H: Indian Ocean

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1. TOPOGRAPHY*

The present chapter includes the coastal waters of the Indian Ocean and adjacent seas from Cape Agulhas, South Africa, to the Thailand-Malaysia border (*c.* 6.4°N lat., 100.1°E long.), the southern coasts of Indonesian islands bordering the Indian Ocean, and the west coast of Australia. Also included are the Red Sea, Persian Gulf, and the banks and waters surrounding the islands of the Indian Ocean. (Some of these boundaries, particularly round Ceylon and Australia, which have been used for past statistical tabulation and in this study, are likely to be amended for future statistics.)

The areas of the shelf and slope regions to the 1,000 m depth contour are given in Table H1 adapted from the data of Moiseev (1969).

The Red Sea extends in a general northwest–southeast direction for about 2,200 km and has a maximum width of 352 km in the vicinity of Massawa in the south. The average depth of the Red Sea is about 700 m, with some deep pockets exceeding 2,000 m. The northern sector has some shallow areas which are trawlable, e.g. in the Gulf of Suez, but for the most part the northern waters are considered to be too deep for trawling. The continental shelf widens in the central and southern Red Sea and in some areas in the south sector the shelf extends for more than 100 km offshore.

The Persian Gulf is a relatively small body of water covering approximately 239,000 km² with an average depth of 35 m and a maximum depth of 150 m. An indication of the extent of shallow areas is indicated in the northern sector, off Iraq, where the depth is only 8 fm at 46 km offshore.

TABLE H1. AREAS OF SHELF AND UPPER CONTINENTAL SLOPE ON THE INDIAN OCEAN FROM MOISEEV (1969) ('000 KM²))

Area	*Shelf (0–200 m)*		*Upper Slope (200–1,000 m)*	
East Africa	390		440	
South Africa (east of 30°E)		140		100
Mozambique		120		180
Tanzania-Kenya / Somalia		10 / 120		160
Arabian Sea	400		300	
Arabia and Gulf of Aden		80		140
India–Pakistan West Coast		320		160
Bay of Bengal	610		240	
India–Pakistan East Coast		190		140
Burma		250		40
Thailand-Malaysia		170		60
Indonesia	130		100	
Western Australia	380		90	
South Australian Coast (to 130°E)	260		90	
Red Sea	180		200	
Persian Gulf	240		—	
Madagascar	210		100	
Oceanic Islands	(200)		(100)	
Total	3,000		1,600	

Brackets denote approximation.

Except for the relatively wide shelf zones in the eastern sector of the Arabian Sea, the eastern sector of the Bay of Bengal and the northwest coast of Australia, the continental shelf of much of the Indian Ocean and adjacent seas is extremely narrow and in places precipitous. Along the East African coast, the 200 m contour line is in many places less than 4 km from shore. In addition to the narrow shelf, coral reefs and coral outcroppings are found throughout the area, especially along the African coast.

* The boundary between Eastern and Western Indian Ocean around Ceylon has been changed for the purposes of future statistics.

2. HYDROGRAPHY

2.1 Currents

The striking feature of the surface currents in the Indian Ocean is the reversal occurring in the northern parts—Arabian Sea and Bay of Bengal—following the changes in the wind system with the monsoons. This has no close parallel in other oceans.

The current system in the southern Indian Ocean is similar to those in the Atlantic and Pacific. The South Equatorial Current flows westward at around 10°S, dividing as it approaches the African coast. The southward flowing arm branches each side of Madagascar, uniting to form the Agulhas Current. The West Wind Drift, and a weak and rather confused northward flowing current off Western Australia, completes the anticlockwise gyre in the southern Indian Ocean.

In the northern Indian Ocean, during the southwest monsoon (April–September) the Somali Current flows northwards along the coast of Africa as a swift and narrow current; speeds as high as 7 knots have been reported (Swallow 1965). The width of the Somali Current at the Equator has been estimated at 9 km and the current widens to about 74 km farther north. At the height of development, the Somali Current reaches as far north as 12°N lat.; however, most of the water leaves the coast and flows in an easterly direction as the Monsoon Current south of 10°N lat.

In the Gulf of Aden, the flow of the surface current is from the Gulf into the Arabian Sea from June through August. Along South Arabia, the currents are weak and move in an east and northeasterly direction; along India, the flow is in general southerly.

In the Bay of Bengal, the flow pattern during the southwest monsoon period is generally northeast. Upon reaching the continental coast, most of this water turns southward and flows along the continental shelf. South of Sumatra, the current flows southeasterly along the coast of Sumatra and merges with southeast Asian water flowing into the Indian Ocean through the Timor Sea. These waters form the basis of the South Equatorial Current in the Indian Ocean. It should be noted that during some months there is a southerly flow of water along the east coast of India.

The northeast monsoon (October–March) brings about considerable changes in the circulatory pattern, especially in the northern seas. The Somali Current reverses direction and flows southerly from December through February. Surface current flow in the Gulf of Aden is from the Arabian Sea into the Gulf. For much of the northern sector of the Arabian Sea, the surface currents are weak and variable with no one direction generally prevailing. For a brief period, November–December, a weak current flows northward along the coast of India. In the Bay of Bengal, a cyclonic circulation occupies the entire Bay in February; however, this pattern does not prevail during the entire northeast monsoon period.

2.2 Upwelling

Zones of upwelling have been discovered in various localities throughout the area under consideration. In the Arabian Sea, one of the most pronounced zones of upwelling occurs in waters off South Arabia from Kuria Muria Bay to Ras al Haad during the southwest monsoon. The upwelling appears to be seasonal; there is no evidence that upwelling occurs during the northeast monsoon.

In the Arabian Sea, a second pronounced area of upwelling occurs off northern Somalia within 40 km of the coast (Swallow 1965). Although the cold water is rich in nutrients, there is very little evidence of a high level of biological activity. A high standing crop of plankton is evident only in the northern part of the cold water area, in the vicinity of Cape Guardafui.

In the Bay of Bengal, La Fond (1958) reported areas of upwelling along the east coast of India during the southwest monsoon. Wyrtki (1961) indicated that some upwelling seems to develop in the Andaman Sea during the northeast monsoon.

Possibly the most important upwelling occurs in the eastern Indian Ocean south of Java. Wyrtki (1962) estimated the extent of the area of upwelling as 400 km wide and 1,200 km long. He computed the rate of flow of water as 2.4 million m^3/sec.

Another area of upwelling in the eastern Indian Ocean occurs off the northwest coast of Australia. Rochford (1962) showed that in the area of upwelling the inorganic phosphate values in the surface waters measured 0.3 μg at/l, values considerably higher than the 0.1 μg at/l for adjacent waters.

A general review of the upwelling areas of the world, and their biological productivity has been given by Cushing (FAO, 1969).

In addition to the areas listed by Cushing, there appears to be an important upwelling area off southwest India (Banse 1968).

3. PRIMARY PRODUCTION

Except for some areas along the west coast of India, eastern south Africa (Burchall 1968), and the west coast of Australia, very little published information is available on primary production of coastal waters in the Indian Ocean. Undoubtedly, efforts during the International Indian Ocean Expedition (IIOE) have added considerable amounts of biological and oceanographic data to the fund of information of the Indian Ocean; however, data on phytoplankton and zooplankton are still inadequate for proper evaluation of the total annual standing crop still less of production, in time and space.

Ryther and Menzel (1965) provided some indication of the richness of the waters off South Arabia. On two stations occupied off the Gulf of Oman, they obtained values of 5.7 and 6.4 gC/m^2/day, values which compare favourably with waters off Peru. As shown in the Atlas of the Arabian Sea for Fishery Oceanography (Wooster *et al.* 1967), data on primary production in the Arabian Sea are sparse and inadequate to provide anything but a general indication of the production of the northern Arabian Sea. For the June–July–August period data, only five C^{14} observations were available to Wooster *et al.* (1967). Undoubtedly, more measurements have since been made; to date these data have not been made available. It is doubtful, however, that all of the observations made to date add to a large total.

Subrahmanyan (1959) provides the only estimate of the phytoplankton production for the entire west coast of India. He considered an area 1,200 mi (2,000 km) long (coastline of west India) by 50 mi (90 km) wide and estimated the production to be 1.813 million tons, wet weight.

4. ZOOPLANKTON

Much of the zooplankton data collected during IIOE are still being processed and analyzed. It is doubtful, however, that these data are sufficient to give more than a generalized view of the zooplankton distribution in coastal waters of the Indian Ocean. Tranter (1962) estimated the average standing crop of zooplankton from the Australian continental shelf waters as 100 mg/m^3 and less than 50 mg/m^3 for the open ocean. He further indicated that the waters of the upwelling area off northwest Australia were as rich as waters over the continental shelf.

The standing crop in the Indian Ocean was included in the world summary given by Bogorov *et al.* (1968). These studies show few rich areas in the Indian Ocean. A density of 200 mg/m^3, found in most of the fertile areas of the North Atlantic and North Pacific, and a large part of the upwelling areas off the western Americas and west Africa, is reached in the Indian Ocean only on a narrow band along the western Indian peninsula, and off southern Arabia. The general level in the coastal as is 100–200 mg/m^3.

5. FISH STOCK AND FISHERIES

The marine catch from the Indian Ocean and adjacent seas is about 2 million metric tons (see Appendix Table H6). On the basis of yield per unit surface area, the Indian Ocean yield was only about 1/5 of the Atlantic and the Pacific yields (FAO, 1967a). Much of this relatively low yield can be attributed to the low level of fishing effort, using for the most part primitive gear of the type employed in subsistence fishing. Fishing in many parts of the coastal waters of the Indian Ocean, especially along Africa, is still carried out in non-motorized boats with simple gear. Large-scale fishing with large vessels is confined to (1) the high seas longlining for tunas and billfishes conducted by fishermen of Japan, USSR, China (Taiwan) and more recently Korea, and (2) bottom trawling and purse seining, in the Gulf of Aden and waters off south Arabia, by USSR, southern European and Japanese fishing vessels, though this has been effectively halted since the closure of the Suez Canal in 1967.

5.1 The fisheries

(a) East African Coastal Region (South Africa, Mozambique, Tanzania, Kenya)

Much of the fishing carried out along the east African coastline is of a subsistence type and confined to the immediate coastal waters. Presently, the fish species exploited include *Sardinella*, seerfishes, sharks, and various demersal and pelagic fishes which are caught throughout the area. Recent attempts to catch sardines and other small schooling pelagic fish with purse-seines and stick-held dipnets (bouke-ami) using light in Tanzania waters have met with fair success. Catches in the purse-seine fishery have averaged 1.8 tons/boat/night during the period 1963–6.

Very little experimental bottom trawling has been conducted in this area. For the most part, the results have been negative and indicate that trawl gear cannot increase the fish yield in east African waters. The lack of success has been attributed to the extensive coral outcroppings in this area and to the narrowness of the continental shelf. Trawling, however, should not be ruled out, since most of the trawling was done by large vessels working in shallow depths. It is possible that successful results could be achieved with small trawlers. A similar situation existed in the Gulf of Thailand, where only after the introduction of offshore trawling with small boats and small nets did the fishery flourish (Tiews 1966).

(b) Arabian Sea

Very little fishing is carried out in western Arabian Sea, more because of the lack of markets for a local fishery than through lack of fish. A rough estimate of 100,000 tons has been made for the catch of sardinella in Muscat and Oman, caught close along the shore. Recently a number of long range trawlers from Greece, USSR and Japan have worked off the southern coast of Arabia and northeast coast of Somalia, reporting catches of some 30 tons/day; the number of those ships has decreased since the Suez Canal was closed.

Important shrimp fisheries, discussed in detail in another chapter, have developed in waters off Iran and off Kuwait, Qatar, and other Arabian States and along the Pakistan and Indian west coast.

The Indian west coast also supports important traditional fisheries, particularly the seasonal fishery for sardinella and mackerel. This fishery, and the other fisheries for shrimp and bottom fish, are all carried out by medium to small vessels with a limited radius of action.

(c) Bay of Bengal

In the northern parts of the Bay of Bengal the fishing season begins in November and ends in February, principally because of the rough weather brought on by the southwest monsoon. The fishing gear consists primarily of drift nets, set nets, stake nets, and longlines. Trawling for demersal fish is conducted throughout the area. The most important fishery in East Pakistan is for the threadfin (*Polynemus indicus*).

The fishery resources along the Indian Ocean coast of Thailand were until recently virtually untapped. Marketing problems, primarily resulting from the long distances from population centres, and the emphasis on trawling in the Gulf of Thailand have until recently retarded the development of the west coast fisheries.

The Thai fishery in this area has expanded very rapidly since 1966, many fishing boats being transferred from the east coast, and newer and larger boats (20–25 m) have been built. 1967 catches of mackerel (*Rastrelliger*) by Thailand were around 45,000 tons. The longer established Malay fishery in the Strait of Malacca is at present at around the same level.

(d) Indonesia

The estimated catches for the southern coasts of the Indonesian islands bordering the Indian Ocean are provided in Appendix Table H6. The catch for Indonesia was obtained by taking 25% of the total Indonesian marine catch. The basis for this separation is that the available literature, which is extremely limited, indicates that most of the fishing takes place in the northern waters. The important species include sardines, anchovies (*Stolephorus* spp.), mackerel, mackerel scad, and skipjack tuna. One of the most important fisheries for sardine occurs in the strait between east Java and Bali. All the fishing is carried out by small boats, usually close to shore and with simple equipment.

(e) Western Australia

The catches of fish (in the narrow sense) round western Australia are very small. Some catches of Australian salmon (*Arripis trutta*) are taken inshore along the southwest coast, and local fishermen take a variety of other species in small quantities. Japanese trawlers have worked occasionally off the northwest coast. The large fisheries are for crustaceans, which are discussed in the relevant chapter. The stocks of crayfish (spiny lobster, *Panulirus cygnus*) seem fully exploited in the present areas, but offer potential for expansion from Shark Bay and Exmouth Gulf northwards. The shrimp fishery has been expanding steadily northwards to Shark Bay and Exmouth Gulf.

(f) Red Sea

Presently the major fisheries in the Red Sea are the sardine fisheries in the northern part of the Red Sea, and along the Ethiopian coastline, and the bottom trawl fishery in the southern waters of the Red Sea. Ben Tuvia (MS), who provides the most comprehensive review of the fisheries in the Red Sea, indicated that the northern waters did not appear to be productive enough to support much more than is being taken at present. To date, efforts to harvest tunas in commercial quantities with purse-seine, longline, and gillnets have met with little success (Ben-Yami 1964). Also, the purse-seine and light method used successfully to catch sardines and other small pelagic fishes in other areas has not been very successful in the Red Sea.

(g) Islands and banks

With some exceptions, e.g. the trawl fishery of Ceylon and a small tuna fishery operating from Minicoy Islands in the Maldive Island Chain, most of the island fisheries have been of the subsistence type using predominantly handlines, set nets, and traps, catching a variety of species, mainly bottom living species. In Madagascar, a shrimp fishery for export has recently developed.

5.2 Statistics

Basic catch and effort statistics are virtually non-existent for much of the Indian Ocean. In many areas, some subsistence fishing undoubtedly goes unreported, thereby under-estimating the reported total catches. In other areas, e.g. Burma, the reported catch has not changed over the years, a condition highly improbable and one which indicates a lack of adequate data.

The fisheries of western Australia, especially the crustacean fisheries, have probably the best statistics; fair statistics are also available for the fisheries of India. Long-range fishing, except for tuna, is still very uncommon, so that information on place of landing also gives good information on place of capture.

5.3 Stock assessments

(a) Demersal fish

The Wadge Bank off southern tip of India, with an area of 4,000 n.mi^2 (13,500 km^2) is one of the few areas where even approximate assessments can be made. It has been fished for many years by trawlers from Ceylon, and there exist good records of these operations, which have been going on, with interruptions, for some 50 years (Mendis 1967). It has also been fished by Indian vessels from Tamil Nadu and Kerala coasts, but statistics of these catches are not available.

Until 1966, only two or three trawlers operated, but recently five new stern trawlers have been added to the fleet. The total catch in 1967 was 2,000 tons, compared with peak production in early years of under 1,500 tons. (These figures exclude quantities of low valued fish rejected at sea, estimated by Mendis as some 20%).

Sivalingam (1966, MS) has studied the relation between the amount of fishing and the catch per unit effort, considering separately three groups of species; the larger resident species (snappers, etc.), smaller resident species, and migrants (mainly carangids), the last being only caught in quantity during the southwest monsoon. For the big fish, he noted a decline in both catch per unit effort and average size when fishing was increasing, and deduced that the maximum sustained yield of these species was around 500 tons. The catch per unit effort of smaller species showed no decline, probably because of a shorter life-span, less intense fishing, and a possible switch in fishing attention onto these as the larger species declined. Though in the period studied the smaller species never totalled more than half the larger species, it is probable that their potential is as large. The heavily exploited area is only a fraction of the total bank —estimated by Sivalingam (MS) as 1,250 n.mi^2 out of the total of 4,000 n.mi^2. The density of the unexploited areas is presumably less, but even if it is only half that of the exploited areas the total potential in the former areas would be slightly greater. Altogether, making some allowance for migration between exploited and unexploited areas, the total annual potential of the two first groups of species on the whole bank may be rather more than five times the potential of big fish in the exploited parts, say 2,500–3,500 tons.

The most recent information of the species composition of the trawl catch has been given by Fernando (1970); 66% were resident species, the rest being migrants, appearing only in the southwest monsoon, nearly equally divided between carangids, elasmobranchs, and catfish (*Netuma thalassinus*). Since the migrants appear in the catches for half the year only, it is a reasonable supposition that the ratio of potential to present catch is twice that for resident species. This implies a total potential of 5–7,000 tons.

Two independent estimates of the fish stocks have been made. Mendis (1965) estimated the total standing stock, from trawl catches, and the area swept by the trawl, as 18.5 million lb, or 8,500 tons. Using the formula, potential = 0.5 × unfished standing stock × natural mortality, this would be consistent with the above estimate if natural mortality were 1.2–1.6; these seem rather high, but Mendis' data referred to a period of moderately heavy exploitation, when the standing stock would be less than in the unfished condition. The two estimates are, therefore, in fair agreement.

Mendis (1967) also obtained estimates, based on the primary production, of the potential fish production of 54 million lb (25,000 tons) of all species of fish, 65% of which would be good quality. This estimate is very sensitive to the precise figure used for the efficiency of transfer from one trophic level to another, as well as to the position of the fish in the food chain. It, therefore, agrees moderately well with other estimates, but suggests that the upper figure (7,000 tons) is perhaps the more likely. This implies a potential of bottom fish of about 5 kg/ha.

A rough assessment can also be made for the area off Karachi. Zupanovic (FAO internal reports) has noted that locally fishing appears very intense, and the local stocks are probably fully exploited. This applies only to depths out to about 15 fm (30 m) and to the area close to Karachi, i.e. to a strip about 20–25 n.mi wide, and perhaps 80–100 n.mi long, with an area of *c.* 7,000 km². Landings of demersal fish at Karachi averaged around 20,000 tons in 1965–7, presumably mostly from the heavily fished area, equivalent to a yield of a little under 30 kg/ha. Assuming that this could be increased somewhat by better management, the potential might be as much as 40 kg/ha.

Exploratory fishing: Ocean islands and banks

A quantitative survey of the ocean banks, e.g. by trawling, is made difficult by the rough ground. Wheeler (1953) lost three trawls without catching a fish, and based his estimates of standing stock on line fishing. His technique was to allow the ship to drift sideways, thus effectively sweeping an area equal to the length of the drift times the width, taken as 40 ft, the distance apart of the outside lines. Clearly this could easily result in over-estimates if fish are attracted in from outside the path (especially likely for sharks), or an under-estimate if not all the fish in the path take the bait. In particular, the smaller fish will be greatly under-estimated. However, the data do provide a first estimate of the standing stock.

These estimates, derived from the data of Wheeler (1953, section VI) are given in Table H2. The totals differ from his totals of 1.1 million tons of fish, and 0.8 million tons of sharks because there appears to be an arithmetical mistake in his estimate for the Sava de Malha corpus. Making allowance for the other banks and islands, e.g. the Maldives, not included in Wheeler's study, suggests a total standing crop of about 0.5 million tons of larger bottom fish and sharks.

For sharks, the above figures are more likely to be an over-estimate than an under-estimate of standing crop; also, due to the low fecundity and long life of sharks the potential yield is probably a small fraction of the unexploited standing stock. Probably the potential yield on the banks is no more than around 100,000 tons, unless there is continual immigration from the open oceans.

For the other fish (*Lutianus* spp., *Lethrinus* spp., etc.), the standing stock is less likely to be over-estimated, and the potential is likely to be a bigger fraction of it. Little is known of the average life-span of these fishes. There is some general experience with reef fisheries that initially high catch rates cannot be maintained, which suggests a

TABLE H2. ESTIMATES OF STANDING CROP OF LARGE FISHES AND SHARKS AROUND THE ISLANDS AND BANKS OF THE WESTERN INDIAN OCEAN (DERIVED FROM WHEELER 1953)

	Fishable area (*n.mi²*)	*Tons/mi²*		*Total standing crop (tons)*	
		Fish	*Sharks*	*Fish*	*Sharks*
Chagos					
Speakers Bank	216	39.4	48.3	8,510	10,432
Peros Banhos	117	31.2	4.5	3,650	526
Great Chagos	2,000	41.3	65.3	82,600	130,600
Pitt Bank	100	5.6	53.1	560	3,310
Total	2,433			95,320	144,868
Oceanic Banks					
Hawkins Bank	70	1*	30*	70	2,100
Soudan Bank	240	8.5	5	2,040	1,200
Nazareth Bank, south	900	8.5	6.9	7,650	6,210
Nazareth Bank	3,100	22.3	7.5	69,130	23,250
Sava de Malha, coccyx	100	2.1	62	210	6,210
Sava de Malha, corpus	4,450	26.9	18.3	119,705	81,435
Sava de Malha, cervix	700	48.4	65	33,880	45,500
Sava de Malha, caput	150	26	67.3	3,900	10,095
Fortune Bank	126	5.2	84.3	655	10,622
Constant Bank	200	8.8	41.5	1,760	8,300
Anivantes	640	26.6	23.7	17,024	15,168
Total	10,676			256,024	210,090
Seychelles	3,000	15.5	18.7	46,500	56,100
Total (n.mi²)	16,109	24.7	25.5	397,844	411,058
Total (km²)	55,300	7.2	7.4		

* Estimated from catch per man.

low rate of replacement, and presumably also of mortality. However, the natural mortality in tropical waters, even of relatively long-lived fish, may be higher than is common in temperate waters, so that the potential may be half to a quarter of the unexploited standing crop. Allowing for some under-estimation of this latter, the potential of the larger bottom fish may be around half the estimated standing crop, in Table H2, i.e. 0.25 million tons (the figures of 9.8 and 2.8 million tons given by Wheeler appear to be due to a confusion between total quantity and quantity per mi^2, on the Soudan Bank). This is equivalent to about 12 tons per mi^2 or 3.5 tons per km^2. This is about a little greater than the existing yields estimated by Wheeler for the waters around Mauritius (10 tons/mi^2), which were believed to be over-exploited.

No estimate is possible of the potential of the smaller reef fishes, not vulnerable to the type of line fishing used by Wheeler.

Coastal trawling

In the western Indian Ocean (off the Arabian and African coasts) little exploratory fishery has been done. Some experimental trawling has been done by Kenya and by the East African Marine Fisheries Research Organization. Catches of teleosts have been light, and this may be attributable to the clear water, and the fact that most of the demersal fish live near the coral, where trawls cannot be used.

In the northern and eastern part of the area—in the arc from West Pakistan around India to Malaysia—there has been during the last decade a large amount of exploratory and research trawling, much of which, and also a summary of earlier surveys, was reported to the 1968 IPFC Symposium on Demersal Resources (Rao 1970). These operations were carried out by a variety of different vessels, using a wide range of gears, and operating in different ways—on a semi-commercial basis, with fishing concentrated on the best areas, or on a predetermined grid, etc. Too much, therefore, should not be made of these data in the way of detailed comparison between areas, though they can be used to provide a rough guide to the potential, particularly the species composition, and the depth distribution.

Exploratory fishing off West Pakistan has been described by Hussain *et al.* (1970); these operations, by M.F.V. *Machhera* (52 tons, 120 hp engine) were restricted to waters within 70 mi. In some areas, e.g. off Karachi, catch rates have been falling during the period of the surveys (1960–7), and this decrease appears to be due to the heavy fishing there. The average catch per hour was 44 kg—or 0.37 kg/HP/hour. Of this a proportion 10–30% was inedible or unmarketable fish which were discarded at sea.

Further exploratory fishing in the offshore waters of West Pakistan (outside 12 mi, down to 1,000 m) was carried out in the early part of 1969 by USSR vessels, in collaboration with Pakistan. In the western part, to the Ras Malan Cape the narrow shelf and steep continental shelf offered no suitable trawling grounds. In the other part, off Karachi and the mouth of the Indus, some good catches were taken. Between 25 m and about 100 m catches by the vessels (RTM and SRTM type) were around 1.0–1.5 tons/hour or about 0.2–0.3 kg/HP/hour. Beyond 100 m catches tended to decrease, becoming small at 300 m, and the limited number of hauls between 800 m and 1,000 m caught virtually nothing.

The results of the exploratory fishing by Government of India vessels between 23°10′N and 15°N has been summarized by Rao *et al.* (1970). The larger vessels (*c.* 300 bhp, 120 GRT) averaged 194–387 kg/hour in different latitudinal zones, the lowest being at 18°N, south of Bombay, and catches increasing to the north and south, being approximately equal at 22°N (365 kg/hour) and 15°N (387 kg/hour). Some, at least, of the differences may be due to the heavier fishing around Bombay.

In terms of depth, best catches were between 50 and 60 m (365 kg/hour), decreasing to around 100 kg/hour both in deeper water (80–90 m)—though few hauls were made at this depth—and in shallow water (<10 m)—though the smaller vessels may have made relatively more hauls on these depths. There appeared to be a tendency for the optimum depth to increase from south to north.

Slightly different variations of catch rates with depth for catches by commercial bull-trawlers from Bombay were noted by Rao (1969). Most fishing (*c.* 78%) was done between 25 and 45 m, with catches around 900 kg/hour. About the same weight per hour was caught in shallow water, but were less valuable species—nearly half of those in the 16–20 m zone were elasmobranchs. Catches in deeper water decreased to only 420 kg/hour in 71–75 m, the deepest zone fished.

The seasonal range in catch rates was relatively small, perhaps surprisingly so in view of the big environmental changes due to the monsoon; the best month was August (310 kg/hour) and the worst January (166 kg/hour).

Trawling in the south-western region (from Cape Cormorin to 15°N) has been described by Rao (1967, 1969). The area includes some rich shrimp grounds, discussed separately, but fish catches were rather poor, around 100 kg/hour, but higher in the north (off Mangalore) mainly of small sized uneconomic varieties. Towards the end of 1967 the surveys were extended into deep water off Cochin where good catches of deep sea prawns (*Parapandalus, Aristacus,* etc.) were taken (Rao 1970), but it is not known how large the fish catches were.

Catches off the east coast of India have been discussed by Rao (1969). Catch rates tended to increase from south to north, and were generally lower than on the Indian west coast. Government of India vessels from the Tuticorin base operating between Cape Cormorin and Pondicherry (12°) averaged 106 kg/hour in 1961–5, those from the Visakhapatnam base (mainly fishing between 17°N and 21°N), averaged 120 kg/hour. Rather higher rates (210 kg/hour) were achieved by Indo-Norwegian Project vessels fishing in the Gulf of Nannar and Palk Bay, but nearly all the catch (over 90%) were low valued silver bellies (Leiognathidae).

Surveys in the northern part of the Bay of Bengal have been carried out in collaboration between FAO and West Pakistan (FAO 1965, internal reports of the UNDP(SF) project). The best fishing (up to 500 kg/hour) is in a band about 20 km wide between 5 and 30 fm (10–60 m), extending from off the Indian border to

Coxes Bazar. Catches in water deeper than 60 m were very poor.

Observations off southern Burma have been reported by Druzhinin and Hlaing (1970). Catches of F.V. *Linzin* (250 tons, 500 hp) averaged around 200 kg/hour, being rather higher in the southern (around 13°N), than in the northern (*c.* 14°N) part of the survey area.

Finally exploratory fishing has recently been carried out by Thailand off her west coast; catches have been comparable with those in the Gulf of Thailand in the period before the development of large-scale trawling.

Most of these areas are only lightly fished for demersal species, except very close inshore. The exception is off the west coast of India and Pakistan, especially near Bombay and Karachi, where fishing is intense; despite this, catch rates in the area are good. Fishing is also heavy around Cochin, mainly for shrimps, and the catches of fish are poor. It appears, therefore, that the parts of the Indian Ocean Shelf area covered by these surveys can be roughly grouped into three classes:

Rich: Exploited—fair catch rates (over 200 kg/hour), India–Pakistan west coast, from Karachi to *c.* 15°N
Fair: Little exploited—fair catch rates; or exploited—poor catch rates, Indian west coast, south of 15°N; northern and eastern coasts, Bay of Bengal
Poor: Little exploited—poor catch rates (150 kg/hour, or less), Indian east coast

To convert these qualitative descriptions into quantitative estimates, the only data from the area are the estimates above—5 kg/ha on the Wadge Bank, and 40 kg/ha off Karachi. The basic productivity off Karachi is higher than on the Wadge Bank, but the difference is not so great as the 1:8 ratio in fish potential. It may be that the lower figure does not take full account of the smaller and less valuable species not sought out by the trawlers.

Two other figures for the Indo-Pacific region have been obtained in the section on the Western Central Pacific—25 kg/ha in the Yellow Sea, and 50 kg/ha in the northern part of the Gulf of Thailand. Putting these together suggests potential annual yields per unit area of 50 kg/ha in the rich zone, 25 kg/ha in the intermediate zone, and 10 kg/ha in the poor zone, though these figures should be considered only as rough approximations, with a range of perhaps $\pm$ 50%.

These estimates, again in default of anything better, may be extrapolated to other parts of the Indian Ocean. To the westward, it appears likely, from the oceanographical conditions, that the richness of the grounds off the northwest Indian peninsula is continued round the coast of the Arabian Sea, including the east coast of Somalia, probably as far as 5°N. The rest of the coast of east Africa south to the Zambesi appears to be unproductive; in any case, the shelf is narrow, so that the total bottom resources are small and the steepness and roughness of the bottom makes bottom fishing, at least with nets, difficult. Further south, the potential may be rather higher. In default of further evidence the density of stocks round Madagascar will be assumed to be similar to that off the African coast.

These very rough estimates for the bottom resources of the western Indian Ocean may be summarized as in Table H3.

A similar extrapolation can be made to the southeastward. The area off Malaya is probably similar to that off Thailand, i.e. with a moderate production.

Little is known of conditions along the western coasts of Indonesia, but there is at least local upwelling, and productivity may be high.

Japanese trawlers have worked off northwest Australia, but not very intensely or for a long period, so that the potential is probably no more than average.

The potential of the eastern part of the Great Australian Bight was considered in the chapter on the Southwest Pacific. It appears to be a very poor area, with a potential estimated from exploratory fishing, at only 0.5–3 kg/ha. Probably the southern Australian coast, west of 130°E, has a similar potential of say 2 kg/ha.

The potential bottom fish catches for the eastern Indian Ocean can be summarized as in Table H4—with the reservation that the estimates are in all cases very tentative.

TABLE H3. POTENTIAL DEMERSAL RESOURCES OF THE SHELF REGIONS OF THE WESTERN INDIAN OCEAN

Region	*Area* (*'000 km²*)	*Density* (*kg/ha/year*)	*Potential* (*'000 tons/year*)
South Africa	140	25	350
Mozambique	120	25	300
Tanzania–Kenya	10	10–20	10–20
Somalia (2°S–5°N)	50	10–20	50–100
Somalia (north of 5°N)	70	50	350
Arabia and Gulf of Aden	80	50	400
India–Pakistan (north of 15°N)	245	50	1,250
India (south of 15°N)	75	25	180
Red Sea	180	10	180
Gulf of Iran, Iraq, Kuwait etc.	240	25	600
Madagascar	210	25	525
Total	1,420		4,225
Oceanic Islands (larger fish only)			250
Total, all bottom fish			4,475, say 4,500

TABLE H4. POTENTIAL BOTTOM FISH RESOURCES OF THE SHELF AREAS OF THE EASTERN INDIAN OCEAN

Region	*Area ('000 km²)*	*Density (kg/ha/year)*	*Potential ('000 tons)*
India–Ceylon (south of 20°N)	85	10	80
India–Pakistan (north of 20°N)	105	25	260
Burma	250	25	625
Thailand–Malaysia	170	25	425
Indonesia	130	50	650
Western Australia	380	25	950
Southern Australia	260	2	50
Total	1,380		3,040, say 3,000

(b) Pelagic fish

There seems little doubt that the small shoaling pelagic fish (sardine, anchovies, mackerels, etc.) form a large resource in several parts of the Indian Ocean, especially in the Arabian Sea, and one that is less than fully exploited (e.g. Panikkar and Dwivedi 1966). There is, however, very little information from which this general impression of rich resources can be expressed in a quantitative form.

The biggest present catches of pelagic fish are taken off the Indian southwest coast. The most important species is the oil sardine (*Sardinella longiceps*) of which the catches fluctuated widely. The worst recent year was 1956 (7,400 tons) and the best 1964 (274,000 tons) (Prabhu 1967); in the last few years catches do not seem to have fluctuated so much (Appendix Table H7). The reasons for the fluctuations are not known with complete certainty. Possible reasons are real changes in the abundance of the stocks (year-class changes), or changes in the pattern of migration (nearly all fishing is done close inshore, and if the fish remain offshore catches would be low). Bennett (1968) suggests the fluctuations are of year-class strength, correlated with the abundance of the existing stock.

There is no evidence that fishing is having any serious effect on the stock; equally, the natural fluctuations are such that fishing could be having a large effect without being detectible, especially since the same pattern of fishing—large numbers of small inshore vessels—has been in existence for some time without much change. Also there are no good records of total fishing effort.

The same remarks hold good of the other major pelagic fishery round India, that for Indian mackerel (*Rastrelliger kanagurta*). Fishing takes place on both coasts, and recent catches have fluctuated between 25,000 (1964) and 130,000 tons (1960) (Venkatavaman 1967).

Substantial and increasing catches of mackerel (*R. kanagurta* and *R. neglectus*) are being taken by Thailand and Malaysia on the eastern side of the Bay of Bengal, and in the Strait of Malacca; it is believed (Menasveta personal communication) that the Thai and Malaysian fishermen, each taking 40–45,000 tons of fish in 1967, are harvesting the same stocks of mackerel. Stock assessment studies carried out by Thai scientists suggest that this stock is being exploited at about the optimum level, and little increase of total catch can be achieved. The Thai fishery on the Indian Ocean coast has developed very recently, and though results of stock assessment studies are not yet available, it is likely the effects of this new fishery will soon become apparent, and enable some quantitative estimate of the resources to be made.

In the other fisheries in which substantial quantities of pelagic fish are probably caught along the coast of the Arabian peninsula, and off Indonesia, reliable information even of total catch is not available, still less any data from which assessments could be made.

Eggs and larvae

Wide-spread collection of fish eggs and larvae were made during the International Indian Ocean Expedition (IIOE), but have not yet been fully worked up and published. An analysis of the numbers of eggs and larvae, without distinction of species, has been made by Peter (1967). The maximum concentration of eggs (over 400/haul) occurred east of Socotra Island, and in the Gulf of Oman. Larvae were common in these areas, and also off the central part of the Indian west coast, and at the head of the Bay of Bengal. A preliminary examination has been made of the species composition of samples from 50 stations by Ahlstrom (1968). These were grouped into three zones—oceanic (19 stations), intermediate (27 stations) and coastal (4 stations).

The oceanic stations were dominated by larvae of deep sea fishes, two families (Myctophidae and Gonostomatidae) accounting for three-quarters of the larvae caught.

The intermediate stations also contained large numbers of these families, but in addition numbers of anchovies (12% of the total) and of several predominantly demersal families (*c.* 20% in all) were caught.

In the very limited number of coastal stations anchovies again accounted for about 13% of the total, and nearly all the other identifiable larvae belonged to bottom-living groups (Scorpaenidae, etc.).

A surprising feature of the collection, noted by Ahlstrom, was that only one clupeoid larvae was found, and no specimens of *Rastrelliger*, though a few *Rastrelliger* larvae had previously been identified by Peter (1967) in other IIOE material.

The data are too few to attempt quantitative assessments, but some general conclusions seem valid.

(a) As in other regions, myctophids and gonostomatids form a major resource in the oceanic areas.

(b) There is a large resource of engraulids (anchovies).
(c) The oil sardine and mackerel resources are not extremely large, and their potential may not be much above present catch levels.
(d) In the coastal zone the demersal species may form the bulk of the potential fish resource.

The distribution of both eggs and larvae, without separation by species or family, has also been shown in charts issued after the Indian Ocean Expedition (Anon 1970), covering the whole Indian Ocean. The larval distribution shows high abundance in the north-western area (from Mombasa around to Muscat), and also off southern India. More surprising features are the high abundance (over 100 larvae per haul) in the western Bay of Bengal, and the relatively low abundance (less than 25 per haul) southwest of Indonesia.

Another approach to the estimation of resources is from primary production.

On the basis of some measurements of primary productivity in the Arabian Sea area, Schaefer (as reported in FAO. 1967) indicated that the potential yield from the Arabian Sea could be as high as 10 million metric tons. The study made by Subrahmanyan (1959) is interesting in that it represents another estimate of the potential yield from a relatively large portion of the coastal waters of the Arabian Sea. On the basis of his studies on phytoplankton, Subrahmanyan estimated the phytoplankton production along the 1,200 mi (2,224 km) coast of India and extending offshore for 50 mi (93 km) as 1.8×109 metric tons. Subrahmanyan indicated that the annual catch of fish from the west coast of India for the period 1950–4 was about 455,000 tons; the fish catch was thus computed to be 0.025% of the phytoplankton production. He compared this ratio with that for the English Channel, an area of intensive fishing. For the English Channel, Subrahmanyan stated that the 1928 fish catch was 71,000 tons and the phytoplankton production was estimated at 15 million tons. If the assumption is made that the fish-phytoplankton relationship of 0.06% for the English Channel is a reasonable average figure, then the fish yield from the west coast of India could be increased by a factor of 2.5 to 1.119 million tons. This is approximately equal to the estimated demersal potential of the area given in Table H3.

Cushing (FAO, 1969) in his review of the upwelling areas of the world estimated that the carbon fixation in the upwelling areas of the western Indian Ocean was 70×10^6 tons, with a corresponding estimate of production at the tertiary level of around 10×10^6 tons wet weight. He also gave corresponding estimates for the area of northwest Australia and Java, of 50×10^6 tons carbon, and $7–8 \times 10^6$ tons wet weight of tertiary production. He believed that half to one-third of the production could be harvested by man, giving estimates of say 4 million tons in the Arabian Sea, and 3 million tons in the Java–Australian zone. Probably, in common with other upwelling areas, most of the production is of pelagic fish. This is in general agreement with the demersal estimates in Tables H3 and H4 of 0.65 and 1.6 million tons respectively; these would imply other potential resources of about 3.5 and 1.5 million tons, most of which are likely to be shoaling pelagic fish. These estimates are probably as reliable as can be obtained with present information.

Off the Indian west coast, the egg and larval data, and the close agreement between estimated demersal potential and potential estimated from primary production suggest that the pelagic potential is not very great. A guess might be a little higher than recent catches, say 500,000 tons, though this could be an under-estimate.

In the Bay of Bengal, and eastward to Malaysia, there is very little evidence concerning the pelagic potential. In the northern part, off East Pakistan, vessels of the FAO/UNDP project have noted echo traces in mid-water, which might be small fish or zooplankton; though extensive they are rather diffuse and do not suggest a very promising resource. Also the traces do not extend far offshore over the deeper water. Probably in this area the pelagic resources of shoaling fish (sardines, mackerel, etc.) are rather less than those of demersal fish, and may be of the order of 1 million tons, for the whole Bay of Bengal.

In the extreme southeast of the Indian Ocean, south of the Indonesia-northwest Australian upwelling area, there is again very little information on pelagic fish. The estimate of demersal potential, principally derived from limited exploratory fishing on the Great Australian Bight is very low—50,000 tons. The pelagic potential may not be much higher—say of the order of 100–200,000 tons.

The western side, off the African coast south of the Somalia upwelling area, does not appear to be highly productive. The nature of the coast generally with a steep and narrow concentrated shelf suggests that the pelagic resources are likely to be rather larger than the demersal ones—estimated in Table H3 as 730,000 tons. One million tons is a round figure which might be a fairly reasonable estimate.

Mass mortalities

A feature of the northwest Indian Ocean has been the occasional occurrence of dead fish on the surface over wide areas. The most striking such mass mortality occurred in 1957 when quantities estimated as high as a million tons occurred in the central Arabian Sea between 60° and 70°E, and 10° and 20°N (Pannikar and Dwivedi 1966). The species concerned have not been definitely identified, but the occurrence confirmed the existence of large fish resources of some kind in the area.

A more local mortality has been reported by Foxton (1965), who found large numbers of small inshore species (mostly porcupine fish, *Cyclicthys echinatus*) close inshore between 9° and 12° along the Somali coast, probably killed by the upwelling of cold water. The quantity of fish observed was probably consistent with the estimates of potential noted above.

Cephalopods

There is little information about the resources of cephalopods in the area, even in comparison with the same data on fish. Almost certainly the production of larger animals in the upwelling areas will include a substantial quantity of squids, possibly at least several hundreds of thousands of tons.

6. SUMMARY AND DISCUSSIONS

The estimates in the above sections may be summarized in round figures as shown in Table H5 (including also estimates of crustacean and tuna resources taken from the relevant chapters).

These figures should be treated with a fair degree of caution; the tuna and larger crustaceans are likely to be fairly accurate, the others, with the exception of the cephalopods, are probably accurate within a factor of two, and possibly within 50% of the true value. They do show with a fair certainty that present total catches of fish from the Indian Ocean could be greatly increased, even if some individual stocks (large tuna, some shrimp, possibly some local stocks of demersal fish) are fully exploited.

Though most of the observations made on the IIOE are not immediately useful for estimating resources, some of the data could be so used. In particular, the examination of collections of material of eggs and larvae could be carried forward from the preliminary analysis described above to provide a much better estimate of the adult stock and spawning distribution of the major species. Such examination may show whether further egg and larvae surveys, in selected times and areas, might produce useful information at reasonable cost.

Other surveys which appear likely to yield useful results are trawl surveys in the less known areas, especially in deeper water off most coasts, and along the Indonesian coasts. For pelagic fish, echo surveys seem especially promising. Promising traces have been observed by oceanographic vessels off southern Arabia, but a systematic survey, preferably backed up with a fishing vessel with suitable equipment (purse-seine, or mid-water trawl) should provide much better estimates of the magnitude of the resource, and of the practical prospects of developing a fishery. Other fruitful areas for such surveys appear to be off the Indian west coast, especially beyond the range of the existing fishery (this may well reveal whether or not most of the stocks are being exploited) and off Indonesia.

TABLE H5. ESTIMATED POTENTIAL ANNUAL CATCHES ('000 TONS), FROM THE INDIAN OCEAN

Species	*Western Indian Ocean*		*Eastern Indian Ocean*
Demersal fish	4,500		3,000
Shoaling pelagic fish	4,000		2,000
Tunas and skipjack		-300-	
Crustaceans	150		100
Cephalopods	(×100)		(×100)

Much can be done to improve the estimates. Assessments of existing fisheries could be improved by better statistics of catch and fishing effort, plus related data on size and (where possible age) composition, growth, mortality rates and stock separation. While there is a large volume of biological data on fish in the Indian Ocean, little of it is directly related to the commercial fisheries.

TABLE H6. CATCHES FROM THE INDIAN OCEAN ('000 METRIC TONS)

Country	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
South Africa (a)	3	3	3	3	3	3	3	3	3	
Mozambique	3	3	4	4	4	5	5	6	7	
Madagascar	4	4	5	6	8	18	17	17	18	
Tanzania	16	17	19	20	22	29	29	13	12	
Kenya	5	5	5	5	6	7	6	6	7	
Somalia	4	4	4	...	...	...	...	...	...	
Ethiopia	17	14	9	12	15	13	11	...	...	
UAR	...	25	24	18	15	12	...	...	...	
Saudi Arabia	16	18	20	20	19	20	22	25	30	
Southern Yemen	47	54	55	52	52	50	40	46	...	
Muscat, Oman (a)	100	100	100	100	100	100	100	100	100	
Iran	...	...	...	...	...	19	19	...	...	
Pakistan (West)	67	73	76	88	98	131	129	130	150	
India (West coast)	521	487	492	677	654	680	664	700	708	
Maldives	...	...	12	12	20	22	25	24	32	
Ceylon	71	79	88	96	87	97	106	135	...	
India (East coast)	163	157	164	184	171	210	200	204	204	
Pakistan (East)	36	35	42	46	44	44	51	52	58	
Burma	360	360	360	360	360	360	381	396	414	432
Thailand	23	27	32	22	16	30	114	162	...	
Indonesia	105	109	112	118	133	144	136	188	197	
Australia	...	...	...	44	46	56	59	66	55	
Japan	5	127	100	81	91	87	131	126	105	
China (Taiwan)	8	8	9	9	7	4	14	37	38	
Korea	—	—	—	—	—	1	4	12	19	
USSR	—	...	2	5	36	76	38	10	21	
Total (b)	1,530	1,660	1,680	1,960	1,980	2,170	2,260	2,420	2,700	

Notes: (a) Estimates
(b) Includes catches by countries not listed separately
... No data
— Information zero

TABLE H7. CATCHES OF MAJOR SPECIES AND SPECIES GROUPS FROM THE INDIAN OCEAN ('000 METRIC TONS)

Species/Species group	1962	1963	1964	1965	1966	1967	1968	1969
Salmonids	1	6	7	6	6	3	3	8
Shads, etc.	15	15	17	18	19	16	13	13
Flatfish	18	10	7	11	9	8	12	15
Gadoids	3	7	5	7	5	4	3	3
Basses, croakers, etc.	257	257	266	270	337	321	316	346
Bombay Duck (India)	84	92	81	74	77	75	82	76
Jacks, mullets, etc.	...	...	86	77	93	100	87	73
Sardines, anchovies	271	215	431	416	430	407	462	353
Oil sardine (India)	110	64	274	262	253	259	301	174
Oil sardine (Pakistan)	5	6	7	8	9	10	10	12
Tunas	...	...	155	168	179	234	276	231
Mackerels	...	...	30	47	35	75	86	135
Rastrelliger (India)	29	77	24	43	32	29	21	92
Rastrelliger (Thailand)	...	...	6	4	3	46	65	43
Elasmobranchs	80	86	82	83	97	95	99	118
Unsorted and unidentified fish	616	638	661	677	730	763	815	977
Crustaceans	120	121	160	134	156	168	176	202
Shrimps (India)	83	82	95	77	91	92	100	108
Shrimps (Pakistan)	14	14	21	22	22	25	23	26
Molluscs	...	...	11	15	18	25	35	21

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