system. Thus, it is not uncommon for countries to

send incorrect or incomplete fishery data (Pauly and Froese 2012), and FAO does not have a legal or procedural mandate to refuse such data. Even more problematic, the technical reports produced by FAO staff or consultants are not reflected in the database. Thus, the global estimates of discards documented in successive *Technical Papers* and other FAO documents were never included in the FAO statistics (Zeller and Pauly 2005).

Another example, applying specifically to the Red Sea, is that most of the early fishery data for the Red Sea comes from national or regional projects executed by FAO, especially the project 'Development of fisheries in areas of the Red Sea and Gulf of Aden', which ran from the late 1970s to the mid-1980s under the United Nations Development Programme (UNDP) and FAO. Among other things, the projects surveyed the fisheries and estimated national catches (Chakraborty 1984), but they were not incorporated into the FAO catch database. Moreover, while the countries around the Red Sea are all members of FAO, and hence they send their fishery data to FAO, many suffer from political and institutional instability, which affects their fishery agencies, and thus there are gaps and inconsistencies in the data supplied to FAO.

FAO's mandate, while broad, does not include detailed analysis and review of the data supplied by member countries, which thus remain limited in their reliability and usefulness. It is assessed by FAO itself that the catch data it receives from over half of its developing country members, and one quarter of developed country members are unreli-

able (Garibaldi 2012). The following are the major constraints with the fishery statistics in the FAO database, and affect all countries, and not only those around the Red Sea:

1. The FAO database reports global marine catches spatially only to the extent that they are allocated to 19 giant ‘statistical areas’. In the cases of Red Sea catches, this is area 51, the ‘Western Indian Ocean’, extending from the tip of the Gulf of Suez in the North to the Antarctic Convergence in the South, and from Sri Lanka in the East to South Africa in the West;
2. The level of taxonomic aggregation of the catch is usually very high, and a large part of the catch is reported as ‘miscellaneous’ or ‘unidentified species’, which masks qualitative changes occurring within the ecosystem;
3. FAO’s member countries often send in catch data (usually emanating from a Department of Fisheries or similar institution) through their Ministry of Trade, or some central statistics office or other government agency not directly connected with fisheries, where they are often over-aggregated and/or otherwise modified before being sent off;
4. Some countries may have political reasons to misreport their catch, including over-reporting of catches as China did to FAO for at least two decades (Watson and Pauly 2001) and, gravest of all:
5. When data for certain fisheries are not available (because the fisheries in question were not monitored), no estimates for the missing catch data are submitted. Subsequently, absent catch data for a given year become an annual catch of precisely ‘0’ tonne (Pitcher et al. 2002). Thus, the FAO database does not account for illegal, unreported and unregulated (IUU) catch (Alverson et al. 1994; Kelleher 2004), nor does it suggest where gaps in its coverage may occur.

FAO has taken initiatives to improve the content of its catch database, and indeed, it has improved over time. Also, there is a university-based research project, the *Sea Around Us* ([www.seaaroundus.org](http://www.seaaroundus.org)), which aims to improve the quality of global marine fishery data. Being non-governmental, *Sea Around Us* is not limited by formal procedures. Hence, country catch reports can be critically examined, and when fisheries were omitted, their catch can be estimated using the best available information. In effect, the major issues with the FAO database can be overcome through reconstructing historical catch time series (Pauly 1998; Pauly and Zeller 2003; Pauly and Froese 2012). Reconstructed time series of catch (and effort) data from the past are not merely useful for historical purposes. Rather, they provide a basis for overcoming the shifting baseline syndrome (Pauly 1995), i.e., for improved assessment of past and current impacts of fishing on marine ecosystems, and for ecological restoration (Scott

Baker and Clapham 2004; Pitcher 2005). The lessons learned from catch reconstruction in different circumstances of the fisheries can be informative, similar to ‘scenarios’ in adaptive management of resources (Walters 1986).

Catch reconstruction involves quantifying the catch of each fishery known to have existed, based either on ‘hard’ catch data, or when such data are not available, on the ‘shadow’ that the fishery – a social activity - throws on the society in which it is embedded. This shadow may consist of household fish consumption figures, number and income of fishers, export figures, etc... (Pauly 1998). Estimates from catch reconstruction, while approximate, will generally be closer to reality than the misreported catches, e.g., the precise estimate of zero in the official databases alluded to in the above (Pitcher et al. 2002; Zeller et al. 2007).

The main objective of this book is to present reconstructed catches of the Red Sea fisheries from 1950, the year FAO started to publish annual statistical reports on the fisheries of the world, up to 2010. Included here are all the Red Sea countries: Egypt, Sudan, Eritrea, Yemen, Saudi Arabia, Jordan and Israel and all the fishing sectors of these countries. The major outputs are a time series of standardized fishery catches for the Red Sea, by sector and species or other groupings. We do not claim these catch reconstructions data to be final. Rather, we see them as the start of an iteration, and as a basis to kick start the discussion on how to improve fishery data for the Red Sea, and ultimately, the management of its fisheries resources.

## Sources and Catch Reconstruction Procedures

The main procedure in catch reconstruction is digging into different sources reporting the catches of the countries, critically analyzing them, and organizing them to a common standard, which can be used for comparison and carrying out analysis for the assessment of the resources (Mohammed 2003; Tesfamichael and Pauly 2011). The sources used here include peer-reviewed published papers, grey literature (mainly government, consultant, and FAO reports), and national databases, complemented by field trips by the first author to Egypt, Sudan, Eritrea, and Yemen from December 2006 to September 2007. The information collected was enriched by the insights of local experts and colleagues who provided data through personal communications. The catch reconstruction for the whole Red Sea was first compiled in the form of individual country reports, co-authored by country experts: Egypt (Tesfamichael and Mehanna 2012), Sudan (Tesfamichael and Elawad 2012), Eritrea (Tesfamichael and Mohamud 2012), Yemen (Tesfamichael et al. 2012b), Saudi Arabia (Tesfamichael and Rossing 2012), and Jordan and Israel (Tesfamichael et al. 2012a), which give country-specific details (see also [www.seaaroundus.org/eez/](http://www.seaaroundus.org/eez/)). Here, a

summary of the general methodology and the procedure to establish one coherent data set for the whole Red Sea are described.

## Sources

The earliest data sources for the Red Sea countries were technical reports of the assessments of the fishery resources for planning the development of the fishing industry, starting in the decades following WWII. The 1950s was also a period where several of these countries became independent and started to run their national economies, and food security became a critical issue. These assessments/surveys were made by foreign experts (except for Egypt and Israel), usually recruited through the FAO. The earliest sources available were for Saudi Arabia (El-Saby and Farina 1954), Sudan (Kristjansson 1956), Eritrea (Ben-Yami 1964), Egypt (Al-Kholy and El-Hawary 1970) and Yemen (Lisac 1971; Losse 1973). Other early assessments were performed through bilateral arrangements or consultants hired directly by the countries (e.g. see Ben-Yami 1964; Atkins 1965; Grofit 1971 for Eritrea). In the 1970s and 1980s, in part because of the Cold War and ensuing East-West competition, development aid was pouring into the Red Sea countries. A fraction of these funds were assigned to fisheries development projects, which led to an improvement in documented knowledge about the fisheries (catches, catch composition, gear, etc). A regional project for the Red Sea area, 'Development of fisheries in areas of the Red Sea and Gulf of Aden', was carried out from the end of the 1970s until the mid-1980s and led to an improvement of the quality (comprehensiveness and taxonomic resolution) of fishery catch data. Additional sources were also used, notably tax offices and export records. For example, the catch of the Eritrean beach seine small pelagic fishery was reconstructed from export figures for fish meal, which was the output of the fishery (Ben-Yami 1964).

Organized databases and/or annual fishery statistical reports are a relatively new development for the Red Sea countries. The oldest database is that of Egypt, which starts in 1979, while Saudi Arabia started publishing its annual fishery statistics in the 1980s. Eritrea has had annual reports since its independence in 1991, but its fishery database started only in 1996. Sporadic annual reports are available for Yemen and a database system is being established. Sudan does not have any fishery data reporting system yet; however, daily catch data are collected at the main fishing market of Port Sudan, which are stored, but not issued as annual reports. All these sources were accessed for the catch reconstruction of the respective countries.

Once the sources were accessed, their contents were analyzed for their spatial, temporal and sectoral coverage. Some reports were written only for a certain section of the countries or only a specific sector of the fisheries. Then, the sources were critically examined with regards to the method(s) and assumptions used in collecting their data. For some years, data were available from different sources, some simply regurgitating previously reported data. In such cases, an effort was made to locate the original reports. When there were multiple independent sources, the ones which have detailed explanations of the methodology and comprehensive coverage were selected. In a few cases, the information from one source was used to correct data from another.

## Interviews

Field interviews (Fig. 1.7) were conducted, in Sudan, Eritrea and Yemen, by the first author and assistants with fishers ranging from 15 to 82 years of age, and with fishing village elders and the employees of fisheries administrations (Tesfamichael et al. 2014). The main goal of the interviews was to assess long-term change in fisheries productivity by



**Fig. 1.7** A researcher interviewing a Yemeni fisher while his son watches (Photo: Dawit Tesfamichael)

accessing fishers' memories, which provided two major inputs to the catch reconstructions. First, the interviews were very useful in filling data gaps. For some periods there were no records at all, so interviewees were asked to explain what occurred during those periods, i.e., whether the catches were higher or lower than, or about equal, to the adjacent periods with records. The other type of information supplied by the interviews was the unreported catch, i.e., the catch missed by official records. For many artisanal fisheries in the Red Sea, this included the catch given freely to some members of the community and the catch landed at remote landing places, away from data collectors. Regarding the former, there is a strong tradition, shared by the maritime cultures of Red Sea countries, that part of the catch is expected to be given freely to family, friends and people who need assistance (e.g., the elderly, disabled, and widows). The amount given freely is called '*kusar*' and is a form of food security social network. Not to give '*kusar*' leads to loss of prestige, which may have serious consequences, e.g., with regards to market transactions and eventual marriages. The amount was about half of the total catch in the 1950s and 1960s; however, as the catches started to decrease and the fish accrued market value, the proportion of the catch devoted to *kusar* started to decrease.

Another input from the interviews was explanations of discrepancies among reports. The insights from older fishers and people who have been involved in the management of fisheries helped resolve ambiguities in reports and/or records. Although they did not give specific quantitative values, their ability to give comparative qualitative information helped to base the assumptions used in quantifying the catch. In the absence of any other source, anecdotal information can be a good starting point (Pauly 1995) and quantitative data can be inferred from qualitative information, given some anchoring (Tsfamichael and Pitcher 2007). In addition to acquiring information through interviews, the effectiveness of a fishery management scheme and compliance of fishers is higher when fishers are involved in information gathering and management processes.

## Missing Data

For the years data were missing, interpolations or extrapolations were made to fill in the data gaps. These were made on the basis of explicitly stated assumptions, given the best knowledge of the fisheries available at the time. Population size and per capita consumption were frequently used as a proxy for inferring catches. In a few instances, information from one country was used for another country with a similar fishery, particularly in the case of catch composition data.

## Comparison and Compilation

Using the different sources and procedures, the catches of each country were reconstructed by sector, and the catch compositions were inferred. Then, the reconstructed catches were compared to the catch data reported to FAO (see <http://www.fao.org/fishery/statistics/software/fishstat/en>) by the respective country. The FAO data are used as a reference for comparison because they are a good source of time series catch data for the Red Sea countries and are used by many organizations (local and foreign) for analysis and planning. Thus, the part of the reconstructed catch of a given taxon that was accounted for in the FAO data was assigned as 'reported' catch in our analysis and results. When the reported catch of a taxon was higher than what is reported for that taxon in the FAO database, the difference was assigned to the 'unreported' catch. In contrast, when the FAO catch for a taxon was higher than the reconstructed catch, it was assigned as 'over-reported' catch. As will be seen in the country chapters, reported and unreported catches are identified separately in the catch reconstructions. Note that if there was a part of the catch that was not reported (e.g., catches were sold outside landing sites where catch data recordings are carried out and we managed to get an estimate of the amount), then that part of the catch is referred as 'unreported' catch in our computations. This should not be confused with the reported and unreported catches of the results as compared to the FAO data. Once the catches were reconstructed for each country, by sector, and the catch composition calculated, they added up to represent the catches of the Red Sea as a whole, i.e., as a Large Marine Ecosystem (see also [www.seaaroundus.org/lme/33.aspx](http://www.seaaroundus.org/lme/33.aspx)).

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## Summary Results and Discussion

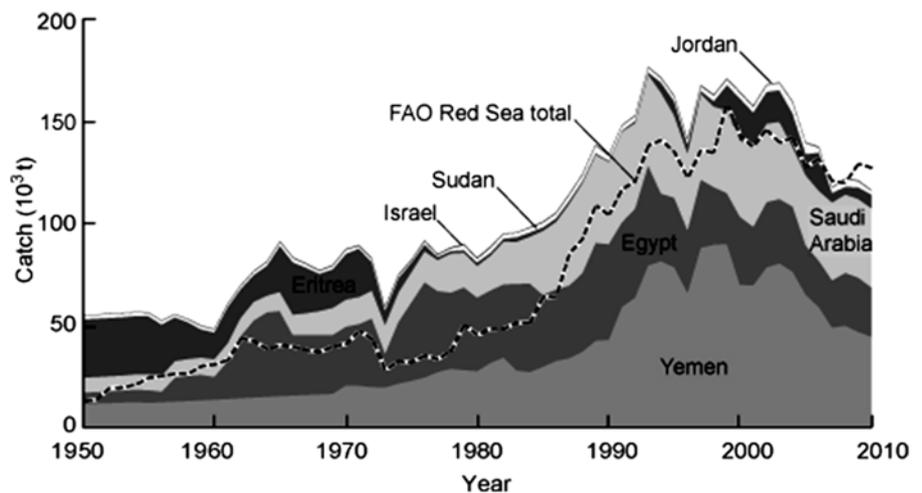
The total reconstructed catch from the Red Sea from 1950 to 2010 was 6,333,000 t, 1.5 times higher than what is reported to FAO by the surrounding countries for the same period. The total catch was low (around 50,000 t·year<sup>-1</sup>) until 1960, when it started its first increase until a decline in the early 1970s (Fig. 1.8), due to the war between Israel and Egypt. The catch increased again from the mid-1970s, until it reached a peak of 177,000 t in 1993. This phase is characterised by massive boat motorization and the introduction of industrial fishing by several Red Sea countries. This increased the effort and also allowed the expansion of the fisheries to areas they did not access previously. The total catch remained high, with some fluctuations, until the mid-2000s when it started to decline. This decline is here interpreted as a sign of resource depletion, especially in Yemen (Tsfamichael et al. 2012b).

The reconstructed catch was higher than the FAO data, except for the last few years. An obvious reason why the reconstructed catch is generally higher is that we included discards, subsistence and recreational fisheries, which are not usually included in FAO data for the Red Sea. The higher FAO catch in the last few years of our analysis was caused by double counting of some fishery catches in the FAO database. This is due mainly to Egypt fishing outside its EEZ in the waters of Sudan, Eritrea and Yemen, and reporting all their catches as Egyptian, while Sudan, Eritrea and Yemen report some of these same catches to FAO as well, as they are taken within their EEZ. One can argue this catch should be reported by area, i.e., by the EEZ it was taken from, or by the country that has taken it. Here, in view of the current emphasis on ecosystem-based fisheries management, we focused on the area, i.e., the EEZ from which the catch originates, as it provides the spatial context for fisheries management. For completeness, we also indicate, the country fishing in the database. Presently, there is no a regional fishery management agency for the Red Sea LME, and whatever manage-

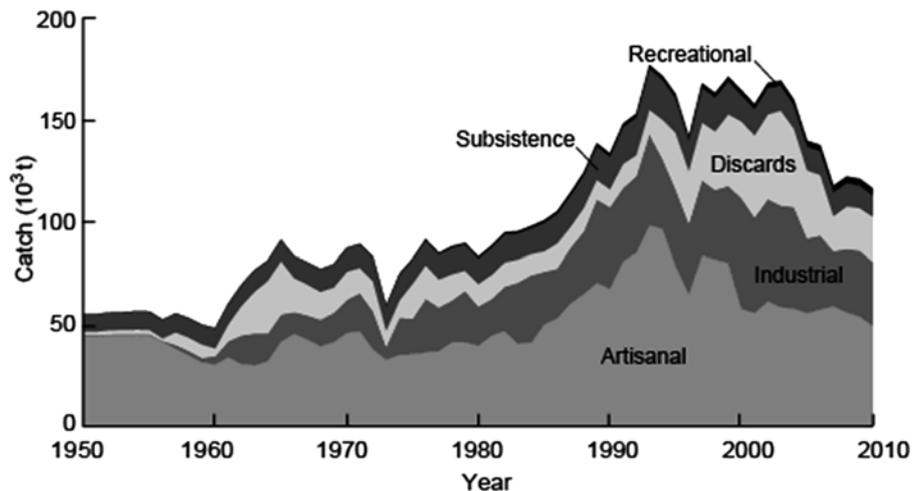
ment there is extends only to national schemes, pertaining to single EEZs. By country, Yemen has the highest percentages of the Red Sea catch (36 %), followed by Egypt (28 %), Saudi Arabia (23 %), Eritrea (11 %) and Sudan (2 %), while Jordan and Israel contribute less than 0.2 % each.

The artisanal fisheries accounted for 49 % of the total catch from 1950 to 2010 (Fig. 1.9). Their contribution was dominant throughout the whole period, unlike the industrial sector (22 %), which is important only in the later part of the period covered here. This has major economic and social implications, as artisanal fisheries employ a higher number of fishers per tonne of catch (Pauly 2006), which translates to higher employment and livelihood in the communities. The discards (near exclusively from industrial fishing), which are usually ignored in official reports, represented 16 % of the total catch. The subsistence catch was 12 %, while the recreational fishery (1 %), which started only recently, is still negligible. Egypt is the country with the most developed recreational fishery and even in that country, recreational catches are low.

**Fig. 1.8** Reconstructed catch of the countries bordering the Red Sea from 1950 to 2010 and its comparison to the data reported to FAO



**Fig. 1.9** Reconstructed catch of the Red Sea fisheries by sector from 1950 to 2010



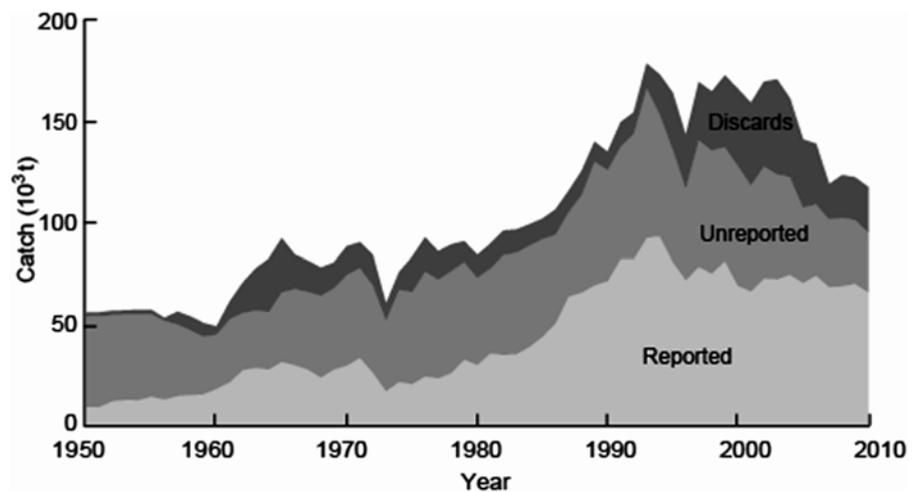
Comparing the reconstructed catch with the FAO data in terms of taxonomy, only 42 % of the reconstructed catch was accounted in the FAO data, i.e., the reported catch (Fig. 1.10). The remaining 58 % was not accounted for at all. This included 43 % unreported, but landed catch and 15 % discarded bycatch catch, which is also not reported.

A total of 209 taxa or taxonomic groups were identified as contributing to Red Sea catches, in addition to a group 'others' encompassing the minor taxa that were not represented separately. The taxa contributing most to the catch was Indian mackerel (*Rastrelliger kanagurta*; 8 %), Spanish mackerel (*Scomberomorus commerson*; 7 %), and jacks (Carangidae; 7 %). Emperors (Lethrinidae) and ponyfishes (Leiognathidae) each accounted for 5 % of the total catch, the former prized fishes, the latter the dominant taxon in the discarded catch of industrial trawlers. These percentages suggest that there is no a single taxon that is overly dominant in the Red Sea fisheries, a reflection of their multi-species nature, and one of the main challenges in managing the Red

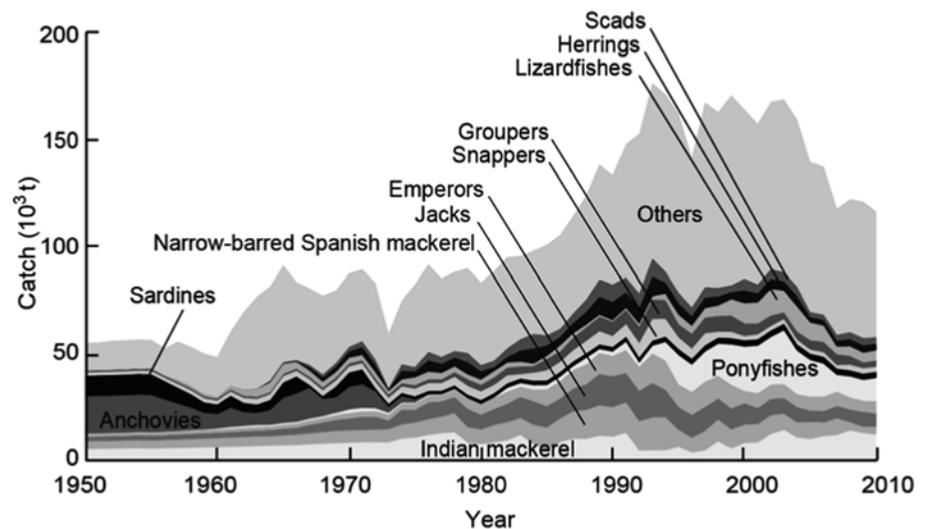
Sea fisheries. The major taxonomic groups of the total catch composition are presented in (Fig. 1.11). Only a few taxa are included here for better visual effect of the figure; supplementary tables with extensive taxonomic composition are presented in the electronic supplementary materials (ESM) <http://extras.springer.com/> and the spatial distribution of the catch is given at [www.seararoundus.org](http://www.seararoundus.org).

In the following, a brief per-country account is given, starting with Egypt and moving counter-clockwise along the Red Sea coast as the different chapters are introduced. For Egypt (Chap. 2), the reconstructed catch is higher than the fisheries catch statistics that Egypt submits to FAO from the beginning of 1960s until the beginning of 1990s, but the reverse occurs after the mid-1990s. This discrepancy is due to the fact that Egypt fishes outside its own waters (e.g., in Eritrean waters starting early 1990s and these catches are not included in the reconstruction, as the focus of the reconstruction is to quantify the amount fished in the waters of various countries (also clearly identifying the fishing country) and

**Fig. 1.10** Reconstructed catch of the Red Sea fisheries by components from 1950 to 2010



**Fig. 1.11** The major taxonomic composition of the total reconstructed catch of the Red Sea from 1950 to 2010



not where they were landed. The catch of Egyptian vessels from Eritrean waters is reported in the reconstruction of Eritrea.

The Sudanese data (Chap. 3) submitted to FAO does not include the catches of shells (trochus and mother-of-pearl), which were very important before 1980s. Generally, there is no large difference between the reconstructed data and the data submitted to FAO for Sudan. The sudden spike of Sudanese catch reported to FAO in 1983, on the other hand, is likely due to a reporting error, as there was no major change in the fisheries likely to cause such a sudden jump for only 1 year. The higher catches reported to FAO after the 1990s are also suspicious, as they contradict locally available data.

For Eritrea (Chap. 4), Yemen (Chap. 5) and Saudi Arabia (Chap. 6), the reconstructed catches are higher than those reported to FAO, due to the latter not including various fisheries and omitting discards. The major discrepancies between the reconstructed data and the data submitted to FAO for Eritrea are in the early decades (1950s and 1960s) and later, after 2000. Between those periods the fishery was largely inactive, hence catches were low. For Yemen in the Red Sea, the reconstructed catch is higher than the reported catch, the difference being more consistent for Yemen than for any other country. There is a clear difference between the reconstructed and reported catch for Saudi Arabia in the Red Sea until the mid-1980s. After the mid-1980s, trawlers were introduced into the Saudi fishery, and hence the differences between the two data sets consist mainly of discards. The reconstructed catches of Jordan and Israel (Chaps. 7 and 8) are negligible compared to those of the other countries, which is understandable given their minuscule footholds in the inner Gulf of Aqaba. They also exhibited less fluctuation than the FAO data. For each country (Chapter), the ecosystem and fisheries are described and the reconstructed catch presented from 1950 to 2010. The details of the sources and procedures of the reconstruction are put at the end. Supplementary tables and results are available at (ESM) <http://extras.springer.com/> and the spatial distribution of the catch is given at [www.seaaroundus.org](http://www.seaaroundus.org).

In addition to the catch reconstruction for each country bordering the Red Sea, an ecosystem model of the Red Sea Large Marine Ecosystem (LME) is presented (Chap. 9) using Ecopath with Ecosim (EwE), where the interactions of the organisms in the ecosystem and the impact of fisheries are quantified. The model can be used to simulate policy scenarios and predict the outcomes, which is an important tool for informed management of the ecosystem. Last but not least, a list is provided of common commercial fishes caught by the fisheries in the Red Sea and their corresponding local names (Chap. 10). The names include valid scientific names, common English names, local (Arabic) names written in both Arabic script and Roman characters. We believe this

will help researchers, resource users and managers. Jointly, the information presented here can help in better understanding the Red Sea and provide a basis for the management schemes that the future will require (Tesfamichael 2012).

**Acknowledgements** The work documented here was mostly supported by the *Sea Around Us*, itself funded by the Pew Charitable Trusts. There were many people who helped us in each country that should be acknowledged individually. However, as their contributions were country-specific, we have opted to thank them in each country's chapter. Here, we would like to thank Gwilym Rowlands for Fig. 1.3 and Callum Roberts for reviewing the chapter.

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