BYCATCH IN THE PURSE SEINE TUNA FISHERIES IN THE WESTERN INDIAN OCEAN[1]

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ABSTRACT

The yield of associated and dependent species taken as bycatch by the purse seine tuna fishery from the Indian Ocean pelagic ecosystem is estimated from data collected by scientific observers aboard Soviet purse seiners in the Western Indian Ocean (WIO), 1986-1992. 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 registered. Among them only two species, yellowfin and skipjack tunas, are target species. Average levels of non-tuna bycatch equal 0.518 t per set, 27.2 t for 1,000 t of target species. By the author's estimates, the annual catch of yellowfin and skipjack tunas in 1990-1995 of the total international WIO purse seine fishery was within the range 215,000-285,000 t. The annual non-registered catch included 1,700-2,300 t of pelagic oceanic sharks, 1,300-1,700 t rainbow runners, 1,250-1,650 t dolphinfish, 900-1,200 t triggerfish, 200-270 t wahoo, 190-250 t billfishes, 100-130 t of mobulas and mantas, 60-80 t of mackerel scad, 15-25 t of barracudas, and 120-160 t of other fish; bycatch of turtles and whale mortality were possible. Absence of bycatch records in purse seining does not make it possible to assess, to the full extent, the impact of the fisheries on the pelagic ecosystem in the Indian Ocean. The first step to the solution of this problem is for the Indian Ocean Tuna Commission to develop a system of scientific control over tuna purse seine and longline fisheries by means of a wide network of Commission scientific observers on board fishing vessels in the area.

RÉSUMÉ

Le rendement des espèces associées pêchés à la senne par les thoniers dans le système de l'écologie pélagique de l'océan Indien a été estimé à partir des données collectées par des observateurs scientifiques sur des senneurs soviétiques opérant dans l'ouest de l'océan Indien entre 1986 et 1992. L'analyse a touché des coups sur 464 bancs libres et associés à des requins baleine, à des baleines et à des épaves dérivantes. Plus de 40 espèces de poisson et d'autres animaux marins ont été répertoriés. Seule deux espèces, les albacores et les listaos étaient ciblés. La moyenne des captures associées était de 0,518 t par opération de pêche, représentant 27,2 t pour 1.000 t de prises des espèces ciblées. Selon l'estimation de l'auteur, les captures annuelles d'albacore et de listaos dans l'ouest de l'océan Indien entre 1990 et 1995 se situent entre 215.000 et 185.000 t. Sur cette base, les captures non enregistrées de requins pélagiques océaniques auraient été de 1.700 à 2.300 t, celles des comètes saumon, 1.300 à 1.700 t, des coryphènes, 1.250 à 1.650 t, des balistes, 900 à 1.200 t, des thazards bâtards, 200 à 270 t, des poissons épée, 190 à 250 t, des mobulas et mantas, 100 à 130 t, des chinchards, 60 à 80 t, des barracudas, 15 à 25 t, avec en plus 120 à 160 t d'autres espèces. Il est probable qu'il y ait eu des captures de tortues et des mortalités de baleines. Il n'est pas possible d'évaluer de façon complète l'effet sur les écosystèmes la pêche à la senne dans l'océan Indien due à l'absence de collecte exhaustives de données. Le premier pas que doit prendre la CTOI est de développer un système de contrôle scientifique sue les pêches à la senne et à la palangre par le moyen d'observateurs scientifiques dépendant de la Commission embarqués sur les bateaux.

Introduction

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 the necessity to take into account the impact of target species 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 bycatch is one of the first steps to establish impacts of fisheries on populations of associated species.

The tuna purse seine fishery is the most intensive direct human impact on the ecosystem of the tropical epipelagic zone in the World Ocean at present. Taking into account the existing worldwide scale of this fishery, assessment of its impact on associated and dependent species is essential. Bycatch of associated species as well as of marine animals not-associated with tuna during purse seining of tropical tunas may be rather high and depend on the fishing tactics employed by fishermen.

In this fishery, there are as a rule two target species, yellowfin *Thunnus albacares* (Bonnaterre, 1788) and skipjack *Katsuwonus pelamis* (Linnaeus, 1758). In this paper all non-target species of marine animals (including other species of tuna) which were encircled by the fishing gear and are unable to escape by themselves are considered as bycatch.

The species composition of the bycatch depends on the structure, behavior and spatial organization of surface multispecies associations, consisting of schools of different tuna species, schools (or single individuals) of other pelagic fish, marine mammals, and other marine animals, which have aggregated distributions and occur together in the epipelagic zone. Marine birds, perhaps, may be components of such temporal groups; from our observations and in the opinion of other researchers (Au and Perryman, 1985; Au and Pitman, 1986; Au, 1991; Cort, 1992), birds are an integral aerial component of the majority of multispecies groups in which tuna take part.

Tuna, as a rule, prevail by biomass and abundance in such temporal groups. In accordance with the traditional classification of multispecies tuna associations (schools),

[1] *Dedicated to the 75th anniversary of YugNIRO**

used both by fishermen and scientists (Scott, 1969; Petit and Stretta, 1989), tunas are considered as species associated with the most visually distinct part of the group – floating objects, marine mammals, etc. Associations between schools of different species of tuna are considered as "free swimming schools". For each type of associations its various components occur in different ratios.

Assessments of bycatch levels are known for the Eastern Tropical Pacific purse seine tuna fishery (Carpenter, 1994; Joseph, 1994; Garcia and Hall, 1995; Anon., 1997a; Hall, 1998), where the bycatch problem attracted particular attention because of dolphin mortality during sets on dolphin-associated schools. This problem and its economic, political and ecological implications produced wide international echoes (Joseph, 1991, 1994; Levy, 1991). Bycatch estimates for the Western Pacific purse seine tuna fisheries have been published recently (Bailey *et al.*, 1996).

In the western Indian Ocean (WIO) tuna-dolphin associations are rare, purse seining for them is not practiced, and the problem of dolphin bycatch is absent. Perhaps for this reason there is no literature available on the magnitude of non-target species bycatch. Bycatch is not registered, as a rule (except bycatch of non-target tuna species), in logbooks and statistical records of tuna seiners operating in the area. In this paper a first attempt is made to estimate approximate non-registered volumes of yield for associated species from the pelagic ecosystem in the WIO by tuna purse seine fishery, based on available, but rather scarce materials 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 (the vessels of BST[2] type – "Rodina", "Tiora", "Evgenyi Preobrazhenskyi", "Ivan Borzov", and "Tridakna" all owned by KUTF[3]), in the WIO, in 1990-1991. In addition, observer data from AtlantNIRO[4] and "Rybprognoz"[5], collected in 1986-1990 in the same area (above-mentioned KUTF[6] vessels) as well as materials from TINRO[7] and TURNIF[8] observers (1990, 1992 – the vessels "Uzhgorsk", "Zemlyansk" owned by VBTRF[9]) were used.

Observers recorded results of each set. The type of school on which set was made (Scott, 1969; Petit and Stretta, 1989) was recorded. For positive sets, species composition of catch, total weight and numbers of each species in the catch were recorded. Sometimes bycatch was recorded only in numbers; in such rare cases, the weight of fishes was estimated by the author from the average weight of these species in previous catches. Only bycatch taken on board was recorded.

The fishing vessels used purse seines 1,800 m in length, and 250-280 m in depth; mesh size in the bunt was 90-100 mm.

I considered sets in which an observer recorded catch in any quantity as positive sets. Set with a catch of more than 0.5 metric tonnes (t) without malfunctions during the set (that might bias the determination of species composition of surface schools, such as partial escaping of fish from the seine) were considered representative. The latter sets were used for studies of the species composition of associations.

Results of an analysis of the following types of surface tuna schools are presented: free-swimming schools (including associations between schools of different species of tuna) and associated schools. The latter include: whale associated schools and schools associated with floating objects (log associated schools).

Schools caught in the area of seamounts and shoals – Equator, Travin mounts, Saya-de-Malha bank – were referred to as free-swimming schools. Catches from areas with surface evidence of water masses or current interactions (rips) were treated as free-swimming schools in the primary analysis; however the presence in the catches of species characteristic of log-associated schools and the occurrence of small scattered debris in such areas lead to grouping of the catches in rips together with catches from log sets. Two schools identified as free-swimming schools prior to the set, later on turned to be associated with the whale shark *Rincodon typus* Smith, 1828. For log-associated sets, associations with natural floating objects and fish aggregation devices (FADs) were not treated separately.

As tuna purse seining in the WIO is clearly a seasonal fishery with monsoons governing the rhythm and techniques of operations, data were analyzed with this factor taken into account. The division of a year into seasons for the tropical zone of the WIO follows that suggested by Yu. A. Romanov (1982) – in accordance with long-term average seasonal variations in the monsoon atmospheric circulation. The winter season (north-eastern monsoon) lasts from December to March, the spring inter-monsoon period falls in April and May, the summer (south-western monsoon) lasts from June to August, the autumn inter-monsoon period lasts from September through November. The wind regime determines the onset and duration of hydrological seasons, which do not quite coincide with seasons of the atmospheric circulation due to considerable time lag of the processes occurring in the hydrosphere. Yet, the wind regime is instrumental in determining the tactics of purse seining for tuna surface schools. That is why the seasonal division of the year based on atmospheric rather than on hydrological processes has been adopted in this paper.

Also used in this paper was the YugNIRO database (DB) on Soviet tuna purse seine fishery in the Indian Ocean formed by the author based on daily radio reports from vessels

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[2] Length overall – 85 m, GRT – 2634, carrying capacity ~ 1600 m3.
[3] KUTF – The Kaliningrad Authority of Trawl Fleet. 1, 5[th] Prichalnaya St., 236035 Kaliningrad, Russia.
[4] AtlantNIRO – The Atlantic Scientific Research Institute of Marine Fisheries and Oceanography. 5 Dmitry Donskoi St., 236000 Kaliningrad, Russia.
[5] The Joint Stock Company "Rybprognoz", formely untill 1993 The Department of Searching and Scientific Research Fleet of the Western Basin "Zaprybpromrazvedka". 5[a] Dmitry Donskoi St., 236000 Kaliningrad, Russia.
[6] Except "Evgenyi Preobrazhenskyi".
[7] TINRO – The Pacific Scientific Research Institute of Marine Fisheries and Oceanography. 1, Shevchenko Alley, 690600 Vladivostok, Russia.
[8] TURNIF – The Pacific Department of Fish Searching and Scientific Research Fleet. 2, Pervogo Maya St., 690600 Vladivostok, Russia.
[9] VBTRF – The Vladivostok Base of Trawl and Refrigerating Fleet. 51, Leninskaya St., 690600 Vladivostok, Russia.

owned by KUTF and VBTRF (1985-1994)[10], carrying out purse seining in the Indian Ocean from 1983[11] till mid-90ies. This paper does not take into account reflagging of some Soviet (from 1992 – Russian) vessels to Liberian flag and the vessel nationality is defined here by the location of their owners.

The Aquatic Sciences and Fisheries Abstracts information system (ASFA) CD-ROMs and the electronic encyclopedia FishBase 96 were used to search for bibliographic information. Coastline and bathymetry from GEBCO sheets 5.05 and 5.09, compiled by A. S. Laughton, D. Monahan, and R. L. Fisher and made available through GEBCO Digital Atlas (1994), were used for charting.

Bycatch was used, as a rule, in limited quantities on board fishing vessels. Non-utilized bycatch was discarded in the ocean. Because of scarcity of data, it is not possible in this paper to assess quantitatively the discards of tuna and bycatch species.

Average values were calculated as arithmetic means, confidence intervals were calculated for 95 % probability, estimates of non-registered bycatch volumes (all fish groups, except tunas) in numbers and in kilograms were made for one positive set and for 1,000 t of target species.

Results

Primary data and representativeness of sample

A total of 494 purse seine sets were sampled and 377 positive sets were analyzed; the total catch in sampled sets amounted to 7,713 t. Distribution of sampled sets by year, season and type of schools is given in Tables 1 and 2, sampled catch by types of schools is presented in Table 3.

In the periods when observers were on board the vessels in the fishing areas of the WIO (1986-1992) their coverage of the Soviet purse seine catch varied from 5 to 75 %. Tuna catch data used in the author's calculations (catch in representative sets) comprised 30 % (7,252 t) of the aggregate tuna catch by Soviet seiners during the periods mentioned (24,000 t). The spatial distribution of sampled sets agrees quite well with distribution of total fishing effort of the Soviet fleet in the WIO (Figure 1). Thus the author has every reason to believe that the observer data cover the catch by Soviet purse seiners in respect to both the magnitude of analysed samples and to geographic distribution of sets fully enough and can be used for the species composition analysis of the total catch.

The data series available for analysis has been treated by seasons as average annual data, yet it is an aggregate of samples of different size, obtained in different years and seasons (Tables 1-3). Therefore, results of all analyses may be subject to interannual variability (it is impossible to evaluate its influence from the data available), and the estimated average annual figures may be subject to seasonal variability as well on account of unequal size of samples taken in different seasons.

The daily radio reports from which the database was formed did not yield information on sets according to school types. This does not allow to directly raise the observer data to the catch of the whole Soviet fishing fleet separately by school type. However, taking into account the percentage of the catch under the observers' control, their data, in the author's opinion, correctly reflect the seasonal ratio of sets on different school types.

In order to assess the possibility of using annual averages (resulting from available samples) and raising them to the whole catch of the Soviet fleet, the author compared the seasonal magnitudes of the total fishing effort (fishing days, sets) and catches reported by the Soviet fishing fleet (source – database) with the seasonal magnitudes of effort and catch (number of sets and catch in tonnes) sampled by observers (Figure 2 a, b).

The seasonal distribution of the sampled catch in weight follows the same pattern as the long-term average seasonal distribution of the catch by the fishing fleet (Figure 2 b). The effort sampled does not fully agree with the seasonal increase in the fishing effort of Soviet vessels during the autumn season (Figure 2 a) which apparently may result in certain underestimation of average annual values of bycatch from log-associated schools. The author did not attempt to take this factor into consideration to avoid further subjective errors.

Species composition and catch by school type

A total of 43 species (or higher taxa) of fish and other marine animals were registered in the catch of fishing vessels (Table 4).

Free swimming schools

This is one of the predominant types of surface schools in the WIO. Such schools occurred in the area throughout the year (Table 2, Figure 2 a, b). Soviet purse seiners made free school sets in the WIO generally south of the equator (including the Mozambique Channel)(Figure 1 b). Yellowfin, skipjack and bigeye (*T. obesus*) tunas are the principal components of free swimming schools – 81 %, 14 % and 4 %, respectively (Table 5). Among sets on such types of schools, monospecific (non-associated) schools, consisting completely of yellowfin or skipjack were found to occur quite frequently (in 47 % of free school sets). Multispecies free schools were observed in 53 % of cases and consisted of two target species and bycatch, which occurred in 45 % of the total of free school sets, including non-tuna bycatch in 22 %. Principal types of observed multispecies free schools are presented in Table 6.

A total of 18 species (or higher taxa of fishes) were observed in catches on free schools (Table 4), some species (*G. serpens, C. maculatus, Diodon* spp.) are considered as accidental bycatch or as tuna preys (Exocoetidae). Non-tuna bycatch in this type of associations is on average 0.060± 0.031 t per positive set or 3.403± 2.770 t for 1,000 t of target species (Figure 3). The bulk of bycatch are sharks of the

[10] Since 1995 the income of reliable information on fishing operations from Russian shipowners ceased.

[11] In 1983 tuna seiners from Russian Far East were under ownership of "Sakhalinrybprom" Company, Nevelsk, Sakhalin Is., Russia. Complete information on results of fishing activity of these vessels in the Indian Ocean were not available.

genus *Carcharhinus* (0.023 t/1.296 t[12]), rays of the Mobulidae family (0.020 t/1.128 t), marlins of *Makaira* genus and sailfish (*I. platypterus*) (0.016 t/0.895 t)(Table 4, 7).

Whale shark associated schools

Two schools associated with whale shark were found only in the winter season (Table 2, Figure 2 a, b) south of the equator (Figure 1 c). In these sets, bycatch consisted of the shark itself and a small quantity of albacore (*T. alalunga*)(Table 4). The small numbers of such sets did not permit making reliable bycatch estimates for whale shark associated schools nor to infer species compositions of such associations.

Whale associated schools

Schools of this type include all types of tuna schools associated with individuals or groups of whales. In observers' logbooks, among 45 sets on whale associated schools, 13 sets were made on schools associated with sei whales – *Balaenoptera borealis* Lesson, 1828, for one time a set on a school associated with fin whale – *B. physalis* (Linnaeus, 1758)[13]. The remaining sets were made on unidentified baleen whales. According to oral reports of some observers (Bashmakov, 1998 *pers. comm.* [14]) schools associated with Bryde's whale – *B. edeni* Anderson, 1878, Minke whale *B. acutorostrata* Lacepede, 1804 and pygmy blue whales *B. musculus brevicauda* (Linnaeus, 1758) were also observed in the WIO. From the author's personal observations and the observer evidence, sperm whales – *Physeter catodon* Linnaeus, 1758 are found very often in the areas of the tuna purse seine fishery; however, tuna-sperm whale associations were not recorded. According to observations made during setting and searching operations, whales in association with tunas generally occur in groups of up to 8 individuals, more often in groups of 2-3 whales.

Whale associated schools are most often seen from January to April. A single case of such an association was observed in July (Table 2, Figure 2 a, b; 4). In the sampled area, schools of this type were distributed mainly south of equator in latitudes 4-9°S. The only summer set on this type of school was made north of the equator (Figure 1 c). Skipjack, yellowfin and bigeye tunas are dominant in the whale-associated schools – 64 %, 23 % and 11 % respectively (Table 5). The percentage of each species in different sets may vary greatly and comprise 0-100 % for skipjack, 0-100 % for yellowfin, 0-74 % for bigeye; however, associations consisting of one tuna species and a whale are encountered rather rarely – in eight cases (22 %). Bycatch in whale associations was found in 68 % of sets on this type of school, including non-tuna bycatch in 43 % of the sets. Generally, the composition of associations with whales is as presented in Table 6. No whale associated schools were found in which skipjack, yellowfin and bigeye tunas occured in equal weight proportions and associations of the type "whales – skipjack > bigeye > other bycatch" were ever never recorded.

During sets on whale-associated schools, the ships' crews see to it that the whale(s) remain inside the purse seine as long as possible. Whales often remain in the encircled area till the end of pursing. Whales break out from the purse seine by one of the following ways: by sounding under the purse line, by ramming their way through the net wall, by drowning the corkline (a rare occurrence in our observations).

Observers registered a case of entangling in the net and subsequent death of young sei whale about 10 m in length and 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. This being a single event, it is not possible to assess the frequency and probability of whale mortality in such type of fisheries.

There were 17 species (groups) of marine animals found in catches (Table 4) including salps, ctenophores, batfish (*Platax* spp.) which I considered as accidental bycatch, while long-finned fathead (*C. pauciradiatus*) is hunted by both tunas and whales. Non-tuna bycatch in this type of association averages 0.306± 0.344 t for a positive set or 11.032± 15.991 t per 1,000 t of target species (Figure 3). Sharks of *Carcharhinus* and *Isurus* genus (0.289 t/10.435 t)(Table 4, 7) make up the bulk of bycatch in whale-associated school sets.

Log associated schools

This is one of the predominant types of schools found in the fishing area all year round (Table 2, Figure 2 a, b). In the WIO, sets on this type of school were carried out over all the area sampled as far south as 15°S (Figure 1d). In log schools, the bulk of the catch are skipjack, yellowfin and bigeye tunas – 68 %, 24 % and 2 % respectively (Table 5). Log schools in all cases consist of several fish species. Bycatch was found in 93 % of sets, including non-tuna bycatch in 87 %. In rare cases, there was no bycatch observed during successive sets on the same floating object. Several types of association around flotsam were observed which were mostly formed from the groups presented in Table 6.

The species composition of associations with floating objects is most diverse and includes 34 species of marine animals (Table 4). Fish bycatch is at its highest level in log-associated school sets – as much as 0.780± 0.144 t per positive set or 41.337± 14.281 t per 1000 t of target species (Figure 3). The bulk of bycatch in sets on flotsam-associated schools is made up of rainbow runner *E. bipinnulata* (0.195 t/10.315 t), dolphinfish *C. hippurus* (0.190 t/10.094 t), triggerfish of the genus *Canthidermis* (0.137 t/7.255 t), sharks of the genus *Carcharhinus* (0.176 t/9.305 t), wahoo *A. solandri* (0.031 t/1.621 t), billfishes of the genera *Makaira, Tetrapturus* (0.019 t/1.017 t), mackerel scad *D. macarellus* (0.0092 t/0.487 kg). Capture of a sea turtle (the species was not identified) was recorded as a single event (Table 4, 7).

All types of schools

Considering all school types in the aggregate, skipjack, yellowfin, and bigeye prevail in the catch – 50 %, 43 %, and 4 % by weight, respectively (Table 5). Albacore comprises a mere 0.2 %, frigate tuna – 0.8 %, kawakawa less than 0.1 %. Non-tuna catch accounts for less 2 % of the catch.

On the average there is 0.518± 0.099 t of bycatch per positive purse seine set, or 27.166± 8.882 t per 1000 t of target

[12] Here and further bycatch in parenthesises presented as follows: (per positive set/per 1000 t of target species).
[13] Species identification could be erroneous.
[14] Bashmakov, V. F., 1990, pers. comm. AtlantNIRO, Kaliningrad, Russia.

species without separation by school type (Figure 3). Fish bycatch levels by species (groups) are given in Table 7.

Discussion

The lowest fish bycatch in the WIO tuna purse seine fishery is taken from free schools (mainly carcharhinid sharks and rays of the Mobulidae family)(Figure 3, Table 4, 7). When fishing on log schools, fish bycatch is highest and diverse (rainbow runner, dolphin fish, triggerfish, carcharhinid sharks, wahoo, billfishes, mackerel scad are predominant). Whale-associated schools are characterized by intermediate level of bycatch (mainly carcharhinid and lamnid sharks)(Figure 3, Table 4, 7).

It is interesting to compare the bycatch rates obtained by the author with those published for other regions of the World Ocean. Principal bycatch fish species in the Pacific (Carpenter, 1994; Bailey *et al.*, 1996; Anon, 1997a; Hall, 1998) are the same as in YugNIRO observations. Bycatch levels are known to vary considerably by years, areas, fleets (Bailey *et al.*, 1996, Anon, 1997a), and, of course, school type, which hampers a direct comparison of the results of this study with the published data. However I made an attempt to assess the consistency of this findings and values obtained by other investigators on the basis of bycatch levels for various regions of the Pacific Ocean (Carpenter, 1994; Bailey *et al.*, 1996; Anon, 1997a). For the purpose of comparison I have pooled my estimates by groups of bycatch in accordance with the published data. The comparison shows that bycatch levels per set and per 1,000 t of target species for various regions of the Pacific and the author's estimates for the Indian Ocean are of the same order of magnitude for most bycatch groups in similar types of associations (Figure 5 a, b, c, d, e, f; 6 a, b, c, d, e, f).

I also made an attempt to assess an overall possible non-registered bycatch by purse seine fleets of the principal fishing nations in the Western Indian Ocean proceeding from similarity in the fishing tactics applied by vessels of certain countries.

The tactics of the Soviet fishing fleet in the WIO were characterized by the equal proportion of sets made during the year on free swimming schools and on log associated schools (Table 2) as well as by clearly defined seasonal switch of effort from sets on schools/associations of the former type to fishing on associations of the latter type (Figure 7 a, b). French and Spanish tuna seiners show similar seasonality in their fishing practice (Anon, 1992; Anon., 1994 a, b; Pianet, 1994 a, b; Moron, 1996).

Fishing tactics of the Japanese (Hallier, 1991; Okamoto and Miyabe, 1996) and Mauritian (Norungee *et al.*, 1994; Norungee and Lim Shung, 1996) purse seine fleets differs considerably from that described above. Japanese and Mauritian vessels make sets on log associated schools all year round, with single instances of sets on other schools types.

In publications on tuna purse seine fishery in the Indian Ocean (Hallier, 1991; 1994; Parajua Aranda, 1991; Anon., 1992; Anon., 1994a, b; Pianet, 1994 a, b; Hastings and Domingue, 1996; Moron, 1996) two school types are recognized only: log schools and free schools. In analyses of commercial fishery data for the Indian Ocean, the latter, as a rule, incorporates all types of associations with marine animals. Data on the proportion of sets of the French fleet on other types of schools and on resulting catches are not found in the literature available to the author. Such data based on fishing logbooks are presented by J. L. Cort (1992) for Spanish vessels only.

Hence I have made an attempt to assess these values indirectly from the Seychelles Fishing Authority (SFA) observer data (Cort, 1992), generalized for the vessels of the principal fishing countries (France, Spain, Japan and USSR) operating in the WIO. The percentage of sets on whale-associated schools varied from 1.7 % to 8.8 % in 1986-1990, the proportion of such schools among positive sets being from 1.2 % to 9.1 %, and the catch from such schools – from 1.6 % to 7.8 % (cited from Cort, 1992). These values are slightly lower than the observer data in my analysis (9 %, 10 % and 14 % respectively), which is readily explained by the fact that the SFA sample analysed by J. L. Cort (1992) includes Japanese vessels known to fish on log-associated schools only; nevertheless, the SFA values and those from our observers' are comparable figures of the same order of magnitude. Proceeding from this, I estimated the ratio between sets on various school types (including those associated with whales), the magnitude and species composition of bycatch by French and Spanish vessels, which have values that are close to the figures for the Soviet fleet employing similar fishing tactics[15].

When annual purse seine fishery yield in the area reached high levels (from 1985 till now), France and Spain[16] shared the lion's part of the total tuna purse seine catch in the WIO (75-95 %, on the average 86 %)(Anon, 1997b). The aggregate catch of these two fishing nations plus the catch of the USSR made up 77-96 %, and 90 % on the average, of the total catch (Figure 8). The pooled catch of Japan and Mauritius has never exceeded 18 % (1992 and 1993), averaging about 9 % (Figure 8). Thus the author holds that his bycatch estimates, with certain caution, can be extended to the total purse-seine catch in the WIO tuna fishery.

The annual catch of yellowfin and skipjack tunas with purse seines in the WIO fluctuated in the range between 215,000 and 285,000 t in 1990-1995 (Anon., 1997b). Proceeding from these values, some 5,800 to 7,800 t of various fish species is estimated to have been caught annually as bycatch (and not registered) during the same period (Table 8). These figures are considerable food resource, which might be used as additional food source for the population of coastal countries of the area or otherwise commercially marketed.

Turtle bycatch and whale mortality in purse seines are possible but the probability of the latter is very low. In the tuna purse seine fishery at least, no instances of whale mortality have been recorded to date (Northridge, 1984, 1991a, b; Medina-Gaertner and Gaertner, 1991; Santana *et al.*, 1991; Cort, 1992; Cayre *et al.*, 1993; Bailey *et al.*, 1996). To the best of the author's knowledge no loss of avian life in the Soviet tuna purse seine fishery has been noted by

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

[16] Along with catch by the vessels from these countries flying "flags of convenience" (Panama, Côte d'Ivoire, recently – Belize) and applying the same fishing tactics.

observers. A similar fact has been reported for the western Pacific also (Bailey *et al.*, 1996).

Target fishing for the most of the above-mentioned species (rainbow runner, dolphinfish, triggerfish, wahoo, mackerel scad, and barracuda) is not conducted, they are taken as bycatch only. The level of their harvesting by the tuna purse seine fishery, as estimated in this study, does not seem to endanger the state of populations of these species.

Non-registered bycatch of billfishes (190-250 t annually) is considerably lower than their catch in target fishery (mainly longline) and is less than 1 % of the total catch for these species (14,000-40,000 t in 1985-1995) in the WIO (Anon., 1997b)) so the additional removal through the purse seine fishery is unlikely to substantially affect the billfish stocks.

Many pelagic shark species are taken as a bycatch by other fisheries (longline, trawl, coastal driftnets, etc.) where their catch generally is not registered either. A total shark catch by all fisheries may be considerable. Many shark species are characterized by low abundance, low fecundity, long life span and, consequently, high vulnerability to fishing pressure. Underestimation of the removal through fisheries of a number of pelagic shark species and, accordingly, the impact of the fisheries on their populations may lead to the reduction in their abundance to critical levels, over-fishing and diminishing in biodiversity in the pelagic ecosystem of the Indian Ocean as a whole.

Some part of the bycatch is released into the ocean alive; however, the survival rate of the animals released is unknown. The lack of both bycatch and discard records and of estimates of survival rates of released species in the purse seine fishery does not permit a full assessment of the impact of the fishery on the Indian Ocean pelagic ecosystem and on its biodiversity, and this is a matter of concern.

The establishment by the Indian Ocean Tuna Commission of a scientific programme to monitor the principal (purse seine and longline) tuna fisheries in the region by scientific observers placed on fishing vessels might be the firs step toward a more accurate assessment of the impact of bycatch in the pelagic fisheries on the state of the epipelagic ecosystem of the Indian Ocean. This would enable a detailed account of the quantities by-caught and discarded to be kept and technical and management measures developed to reduce the bycatch or reasonably utilize it.

On the whole, the solution to the bycatch problem is to be sought in the author's opinion in two directions: reducing and eventually eliminating bycatch of undesired species or, alternatively, the translation of bycatch into the category of target species and its utilization.

The former involves, as a most rational approach, the development of gear modifications or changes in fishing tactics to reduce the proportion of bycatch. The latter involves management regulation of the fishery on common principles with other target species.

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Table 1: Numbers of sampled sets by year

Years	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 sampled sets by season and type of schools

Type of school	Seasons				Total/with catch
	Winter	Spring	Summer	Autumn	
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

Table 3: Sampled catch by seasons and types of schools

Type of school	Seasons				
	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

Table 4: Species composition of tuna purse seine catches in the western Indian Ocean

Family, species	School type			
	Free swimming	Whale shark associated	Whale associated	Log associated
PISCES				
Mobulidae				
Manta birostris (Donndorff, 1798)	+?*	-	+?	+
Mobula spp.	+	-	+	+
Rhincodontidae				
Rhincodon typus Smith, 1828	-	+	-	-
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 gen. sp.	+	-	-	-
Belonidae gen. sp.	-	-	-	+
Sphyraenidae				
Sphyraena barracuda (Walbaum, 1792)	-	-	-	+
Carangidae				
Caranx spp.	-	-	-	+
Decapterus macarellus Cuvier, 1833	-	-	-	+
Elagatis bipinnulata (Quoy & Gaimard, 1824)	+	-	-	+
Seriola spp.	+	-	-	+
Naucrates ductor (Linnaeus, 1758)	-	-	-	+
Coryphaenidae				
Coryphaena hippurus Linnaeus, 1758	-	-	+	+
Kyphosidae				
Kyphosus cinerascens (Forsskel, 1775)	-	-	-	+
Gempylidae				
Gempylus serpens Cuvier, 1829	+	-	-	-
Ruvettus pretiosus Cocco, 1829	-	-	-	+
Ephippididae				
Platax spp.	-	-	+	+
Scomberomoridae				
Scomberomorus spp.	-	-	-	+

Scombridae				
Acanthocybium solandri (Cuvier, 1831)	-	-	-	+
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 Gьnter, 1872	-	-	+	-
Balistidae				
Canthidermis maculatus (Bloch, 1786)	+	-	-	+
Monacanthidae				
Aluterus spp.	-	-	-	+
Diodontidae				
Diodon spp.	+	-	-	+?
Balaenopteridae				
Balaenoptera borealis Lesson, 1828	-	-	+	-
SALPAE	-	-	+	-
CTENOPHORA	-	-	+	-
CHELONIDEA	-	-	-	+
Number of species (taxa)	18	4	17	34

*The sign (?) denotes doubtful, in the author's opinion, species identification by observer.

Table 5: Average catch per positive set (t) of BST type Soviet vessels in the western Indian Ocean (total and by tuna species)

Type of school	Total	Species					
		YFT*	SKJ	BET	ALB	FRI	KAW
Free swimming	18.4± 5.2	14.7± 4.9	2.7± 1.7	0.8± 1.0	0.03± 0.03	0.05± 0.06	-
Whale associated	30.6± 9.2	9.8± 4.3	17.9± 8.5	2.0± 2.5	-	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	0.01± 0.01
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	+

*YFT – yellowfin, SKJ – skipjack, BET – bigeye, ALB – albacore, FRI – frigate tuna, KAW – kawakawa.

Table 6: Composition of multispecies tuna associations observed in the Western Indian Ocean by principal components*

Types of school		
Free swimming	Whale associated	Log associated
YFT>SKJ**	WHL – SKJ>YFT>OTH	SKJ>YFT>BET>MIS
SKJ>YFT>BET	WHL – YFT>BET>OTH	SKJ>YFT>OTH
SKJ>YFT	WHL – BET>YFT>OTH	YFT>SKJ>OTH
YFT>BET	WHL – YFT>SKJ>OTH	YFT>SKJ>MET>MIS
		SKJ>BET>YFT>MIS

* Fish species in each association are arranged in order of decreasing of species biomass, within school types associations are arranged in the order of decreasing occurrence.

**Species codes are the same as in Table 5, except WHL – whales, OTH – other species (including non-target tuna species), MIS – other miscellaneous non-tuna species.

Table 7: Estimates of the bycatch (t)* of various species (groups) of marine animals by school types

Species, group of species		School type**			
		Free swimming	Whale associated	Log associated	All types of schools
Billfishes (Istiophoridae, Xiphiidae)		0.016/0.895	0.006/0.220	0.019/1.017	0.017/0.882
Wahoo (*A. Solandri*)		-	-	0.031/1.621	0.018/0.936
Sharks (Rhincodontidae, Lamnidae, Carcharhinidae, Sphyrnidae)		0.023/1.296	0.289/10.435	0.176/9.305	0.151/7.949
Rainbow runner (*E. bipinnulata*)		0.001/0.054	-	0.195/10.315	0.114/5.971
Dolphinfishes (*C. hippurus*)		+/0.027	0.001/0.052	0.190/10.094	0.111/5.844
Barracuda (*S. Barracuda*)		-	-	0.003/0.136	0.001/0.076
Triggerfishes (*C. maculatus, Aluterus* spp.)		+	-	0.137/7.255	0.080/4.201
Mackerel scad (*D. macarellus*)		-	-	0.0092/0.487	0.005/0.284
Mantas, mobulas (Mobulidae)		0.020/1.128	0.009/0.322	0.002/0.126	0.009/0.455
Sea turtles		-	-	+/0.025	+/0.015
Other bycatch		+/0.002	+/0.003	0.018/0.958	0.011/0.554
Total	For positive set	0.060± 0.031	0.306± 0.344	0.518± 0.099	
	For 1000 t of target species	3.403± 2.770	11.032± 15.991	27.166± 8.882	

*In numerator, average values per a positive set, in denominator per 1,000 t of target species.

**Because of small sample size, whale shark-associated schools, are not presented in the Table.

Table 8: Bycatch estimates for the minimum and maximum yellowfin+skipjack catch by purse seines in the western Indian Ocean in 1990-1995

Species, group of species	Bycatch in tonnes		Bycatch in numbers	
	Min	Max	Min	Max
Pelagic oceanic sharks	1,700	2,300	85,000	115,000
Rainbow runners	1,300	1,700	300,000	400,000
Dolphinfishes	1,250	1,650	200,000	270,000
Triggerfishes	900	1,200	1,160,000	1,550,000
Wahoo	200	270	30,000	45,000
Billfishes	190	250	1,400	1,900
Mobulas and mantas	100	130	450	620
Mackerel scad	60	80	85,000	115,000
Barracudas	15	25	2,500	3,400
Other fishes	120	160	*–	–
Total**	5,800	7,800	–	–

*– bycatch in numbers not estimated.

**Figures rounded to 100 t.

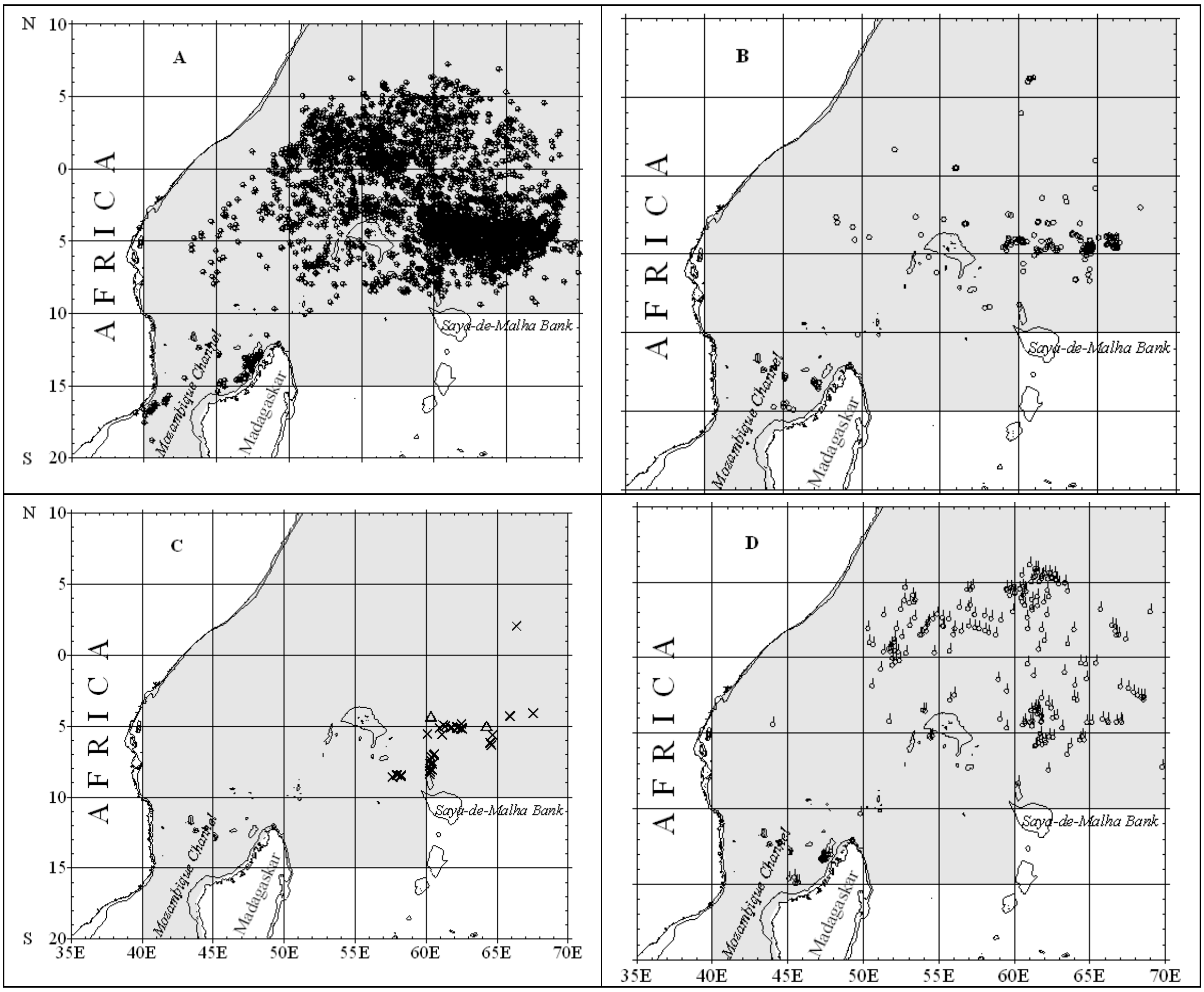


Figure 1 (a, b, c, d). Fishing effort distribution (crossed ring – noon positions of vessels, fishing days with sets) of the Soviet tuna purse seine fishery 1985-1994 – A; sampled set positions: free swimming schools (open ring) – B, whale shark (Δ) and whale-associated schools (cross) – C, log-associated schools (ring with mast) – D. Shaded area represent region of main international purse seine tuna fishing activity in the WIO (Ardill, 1995).

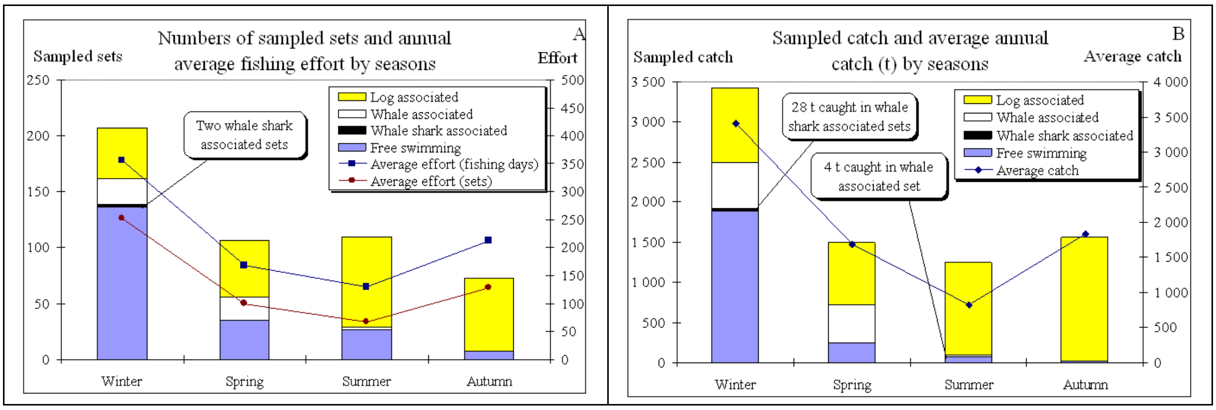


Figure 2 (a, b). Sampled effort (by school type) and long-term average seasonal fishing effort – A, sampled catch (by school type) and long-term average seasonal catch – B of the Soviet tuna fleet.

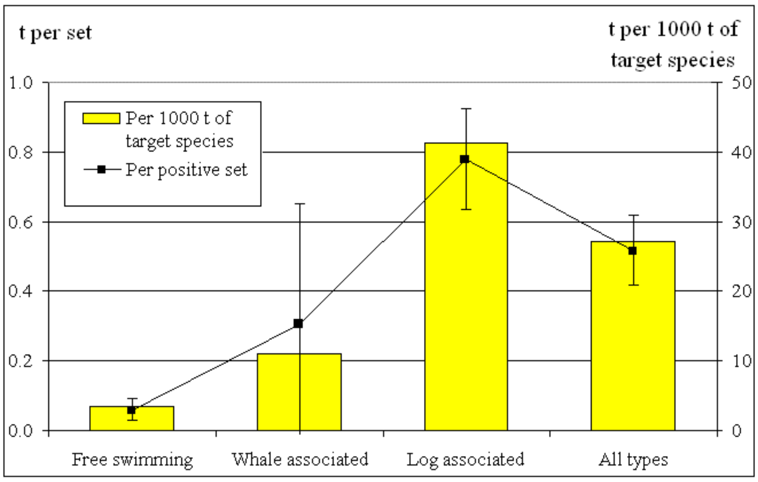


Figure 3. Bycatch estimates in the Soviet purse seine tuna fishery for different types of schools.

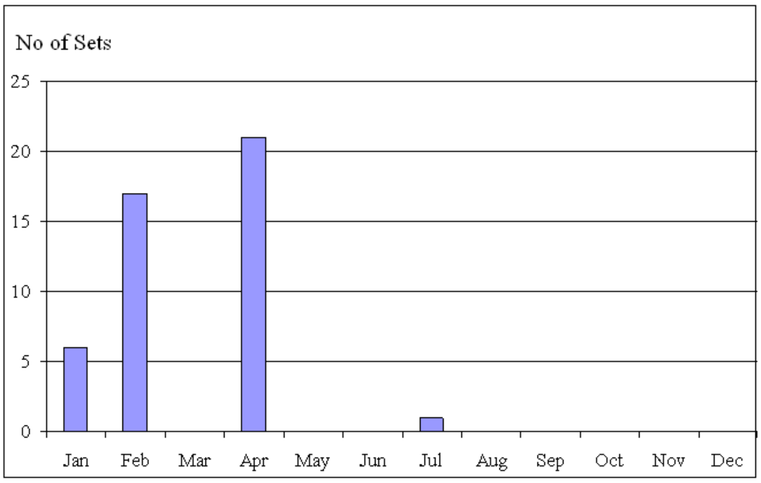


Figure 4. Monthly distribution of whale-associated sets.

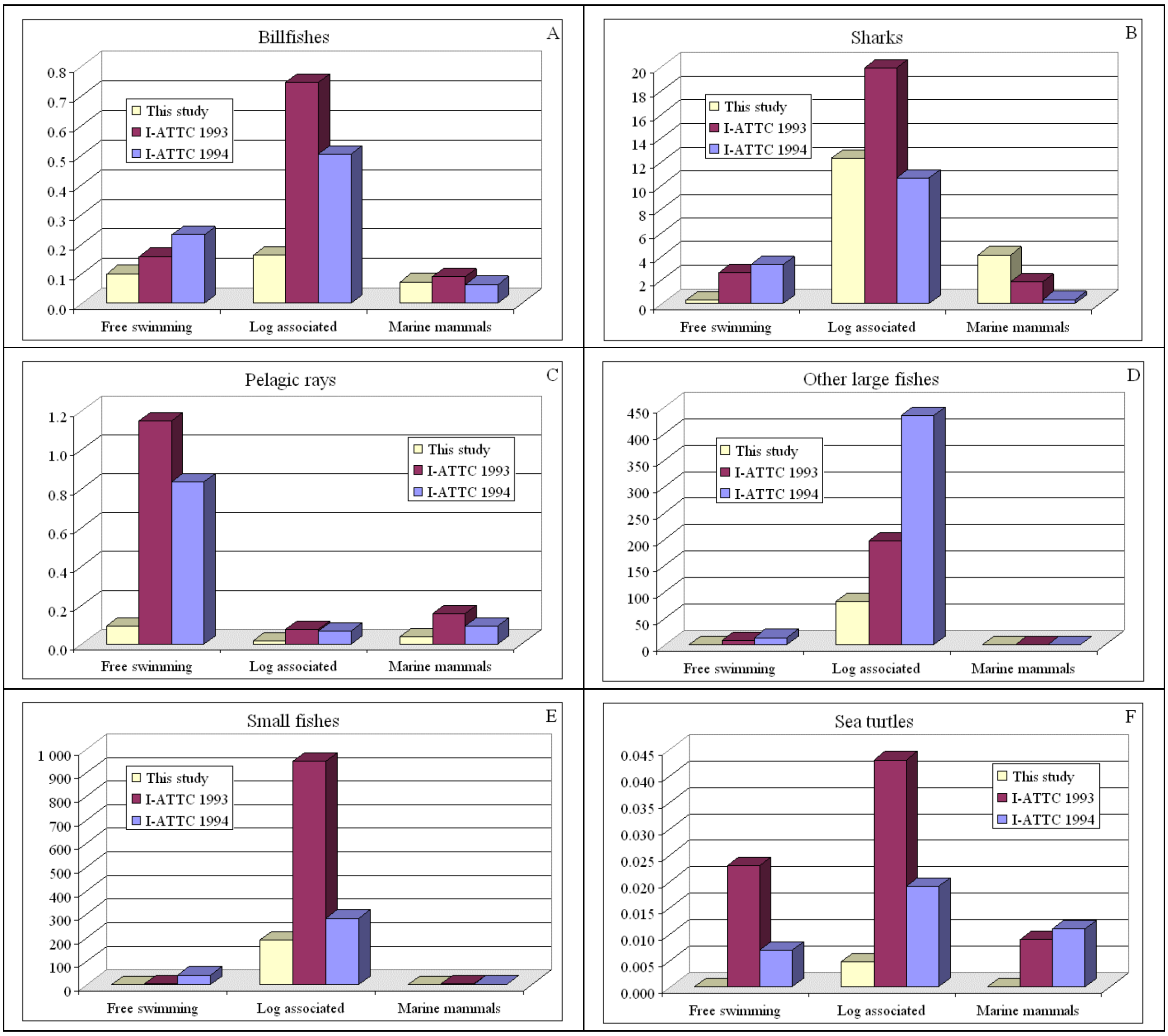


Figure 5 (a, b, c, d, e, f). Comparison of bycatch levels by groups of species and types of school in the Western Indian Ocean and Eastern Tropical Pacific (Anon., 1997)(No/set).

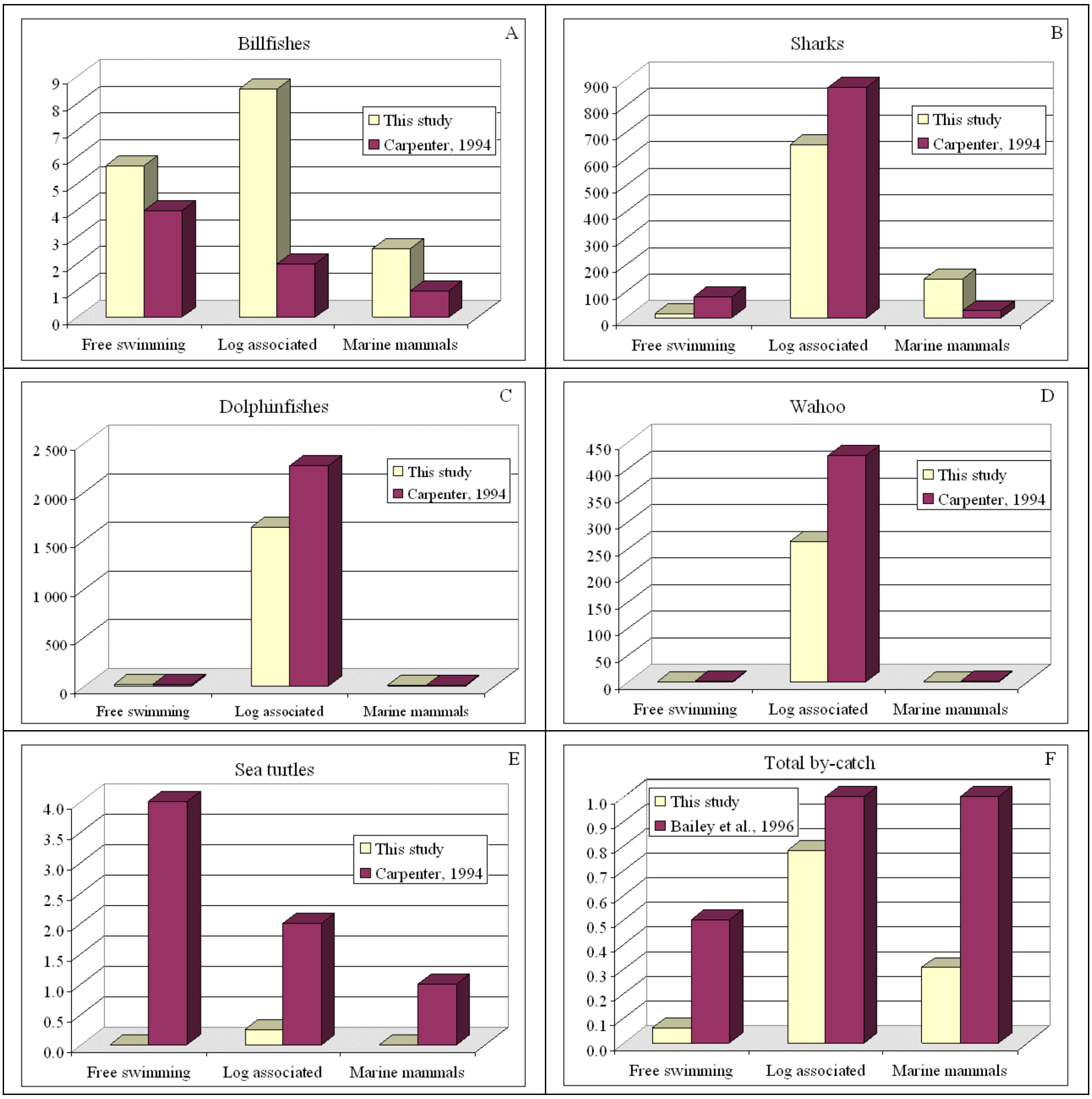
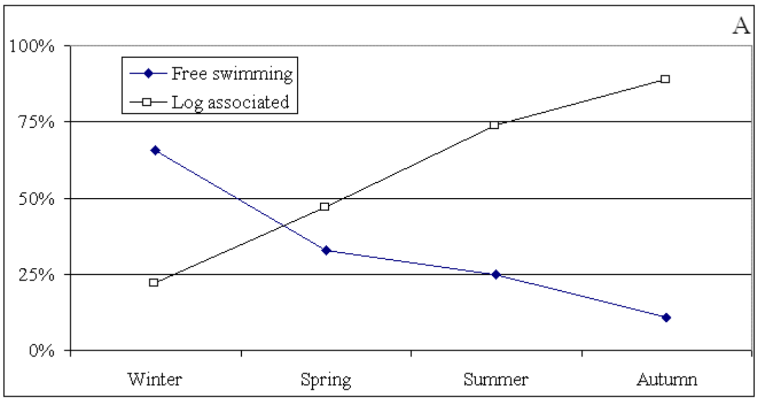


Figure 6 (a, b, c, d, e, f). Comparison of bycatch levels by group of species and type of schools in the Western Indian Ocean and Eastern Tropical Pacific (No/per 1,000 t of target species) – A, B, C, D, E; and overall bycatch levels by types of schools in the Western Indian Ocean and Western Pacific (t/set) – F.



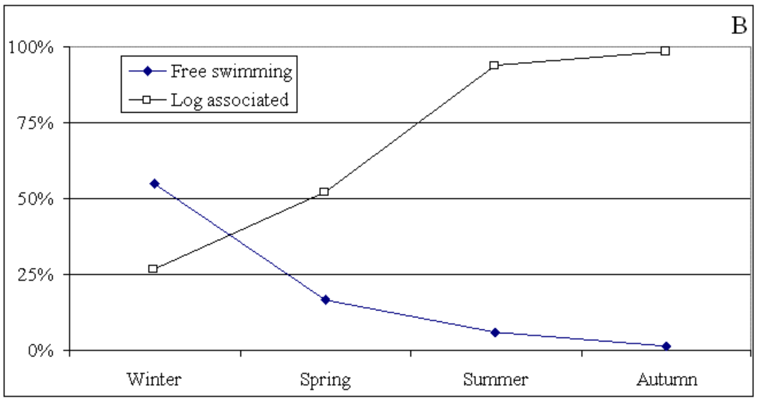


Figure 7 (a, b). Free vs. log schools sets – A and catch – B of Soviet purse seine tuna fleet.

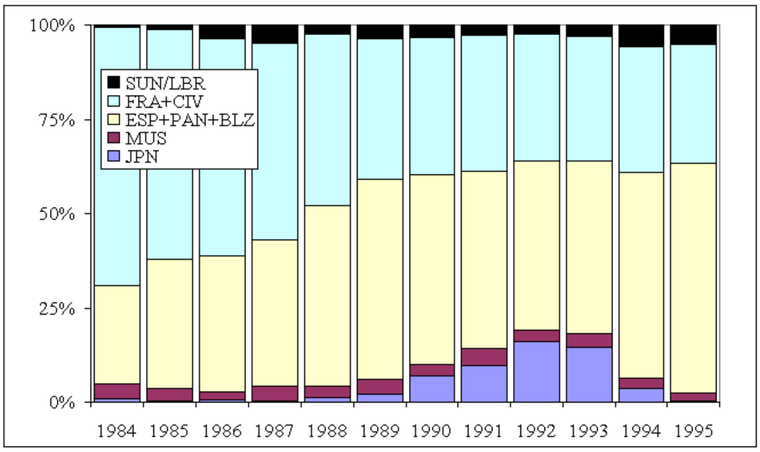


Figure 8: Purse seine catches of the principal fishing countries in the western Indian Ocean (BLZ – Belize, CIV – Côte d'Ivoire, ESP – Spain, FRA – France, JPN – Japan, LBR – Liberia, MUS – Mauritius, PAN – Panama and SUN – Soviet Union).