The Ichthyodiversity of the Red Sea: A Unique Extension of the Indian Ocean Biota

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Abstract The Red Sea presents a narrow extension of the Indian Ocean surrounded by deserts. Its ichthyofauna comprises 1264 species (July 2019) belonging to 155 families. The Gobiidae is the richest family, with 143 species, followed by the Labridae, Apogonidae, Serranidae, and Blenniidae, with over 45 species each. The number of endemic species is estimated as 13–14%. About two-thirds of the fishes are reef-associated species. The deep sea is poor in typical deep-sea species (ca. 3.4%) compared to other tropical seas, and most of its deep-sea fishes are actually shallow-water fish that have adapted to the depths. The proportion of low trophic species is similar to that in other tropical seas but significantly higher than in temperate and cold-water seas. Many of the Red Sea fish species are associated, directly or indirectly, with corals, sponges, and sea urchins. The Red Sea is an oligotrophic sea with low levels of nutrients that affect the potential for fishery.

Keywords Red Sea · Ichthyodiversity · Ecology · Fishery

1 Introduction

The Red Sea is an extension of the Indian Ocean at its northwestern corner, stretching along the northeastern side of Africa. It borders seven countries: Eritrea, Sudan, Egypt, Israel, Jordan, Saudi Arabia, and Yemen. Its surface area is ca. 458,620 km^2 (Heileman and Mistafa 2008). Although it comprises ca. 0.13% of the hydrosphere, it hosts ca. 7% of the world's marine fish species.

The regions around the Red Sea are dry deserts, devoid of any stable river carrying nutrients from the continent into the sea. The sole source of continental nutrients is that of the sporadic floods from neighboring deserts.

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The history of the Red Sea is relatively short. It was created during the Miocene as an extension of the Indian Ocean (Bosworth 2015). It then became disconnected from the Indian Ocean during a low eustatic sea level in the glacial era (Por 1989). The ecological conditions during that period were extremely poor for tropical biota: temperature was low (17 °C), and salinity reached 50 ppt. This led to the extinction of the coral reefs and many of their dependent species (Por 1989; Goren 1993).

The fishes of the Red Sea comprise an interesting and colorful group of animals that demonstrate a wide variety of sizes, habitats, behaviors, and life histories.

The first scientist to study the biota of the Red Sea was Forskål. Unfortunately, he and other members of his expedition died during their journey, and the sole survivor, Carsten Niebuhr, published the findings of Forskål's expedition in 1775 (Forskål 1775). Since then, thousands of scientific articles have been published that engage with the many aspects of the biology of the Red Sea fishes: e.g., identification, systematics, feeding habits, inter- and intraspecific interactions, mimicry, venomous and poisonous fish, etc. In the present chapter, we focus on several biodiversity aspects that emphasize the uniqueness of the Red Sea fish biota.

The fishes inhabit all types of habitat in the Red Sea, from the deep bathyal to above sea level, where some fish can be observed basking on rocks or on muddy intertidal ground. The exception may be the deep-sea hot brines of the Red Sea reported by Miller et al. (1966), on which we have no information regarding their biota.

Most of the fishes dwell in and among coral and rocky reefs, and many of them are associated with various invertebrates such as crustaceans and coelenterates. The magnificent coral reefs and biota communities that surround them, in addition to the convenient research conditions, such as the close vicinity of rich coral reefs to the shore, attract many scientists who have published thousands of scientific articles and books dealing with the Red Sea fishes. A partial list of references can be found in Dor (1984) and Goren and Dor (1994).

2 How Many Fish Species Inhabit the Red Sea?

In spite of the extensive study of the ichthyofauna of the Red Sea, the number of reported fish species is still increasing, especially over the last 50 years. Dor (1984) listed 996 species and Goren and Dor (1994) counted 1248 species. Golani and Bogorodsky (2010), who revised a previous literature list, noted only 1078 species, and DiBattista et al. (2016a) counted 1071 species. Goren (2013a), who updated their lists, counted 1123 fish species, and Golani and Fricke (2018) counted 1207 species in the northern Red Sea and the Gulfs of Suez and Aqaba. A search in FishBase (Froese and Pauly 2019) revealed 1246 native species (uncertain species were not counted). Some of the differences in the counts of species can be related to the different criteria used for validation of the reported records.

The present study (updated to February 2019) revealed 1264 fish species, as elaborated upon below. In addition to the ongoing findings of new records and species in the Red Sea, present-day studies employ molecular tools in order to update the status of species. Some names are considered as synonyms, others have their generic affiliation reassigned, and some are defined as cryptic species. My current estimate of the number of valid fish species in the Red Sea is 1350–1400.

3 Ichthyodiversity of the Red Sea

Out of the 1264 species known from the Red Sea, 63 are Chondrichthyes, assigned to 18 families, and 1201 species are Osteichthyes, belonging to 137 families. The division of the species into families is presented in Table 1. As evident from this table, the richest families among the Chondrichthyes are the Carcharhinidae and Dasyatidae, with 16 and 14 species, respectively. Among the Osteichthyes, the richest family is the Gobiidae, with 143 species, and then the Labridae, Apogonidae, Serranidae, and Blenniidae, with 73, 68, 48, and 46 species, respectively.The average number of fish species per family in the Red Sea is 8.17 (3.5 among the Chondrichthyes and 8.78 among the Osteichthyes). Family diversity is 1.8129 (calculated as $-\sum_{n=1}^{s}(Pi \times \log Pi)$, equation modified from Pielou (1969). $S =$ number of species in the Red Sea; and $Pi =$ the proportion of species of the ith family out of the total number of species). This index is very high compared to that of the neighboring Mediterranean Sea, where the average number of species per family is 3.82 (Goren 2013b). A comparison with other tropical seas (Table 2) reveals that the Red Sea has similar ecological characteristics (species and family diversities and evenness rate indices) to those of the Indian Ocean, the Indonesian Sea, and the Caribbean. The high family diversity index reflects the high variability of ecological niches deriving from the complexity and richness of the coral reefs.

4 Endemism

The Red Sea is characterized by a high rate of endemism. This is the outcome of the extreme ecological conditions during the glacial period, especially due to the low eustatic sea level that led to its partial or complete isolation from the Indian Ocean (Por 1989: 68; Goren 1986; DiBattista et al. 2016b). The phenomenon of a high rate of endemism is typical to peripheral ecosystems, as noted by DiBattista et al. (2016a): “The importance of peripheral regions, such as the Red Sea, the Hawaiian Archipelago and the Marquesas Islands as ‘evolutionary incubators’ that contribute unique genetic lineages to other regions of the Indo-West Pacific.”

The rate of endemism in the Red Sea counted by Goren (1993) is 13.7%. According to Golani and Fricke (2018), 174 species out of a total of 1207 are endemic to the Red Sea (14.4%). DiBattista et al. (2016a) counted 12.9% endemic species in the Red Sea, and when the endemic species of the Gulf of Aden are added,

Table 1 Species richness of Red Sea fish families

Taxon	No. of species
Chondrichthyes	**63**
Carcharhinidae	16
Dasyatidae	14
Myliobatidae	9
Torpedinidae	4
Triakidae, Sphyrnidae, Rhinobatidae, Rhinidae, Pristidae, Glaucostegidae	2
Stegostomatidae, Rhincodontidae, Odontaspididae, Narkidae, Lamnidae, Gymnuridae, Ginglymostomatidae, Alopiidae	1
Osteichthyes	**1201**
Gobiidae	143
Labridae	73
Apogonidae	68
Serranidae	48
Blenniidae	46
Pomacentridae	38
Carangidae, Syngnathidae	37
Muraenidae	36
Lutjanidae	24
Ophichthidae, Scorpaenidae	22
Chaetodontidae	21
Scaridae	19
Holocentridae, Mullidae	18
Haemulidae	17
Balistidae, Monacanthidae	14
Callionymidae, Lethrinidae, Nemipteridae, Pempheridae, Scombridae, Tetraodontidae	13
Acanthuridae, Bothidae, Pseudochromidae, Synodontidae, Tripterygiidae	12
Congridae, Mugilidae, Sparidae	11
Cynoglossidae, Leiognathidae, Platycephalidae	10
Soleidae, Sphyraenidae	9
Antennariidae, Caesionidae, Microdesmidae, Pomacanthidae, Uranoscopidae	8
Clupeidae, Engraulidae, Hemiramphidae	7
Belonidae, Gerreidae, Synanceiidae	6
Diodontidae, Malacanthidae, Nettastomatidae, Plesiopidae, Priacanthidae	5
Atherinidae, Bythitidae, Cirrhitidae, Echeneidae, Exocoetidae, Ophidiidae, Ostraciidae, Pinguipedidae, Siganidae, Terapontidae, Trichiuridae, Triglidae, Xenisthmidae	4
Acropomatidae, Ambassidae, Carapidae, Dactylopteridae, Gobiesocidae, Istiophoridae, Kyphosidae, Molidae, Opistognathidae, Schindleriidae	3
Aploactinidae, Ariommatidae, Bregmacerotidae, Champsodontidae, Chirocentridae, Coryphaenidae, Creediidae, Dussumieriidae, Ephippidae, Fistulariidae, Hemigaleidae, Kraemeriidae, Moridae, Muraenesocidae,	2

(continued)

Table 1 (continued)

Taxon	No. of species
Myctophidae, Paralepididae, Samaridae, Sciaenidae, Sillaginidae, Solenostomidae, Stomiidae	
Albulidae, Anomalopidae, Apistidae, Ariidae, Ateleopodidae, Batrachoididae, Bramidae, Caproidae, Centriscidae, Chanidae, Chlopsidae, Cyprinodontidae, Drepaneidae, Elopidae, Emmelichthyidae, Epigonidae, Gempylidae, Kuhliidae, Liparidae, Lobotidae, Lophiidae, Megalopidae, Monocentridae, Monodactylidae, Paralichthyidae, Pegasidae, Pentacerotidae, Percophidae, Phosichthyidae, Plotosidae, Psettodidae, Setarchidae, Sternoptychidae, Symphysanodontidae, Synaphobranchidae, Tetrarogidae, Trachichthyidae, Trichonotidae, Xiphiidae	1

Table 2 A comparison of several ecological characteristics between the Red Sea and selected tropical ecosystems. Data extracted from FishBase (December 2017, uncertain and introduced species are excluded from the counts)

	Red Sea	Persian Gulf	Bay of Bengal	Indian Ocean	Indonesian Sea	Caribbean Sea
No. of species	1264	862	766	5380	2418	1598
Number of families	155	144	157	347	230	204
Average number of species per family	8.17	5.98	4.38	15.5	10.5	7.5
Family diversity	1.8129	1.8649	1.9690	2.1208	1.9509	2.0223
Evenness index	0.8277	0.8643	0.8778	0.8348	0.8247	0.8666

the rate rises to 14.1%. Goren (1986) suggested that during the post-glacial period, the eustatic increase in sea level that enabled recolonization of the Red Sea also enabled some endemic species to expand their distribution to the Gulf of Aden and thus should be considered as part of the endemic ichthyofaunal of the Red Sea. The number of validated endemic species is expected to fluctuate following genetic studies of the Red Sea ichthyofauna, which is expected to synonymize some species and validate others.

The families with a high rate of endemic species are the Gobiidae, Blenniidae, Tripterygiidae, Pseudochromidae, and Chaetodontidae, with ca. 20–40% endemic species. Most species assigned to these families comprise small fish with a short life span.

5 Habitat Occupation

The present analysis of habitat occupation by the Red Sea fishes reveals that almost two-thirds of the species are associated with coral reefs. This proportion is higher than in any other compared habitat (Table 3). The number of deep-sea species is

Table 3 A comparison of habitat occupation by fish species in selected tropical regions (in %)

Habitat	Red Sea	Caribbean Sea	Indian Ocean	Persian Gulf	Gulf of Bengal	Indonesian Sea
Reef-associated	64.4	36.6	39.8	56.3	40.1	59.4
Demersal	21.0	22.9	28.3	25.9	26.2	22.2
Benthopelagic	5.4	5.9	6.7	5.9	8.7	5.4
Pelagic-neritic	3.7	4.3	4.3	7.3	10.3	4.8
Bathydemersal	2.2	11.8	8.5	1.4	6.8	3.2
Pelagic-oceanic	2.1	5.4	3.1	2.8	5.0	1.7
Bathypelagic	1.2	13.0	9.3	0.5	2.9	3.2

much lower than in any other compared sea (in the Persian Gulf deep sea does not exist). The bathydemersal and bathypelagic species comprise only 3.3% of the Red Sea fish species. Taking into account the mean and the maximum depth of the Red Sea (ca. 500 m and 3000 m, respectively), this low proportion is unexpected. Baranes and Golani (1993), who studied the deep-sea ichthyofauna of the Red Sea, pointed out that "None of the species recorded in this list are considered conventional deep-sea fishes. The ichthyofauna of the aphotic zone of the Gulf of Aqaba is composed of species of shallower origin." They attributed this to the high temperature of the deep water in the Red Sea (above 21 °C; Miller et al. 1966). We may speculate that the presence of a very shallow corridor between the Red Sea and the neighboring Indian Ocean also contributes to this phenomenon. However, we should bear in mind that very little research of the macro and mega biota of the deep waters has taken place in the Red Sea and further studies may uncover the number of deep-sea species.

6 Trophic Level

The fishes of the Red Sea demonstrate a similar trophic pattern to that of other tropical seas. These seas are characterized by a relatively high proportion of herbivorous fishes (12–15%) that are assigned to a low trophic level of 2–2.9. This proportion is much higher than in the ichthyofauna of the Mediterranean and other temperate and cold-water seas (2–6%). It reflects the presence of many herbivorous species, such as rabbitfishes (Siganidae), surgeonfish (Acanthuridae), parrot fishes (Scaridae), and many species of blennies (Blenniidae) in warm seas. In temperate and cold-water seas, only a few fish species feed exclusively on plant material (Fig. 1).

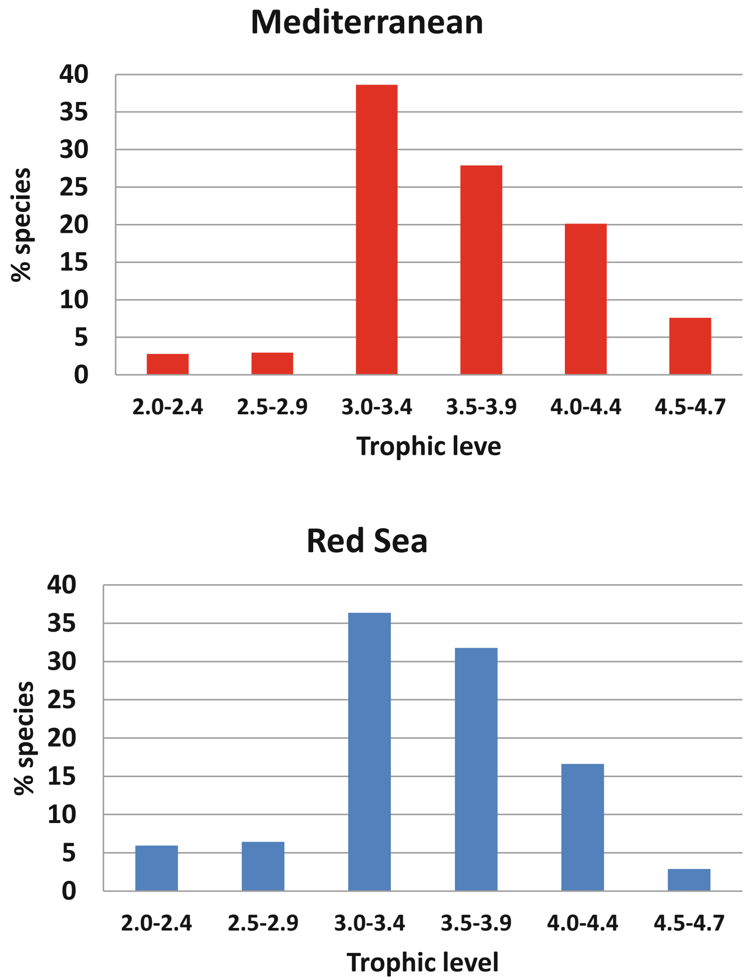

Fig. 1 A comparison of the proportional distribution of the trophic guilds in the Red Sea (**a**) and the Mediterranean (**b**)

7 Interspecific Association

Most Red Sea fish species are dependent for survival, directly or indirectly, on coral reefs (see above), and the great majority of them live in association with a variety of taxa found on the reef. Karplus (2014) counted eight categories of associations of fish with bacteria and invertebrates. The majority of associations are between fish and cnidarians: e.g., *Dascyllus aruanus*, *D. marginatus*, *Scorpaenodes guamensis*, *Amphiprion bicinctus*, and many gobies and blennies. Other types of common association are those of young cardinal fishes seeking shelter among the spines of sea stars (especially *Diadema setosum*) and that between gobies and alpheid shrimp.

The Gobiidae, the richest family in the Red Sea (11.3%), presents the highest proportion of obligatory association with invertebrates. Goren (1986) reported that out of the 85 gobiid species known at that time from the Red Sea, ca. 19% were obligatory alpheid shrimp associated, and ca. 18% were obligatory cnidarian or sponge associated. The present study has revealed similar proportions (21 and 18%, respectively) although the number of reported gobies has increased to 143 species. The nature of the association between fish and other organism varies among and between taxonomic groups. A fundamental review of these phenomena was published by Karplus (2014).

Associations of fish with other fish species are also common in the Red Sea. Some associations express mutualism, such as the case of the very common "cleaning stations" of the bluestreak cleaner wrasse (*Labroides dimidiatus*), which are always observed with many "clients" awaiting treatment (the removal of parasites) surrounding the station (Slobodkin and Fishelson 1974). Another type of association is that of mimetic fish, which can be observed inserting themselves into schools of another species in order to get closer to their prey. A common species of this type, in the Red Sea, is the Persian blenny (*Ecsenius midas*), which can often be seen among schools of the sea goldie (*Pseudanthias squamipinnis*).

8 Fishery in the Red Sea

The Red Sea is an oligotrophic sea. The primary production is low throughout its area although the southern part is richer than the rest of the sea due to an inflow of nutrient-rich water from the Gulf of Aden. The rest of the sea, however, does not receive much runoff water from the surrounding regions and thus receives very little continental nutrients. A decreasing gradient of primary production from south to north has also been reported (Levanon-Spanier et al. 1979; Halim 1984; Sanders and Morgan 1989).

Fishery in the Red Sea is mainly artisanal, with a very poor catch (with the exception of Saudi Arabia and Yemen). The total fishery in the Red Sea in 1976 was ca. 39,000 tons and had gradually increased to ca. 61,000 tons by 1986 (Sanders and Morgan 1989). By the mid-1990s, the catch in most countries had reached its maximum and then dropped (Fig. 2). The estimated total catch in 2010 was ca. 137,450 tons (calculated from Pauly and Zeller 2016). The sharp increase in the catch during the 1990s was apparently due to the introduction of many trawlers into the Red Sea, most of them Egyptian, which trawled along most of the western coasts of the Red Sea (including Sudan and Eritrea). In the last decade, the catch in the Red Sea has been gradually increasing and reached ca. 158,000 tons in 2017 (fish only, calculated from FAO 2019). The main source of fishes is that of species living in or around coral reefs, most of them belonging to the fish order Perciformes (Heileman and Mistafa 2008). This emphasizes the importance of the coral reefs as a contributing component in supplying protein for the surrounding human population.

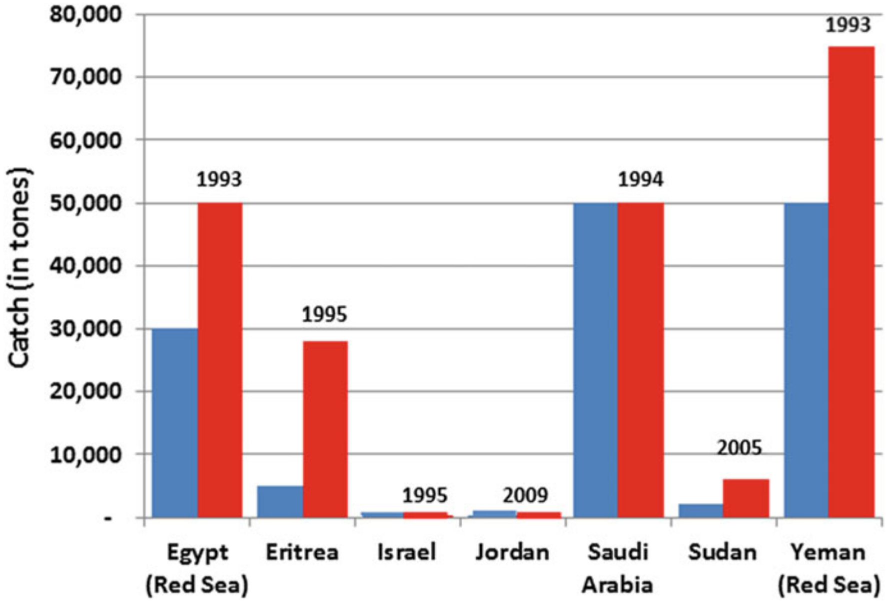

Fig. 2 Fish catch in the various Red Sea countries in 2010 (in blue) and the maximum catch (in red). Numbers above the red bars indicate the year with maximum catch (data extracted from Pauly and Zeller 2016)

9 Closing Comment: Conservation in the Red Sea

The Red Sea is a closed sea with a unique geological and ecological history and unique ecological conditions. Its isolation and small size make the sea highly sensitive to anthropogenic impact. Eutrophication caused by human effluents, overfishing, oil spills, and coral-reef quarrying, in addition to global climate change and sea level rise and the ever-increasing marine transportation are severely affecting the biota of the Red Sea. Even minor disturbances can trigger significant chain reactions over a large area, which impact the communities that dwell in it. In light of all the above, the conservation of the Red Sea habitats should involve scientists from all the surrounding countries, as well as from those countries and companies that own the numerous vessels that pass through the Red Sea and have an ethical obligation to conserve it for all future generations.

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