Bycatch in the tuna purse-seine fisheries of the western Indian Ocean

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Abstract–Bycatch taken by the tuna purse-seine fishery from the Indian Ocean pelagic ecosystem was estimated from data collected by scientific observers aboard Soviet purse seiners in the western Indian Ocean (WIO) during 1986–92. A total of 494 sets on free-swimming schools, whale-shark-associated schools, whale-associated schools, and log-associated schools were analyzed. More than 40 fish species and other marine animals were recorded. Among them only two species, yellowfin and skipjack tunas, were target species. Average levels of bycatch were 0.518 metric tons (t) per set, and 27.1 t per 1000 t of target species. The total annual purse-seine catch of yellowfin and skipjack tunas by principal fishing nations in the WIO during 1985–94 was 118,000–277,000 t. Nonrecorded annual bycatch for this period was estimated at 944–2270 t of pelagic oceanic sharks, 720–1877 t of rainbow runners, 705–1836 t of dolphinfishes, 507–1322 t of triggerfishes, 113–294 t of wahoo, 104–251 t of billfishes, 53–112 t of mobulas and mantas, 35–89 t of mackerel scad, 9–24 t of barracudas, and 67–174 t of other fishes. In addition, turtle bycatch and whale mortalities may have occurred. Because the bycatches were not recorded by some purse-seine vessels, it was not possible to assess the full impact of the fisheries on the pelagic ecosystem of the Indian Ocean. The first step to solving this problem is for the Indian Ocean Tuna Commission to establish a program in which scientific observers are placed on board tuna purse-seine and longline vessels fishing in the WIO.

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One of the most important requirements of the UN Convention on the Law of the Sea of 1982, which determines strategies for exploitation of marine living resources (Article 119, b), is to take into account the impact of fisheries on ". . . species associated with or dependent upon harvested species with a view to maintaining or restoring populations of such associated or dependent species above levels at which their reproduction may become seriously threatened. . ." (United Nations, 1983). Estimating the magnitude of bycatch is one of the first steps to determine the impact of fisheries on associated species.

Tuna purse-seine fisheries probably apply the most intensive direct human impact on the tropical epipelagic ecosystems in all oceans. Because of the worldwide scale of purse-seine fisheries, an assessment of their impact on associated and dependent species is essential.

Two tunas, yellowfin *Thunnus albacares* (Bonnaterre, 1788) and skipjack *Katsuwonus pelamis* (Linnaeus, 1758), are the target species of most purse-seine fisheries. In this study bycatch is defined as the fraction of the catch that consists of nontarget species (including other species of tuna) that are encircled by the fishing gear and are unable to escape by themselves. Bycatch of associated and nonassociated species during purse-seine fishing for tropical tunas may be rather high, and generally depends on fishing tactics.

The species composition of bycatch in purse-seine fisheries depends on the structure, behavior, and spatial organization of surface multispecies aggregations. Schools of different tuna species and other pelagic fishes, marine mammals, and other marine animals have aggregated distributions. From our observations and in the opinion of other researchers (Au and Perryman, 1985; Au and Pitman, 1986; Au, 1991; Cort, 1992), marine birds are also an integral component of the majority of these multispecies groups.

The tunas, as a rule, prevail by biomass and abundance in such groups. Tuna schools are traditionally classified by the visually distinctive part of the group or by whether they associate with floating objects or marine mammals (Scott, 1969; Petit and Stretta, 1989). "Free-swimming schools" may include associations between different species of tuna. For each type of school, its various components occur in different ratios.

Some epipelagic species that occur in the purse-seine bycatches are not members of multispecies aggregations. They, instead, may comprise members of the flotsam community or are tuna forage. Several associated components, such as whales and birds, usually escape or avoid the nets and do not become bycatch. Therefore, the composition of the catch often does not represent the actual species composition of the multispecies associations.

Assessments of bycatches have been made for the eastern Pacific Ocean purse-seine tuna fishery (Joseph, 1994; Garcia and Hall, 1995; Hall, 1996, 1998; Anonymous, 1997, 1998, 1999), where the bycatch problem attracted attention because of dolphin mortality during sets on dolphin-associated tuna schools. The economic, political, and ecological implications of this problem produced wide international attention (Charat-Levy, 1991; Joseph, 1991, 1994; Hall, 1998). Bycatch estimates for the western Pacific purse-seine tuna fisheries have been published also (Bailey et al., 1996).

In the western Indian Ocean (WIO), tuna-dolphin associations are well known in coastal pelagic zones, e.g. Gulf of Aden (Demidov[1]) and Sri-Lanka (de Silva and Boniface[2]). They are often used in small-scale troll and pole-and-line fisheries for locating yellowfin tuna. In offshore regions of the WIO tuna-dolphin associations are rare, purse seining for them is not practiced, and there is no dolphin bycatch problem. Perhaps for this reason, the magnitude of bycatch in the WIO is unknown, except for recent information on species composition (Santana et al., 1998). Bycatches are not recorded for tuna seiners operating in the WIO, except bycatches of nontarget tuna species. This paper represents a first attempt to estimate catches of associated species by tuna purse seiners in the WIO, based on scarce information collected by scientific observers.

Materials and methods

Bycatch assessments were based on data collected by YugNIRO scientific observers aboard Soviet (since 1992—Russian) tuna purse seiners in the WIO, during 1987, and 1990–91. The vessels were the "Rodina" type.[3] In addition, observer data collected in the same area aboard sister-ships by AtlantNIRO[4] and "Zaprybpromrazvedka"[5] during 1986–90 and data by TINRO[6] and TURNIF[7] during 1990 and 1992 were used. The fishing vessels all used purse seines of 1800 m in length, 250–280 m in depth, and 90–100 mm mesh size in the bunt.

The principal goal of the observer sampling program was an estimation of the species composition of catches in this fisheries, biological analysis of the principal species, and estimates of the length and weight compositions of these principal species in the catches. The observers were placed on board opportunistically (i.e. if a vessel had a free sleeping bed and if there was available funding), without a sampling scheme and without preference to any vessel type. Thus, the sampling could be considered as random. Two other types of Soviet fishing vessels, "Tibiya"[8] and "Kauri,"[9] which took part in the Indian Ocean fisheries during 1985–87 and since 1991 (under the Liberian flag), were not sampled. In this study coverage rate was estimated as percentage of sampled catch to total catch.

The observers recorded the results of each set. The type of school, according to Scott (1969) and Petit and Stretta (1989), of each set was recorded. I considered sets for which an observer recorded catch in any quantity as positive sets. The average bycatch level was estimated for all positive sets.

For the positive sets, species composition, total weights, and numbers of each species in the catch were recorded. In the vessels of the "Rodina" type, the retained catch was frozen and stored separately. The retained catch was weighed after freezing while being moved to the ship's holds. In nine cases, the weight of some of the catch was estimated by the ship masters because the holds were overloaded and some catch was stored in the freezers till landing. Therfore estimates of retained catch are presented in this study as frozen weights rather than wet weights. The bycatch was estimated as wet weight. Only bycatch taken on board was sampled. The sets when bycatch was not taken onboard but discarded alive (usually with negligible target species catch) and malfunction sets, which do not produce any catch, were not analyzed in this study. Large species, sharks and billfishes generally, were weighed and counted. The weights of specimens heavier than 200 kg (i.e. Mobulidae) were estimated. When the bycatch was more than 200–300 kg, species composition and weight were estimated by using representative samples.

Sometimes the observer recorded the bycatch in numbers. In these rare cases, the total weights of the fishes were estimated from the average weights of these species in previous catches.

The observers had free access to every fish in the catch. Nevertheless, some observers had difficulties identifying some billfishes, sharks, and Mobulidae species. Therefore, I pooled the records with doubtful species identification into these three groups for my analysis. These are marked by "?" in the tables.

The data were grouped and analyzed by free-swimming schools (including associations between schools of different species of tuna) and associated schools. The latter included whale-associated schools and log-associated schools (associated with floating objects).

Schools caught in the area of seamounts and shoals—at the peaks of the Equator Seamount and at Saya-de-Malha bank—were considered free-swimming schools. Some observers did not record the type of floating objects that were set on; therefore the sets on natural floating objects (50% to 90% of the log sets sampled) and on fish aggregation devices (FADs) (10–50%) were grouped. Several log sets were made in areas with surface evidence of water masses or current interactions (rips). A set that could not be clearly identified as to set type was made in such an area and was treated as a log set because of the species composition of the catch and the occurrence of small scattered debris in the rips.

[1] Demidov, V. F. 1998. Personal commun. Southern Scientific Research Institute of Marine Fisheries and Oceanography (YugNIRO), 2, Sverdlov St., 98300, Kerch, Crimea Ukraine.

[2] de Silva, J., and B. Boniface. 1991. The study of the handline fishery on the west coast of Sri Lanka with special reference to the use of dolphin for locating yellowfin tuna (*Thunnus albacares*). *In* Indo-Pacific Tuna Development and Management Programme (IPTP) Coll. Vol. Work. Doc TWS/90/18., Vol. 4, p. 314–324. Food and Agriculture Organization of the United Nations (FAO), Viale delle Terme di Caracalla, 00100, Rome, Italy.

[3] Length overall: 85 m; GRT (gross tonnage): 2634; carrying capacity: ~1600 m^3.

[4] AtlantNIRO—The Atlantic Scientific Research Institute of Marine Fisheries and Oceanography, 5 Dmitry Donskoi St., 236000 Kaliningrad, Russia.

[5] The Department of Searching and Scientific Research Fleet of the Western Basin "Zaprybpromrazvedka," 5[a] Dmitry Donskoi St., 236000 Kaliningrad, Russia.

[6] TINRO—The Pacific Scientific Research Institute of Marine Fisheries and Oceanography, 1 Shevchenko Alley, 690600 Vladivostok, Russia.

[7] TURNIF—The Pacific Department of Fish Searching and Scientific Research Fleet, 2 Pervogo Maya St., 690600 Vladivostok, Russia.

[8] Length overall: 55.5 m, GRT: 736, carrying capacity: ~361 m^3.

[9] Length overall: 79.8 m, GRT: 2100, carrying capacity: ~1200 m^3.

Table 1

Numbers of sets sampled by year. Positive sets are sets in which an observer registered catch in any quantity .

	1986	1987	1988	1989	1990	1991	1992	Total
Total number of sets	115	102	30	41	113	54	39	494
Number of positive sets	68	62	28	41	92	53	33	377
Percentage of sets with catch	59%	63%	93%	100%	81%	98%	85%	76%

Table 2

Numbers of sets sampled by season and type of school.

	Seasons				
Type of school	Winter	Spring	Summer	Autumn	Total/positive
Free-swimming	136	35	27	8	206/121
Whale-shark–associated	2	0	0	0	2/2
Whale-associated	23	21	1	0	45/37
Log-associated	46	50	80	65	241/217
Total	207	106	108	73	494/377

Because tuna purse-seine fishing in the WIO is clearly seasonal (monsoons governing fishing techniques and operations), the data were analyzed by season. I followed Romanov's (1982) seasonal divisions, in accordance with long-term average seasonal variations in the monsoon atmospheric circulation for the WIO. The winter season (northeastern monsoon) lasts from December to March, the spring intermonsoon period falls during April and May, the summer (southwestern monsoon) lasts from June to August, and the autumn intermonsoon period lasts from September through November. The wind regime determines the onset and duration of the hydrological seasons, which do not quite coincide with seasons of atmospheric circulation owing to a considerable time lag of the processes occurring in the ocean. However, the wind regime is instrumental in determining the tactics of purse seining for tuna; therefore I used seasonal strata based on atmospheric rather than on hydrological processes.

The spatial and temporal distribution of catch and effort for the Soviet tuna purse-seine fishery in the Indian Ocean was determined from data in the YugNIRO database, a collection of daily radio reports from vessels fishing in the area from 1983 until the mid-1990s.[10] The catches reported by the author's estimates varied by 96–99% during 1985–91, decreasing to 71% in 1992. This study did not take into account reflagging of some Soviet (from 1992—Russian) vessels with the Liberian flag, and the vessels' nationality was defined in this study by the location of their shipowners. Analysis of fleet activity and extrapolations of results were made on the assumption that the operations and procedures on vessels that did not carry observers did not differ from the operations and procedures on vessels with an observer aboard; similarly it was assumed that the species composition of the catch from these vessels did not differ.

[10] Daily information on fishing activity of these vessels in the Indian Ocean in 1983–84 and since 1995 is not available.

Some of the bycatch was retained on board the fishing vessels. Unused bycatch was discarded in the ocean. The observers usually did not record the levels of discards, and it was not possible to assess quantitatively the discards of tuna and associated species.

Average values are presented as arithmetic means, plus or minus 95% confidence intervals for estimated values. Estimates of unrecorded bycatches for all fishes, except tunas, are provided in numbers and metric tons per positive set and per 1000 t of target species.

Results

Primary data and adequacy of samples

A total of 494 purse-seine sets were sampled and 377 positive sets were analyzed. The total catch in the sets that were sampled amounted to 7713 t. The distribution of sets sampled by years, seasons, and the types of schools is given in Tables 1 and 2. The catch sampled by type of school is presented in Table 3.

The observer coverage rate varied from 0% (no observers at sea) to 75% and averaged 14% during 1986–92. During the periods when observers were on board, the coverage rate averaged 30% and varied from 5% to 75%. The spatial distribution of sampled sets agreed quite well with

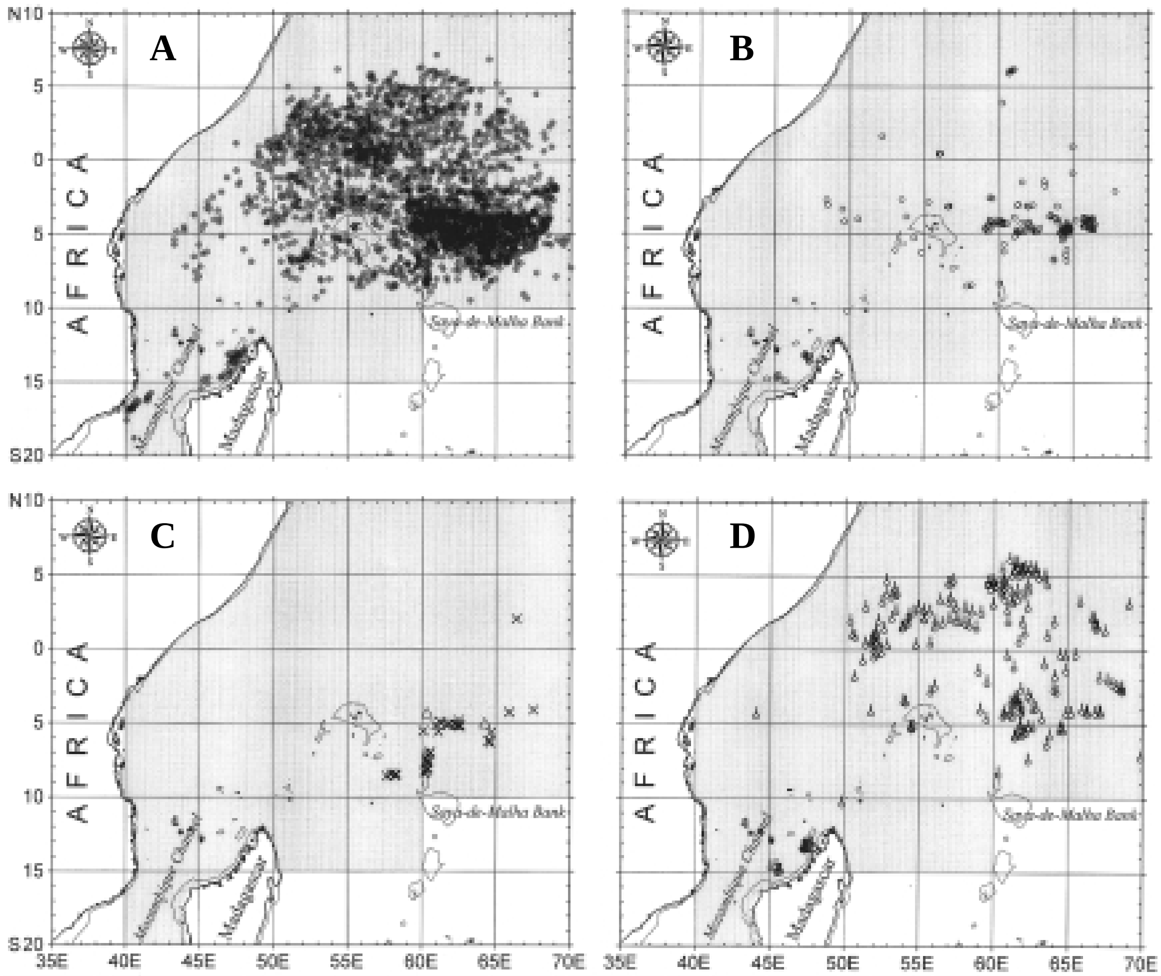

Figure 1

(**A**) Fishing effort distribution (⊗=noon positions of vessels on fishing days with sets) of the Soviet tuna purse-seine fishery in 1985–94; (**B–D**) sampled set positions: (B) on free-swimming schools that were sampled; (C) on whale-shark (△) and whale-associated schools (×); (D) on log-associated schools. The shaded area represents the region of the main international tuna purse-seine fishing activity in the WIO, according to Ardill.[11]

Table 3

Sampled catch (metric tons) by season and type of school.

	Seasons				
Type of school	Winter	Spring	Summer	Autumn	Total
Free-swimming	1884	249	73	24	2230
Whale-shark–associated	28	0	0	0	28
Whale-associated	584	467	4	0	1055
Log-associated	925	785	1156	1534	4400
Total	3421	1501	1213	1558	7713

the distribution of the total fishing effort of the Soviet fleet in the WIO (Fig. 1). Sampled sets were distributed throughout the region of the principal international tuna purse-seine fishing activity in the WIO (Ardill[11]). Thus, I

[11] Ardill, J. D. 1995. Atlas of industrial tuna fisheries in the Indian Ocean (IPTP/95/AT/3). IPTP, Colombo, Sri Lanka, 138 p. FAO, Viale delle Terme di Caracalla, 00100, Rome, Italy.

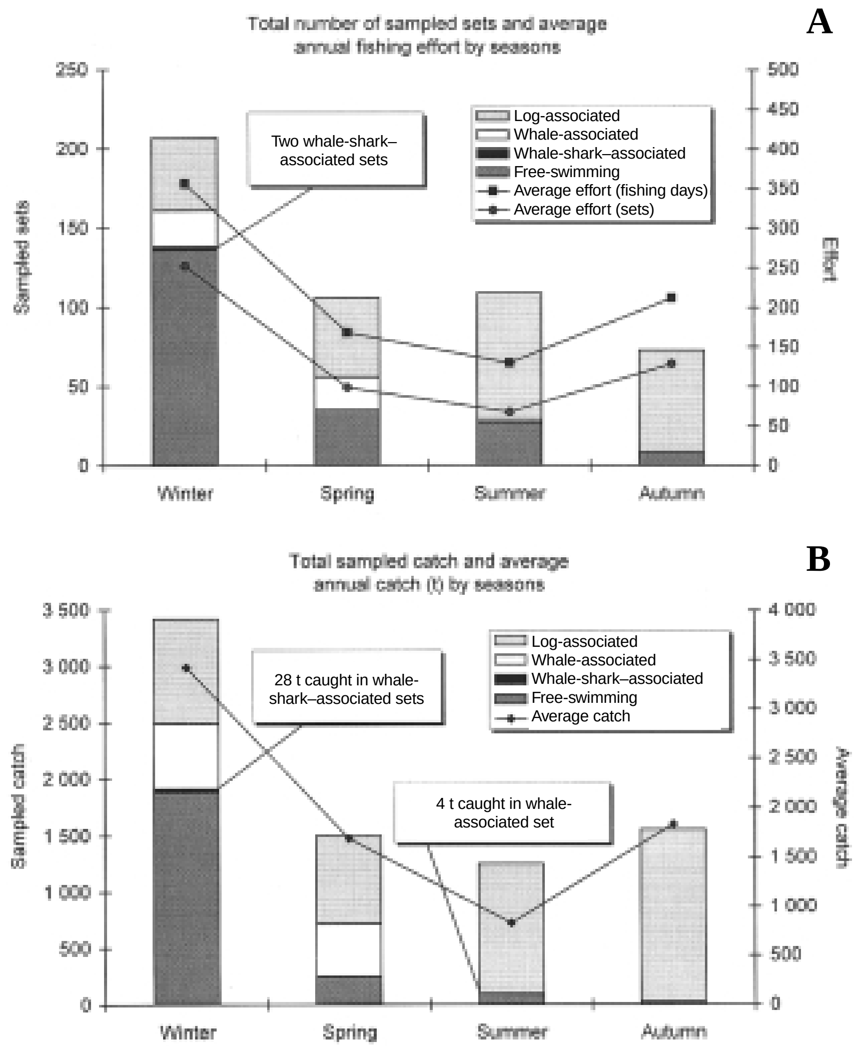

Figure 2

(**A**) Sampled effort (by school type) and the long-term average fishing effort by season; (**B**) sampled catch (by school type) and long-term average catch by season for the Soviet tuna fleet.

believe that the observers' data are representative of the catch by the Soviet purse-seine fleet in terms of sample size and geographical distribution of the sets.

The data series available for analysis was a combination of samples different in size, obtained in different years and seasons (Tables 1–3). Therefore the results of all analyses may have been subject to interannual variability (it is impossible to evaluate the effect of interannual variability from the data available), and the estimated average annual figures may have been subject to seasonal variability as well, on account of the unequal size of samples taken in different seasons.

Because the daily radio reports, which formed the basis of the database, did not include information on sets by school type, it was not possible to directly extrapolate the observers' data to the Soviet fleet separately by school types. However, I believe that the observers' data correctly reflect the seasonal ratio of sets on different school types.

To assess the possibility of using annual averages of the available samples and extrapolating them to the whole catch of the Soviet fleet, the author compared the seasonal magnitudes of total fishing effort (fishing days, sets) and catches reported by the Soviet fishing fleet (from the database) with the seasonal magnitudes of effort (number of sets) and catch (t) sampled by the observers (Fig. 2, A and B). The seasonal distribution of the sampled catch followed the same pattern as the long-term average seasonal distribution of the catch by the fleet (Fig. 2B). The effort did not fully agree with seasonal increase in the fishing effort of Soviet vessels during the autumn season (Fig. 2A), which may have resulted in a slight underestimation of average annual values of bycatch from log-associated

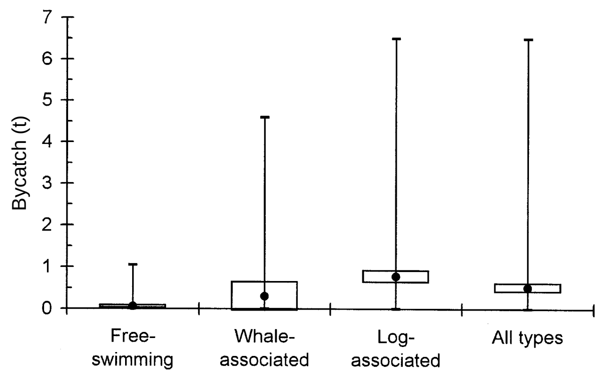

Figure 3

Bycatch per positive set in metric tons (t) by school type for the Soviet tuna purse-seine fishery. Dots are means, bars show range, and boxes are 95% confidence intervals.

schools. I did not attempt, however, to take this factor into consideration.

The average CPUE (e.g. total catch per set) in the purse-seine tuna fisheries varies greatly by type of vessel. I did not find a strong correlation between the bycatch per set and the total catch, or catch of target species in the same set. Level of bycatch generally depends on the type of association and the total fishing effort directed at this type of association.

Species composition and catch by school types

A total of 50 species (or higher taxa) of fishes and other marine animals were recorded in the catch of the fishing vessels (Table 4).

Free-swimming schools

Free-swimming schools are the predominant type of surface schools in the WIO. Such schools occurred in the area all year round (Table 2, Fig. 2, A and B). Soviet purse seiners set on free-swimming schools generally south of the equator (including Mozambique Channel)(Fig. 1B). Yellowfin, skipjack, and bigeye (*Thunnus obesus*) tunas were the principal components of free-swimming schools, comprising 80%, 15%, and 4%, respectively (Table 5). Monospecific (nonassociated) tuna schools, consisting completely of yellowfin or skipjack tuna, were found to occur in 47% of free-school sets. Multispecies free schools were observed in 53% of all free-school sets and generally consisted of two target species and bycatch. Bycatch occurred in 45% of the free-school sets, and nontuna bycatch in 22%.

A total of 19 species (or higher taxa of fishes) were observed in catches on free schools (Table 4). Some species were considered to be tuna prey (e.g. Exocoetidae) and some to be accidental bycatch (e.g. *Gempylus serpens, Canthidermis maculatus, Diodon* spp.). Nontuna bycatch in this type of association was on average 0.060 ±0.031 t per positive set (Fig. 3) and 3.403 ±2.770 t per 1000 t of target species (Fig. 4). The bulk of this bycatch was sharks of the genus *Carcharhinus* (0.023 t/1.296 t), rays of the Mobulidae family (0.020 t/1.128 t), marlins of the genus *Makaira*, and sailfish (*Istiophorus platypterus*) (0.016 t/0.895 t) (Tables 4 and 6). In the present study, bycatches are presented in parentheses as t per positive set/t per 1000 t of target species.

Whale-shark–associated schools

Two schools associated with whale sharks were sampled only in the winter season (Table 2, Fig. 2, A and B) south of the equator (Fig. 1C). In these sets, the bycatch consisted of the shark itself and a small quantity of albacore (*Thunnus alalunga*) (Table 4). This small sample size prohibited reliable bycatch estimates for whale-shark–associated schools and inferences of the species compositions of such associations.

Whale-associated schools

In the observers' logbooks, among the 45 sets on whale-associated tuna schools, 13 sets were made on schools associated with sei whales (*Balaenoptera borealis* Lesson, 1828) and one set on a school associated with a fin whale (*B. physalus* (Linnaeus, 1758)).[12] The remaining sets were made on unidentified baleen whales. According to verbal reports by some observers,[13] tuna schools associated with Bryde's whale (*B. edeni* Anderson, 1878), Minke whales (*B. acutorostrata* Lacépède, 1804), and pygmy blue whales (*B. musculus brevicauda* Linnaeus, 1758) were also observed in the WIO. From personal observations and those of the observers, sperm whales (*Physeter catodon* Linnaeus, 1758) were found often in the areas of the tuna purse-seine fishery; tunas, on the other hand, were not observed to associate with sperm whales. According to observations made during setting and searching operations, whales associated with tunas generally were found in groups of up to 8 individuals, more often in groups of 2–3 whales.

Whale-associated schools were most often observed from January to April. A whale-associated school was observed in July north of the equator (Table 2, Figs. 1C, 2, A and B). Schools of this type were distributed mainly south of the equator at latitudes 4–9°S. Skipjack, yellowfin, and bigeye tunas dominated in whale-associated schools—59%, 32%, and 6%, respectively (Table 5). The percentage of each species in different sets varied greatly: 0–100% for skipjack, 0–100% for yellowfin, and 0–74% for bigeye tuna. Associations consisting of one tuna species and a whale were encountered in eight cases (22%). Bycatch in whale-associated schools was found in 68% of the sets, and nontuna bycatch in 43% of the sets.

During sets on whale-associated schools, the fishermen keep the whale(s) inside the purse seine as long as pos-

[12] Species identification could be erroneous.

[13] Bashmakov, V. F. 1990. Personal commun. Atlantic Scientific Research Institute of Marine Fisheries and Oceanography (AtlantNIRO), 5 Dmitry Donskoy St., Kaliningrad, 236000, Russia.

Table 4

Species composition of tuna purse-seine catches in the western Indian Ocean. "?" denotes doubtful, in the author's opinion, species identification by observer.

Family and species	School type: Free-swimming	Whale-associated	Log-associated
Pisces			
Dasyatidae			
Dasyatis spp.	+		+
Mobulidae			
Manta birostris (Donndorff, 1798)	+?	+?	+
Mobula spp.	+	+	+
Rhincodontidae			
Rhincodon typus Smith, 1828[1]			
Lamnidae			
Isurus oxyrinchus Rafinesque, 1809		+	
Isurus spp.		?	
Carcharhinidae			
Carcharhinus falciformis (Bibron, 1839)	+	+	+
C. longimanus (Poey, 1861)	+	+	+
?*C. obscurus* (LeSueur, 1818)		+?	+?
Carcharhinus spp.		?	?
Sphyrnidae			
Sphyrna lewini (Griffith & Smith, 1834)			+
Sphyrna spp.			+
Exocoetidae sp.	+		
Belonidae sp.			+
Tylosurus crocodilus (Peron & LeSueur, 1821)			+
Lampidae			
Lampris guttatus (Brünnich, 1788)			+
Sphyraenidae			
Sphyraena barracuda (Walbaum, 1792)			+
Sphyraena spp.			+
Carangidae			
Caranx spp.			+
Decapterus macarellus Cuvier, 1833			+
Decapterus spp.			+
Elagatis bipinnulata (Quoy & Gaimard, 1824)	+		+
Seriola spp.	+		+
Naucrates ductor (Linnaeus, 1758)			+
Coryphaenidae			
Coryphaena hippurus Linnaeus, 1758		+	+
Coryphaena spp.			+
Kyphosidae			
Kyphosus cinerascens (Forsskål, 1775)			+
Gempylidae			
Gempylus serpens Cuvier, 1829	+		
Ruvettus pretiosus Cocco, 1829			+
Ephippididae			
Platax spp.		+	+
Scomberomoridae			
Scomberomorus commerson (Lacépède, 1800)			+
Scomberomorus spp.			+
Scombridae			
Acanthocybium solandri (Cuvier, 1831)			+

continued

Table 4 (continued)

Family and species	School type: Free-swimming	Whale-associated	Log-associated
Pisces (continued)			
Auxis rochei (Risso, 1810)			+
Auxis thazard (Lacepede, 1800)	+	+	+
Euthynnus affinis (Cantor, 1849)			+
Katsuwonus pelamis (Linnaeus, 1758)	+	+	+
Thunnus alalunga (Bonnaterre, 1788)	+		+
Thunnus albacares (Bonnaterre, 1788)	+	+	+
Thunnus obesus (Lowe, 1839)	+	+	+
Istiophoridae			
Istiophorus platypterus (Shaw & Nodder, 1792)	+		
Makaira indica (Cuvier, 1832)		+	+
M. mazara (Jordan et Snyder, 1901)	+		+
Makaira spp.	+		+
Tetrapturus audax (Philippi, 1887)			+
Xiphiidae			
Xiphias gladius (Linnaeus, 1758)			+
Nomeidae			
Cubiceps pauciradiatus Günter, 1872		+	
Balistidae			
Canthidermis maculatus (Bloch, 1786)	+		+
Monacanthidae			
Aluterus monoceros (Linnaeus, 1758)			+
Aluterus spp.			+
Diodontidae			
Diodon spp.	+		+?
Mammalia			
Balaenopteridae			
Balaenoptera borealis Lesson, 1828		+	
Salpae		+	
Ctenophora		+	
Chelonidea			+
Number of species (taxa)	19	17	45

[1] Recorded in whale-shark–associated schools.

Table 5

Average tuna catch per positive set (t) by "Rodina"-type Soviet vessels in the western Indian Ocean (total and by species). YFT = yellowfin tuna, SKJ = skipjack tuna, BET = bigeye tuna, ALB =albacore, FRI = frigate tuna, KAW = kawakawa. + = catch was <0.001 t.

Type of school	Total	Species: YFT	SKJ	BET	ALB	FRI	KAW
Free-swimming	18.4 ±5.2	14.7 ±4.9	2.8 ±1.7	0.8 ±1.0	0.03 ±0.03	0.05 ±0.06	—
Whale-associated	31.0 ±9.3	9.8 ±4.3	18.3 ±8.5	2.0 ±2.4	—	0.2 ±0.2	—
Log-associated	20.6 ±3.2	4.9 ±0.9	13.9 ±2.7	0.6 ±0.2	0.04 ±0.04	0.3 ±0.3	0.001 ±0.001
Total	20.6 ±2.7	8.6 ±1.8	10.5 ±1.9	0.8 ±0.4	0.03 ±0.03	0.2 ±0.2	+

Table 6

Estimates of the bycatch (t) of various species (groups) of marine animals by school type. The numerator is the average values per a positive set, the denominator is the average values per 1000 t of target species. + = catch was <0.001 t.

Species or group of species	School type[1] Free-swimming	Whale-associated	Log-associated	All types of schools
Billfishes (Istiophoridae, Xiphiidae)	0.016/0.895	0.006/0.218	0.019/1.008	0.017/0.880
Wahoo (*A. solandri*)	—	—	0.031/1.621	0.018/0.934
Sharks (Lamnidae, Carcharhinidae, Sphyrnidae)	0.023/1.296	0.289/10.302	0.175/9.288	0.151/7.938
Rainbow runner (*E. bipinnulata*)	0.001/0.054	—	0.195/10.314	0.114/5.962
Dolphinfishes (*C. hippurus*)	+/0.027	0.001/0.051	0.191/10.098	0.111/5.836
Barracuda (*S. barracuda*)	—	—	0.002/0.132	0.001/0.076
Triggerfishes (*C. maculatus, Aluterus* spp.)	+/+	—	0.137/7.277	0.080/4.195
Mackerel scad (*D. macarellus*)	—	—	0.0093/0.491	0.005/0.283
Mantas, mobulas (Mobulidae)	0.020/1.128	0.009/0.318	0.002/0.126	0.009/0.455
Sea turtles	—	—	+/0.025	+/0.014
Other bycatch	+/0.002	+/0.003	0.018/0.958	0.011/0.553
Total: For positive set	0.060 ±0.031	0.306 ±0.344	0.780 ±0.144	0.518 ±0.099
Total: For 1000 t of target species	3.403 ±2.770	10.891 ±15.787	41.337 ±14.281	27.127 ±8.869

[1] Because of the small sample size, estimates of bycatch for whale-shark–associated schools are not presented in the Table.

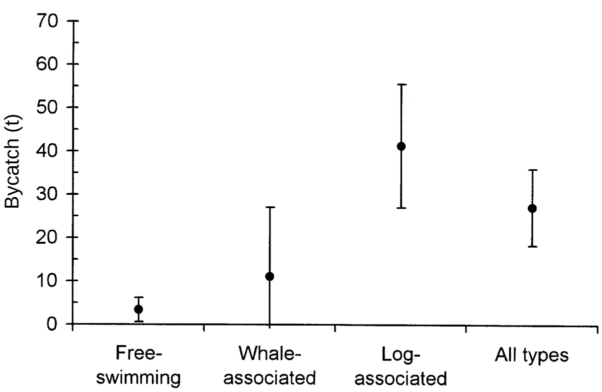

Figure 4

Bycatch (t) per 1000 t of target species by school type for the Soviet tuna purse-seine fishery. Dots are means, bars are 95% confidence intervals.

sible. Whales often remain in the net until the end of pursing and then escape from the purse seine by either diving under the purse line, by ramming through the net wall, or by sinking the corkline (a rare occurrence).

Observers registered a single case of entanglement in the net and subsequent death of a young sei whale about 10 m in length and about 12 t in weight. The dead animal was taken up on the vessel's deck, released from the purse seine, and discarded into the ocean. It is not possible to assess the frequency and probability of whale mortality by the purse-seine fishery in the WIO.

There were 17 species (or groups) of marine animals identified in the catches of whale-associated schools (Table 4). Salps, ctenophores, and batfish (*Platax* spp.) were considered accidental bycatch, whereas long-finned fathead (*Cubiceps pauciradiatus*) was a prey item of both tunas and whales. Nontuna bycatch in this type of association averaged 0.306 ±0.344 t for a positive set or 10.891 ±15.787 t per 1000 t of target species (Figs. 3 and 4). Sharks of the genus *Carcharhinus* and *Isurus* made up the bulk of the bycatch in whale-associated school sets (0.289 t/10.302 t) (Tables 4 and 6).

Log-associated schools

Log-associated schools are one of the predominant school types found in the WIO all year round (Table 2, Fig. 2, A and B). Sets on log-associated schools were made throughout the sampling area as far south as 15°S (Fig. 1D). In log-associated schools the bulk of the catch were skipjack, yellowfin, and bigeye tunas—67%, 24%, and 3%, respectively (Table 5). Log-associated schools in all cases consisted of several fish species. Bycatch was found in 93% of the sets, and nontuna bycatch in 87%. The absence of bycatch was rare, observed only during successive sets on the same floating object.

The species composition associated with floating objects was the most diverse of any set type and included 45 species (or higher taxa of fishes) (Table 4). Nontuna bycatch was at its highest in log-associated sets, as much as 0.780 ±0.144 t per positive set or 41.337 ±14.281 t per 1000 t of target species (Figs. 3 and 4). The bulk of the bycatch in sets on log-associated schools was made up of rainbow runner, *Elagatis bipinnulata* (0.195 t/10.314 t), common dolphinfish, *Coryphaena hippurus* (0.191 t/10.098 t), triggerfish of the genus *Canthidermis* (0.137 t/7.277 t), sharks of the genus *Carcharhinus* (0.175 t/9.288 t), wahoo, *Acanthocybium solandri* (0.031 t/1.621 t), billfishes of the genera *Makaira* and *Tetrapturus* (0.019 t/1.008 t), and mackerel scad, *Decapterus macarellus* (0.0093 t/0.491 kg). One capture of a sea turtle (unknown species) was recorded (Tables 4 and 6).

All types of schools

Considering all school types in the aggregate, skipjack, yellowfin, and bigeye tuna prevailed in the catch —51%, 42%, and 4% by weight, respectively (Table 5). Albacore represented a mere 0.2%, frigate tuna 0.9%, and kawakawa, *Euthynnus affinis*, less than 0.1%. Nontuna bycatch accounted for less than 3% of the catch.

On the average, there was 0.518 ±0.099 t of nontuna bycatch caught per positive set, or 27.127 ±8.869 t per 1000 t of target species (Fig. 3). Bycatch levels by species (groups) are given in Table 6.

Discussion

The lowest fish bycatch in the WIO tuna purse-seine fishery was taken from free schools (mainly carcharhinid sharks and Mobulidae rays) (Figs. 3 and 4, Tables 4 and 6). Bycatch of fishes was highest and most diverse from catches on log-associated schools. Rainbow runner, common dolphinfish, triggerfish, carcharhinid sharks, wahoo, billfishes, and mackerel scad were predominant. Whale-associated schools were characterized by an intermediate level of bycatch (mainly carcharhinid and lamnid sharks) (Figs. 3 and 4, Tables 4 and 6).

It is interesting to compare the bycatch rates obtained in this study with those published for other regions. The principal bycatch fishes in the Pacific (Bailey et al., 1996; Hall, 1996, 1998; Anonymous, 1997) are the same as those presented here. Bycatch levels are known to vary considerably by year, area, fleet (Bailey et al., 1996; Hall, 1996; Anon., 1997), and school type; this variability hampered direct comparisons of the results from the present study with those from published data. However, for the purpose of comparison, I pooled my estimates by groups in accordance with the published data (Bailey et al., 1996; Hall, 1996, 1998; Anonymous, 1997). Bycatch levels per set and per 1000 t of target species for various regions of the Pacific and my estimates for the Indian Ocean are on the same order of magnitude for most groups in similar types of associations (Figs. 5 and 6).

I also attempted to estimate the unrecorded bycatch by the purse-seine fleets of the principal fishing nations of the WIO by a comparison of fishing tactics. The Soviet fleet in the WIO made an equal proportion of sets on free-swimming schools and on log-associated schools during the year (Table 2). Seasonally they switched effort from sets on free-swimming schools to those on log-associated schools (Fig. 7, A and B). The fishing practices of French and Spanish tuna seiners showed similar seasonality until the mid-1990s (Anonymous;[14,15,16] Pianet;[17,18] Moron[19]).

The fishing tactics of the Japanese (Hallier;[20] Okamoto and Miyabe[21]) and Mauritian (Norungee et al.;[22] Norungee and Lim Shung[23]) purse-seine fleets differed considerably from that described above. Japanese and Mauritian vessels made sets on log-associated schools all year round, with single instances of sets on other schools types.

Only two school types (log schools and free schools) have been described by Hallier;[20] Hallier;[24] Parajua Aranda;[25]

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[24] Hallier, J.-P. 1994. Purse seine fishery on floating objects: What kind of fishing effort? What kind of abundance indices? *In*

continued

Table 7

Bycatch estimates in tons in the western Indian Ocean purse-seine fisheries during 1985–94. MIX = fleets targeted all types of schools (France, Spain, USSR), LOG = fleets targeted log-associated schools (Japan and Mauritius).

Species, a group of species		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
	MIX	913	1047	1257	1674	1622	1503	1471	1793	1796	1925
Pelagic oceanic sharks	LOG	31	30	61	81	108	180	278	477	451	143
	Total	944	1077	1318	1755	1730	1683	1749	2270	2247	2068
	MIX	686	786	944	1257	1218	1129	1105	1347	1349	1446
Rainbow runners	LOG	34	33	68	90	120	199	309	530	500	159
	Total	720	819	1012	1347	1338	1328	1414	1877	1849	1605
	MIX	671	770	925	1231	1193	1105	1082	1318	1320	1415
Dolphinfishes	LOG	34	33	67	88	117	195	303	518	490	156
	Total	705	803	992	1319	1310	1300	1385	1836	1810	1571
	MIX	483	554	665	885	857	794	778	948	949	1017
Triggerfishes	LOG	24	24	48	64	84	141	218	374	353	113
	Total	507	578	713	949	941	935	996	1322	1302	1130
	MIX	108	123	148	197	191	177	173	211	211	227
Wahoo	LOG	5	5	11	14	19	31	49	83	79	25
	Total	113	128	159	211	210	208	222	294	290	252
	MIX	101	116	139	185	180	167	163	199	199	213
Billfishes	LOG	3	3	7	9	12	20	30	52	49	16
	Total	104	119	146	194	192	187	193	251	248	229
	MIX	52	60	72	96	93	86	84	103	103	110
Mobulas and mantas	LOG	<1	<1	1	1	1	2	4	6	6	2
	Total	53	60	73	97	94	88	88	109	109	112
	MIX	33	37	45	60	58	54	53	64	64	69
Mackerel scad	LOG	2	2	3	4	6	10	15	25	24	8
	Total	35	39	48	64	64	64	68	89	88	77
	MIX	9	10	12	16	16	14	14	17	17	19
Barracudas	LOG	<1	<1	1	1	1	3	4	7	6	2
	Total	9	11	13	17	17	17	18	24	23	21
	MIX	64	73	88	117	113	105	102	125	125	134
Other fishes	LOG	3	3	6	8	11	18	29	49	47	15
	Total	67	76	94	125	124	123	131	174	172	149
	MIX	3120	3576	4295	5718	5541	5134	5025	6125	6135	6574
Total nontuna bycatch	LOG	137	134	273	360	479	799	1239	2121	2004	638
	Total	3257	3710	4568	6078	6020	5933	6264	8246	8139	7212

Anonymous;[14, 15, 16] Pianet;[17, 18] Hastings and Domingue;[26] and Moron[19] for the tuna purse-seine fishery in the Indian Ocean. Free schools in these analyses included all types of associations with marine animals. The proportion of sets of the French fleet on other types of schools and on resulting catches is not known. Cort (1992) presented such data for Spanish vessels, based on fishing logbooks. Therefore, I used the observers data of the Seychelles Fishing Authority (SFA) (Cort, 1992) for the vessels of France, Spain, Japan, and USSR to assess these values in the WIO. The percentage of sets on whale-associated schools varied from 1.7% to 8.8% in 1986–90, the percentage among positive sets was from 1.2% to 9.1%, and the catch from such schools was 1.6% to 7.8% (cited from Cort, 1992). These values are slightly lower than the observer data I report in the present study (9%, 10%, and

24 (continued) Proceedings of the expert consultation on Indian Ocean tunas, 5th session, Mahe, Seichelles, 4–8 October, 1993 (J. D. Ardill, ed.), p. 192–198. IPTP Coll. Vol. 8., TWS/93/2/25. FAO, Viale delle Terme di Caracalla, 00100, Rome, Italy.

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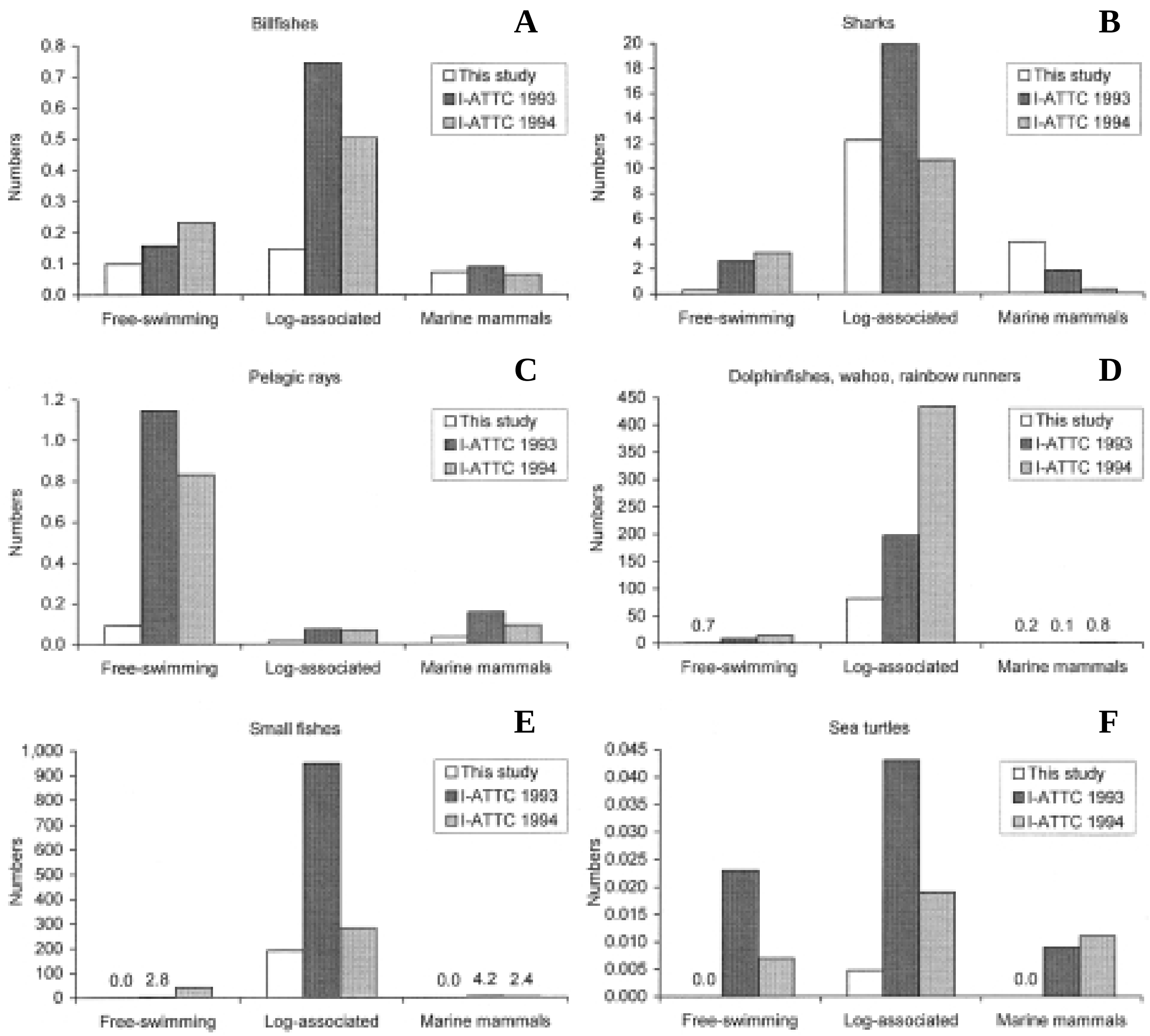

Figure 5

Bycatch levels in numbers per set by groups of species and by types of schools in the western Indian Ocean and eastern Tropical Pacific (Anonymous, 1997).

14%, respectively), which is explained by the fact that the SFA data included Japanese vessels known to fish on log-associated schools only. Nevertheless, the SFA values and those from our observers were on the same order of magnitude. Proceeding from this, I estimated the ratio of sets on various school types and the magnitude and species composition of bycatch by the French and Spanish vessels. These values were close to those for the Soviet fleet employing similar fishing tactics.[27]

Thus, the average bycatch estimates presented in this study can be extrapolated for this period to the total WIO purse-seine catch of principal fishing nations targeting all types of schools.[28] Estimates of bycatch from log-associated schools, I believe, can be extended, with some caution, to the pooled purse-seine catch of Japan and Mauritius in the WIO.

The annual purse-seine catches of yellowfin and skipjack tunas by fleets targeting all types of schools (France,

[27] Data from logbooks (Cort, 1992) show a lower proportion of sets and of catches on whale-associated schools for Spanish vessels, but in the author's view a comparison of data collected in the same way (by observers) is preferable.

[28] France and Spain (along with catch from the vessels from these two countries flying "flags of convenience" [Panama, Côte d'Ivoire, and recently Belize] and applying the same fishing tactics), and USSR (recently Russia or Liberia).

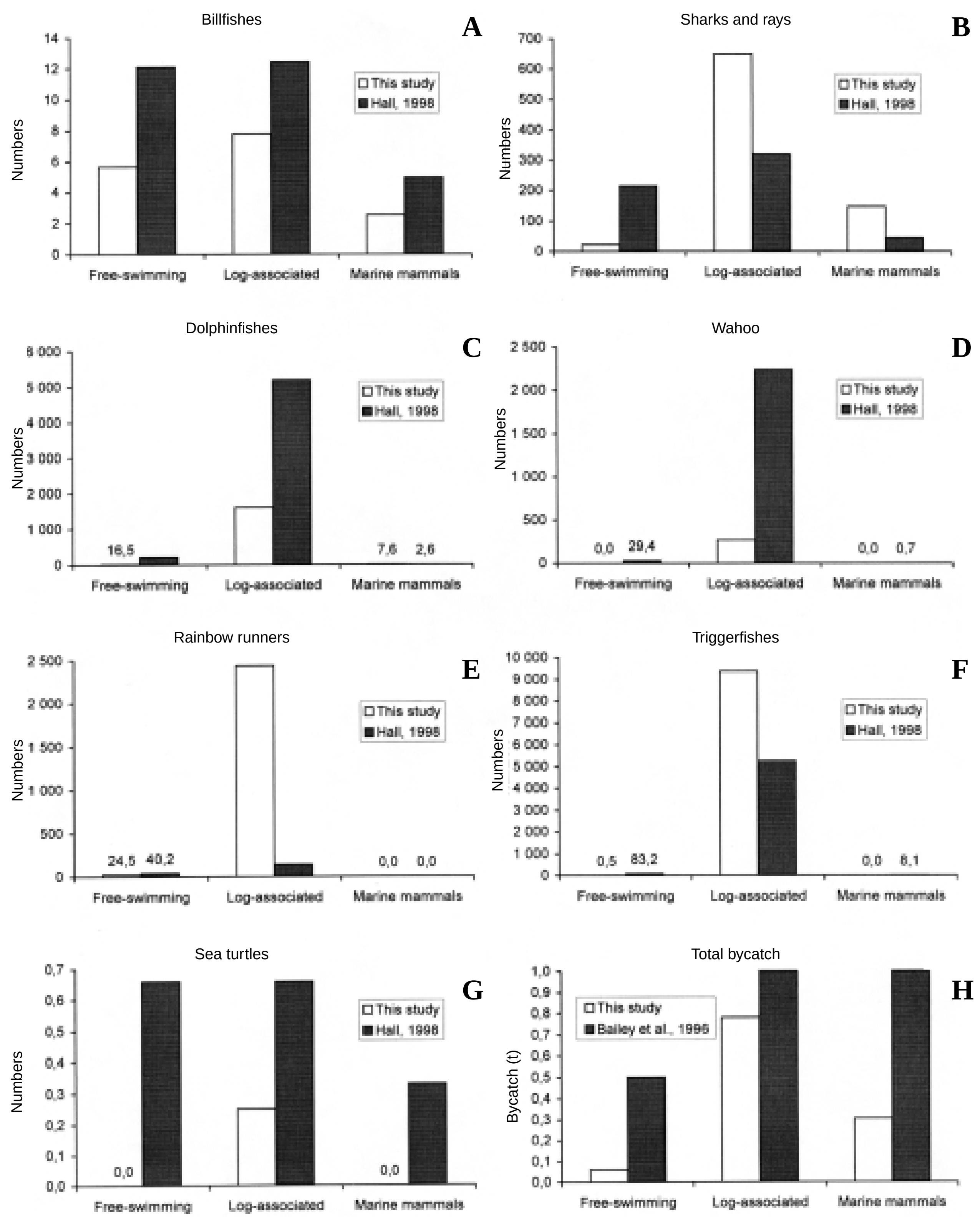

Figure 6

(**A–G**). Bycatch levels, in numbers per 1000 t of target species, by groups of species and by types of schools in the western Indian Ocean and eastern Tropical Pacific; (**H**) bycatch levels, in tons per set by types of schools in the western Indian Ocean and western Pacific Ocean.

Spain, and USSR)[29] in the WIO ranged between 115,000 and 242,000 t in 1985–94 (Anonymous[30]). Japanese and Mauritian catches varied from 3000 to about 51,000 t. Based on these values, the estimated bycatch was 3257 to 8246 t of various fishes during the same period (Table 7). These fishes could serve as food for the coastal countries of the area. Estimated bycatch in numbers is presented in Table 8.

Turtle bycatch and whale mortality in purse seines are also possible in the WIO, but the probability of the latter is very low. No instances of whale mortality have been recorded earlier for tuna purse-seine fisheries in other areas (Northridge, 1984, 1991a, 1991b; Medina-Gaertner and Gaertner, 1991; Santana et al., 1991; Cort, 1992; Cayre et al., 1993; Bailey et al., 1996). No avian mortality by the Soviet tuna purse-seine fishery has been noted by observers. A similar fact was reported for the western Pacific (Bailey et al., 1996).

Target fishing for rainbow runner, dolphinfish, triggerfishes, wahoo, mackerel scad, and barracuda is not conducted in the WIO, and these fish are taken only as bycatch. Their bycatch levels, estimated in this study, do not seem to endanger the populations of these species.

Estimated bycatch of billfishes (104–251 t annually) was less than 1% of the total catch for these species (14,000–33,000 t during 1985–94) in the WIO (Anonymous[30]). The bycatch by the purse-seine fishery was unlikely to substantially affect the billfish stocks.

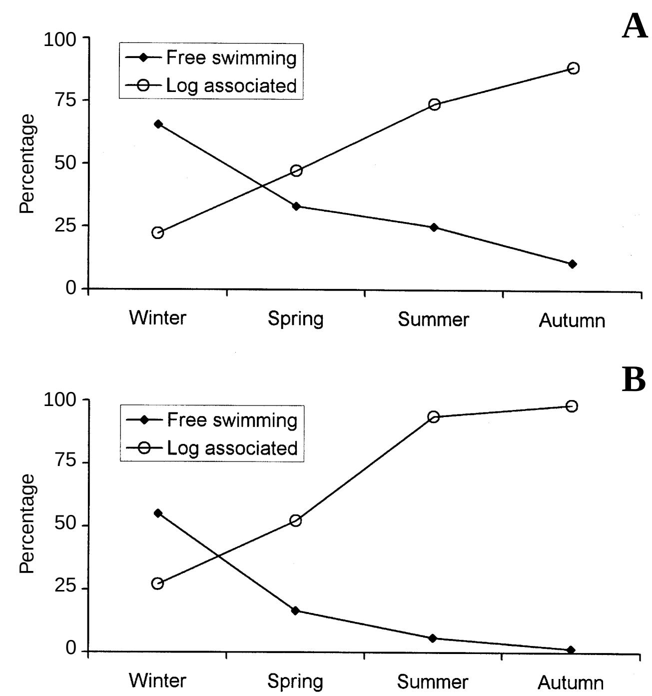

Figure 7

(**A**) Percentages of free-school and log-schools sets; (**B**) percentages of free-school and log-school catch in the Soviet tuna purse-seine fishery.

Many pelagic sharks are taken as bycatch by the longline, trawl, coastal driftnet, and other fisheries, but are not recorded. The total shark catch by all fisheries may be considerable. Many shark species are characterized by low abundance, low fecundity, long life span, and consequently, by high vulnerability to overfishing. Underestimation of the removal through fisheries of a number of pelagic shark species, and the impact of the fisheries on their populations, may lead to a reduction in their abundance to critical levels, diminishing the biodiversity of the pelagic ecosystem of the Indian Ocean.

Some part of the bycatch is released into the ocean alive, although subsequent survival rates are unknown. The lack of bycatch and discard records and estimates of survival rates of discarded animals prevents assessment of the impact of the fishery on the Indian Ocean pelagic ecosystem.

Fishing tactics in the WIO have changed considerably by all principal purse seine fleets toward the extensive use of FADs in recent years (generally from 1995). The majority of Japanese vessels have left the area and have moved to the eastern Indian Ocean. Therefore estimates presented here for total WIO purse-seine fisheries are applicable for a limited time span only (pre-1995). Recent development of the WIO fisheries warrants further investigation of bycatches through extensive observer sampling by time–area strata.

Establishing a scientific program by the Indian Ocean Tuna Commission to monitor the principal tuna fisheries in the region, by placing international scientific observers on purse-seine and longline vessels, might be the first step toward a more accurate assessment of the impact of bycatches on the epipelagic ecosystem of the Indian Ocean. This program might also lead to developing technical and management measures to reduce the bycatches or to use them.

The solution to the bycatch problem should take two directions: 1) an effort to reduce or eliminate bycatches of undesired species; or 2) to use bycatch animals to make them target species. The former involves developing gear modifications or changes in fishing tactics. The latter involves management regulation of the fishery so that bycatch species are treated in the same way as other target species.

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[29] Including vessels flying flags of convenience.

[30] Anonymous. 1998. Indian Ocean tuna fisheries data summary, 1986–1996. Indian Ocean Tuna Commission (IOTC) data summary 18, 180 p. IOTC, P.O. Box 1011, Victoria, Seychelles.

Table 8

Bycatch estimates in numbers in the western Indian Ocean purse-seine fisheries during 1985–94. Codes are same as table 7. MIX = fleets targeted all types of schools (France, Spain, USSR); LOG = fleets targeted log-associated schools (Japan and Mauritius).

Species, a group of species		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
	MIX	45,600	52,273	62,780	83,581	80,993	75,052	73,455	89,529	89,676	96,094
Pelagic oceanic sharks	LOG	2161	2100	4280	5653	7531	12,546	19,456	33,320	31,488	10,030
	Total	47,761	54,373	67,060	89,234	88,524	87,598	92,911	122,849	121,164	106,124
	MIX	162,457	186,232	223,664	297,770	288,550	267,386	261,694	318,961	319,485	342,351
Rainbow runners	LOG	8112	7883	16,065	21,218	28,267	47,090	73,029	125,065	118,190	37,646
	Total	170,569	194,115	239,729	318,988	316,817	314,476	334,723	444,026	437,675	379,997
	MIX	107,711	123,473	148,291	197,424	191,312	177,280	173,505	211,474	211,821	226,982
Dolphinfishes	LOG	5373	5221	10,641	14,053	18,723	31,190	48,370	82,835	78,282	24,934
	Total	113,084	128,694	158,932	211,477	210,035	208,470	221,875	294,309	290,103	251,916
	MIX	621,823	712,823	856,096	1,139,747	1,104,458	1,023,450	1,001,661	1,220,857	1,222,862	1,310,387
Triggerfishes	LOG	31,215	30,334	61,820	81,646	108,774	181,205	281,018	481,252	454,799	144,863
	Total	653,038	743,156	917,916	1,221,393	1,213,232	1,204,655	1,282,679	1,702,109	1,677,661	1,455,250
	MIX	17,444	19,996	24,016	31,973	30,983	28,710	28,099	34,248	34,304	36,760
Wahoo	LOG	876	851	1734	2290	3051	5083	7883	13,501	12,759	4064
	Total	18,320	20,847	25,750	34,263	34,034	33,793	35,982	47,749	47,063	40,824
	MIX	750	859	1032	1374	1332	1234	1208	1472	1474	1580
Billfishes	LOG	26	25	51	68	90	151	233	400	378	120
	Total	776	884	1083	1442	1422	1385	1441	1872	1852	1700
	MIX	250	286	344	458	444	411	403	491	491	527
Mobulas and mantas	LOG	3	2	5	7	9	15	23	39	37	12
	Total	253	288	349	465	453	426	426	530	528	539
	MIX	45,134	51,739	62,138	82,726	80,164	74,285	72,703	88,613	88,758	95,111
Mackerel scad	LOG	2266	2202	4487	5926	7895	13,153	20,398	34,931	33,011	10,515
	Total	47,340	53,941	66,625	88,652	88,059	87,438	93,101	123,544	121,769	105,626
	MIX	1350	1547	1858	2474	2397	2221	2174	2650	2654	2844
Barracudas	LOG	68	66	134	177	236	393	610	1044	987	314
	Total	1418	1613	1992	2651	2633	2614	2784	3694	3641	3158

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