IPTP/91/GEN/20

INDO– PACIFIC TUNA DEVELOPMENT AND MANAGEMENT PROGRAMME

REPORT OF THE WORKSHOP ON STOCK ASSESSMENT OF YELLOWFIN TUNA IN THE INDIAN OCEAN

Colombo, Sri Lanka
7 - 12 October 1991

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INDO-PACIFIC TUNA DEVELOPMENT AND MANAGEMENT PROGRAMME (IPTP)
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REPORT OF THE WORKSHOP ON STOCK ASSESSMENT OF YELLOWFIN TUNA IN THE INDIAN OCEAN

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1. OPENING OF THE MEETING.

The Workshop on Stock Assessment of Yellowfin Tuna in the Indian Ocean was held at the Hotel Ceylon Inter-Continental, Colombo, Sri Lanka, from 7 through 12 October, 1991. The participants were welcomed to the meeting by Mr T. Sakurai, Programme Leader on behalf of the staff of IPTP, and Mr P. Hijmans, FAO Representative for Sri Lanka and Maldives on behalf of FAO.

On behalf of the Hon. Joseph Michael Perera, Minister of Fisheries and Aquatic Resources, Mr N.V.K.K. Weragoda, Secretary of the Ministry of Fisheries and Aquatic Resources read the inaugural address and opened the meeting. The inaugural address is attached as Appendix 1.

2. ADOPTION OF AGENDA AND ARRANGEMENTS FOR THE MEETING.

The Provisional Agenda prepared by the Secretariat was presented and adopted with minor amendments. The adopted agenda is attached as Appendix 2.

Dr A. Fonteneau, from ORSTOM, was nominated as the chairman of the meeting. The following rapporteurs were appointed for the different points of the agenda, and Mr.R. Pianet was designated to coordinate and finalize the report:

Agenda item 3 -	Review of working papers: Dr P. P. Pillai (India).
Agenda item 4 -	Review of the Working Group meetings: Dr S. Tsuji (Japan). Mr J. P. Hallier (ORSTOM, Seychelles)
Agenda item 5 -	Review of the country reports: under the responsibility of each country representative.
Agenda item 6 -	Review of the database: Dr C. Anderson (FAO/BOBP). Mr R. Pianet (ORSTOM).
Agenda item 7 -	Review of biological parameters: Dr P. Cayre (COI).
Agenda item 8 -	Creation of catch-at-length data: Mr F. Marsac (ORSTOM, Seychelles), purse-seine. Dr S. Tsuji (Japan), longline. Mr M. Yesaki (FAO/IPTP), artisanal fisheries.

Agenda item 9 - Status of stock:
Dr J. Majkowski (FAO/HQ), trends of cpue.
Mr P. Ward (Australia), catch-effort relationship.
Mr J. P. Hallier (ORSTOM, Seychelles), catch at age tables.
Mr R. Pianet (ORSTOM), Sequential Population Analysis.
Dr J. Hampton (SPC), yield per recruit analysis.

Agenda item 10 - Recommendations:
Dr J. Majkowski (FAO/HQ).

All participants introduced themselves by their names and functions in their respective governments and organizations. A list of participants is attached as Appendix 3.

3. REVIEW OF WORKING PAPERS

A total of 34 working documents - including the two Working Group reports on surface (Mauritius) and longline (Shimizu) fisheries - dealing with statistics, biology and population dynamics of yellowfin tuna were briefly introduced by participants and the Secretariat. The list of these documents is attached as Appendix 4.

Dr Fonteneau also presented the recently released publication from the ICCAT yellowfin programme, "Fishery, biology and stock assessment of the Atlantic Ocean yellowfin tuna fishery".

4. REPORTS OF THE WORKING GROUP MEETINGS

4.1. Mauritius Preparatory Working Group (TWS/91/04)

Discussion, results and recommendations of the preparatory Working Group held in Mauritius (Albion, 17-23 May, 1991) were reported to the participants by Dr P. Cayre. The group reviewed the yellowfin surface fisheries database for catch, effort and size frequencies. It also addressed some recommendations to the preparatory Shimizu Working Group responsible for the longline fisheries relative to the updating and standardization of data and methods of data substitution.

Regarding artisanal fisheries, the Mauritius Working Group attempted to complete a historical database dating from 1952 and to recommend to IPTP to do the same for countries such as Maldives, Sri Lanka, Pakistan and Indonesia. The Working Group also recommended that the yellowfin statistics be checked for fish caught along the coast of South Africa up to 15°E as these catches are not reported to IPTP despite the fact that these fishes belong to the Indian Ocean stock.

The situation of purse-seine fishery data was recognized as satisfactory; recommendations were to include 1982-83 data in the

French database, to verify if Spanish length data from 1985 to 1989 could be used and, if so, to use a combined French and Spanish length file for catch by size substitution of both fleets. Japanese and USSR purse-seine data remained incomplete despite SFA efforts in collecting them, and help was requested from the corresponding countries and IPTP. In terms of fishing effort, the difficulties in estimating the increasing fishing power of the purse-seine vessels was raised, and the Working Group called for investigations into this issue, which has a direct bearing on the estimation of the indices of abundance.

The Working Group agreed to adopt the standardized formats and codes (species, gear, area, country, ...) used in the ICCAT database for catch and effort as well as size (or catch by size) frequency files, and recommended that all files be presented in these formats for the present Workshop.

The main biological parameters such as length-weight, dorsal and fork length relationships and growth parameters were reviewed through the latest available analysis, and agreement was reached on values to be used for the constitution of the database.

4.2. Shimizu Preparatory Working Group (TWS/91/05)

Discussions, results and recommendations of the preparatory Working Group held in Japan (Shimizu, 24-28 June, 1991) were reported to the participants by Mr. M. Yesaki. The goal of this work was to discuss problems related to longline fisheries statistics in the Indian Ocean with the scientists present from Indonesia, Korea, Japan and IPTP; information was exchanged by FAX during the meeting with the Taiwanese scientist who could not attend. The meeting reviewed the status of catch and effort statistics and size data of all the nations concerned.

The meeting discussed discrepancies in some sets of the nominal catch records provided by each nation. It was noted that, in the Indonesian statistics, the yellowfin catch in 1989 corresponded exactly with the total tuna catch of that year. Korean statistics showed no discrepancies between different nominal catches. Several sets of nominal catches were provided for Japan, including one from FAO statistics and one estimated from catch in number and size data by NRIFSF scientists. The latter set was recommended for use for scientific purposes, the discrepancy between the two data sets being mainly due to differences in methods used and different area definition for statistics. Taiwanese data showed big discrepancies between reported statistics which could not be solved by FAX exchanges with Taiwan University; consequently, the Working Group decided to leave this problem to IPTP for resolution.

Catch and effort data by month and 5 degree square are already installed in the IPTP data base. The time periods covered for respectively Japanese, Korean and Taiwanese fisheries are 1952-88, 1975-87 and 1967-89. Nominal catch rates in the same time-area strata were highest for the Japanese, followed by the Taiwanese and Korean more or less at the same level. CPUEs of all

three nations standardized by the Honma method and overall GLM standardized CPUE showed similar historical trends and seasonal patterns.

Size data are available for 1952-88 for Japanese, 1983-85 for Korean, and 1985-88 for Taiwanese fisheries; however, Korean data were only available in computer files on a yearly grouping. The average size of fish caught decreased by increments of approximately 10 cm from Korean to Japanese and Taiwanese fisheries. While Taiwanese and Japanese size frequencies often showed plural modes, Korean data always showed a single mode.

A quarterly 10 x 20 degree square was adopted as a standard time-area stratum for size frequency data. Although several discrepancies were identified between size frequencies from the three nations, the meeting decided to use the Japanese size data to create catch-at-size matrices unless further improvement was achieved in Korean and Taiwanese size data before the Workshop. The meeting also decided to apply an analytical VPA-type approach only for the period from 1975 through 1990, where detailed catch and effort data were available for all three countries. The NRIFSF was requested to prepare catch-at-size data for longline fleets before the Workshop.

Stock structure, length-weight relationship and growth were discussed. The meeting supported the single-stock hypothesis as well as the length-weight relationships proposed by the Mauritius Meeting. Problems in growth estimation were recognized and further detailed study was encouraged.

5. REVIEW OF THE NATIONAL YELLOWFIN TUNA FISHERIES IN THE INDIAN OCEAN

(1) AUSTRALIA

Yellowfin tuna are an incidental catch of recreational angling for marlins off Exmouth (23°S), and a minor bycatch of other fisheries, such as trolling, in western regions of the Australian fishing zone. Between 5 and 12 joint venture Australian-flagged Japanese style longliners have fished occasionally off the west coast since 1986, annual catches of yellowfin tuna ranging up to 180 mt. These activities are similar to those of Japanese longliners, which report 100-120 mt of yellowfin tuna each year in the area. Japanese longline activity occurs during the summer (October-February), although catch rates of yellowfin tuna do not decline during the winter. Catch rates are generally very low (less than 10 kg/1000 hooks) south of 29°S, where the target species is bigeye tuna.

(2) CHINA (TAIWAN)

The Taiwanese longline fishery in the Indian Ocean had different target species during three distinct periods: yellowfin and bigeye tunas before 1972 and after 1986, and albacore between 1973 and 1985. In 1990, 276 longline vessels were operating in the Indian Ocean, of which 93% were over 200 GRT; approximately

85% of these vessels were classified as fishing with deep long-lines.

The total catch of yellowfin tuna in 1990 is estimated at 15,567 mt, of which 15,483 mt were caught by deep longlines and 84 mt by ordinary longlines. Those amounts are almost equivalent to the annual yellowfin catches by Taiwanese longliners since 1987. The monthly catch statistics by 5 degree square areas are regularly submitted to the IPTP. Some research on yellowfin tuna is currently in progress.

(3) FRANCE

Since 1984 - when the French purse-seine fishery was well established in the western Indian Ocean - yellowfin catches fluctuated within the range of 37-45,000 mt, with a peak of 54,000 mt in 1988, this year being considered as exceptionally good for yellowfin in terms of catch and CPUE. Although the French purse-seine fleet was the larger in this fishery during its first years, it has now been surpassed by the Spanish fleet, whose number of vessels continues to increase while some French vessels have returned to the Atlantic Ocean or are pulled out of the fishery for economic reasons.

Despite the fact that yellowfin is targeted by the French fleet, this species represents less than 50% of the mean 1984-90 total catch, and is mostly caught on free swimming schools (nearly 75% of the total yellowfin catch).

The bulk of the catch is made between 0-5°S and 55-65°E during the first quarter of the year, which corresponds to the main spawning season of large yellowfin (FL>100 cm). Overall, large adult yellowfin are caught from free swimming schools, and small juvenile yellowfin from log associated schools. The total yearly tuna catch per vessel shows an increasing trend since the beginning of the fishery. This is also true for the yearly yellowfin catch per vessel. The CPUE, using fishing or searching days as units of effort, shows an increasing trend from 4.2 (1984-86) to 6.7 (1987-90) mt per searching day. During this time skipjack CPUE showed a high annual variability, from 6.2 (1984) to 7.2 (1990) mt per searching day, with a maximum of 15.5 mt per searching day observed in 1986.

The fishing pattern does not change much from year to year, most of the yellowfin being caught west of 70°E between 5°N-10°S. The only exception is a seasonal fishery on log associated schools from mid-March to May in the Mozambique Channel, except in 1988 which was the best year for yellowfin.

(4) INDIA

The yellowfin tuna fishery in the Indian EEZ in recent years comprises of (1) occasional landings from drift gillnets, troll lines and hooks and lines in the small-scale sector along the mainland coasts, (2) small-scale pole-and-line (live-bait) and troll line fisheries in the Lakshadweep Islands, (3) the oceanic

survey / training longline vessels of the Govt. of India, and (4) longliners commercially operated or chartered from Taiwan.

During the 1986-90 period, the average catch of yellowfin tuna from chartered fleets of Taiwanese origin flying other flags and from commercial vessels is estimated at 4,481 mt. However, in 1990 the total longline and artisanal fisheries recorded a total catch of 12,453 mt.

On the mainland of India, landings of young yellowfin tuna were in the range of 770-880 mt during the period 1986-90, constituting about 5% of the total annual tuna landings in India (45,208 mt in 1989). In Lakshadweep, the total yellowfin catch increased from 730 mt in 1986 to 1,036 mt in 1989. The annual catch rate in the pole-and-line fishery varied between 17.4 and 56.6 kg per day during the period 1976-90, while it ranged from 4.8 to 20.9 kg per day in the troll line fishery.

In the longline fishery, the landings of yellowfin tuna by commercial vessels ranged from 4 to 229 mt (1986-90), those by the GOI vessels from 12 to 416 mt (1983-90) and those by the chartered longliners from 3 to 10,352 mt (1985-90). In 1990, yellowfin tuna constituted 82% of the tuna catch of the 58 chartered vessels operating in the Arabian Sea and 66% in the Bay of Bengal, with CPUE averaging 1.4 mt per day. These vessels concentrated in the area between 19-23°N along northwest coast, 12-18°N along the east coast and 11-15°N west of the Andaman Islands.

The MSY of yellowfin tuna from the Indian EEZ has been tentatively estimated at 21,000 mt (TWS91/22) whereas the total annual catch (surface and longline fisheries) was around 12,500 mt in 1990.

Biological information on yellowfin tuna presented at the meeting are (1) size distributions (1984, 85 and 87) and length-weight relationship from the drift gillnet fishery based at Cochin (West coast of India), (2) size distributions (1984-90), length-weight relationships and mortality estimates from the pole-and-line fishery data, and (3) length-weight relationship, food and feeding habits, sex ratio, size distribution (1983-86; 1989-91 June), gonad index, growth parameters and natural mortality estimates based on longline fishery data.

In addition, the stock status of yellowfin tuna (pole-and--line fishery) was estimated by applying Schaefer, Fox, S&T model and Y/R analysis (TWS/91/22).

(5) INDONESIA

There are two types of yellowfin tuna fisheries in the Indian Ocean: (1) an industrial tuna longline fishery based at Denpasar and Jakarta, and (2) artisanal fisheries using small purse-seines (Banda Aceh, North Sumatra), troll lines (Padang, West Sumatra), gillnets and danish-seines (Pelabuhan Ratu, West Java). The longline fishery commenced in 1972 with three 100 GT

vessels and yellowfin as a target species (yellowfin catch varied from 50% to 85% of the total tuna catch). The fishery was run by the State Enterprise Fishing Company; the number of longliners increased from 18 in 1979 to 24 in 1985, then decreasing to 8 in 1986. The yellowfin catch ranged from 289 to 1,848 mt during 1979-86.

The longline fishery has developed rapidly since 1987, the number of longliners increasing from 48 in 1987 to 168 in 1989, then decreasing to 151 in 1990 due to some vessels moving operations to Biak on the Pacific coast. The yellowfin catches increased from 1,554 to 7,036 mt from 1987 to 1989, and decreased to 3,961 mt in 1990 (preliminary figure).

(6) JAPAN

Longline and purse-seine fisheries currently operate in the Indian Ocean, yellowfin tuna being a secondary target species for both longline and purse-seine fisheries; estimated catches for 1989 are 3,900 and 330 mt, respectively.

Longliners started operation during 1952, initially aiming for tropical tunas. Target species shifted from yellowfin and albacore to bigeye and southern bluefin tuna as of the early 70's, in accord with the shift in demand from canning material to "sashimi" grade tuna. Current fishing grounds for Japanese longliners are tropical to subtropical waters targeting bigeye and waters in the higher latitude south of 30°S for southern bluefin tuna, which is one of the most important fishing grounds for the Japanese longline fishery.

Purse-seiners started operations in the Indian Ocean in the mid 80's, and are currently limited to four vessels.

(7) KOREA

The number of Korean longline vessels operating in the Indian Ocean increased from 105 to 185 during 1970-75, thereafter remaining at a relatively constant level until 1980. Their number has decreased regularly since then to 62 in 1985 and increased again until 1988 to reach 112, although it decreased again to 77 in 1990.

The catch of yellowfin tuna showed a level of 10-19,000 mt between 1975 and 1988, with higher catches of 25-31,000 mt for 1977-78 and the lowest level at 7,000 mt in 1990. The CPUE (in number of yellowfin per 1,000 hooks) fluctuated within a range of 4.0-8.7 during 1975-89, except in 1977 which had the highest level of 13.4. Fork lengths ranged from 60 to 194 cm, with a mode at 130-132 cm and a mean around 131 cm during the 1986-89 period.

(8) MALDIVES

The Maldives is a major artisanal tuna fishing nation. Fishing is mostly carried out from local wooden craft called "masdhonis" which are about 10m long. The main fishing method

employed is live bait pole-and-line fishing, but tunas are also caught by trolling and handlining. The major species caught is skipjack, with yellowfin tuna as the second most important species. Recent yellowfin catches have been of the order of 4-7,000 mt per year, which is about 10% of the total tuna catch. Most of the yellowfin caught in Maldives are juveniles taken by pole-and-line. This fishery is highly seasonal, occurring off the East (northeast monsoon season) and West (southwest monsoon season) coasts.

Since 1986, it has been possible for foreign longliners to operate under licence in the outer waters of the EEZ (i.e. 75 to 200 miles offshore). Taiwanese-Maldivian joint venture longliners operating under this scheme caught a total of about 400 mt of yellowfin during 1986-90.

(9) MAURITIUS

Mauritius has served as a base for transshipment of catches by longliners since 1965: during 1989 and 1990, 315 and 146 mt of yellowfin tuna were unloaded in Port Louis harbor for transshipment by Taiwanese, Japanese and Mauritian longliners. Catches of longliners were dominated by albacore, which comprised about 84% of the catch, yellowfin tuna contributing only for some 5%. An annual average of 315 mt of yellowfin tuna were unloaded since 1987.

The first Mauritian purse-seiner was launched in 1979 and was joined by a second one eight years later. Following expansion of the local canning factory, a third purse-seiner has started operations since 1991. Total catches of yellowfin tuna landed during 1989 and 1990 were respectively 1,680 and 1,350 mt, yellowfin constituting only about 20% of the total catch; an annual average of 1,465 mt have been unloaded since 1987.

An artisanal fishery is actively developing. Tuna has been traditionally caught in the off lagoon region by sports and artisanal fishermen engaged in trolling, handlining and some longlining activities, the catch comprising mostly of yellowfin tuna. During the last two years, the catch of yellowfin tuna had increased sharply, to attain 48 mt in 1989 and 51 mt in 1990.

Conscious of the importance of the tuna fishery, the countries of the Commission de l'Océan Indien (COI: Comoros, Madagascar, Mauritius, Seychelles and France) have set up the Regional Tuna Project since 1987, whose main objective is to assist the member countries in developing their tuna fisheries.

Research on tuna is mainly carried out under the Regional Tuna Project, Mauritius having been allocated the responsibility for studies with a view to stock assessment. Activities include collection of biological information, tagging, and collection and processing of tuna statistics for the COI region. Assistance for research is being provided by a scientist from ORSTOM and a computer specialist under French Voluntary Assistance Programme.

(10) MOZAMBIQUE

Mozambique's domestic tuna catches are all taken by non-target artisanal and recreational fishing, mostly with hand-lines; there is no reliable estimate of annual totals, but they would probably be of the order of a few tens of tons.

(11) OMAN

Yellowfin tuna is increasingly assuming an important role in the Oman fisheries, and at present constitutes for some 20-25% of total landings. The catch has increased sharply from 5,000 mt in 1985, reaching 16,000 mt in 1989. The traditional fishermen using handlines and gillnet continue to harvest the bulk of yellowfin tuna. The industrial longline fishery which commenced its operations in late 1989 caught only 3,663 mt between 1989 and 1990.

Most of the fishing takes place between October and April, the majority of the catch coming from the Gulf of Oman, between Muscat and Sur.

(12) PAKISTAN

There is no aimed fishery for tunas in Pakistan, where an artisanal activity is carried out by 20-25 meter long wooden hull gill-netters, the catch being usually salt-dried on board the vessels. Four major species of tunas are found in Pakistani waters: yellowfin, which constitutes nearly 30% of all the tuna caught in Pakistan, thus occupying the second position in quantity after skipjack (37%) in 1990. The catch rate for yellowfin varied annually between 5 and 346 kg/day during 1987-90, mean sizes ranging between 45-90 cm during this period.

(13) SEYCHELLES

The tuna fishery in Seychelles is of an industrial nature, and is largely dominated by foreign purse-seine fleets. However, during the course of 1990-91, the Government has promoted the idea of a domestic fleet of purse-seine vessels. This fleet at present consists of 2 purse-seiners, one of which is a new and somewhat experimental glass reinforced plastic (GRP) vessel with a capacity for 200 mt of fish; this vessel - the largest GRP seiner yet built - is presently undergoing sea trials.

The Seychelles fleet is due to be expanded by the acquisition of 3 more GRP purse-seiners over the next 3 to 4 years. The sole fully operational vessel, the "Duc de Praslin", has been fishing in the western Indian Ocean region since April this year and has shown satisfactory results to date.

The artisanal and sport fisheries in Seychelles does not target for tuna species, which are regarded as a by-catch; their respective total catches in 1990 were in the order of 2 and 3 mt.

(14) SRI LANKA

Yellowfin tuna contributes about 25% of all tuna landed from the seas of Sri Lanka in recent years. The present annual production has remained around 7,000 mt during the past few years, making it the second species in the Sri Lanka's tuna fisheries.

Practically, the total catch of yellowfin is landed by crafts with inboard engines, mainly the 3.5 GT crafts (which are the mainstay of the tuna fisheries of the island) and 11 meter boats. The majority of these crafts carry out multi-day fishing operations in the offshore areas of the Sri Lanka EEZ. At present, yellowfin and other tuna varieties are exploited by five main gear types: gillnet, troll line, pole-and-line, longline and handline. Most of these craft carry out fishing with a combination of gears, with gillnets as the dominant gear.

(15) SPAIN

The Spanish are conducting an industrial large purse-seine yellowfin tuna fishery, which started in 1984 as the result of a shift of some boats from the Atlantic to the Indian Ocean.

The actual area covered by this fishery is from 15°N-25°S and 30°-75°E. The number of boats have increased to 22. The trend in the catches went up from some 14,000 mt in 1984 to 40,000 mt in 1990. The CPUE shows the same increasing trend as the catch.

Distinction between log-associated and free swimming schools was made in the catch and size distribution files; this clearly puts in evidence the strong difference between the two histograms: smaller fishes on logs, larger ones on free swimming schools. On average, the total catch is shared by 20% on log and the remaining 80% on free schools.

(16) USSR

The Soviet Union yellowfin tuna fishery in the Indian Ocean started in 1959 with research longline vessels, consisting of medium sized trawlers converted for longlining; their total catch did not exceed 50 mt, and no accurate data are available.

The longline fishery started on a commercial basis in 1964, when the first motherboat ship was built. In the Indian Ocean, up to 3 ships of this class operated annually, totalling a yellowfin catch which did not exceeded 3,100 mt in one year. Motherships ended their operations in 1988; in 1989, a small amount of yellowfin was taken by research vessels.

Purse-seine fisheries for yellowfin began in 1983 during one-two months, no catch and effort data being available from this period. From late 1984 to April 1985, four purse-seiners were fishing in the western Indian Ocean, some 10% of their total catch being yellowfin. Since September 1985, the Soviet fleet has continued working in the Indian Ocean all year round, operating

two types of vessels: medium (up to 3 ships until 1988) and large sized (up to 9 ships in 1990) purse-seiners. The maximum yellowfin catch was obtained in 1988, with 3,800 mt.

6. REVIEW OF DATABASE

The entry of Japanese longliners into the Indian Ocean in 1952 marked the start of industrial tuna fishing in this area. IPTP aims to collect and maintain data on all catches from all fisheries as from 1952. The work done by IPTP in collecting this data as well as the impetus provided by the Mauritius and Shimizu workshops to the completion of the data set were acknowledged.

It should be noted that data which feed the IPTP database are coming from different sources, either national (as listed in the following tables) or from scientists of the area. For the present meeting, participants have checked carefully all available data and adopted the best scientific estimates (species composition, contribution by gears, ...) for conducting their future work.

The current status of catch, effort and length frequency statistics by gear (longline, purse-seine and artisanal) in the IPTP database was presented in TWS/91/7; much of the 1990 data are preliminary. Several other papers dealing with national fisheries statistics and presented in section 5 of the report were used, as well as the reports of the Mauritius and Shimizu workshops for surface and longline fisheries, respectively.

6.1. Nominal catch statistics

6.1.1. Longline

Yellowfin catch data from the three major industrial longline fisheries are available in the IPTP database from their inception (Japan in 1952, Taiwan in 1954 and Korea in 1966). As mentioned in the Shimizu report, there was some trouble with several different sets of statistics from Taiwan. A description of the situation was presented at the meeting, and it was decided to use the most recent set available; however, Taiwanese longline data from recent years are still being revised by national scientists.

Over the 3 year period 1988-90, longlining accounted for some 22% of the recorded yellowfin catch. Major changes in longline catches can largely be attributed to changes in target species, from yellowfin to southern bluefin tuna from the end of the 60's for Japanese longliners and to albacore tuna from the beginning of the 70's for Taiwanese longliners. Some shift from regular to deep longlines (aimed at bigeye tuna) also took place from 1975 for Japanese and Korean longliners.

Yellowfin caught off South Africa (in part as a by-catch of the Japanese southern bluefin tuna fishery) are considered to be part of the Indian Ocean yellowfin stock. This is because yellowfin in this area have a continuous distribution with that

of Indian Ocean, but are separated from tropical Atlantic yellowfin by an expanse of cold waters off Angola and Namibia (see 7.4). It is necessary to include all yellowfin catches from off South Africa in the IPTP database with a limit at 15°E, and not be limited to the boundary of FAO statistical area 51 at 30°E.

Longline catches of yellowfin from coastal countries (notably India, Indonesia and Oman) now account for a significant proportion of the Indian Ocean longline catch. This is in part the result of joint-venture operations between the coastal countries and Taiwan.

Table 1 sums the yellowfin catches of the longline fisheries in the Indian Ocean from 1952 to 1990 (preliminary figures).

6.1.2. Purse-seine

Complete purse-seine catch data are available in the IPTP database. The major western Indian Ocean purse-seine fishery started in 1983-84. 1988 was a peak year for yellowfin catches, a fact which can largely be attributed to oceanographic factors. During the three year period 1988-90, purse-seiners accounted for 54% of the total Indian Ocean yellowfin catch.

As there are significant differences in yellowfin catches (such as size distribution or effort estimates) from sets on free swimming schools and on drifting logs, the importance of maintaining separate catch files was noted. France, Ivory Coast and Spain have maintained such separate data; 98% of Japanese purse-seine sets have been on logs, while Mauritian purse-seiners operate exclusively with artificial logs (drifting FADs). Purse-seiners from the USSR have collected separate data only since 1990, but seem to behave in the same manner as French and Spanish fleets.

An important problem with purse-seine tuna catches is the species composition of the small fishes, mainly the mixing of yellowfin and bigeye. Since 1989, a specific sampling procedure deals with this problem and is used to correct the catches.

The Workshop asked to make available the two data sets of purse-seine catches separated between log-associated and free swimming schools. Table 2 sums total, log and free school catches of the different Indian Ocean purse-seine fisheries from 1977 to 1990.

6.1.3. Artisanal fleets

With a few exceptions, yellowfin catch data from the artisanal fisheries of the coastal countries are only available from the 80's, even though many of these fisheries have been in existence for decades or even centuries.

Estimates of yellowfin catches have been made by IPTP back to 1952, taking into account existing fisheries statistics and

in consultation with national scientists. Total yellowfin catches by coastal artisanal fisheries now amount to over 40,000 mt annually, corresponding to some 24% of the total Indian Ocean yellowfin catch over the three year period 1988-90.

Major artisanal fishing nations include India, Indonesia, Maldives, Oman and Sri Lanka. Table 3 sums artisanal fishery catches of yellowfin in the Indian Ocean by country from 1952 to 1990.

6.1.4. Total nominal catches

The best available estimates of Indian Ocean yellowfin catches in total and by gears category (longline, log and free school purse-seine and artisanal) is reported in Table 4. Figure 1 shows the spectacular evolution of yellowfin catches by the three fishing methods from 1952 to 1990.

Year	JPN	KOR	TAI	SUN	IDN	IND	OMN	SYC	MUS	AUS	IRN	KEN	TOTAL
1952	8 858	0	0	0	0	0	0	0	0	0	0	0	8 858
1953	13 258	0	0	0	0	0	0	0	0	0	0	0	13 258
1954	24 883	0	210	0	0	0	0	0	0	0	0	0	25 093
1955	46 459	0	689	0	0	0	0	0	0	0	0	0	47 148
1956	64 402	0	1 089	0	0	0	0	0	0	0	0	0	65 491
1957	36 036	0	1 252	0	52	0	0	0	0	0	0	0	37 340
1958	25 727	0	1 825	0	55	0	0	0	0	0	0	0	27 607
1959	24 428	0	2 380	0	58	0	0	0	0	0	0	0	26 866
1960	40 292	0	2 241	0	65	0	0	0	0	0	0	0	42 598
1961	34 551	0	2 877	0	68	0	0	0	0	0	0	0	37 496
1962	51 665	0	3 468	0	70	0	0	0	0	0	0	0	55 203
1963	25 888	0	3 402	100	73	0	0	0	0	0	0	0	29 463
1964	24 752	0	2 859	300	75	0	0	0	0	0	0	0	27 986
1965	27 579	0	2 180	900	78	0	0	0	0	0	0	0	30 737
1966	44 106	100	4 368	2 600	80	0	0	0	0	0	0	0	51 254
1967	31 597	200	3 404	3 100	83	0	0	0	0	0	0	0	38 384
1968	50 475	4 000	22 652	2 700	85	0	0	0	0	0	0	0	79 912
1969	25 228	6 000	21 172	1 600	88	0	0	0	0	0	0	0	54 088
1970	14 459	7 000	11 135	2 000	84	0	0	0	0	0	0	0	34 678
1971	13 471	6 454	16 427	1 500	120	0	0	0	0	0	0	0	37 972
1972	8 800	9 580	8 868	1 600	140	0	0	0	0	0	0	0	28 988
1973	3 400	9 919	4 271	900	154	0	0	0	0	0	0	0	18 644
1974	4 415	11 563	3 291	500	150	0	0	0	0	0	0	0	19 919
1975	4 719	11 694	3 469	120	122	0	0	0	0	0	0	0	20 124
1976	2 744	12 848	2 513	90	184	0	0	0	0	0	800	0	19 179
1977	2 061	31 383	6 051	230	586	0	0	0	0	0	625	0	40 936
1978	4 024	25 165	3 179	280	1 216	0	0	0	0	0	0	0	33 864
1979	2 023	17 788	2 775	10	1 274	0	0	0	0	0	347	0	24 217
1980	3 304	12 573	2 850	20	1 478	0	0	0	0	0	322	67	20 614
1981	4 699	11 777	3 071	150	1 806	0	0	0	0	0	0	171	21 674
1982	6 355	18 654	3 532	190	1 848	0	0	0	0	0	0	204	30 783
1983	7 039	15 337	4 179	220	1 025	14	0	43	0	0	0	322	28 179
1984	7 467	9 895	4 353	160	1 641	42	0	198	0	0	0	0	23 756
1985	9 263	12 017	5 145	160	1 384	118	0	140	0	0	0	0	28 227
1986	10 955	14 891	12 145	50	289	1 534	0	0	190	0	0	0	40 054
1987	7 552	12 575	16 029	280	1 554	712	0	0	70	4	0	0	38 776
1988	8 554	13 428	14 424	77	1 740	760	0	0	98	7	0	0	39 088
1989	3 568	8 103	13 273	2	7 036	2 922	879	0	105	206	0	0	36 094
1990	3 500	7 006	15 567	0	3 961	10 369	3 663	0	23	66	0	0	44 155

JPN = JAPAN, KOR= KOREA, TAI = CHINA(TAIWAN), SUN = USSR, IDN = INDONESIA, IND = INDIA, OMN = OMAN, SYC = SEYCHELLES, MUS = MAURITIUS, AUS = AUSTRALIA, IRN = IRAN, KEN = KENYA

Table 1: Yellowfin catches of the longline fisheries in the Indian Ocean, 1952-90.

Log schools Catch							
Year	FIS	JAP(1)	MUS(1)	PAN(2)	SPN	SUN(3)	Total
1977	0	34	0	0	0	0	34
1978	0	215	0	0	0	0	215
1979	0	103	0	0	0	0	103
1980	0	122	0	0	0	0	122
1981	98	32	0	0	0	0	130
1982	390	120	0	0	0	0	510
1983	3 624	198	1 057	0	0	0	4 879
1984	8 222	242	1 234	480	1 867	0	12 045
1985	11 120	75	914	1 063	4 082	184	17 438
1986	8 496	160	661	1 432	3 226	643	14 618
1987	14 337	261	1 597	963	4 906	1 148	23 212
1988	9 346	390	1 231	886	8 150	732	20 735
1989	15 376	883	1 679	1 206	16 663	1 183	36 990
1990	10 493	2 973	1 357	2 393	6 724	516	24 456

Free swimming schools Catch							
Year	FIS	JAP(1)	MUS(1)	PAN(2)	SPN	SUN(3)	Total
1977	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0
1981	162	0	0	0	0	0	162
1982	643	0	0	0	0	0	643
1983	7 577	0	0	0	0	0	7 577
1984	34 848	0	0	2 262	9 641	0	46 751
1985	27 064	0	0	3 223	12 955	491	43 733
1986	28 183	0	0	3 074	14 050	2 213	47 520
1987	22 798	0	0	2 796	14 652	2 288	42 534
1988	44 822	0	0	5 571	32 670	3 307	86 370
1989	23 053	0	0	1 891	25 816	1 805	52 565
1990	34 871	0	0	8 176	33 550	1 912	78 509

Total Catch							
Year	FIS	JAP	MUS	PAN	SPN	SUN	Total
1977	0	34	0	0	0	0	34
1978	0	215	0	0	0	0	215
1979	0	103	0	0	0	0	103
1980	0	122	0	0	0	0	122
1981	260	32	0	0	0	0	292
1982	1 033	120	0	0	0	0	1 153
1983	11 201	198	1 057	0	0	0	12 456
1984	43 070	242	1 234	2 742	11 508	0	58 796
1985	38 184	75	914	4 286	17 037	675	61 171
1986	36 679	160	661	4 506	17 276	2 856	62 138
1987	37 135	261	1 597	3 759	19 558	3 436	65 746
1988	54 168	390	1 231	6 457	40 820	4 039	107 105
1989	38 429	883	1 679	3 097	42 479	2 988	89 555
1990	45 364	2 973	1 357	10 569	40 274	2 428	102 965

FIS = FRANCE+ IVORY COAST, JAP = JAPAN, MUS = MAURICIUS,
PAN = PANAMA + MALTA + UK, SPN = SPAIN, SUN = USSR

1- All catches assumed as Log catches
2- Sharing according to Sapnish repartition
3- Sharing according to France + Spain repartition

Table 2: Total, log associated and free swimming schools purse-seine catches in the Indian Ocean purse-seine fisheries, 1977-90.

YEAR	MDV 1,2	LKA 3	AUS	PAK 4	OMN 5	IRN	SYC	SAF 6	TZA 6	YEM 7	MUS 8	MOZ 8	SOM 9,10	IDN 6	IND 11	COM 6	TOTAL
1952	2 000	318	0	1 196	700	0	0	10	60	80	0	15	1 061	180	150	100	5 870
1953	2 000	549	0	1 265	700	0	0	10	60	80	0	15	322	189	150	100	5 440
1954	2 000	1 782	0	1 311	720	0	0	10	60	80	0	15	37	210	150	100	6 475
1955	2 000	1 890	0	1 357	750	0	0	10	60	80	0	15	725	220	150	100	7 357
1956	2 000	3 024	0	1 288	750	0	0	10	60	80	0	15	1 334	240	150	100	9 051
1957	2 000	3 537	0	3 266	760	0	0	10	60	80	0	15	1 177	260	150	100	11 415
1958	2 000	2 619	0	1 587	800	0	0	10	60	80	0	15	1 752	275	150	100	9 448
1959	2 200	3 294	0	1 610	850	0	0	10	60	80	0	15	1 286	289	150	100	9 944
1960	2 100	2 970	0	1 978	1 000	0	0	10	60	80	0	15	1 396	325	150	100	10 184
1961	2 600	4 050	0	1 794	1 100	0	0	10	60	80	0	15	760	337	150	100	11 056
1962	2 200	5 265	0	1 357	1 100	0	0	10	60	80	0	15	543	350	150	100	11 230
1963	2 200	8 721	0	2 070	1 200	0	0	10	60	80	0	15	2 523	363	150	100	17 492
1964	2 200	5 000	0	2 208	1 250	0	0	10	60	80	0	15	1 515	375	150	100	12 963
1965	2 200	5 600	0	1 817	1 300	0	0	10	60	80	0	15	316	349	150	100	11 997
1966	2 000	6 600	0	2 300	1 350	0	0	10	60	80	0	15	798	360	150	100	13 823
1967	2 300	9 400	0	2 346	1 400	0	0	10	60	80	0	15	61	372	150	100	16 294
1968	1 800	12 400	0	2 369	1 450	0	0	10	60	80	0	15	16	383	150	100	18 833
1969	2 300	7 000	0	2 139	1 500	0	0	10	60	80	0	15	621	394	150	100	14 369
1970	1 989	5 800	0	2 875	1 500	0	100	10	60	80	10	15	500	516	150	100	13 705
1971	1 227	4 700	0	2 346	1 550	0	100	10	60	80	10	15	500	480	150	100	11 328
1972	2 076	6 500	0	2 806	1 600	0	100	10	60	80	10	15	500	860	139	100	14 856
1973	5 475	5 100	0	2 208	1 650	0	100	10	60	80	10	15	500	946	200	100	16 454
1974	4 128	6 070	0	3 016	1 650	0	150	10	60	80	10	15	500	921	300	100	17 010
1975	3 774	6 611	0	3 328	1 700	0	100	10	60	80	10	15	500	747	400	100	17 435
1976	4 891	6 915	0	3 122	1 750	0	50	10	60	80	10	15	500	1 133	496	300	19 332
1977	4 473	5 720	3	2 790	1 800	0	80	10	60	80	10	15	500	1 759	611	300	18 211
1978	3 584	5 369	15	1 625	1 850	0	100	10	60	80	12	15	500	1 595	639	300	15 754
1979	4 289	6 166	28	2 809	1 900	0	128	10	60	80	4	15	500	1 962	1 223	300	19 474
1980	4 229	6 906	34	1 297	2 000	0	357	10	60	80	0	15	500	1 870	937	300	18 595
1981	5 284	7 662	20	1 991	2 200	0	949	10	60	80	1	15	500	1 544	819	300	21 435
1982	4 004	8 350	8	2 492	2 400	0	518	10	60	80	0	15	500	1 892	947	300	21 576
1983	6 241	9 046	18	841	2 600	0	114	166	60	80	0	15	500	4 863	780	500	25 824
1984	7 123	6 439	41	909	2 800	0	0	0	60	12	0	188	500	2 606	936	500	22 114
1985	6 066	6 716	43	1 513	3 000	0	13	84	60	511	12	15	500	3 159	1 438	500	23 630
1986	5 321	7 977	42	2 093	5 000	0	26	0	60	510	10	15	500	1 859	1 553	500	25 466
1987	6 670	7 147	40	1 330	5 843	0	16	6	60	399	17	15	500	2 365	1 387	500	26 295
1988	6 535	7 426	12	5 424	15 485	0	9	4	60	1 252	8	15	500	2 857	1 396	600	41 583
1989	6 082	7 536	9	7 681	15 998	980	4	4	60	667	48	15	500	3 550	2 081	700	45 915
1990	5 434	6 406	5	5 409	14 084	2 280	5	4	60	500	51	15	500	3 683	1 837	700	40 973

MDV = MALDIVES, LKA = SRI LANKA, AUS = AUSTRALIA, PAK = PAKISTAN, OMN = OMAN, IRN = IRAN, SYC = SEYCHELLES, SAF = SOUTH AFRICA,, TZA = TANZANIA, YEM = YEMEN, MUS = MAURITIUS, MOZ = MOZAMBIQUE, SOM = SOMALIA, IDN = INDONESIA, IND = INDIA, COM = COMOROS

1- Estimated, 1952-58; 1962-65
2- 14% of small skipjack and yellowfin catch, 1959-61; 1966-69 (Anderson, 1986)
3- 27% of total tuna catch (Administrative report of the Acting Director General of Fisheries, 1952-53; FAO Yearbook of Fisheries statistics, 1954-69)
4- 23% of total tuna catch (FAO, Yearbook of Fishery Statistics, 1952-85), estimated, 1990
5- Estimated, 1952-86
6- Estimated, 1952-69 and 1990
7- Estimated, 1952-81 and 1990
8- Estimated, 1952-1982
9- Canned tuna production, 1952-58 landings at canneries, 1959-69 (Losse, 1970)
10- Estimated, 1970-90
11- Estimated for all years except 1972, 1985, 1987 and 1989, 27% of total tuna catch - IPTP, 1988; Pillai, 1991)

Table 3: Yellowfin tuna artisanal fisheries catches in the Indian Ocean by country, 1952-90.

Year	Longline	Purse-seine		Coastal	Total
		Log	Free		
1952	8 858	0	0	5 870	14 728
1953	13 258	0	0	5 440	18 698
1954	25 093	0	0	6 475	31 568
1955	47 148	0	0	7 357	54 505
1956	65 491	0	0	9 051	74 542
1957	37 340	0	0	11 415	48 755
1958	27 607	0	0	9 448	37 055
1959	26 866	0	0	9 944	36 810
1960	42 598	0	0	10 184	52 782
1961	37 496	0	0	11 056	48 552
1962	55 203	0	0	11 230	66 433
1963	29 463	0	0	17 492	46 955
1964	27 986	0	0	12 963	40 949
1965	30 737	0	0	11 997	42 734
1966	51 254	0	0	13 823	65 077
1967	38 384	0	0	16 294	54 678
1968	79 912	0	0	18 833	98 745
1969	54 088	0	0	14 369	68 457
1970	34 678	0	0	13 705	48 383
1971	37 972	0	0	11 328	49 300
1972	28 988	0	0	14 856	43 844
1973	18 644	0	0	16 454	35 098
1974	19 919	0	0	17 010	36 929
1975	20 124	0	0	17 435	37 559
1976	19 179	0	0	19 332	38 511
1977	40 936	34	0	18 211	59 181
1978	33 864	21	0	15 754	49 833
1979	24 217	10	0	19 474	43 794
1980	20 614	12	0	18 595	39 331
1981	21 674	13	162	21 435	43 401
1982	30 783	510	643	21 576	53 512
1983	28 179	4 879	7 577	25 824	66 459
1984	23 756	12 045	46 751	22 114	104 666
1985	28 227	17 438	43 733	23 630	113 028
1986	40 054	14 618	47 520	25 466	127 658
1987	38 776	23 212	42 534	26 295	130 817
1988	39 088	20 735	86 370	41 583	187 776
1989	36 094	36 990	52 565	45 915	171 564
1990	44 155	24 456	78 509	40 973	188 093

Note : Besides the above catch, the following catches of Gillnet fishery caught by the Taiwanese fleet are recorded in the IPTP Database : 33 MT (1986), 1740 MT (1987), 35 MT (1988), 38 MT (1989) and 13 MT (1990)

Table 4: Indian Ocean yellowfin catches in total and by fishing method (longline, log and free school purse-seine, artisanal), 1952-90.

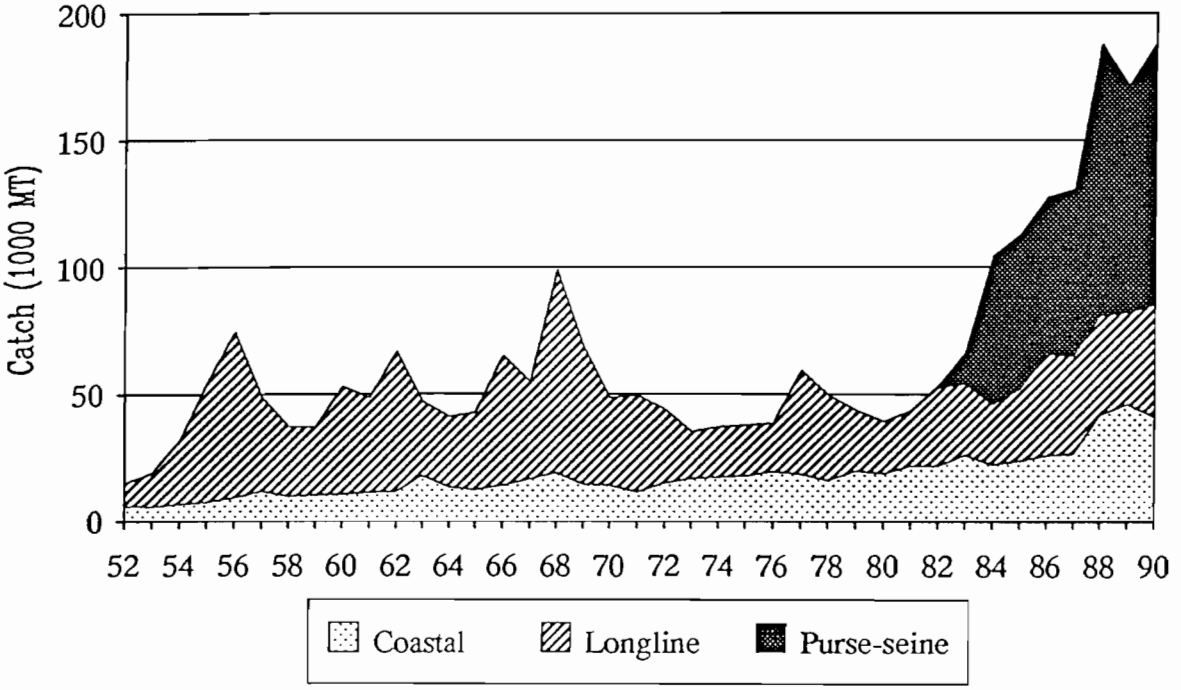


Figure 1: Evolution of yellowfin catches by the three main fishing methods (longline, purse-seine and artisanal), 1952-90.

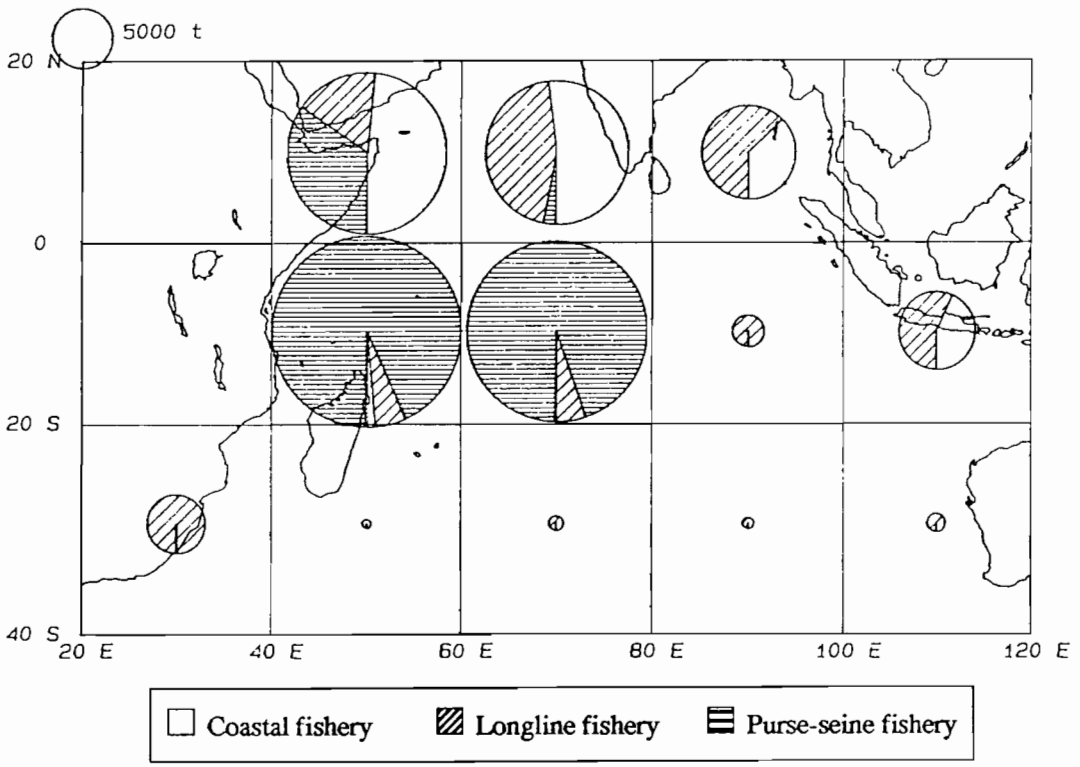


Figure 2: Yellowfin catch distribution by 20 degree squares of the three main fishing methods (longline, purse-seine and artisanal), 1990.

6.2. Catch and effort statistics

Through both Mauritius and Shimizu workshops, IPTP has implemented a standardized database for Indian Ocean yellowfin statistics, with a monthly 5 degree square stratification. The bulk of the fisheries statistics are available on this basis, even though problems remain for some fisheries which are still incompletely covered.

Table 5 recapitulates the present status and characteristics (time-area stratification, type of catch and effort, period available) of the IPTP catch and effort statistics by gear and country. The best estimate of the Indian Ocean yellowfin catch distribution by area for the three main fishing methods (longline, purse-seine and artisanal) is shown on Figure 2.

Table 5: Present status and characteristics (time-area stratification, type of catch and effort, period available) by gear and country of the IPTP catch and effort database.

Country	Gear	Type	Time	Area	Unit of catch	Unit of effort	Years Data Available
			Industrial Fisheries				
Japan	LL	-	Month	5°x5°	No.	Hooks	1952-1989
Korea	LL	-	Month	5°x5°	No.	Hooks	1975-1987
Korea	LL	-	Month	5°x5°	No.	Hooks	1975-1987
Taiwan	LL	-	Month	5°x5°	No./kg	Hooks	1967-1986
Taiwan	LL	Reg/Deep	Month	5°x5°	No./kg	Hooks	1987-1990
Indonesia	LL	-	Quarter	5°x5°	kg	-	1980-1988
France	PS	Log/Free	Month	5°x5°	Ton	No. days	1982-1990
Spain	PS	Log/Free	Month	5°x5°	Ton	No. days	1984-1990
Mauritius	PS	Log	Month	5°x5°	Ton	No. days	1989-1990
U.S.S.R.	PS	-	Daily	-	Ton	No. Sets	1985-1991
			Coastal fisheries				
Sri Lanka	Gill	-	Month	-	kg	No. days	1985-1990
Maldives	P/L	-	Month	Atoll	No./kg	No. days	1970-1990
Pakistan	Gill	-	Month	Local	kg	No. days	1987-1990
Indonesia	PS	-	Month	-	kg	No. days	1979-1990
Indonesia	Trol	-	"	-	"	"	"
Indonesia	Sen	-	"	-	"	"	"

LL = Longline (Reg = regular, Deep = deep)
PS = Purse-seine (Log = log schools, Free = Free swimmingschools)
Gill = Gillnet, Trol = Trolling, P/L = Pole-and-Line, Sen = Artisanal Purse-seine

6.2.1. Longline

For the longline fishery, the major area where yellowfin are caught has remained relatively stable, even though the effort pattern, as shown on Figure 3, has changed between the three periods, 1955-70, 1971-81 and 1982-89; no strong seasonal variations are noticeable (Figure 4). Catch and effort distributions by 5 degree square of the three main longline fisheries (Japan, Korea and Taiwan,) for the period 1982-89 are shown on Figure 5.

Korean longline catch and effort for 1988-89 were only available on an quarterly basis for the Workshop. It was therefore only possible to estimate the fishing effort directed on yellowfin over periods when the major effort shifted south for albacore or southern bluefin tuna.

The Workshop stressed the value of monthly catch and effort data for further analysis.

6.2.2. Purse-seine

A complete set of purse-seine catch and effort data by month and 5 degree square is available in the IPTP database for the period 1977-90. Mean (1983-90) catch (log and schools separately) and total effort distributions by 5 degree square of the combined French-Spanish purse-seine fishery, as well as the catch (on log) distribution of Japanese purse-seiners are shown on Figure 6.

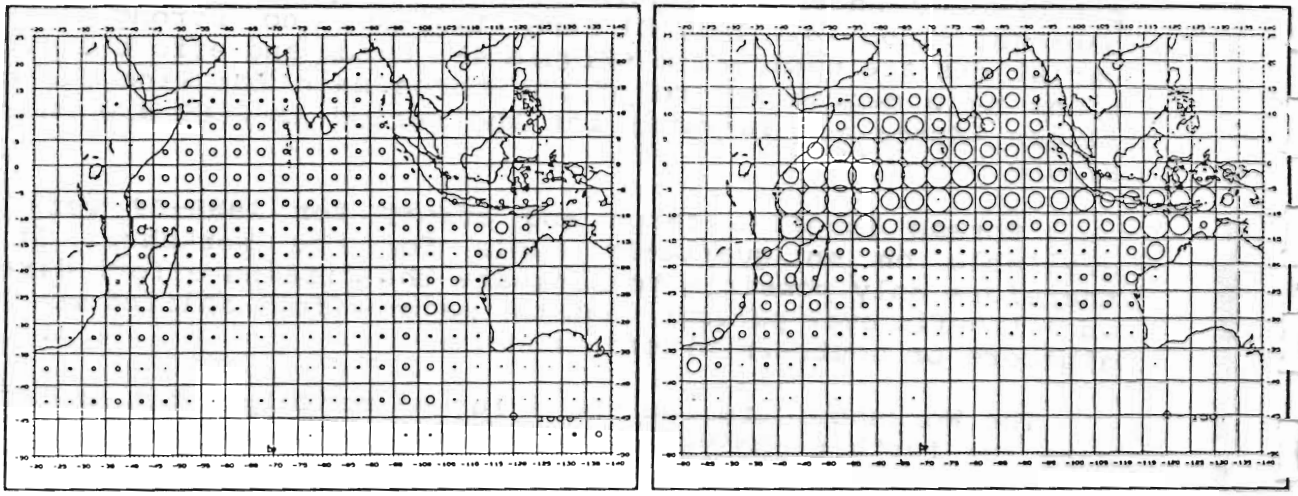
6.2.3. Artisanal fisheries

The artisanal fisheries of the coastal countries represent the major problem in this area; nevertheless, at least an order of magnitude estimate of catch as well as details of fishing areas are available for most of them. However, reliable effort statistics are often not available, and - even when they are - it is difficult to standardize efforts for a multitude of different gears.

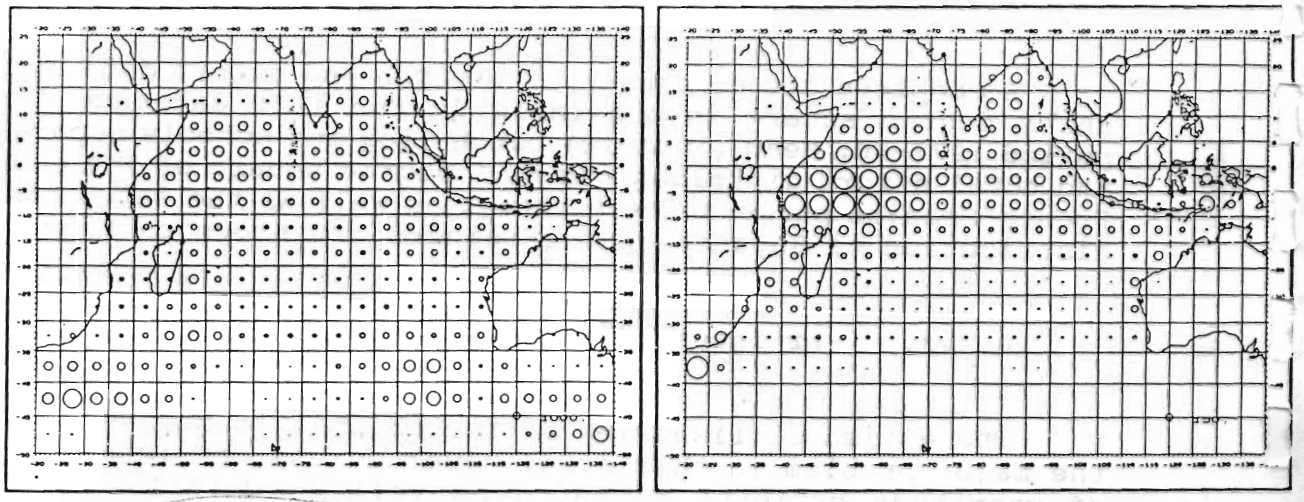
The development of catch-based stock assessment models, as implemented by the South Pacific Commission, may offer some chance of overcoming these problems in the future.

Effort Catch

1955-70



1971-81



1982-89

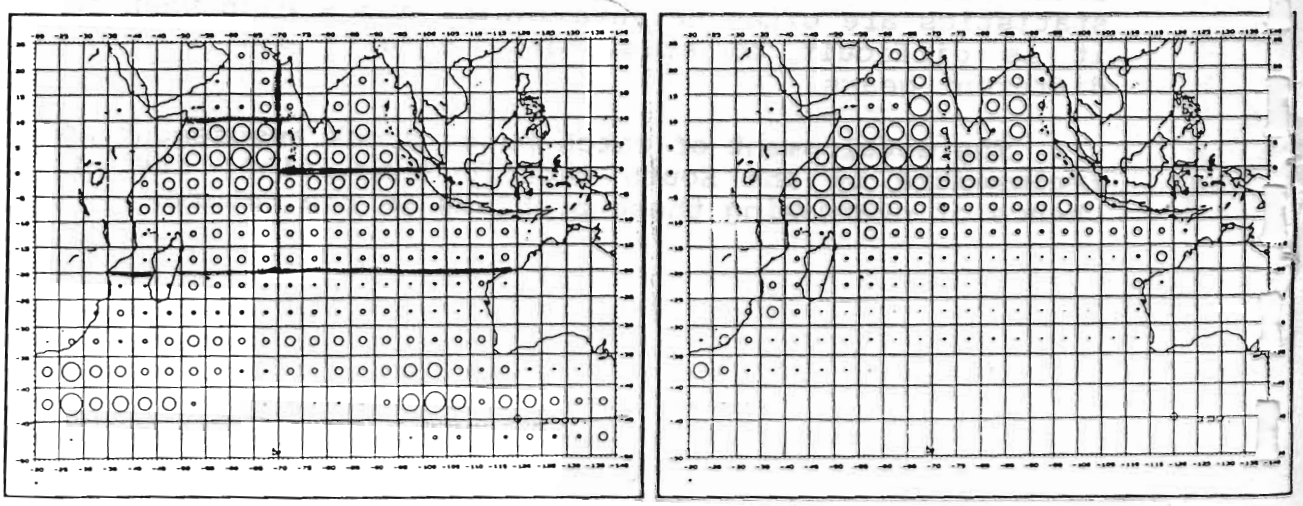


Figure 3: Mean catch and effort distributions of the longline fishery for three periods, 1955-70 (upper), 1971-81 (center) and 1982-89 (lower)

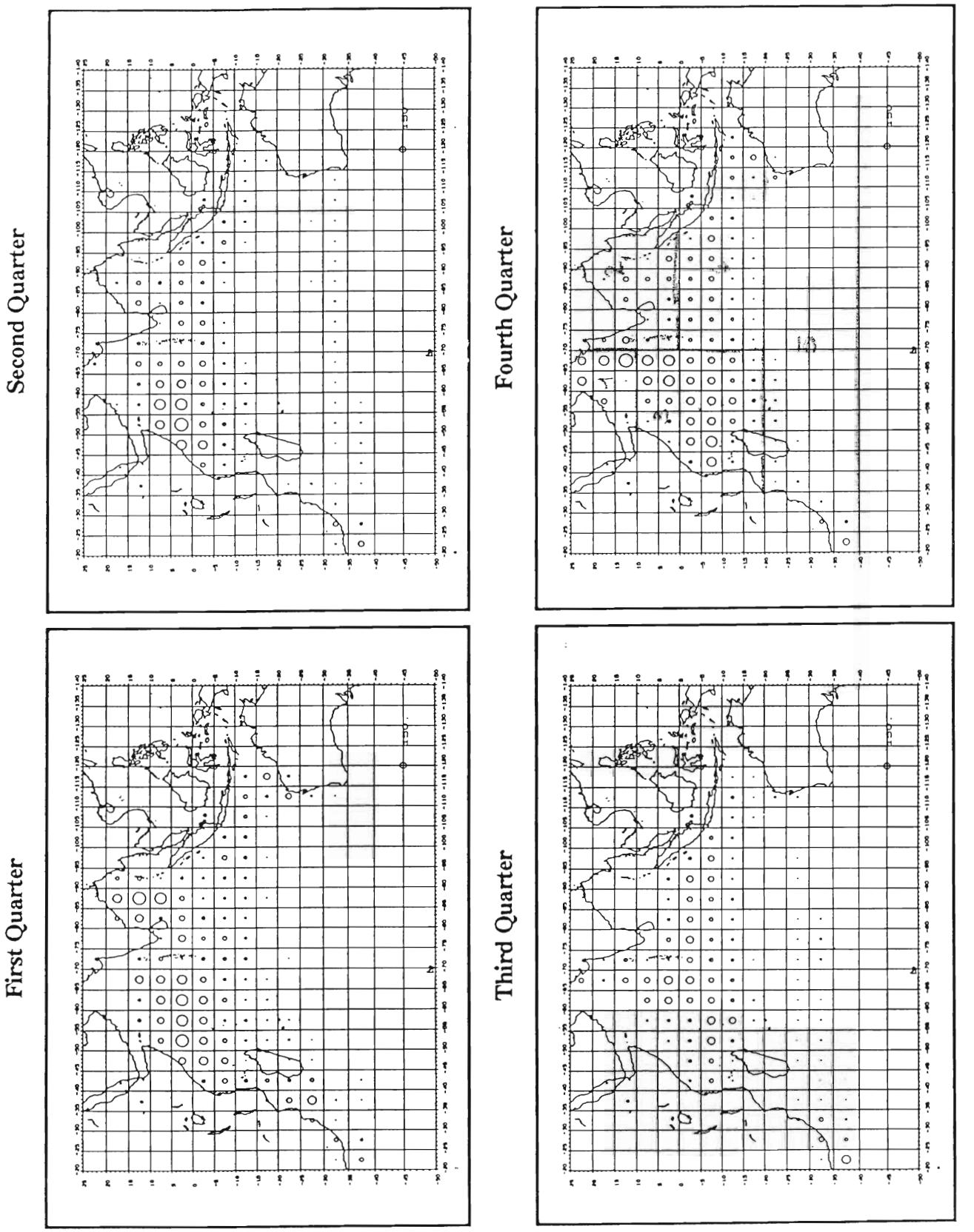


Figure 4: Mean quarterly distribution by 5 degree squares of longline catches in the Indian Ocean, 1982-89.

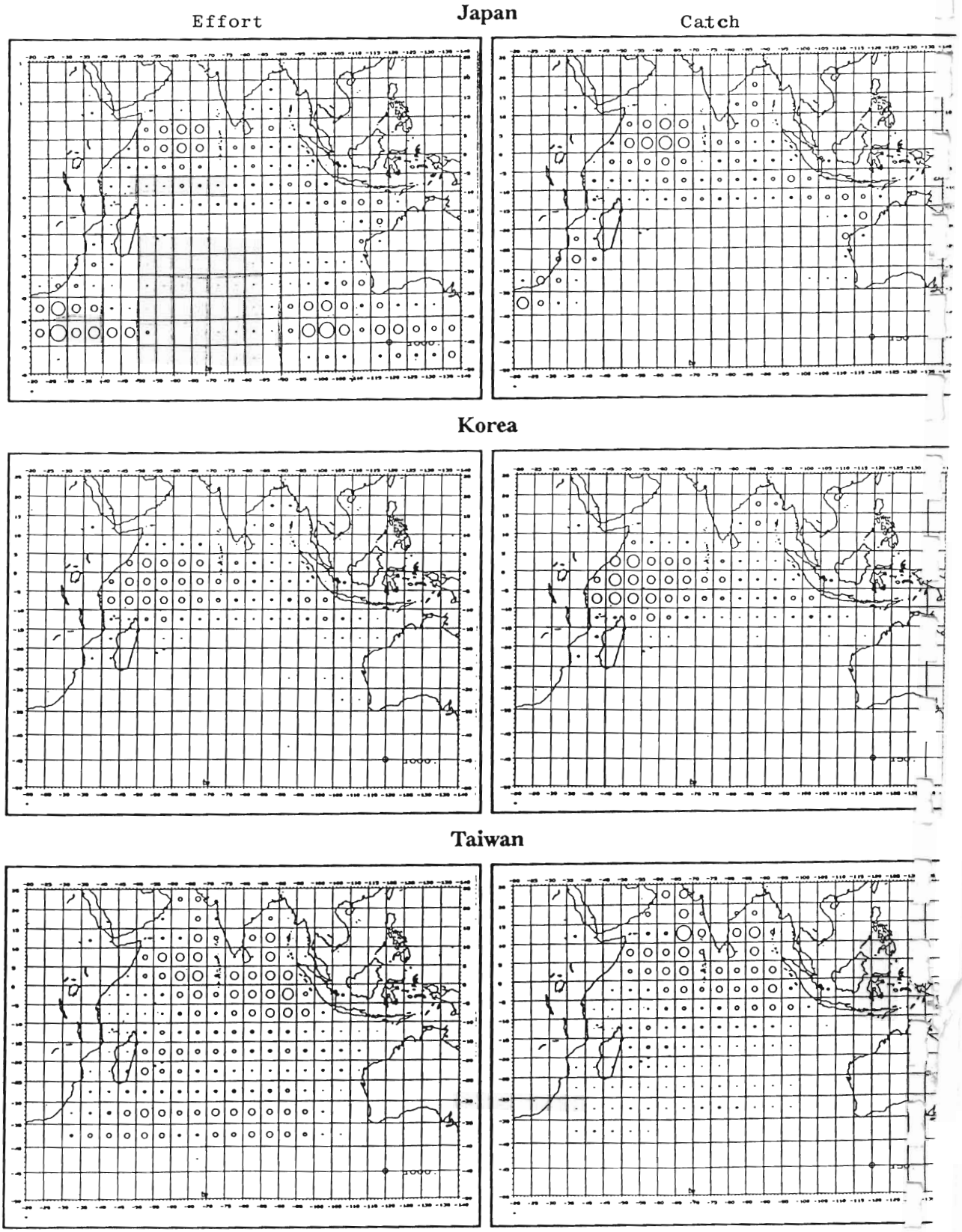


Figure 5: Catch and effort distributions by 5 degree squares of the three main longline fisheries for the period 1982-89: Japan (upper); Korea (center) and Taiwan (lower).

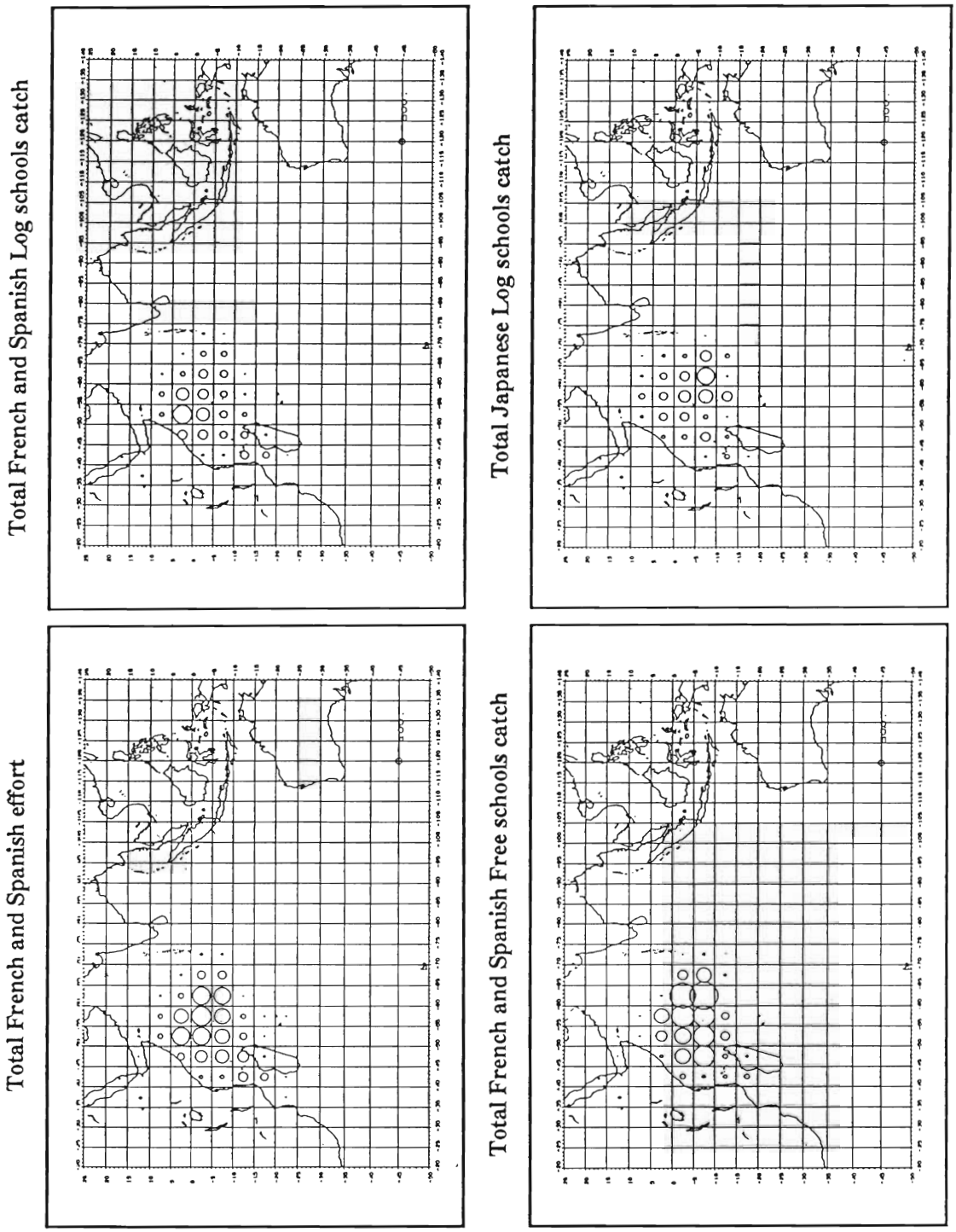


Figure 6: Mean catch and effort distributions by 5 degree square: total French-Spanish purse-seiners effort (upper left), log associated catches (upper, right) and free swimming school catches (lower left); Japanese log associated catches (lower, right), 1983-90.

6.3. Size frequencies

All the size frequency data from the different Indian Ocean yellowfin fisheries held by IPTP are now maintained in a standard computer format, which will make using the data very straightforward. It was recommended that all existing size distribution data still missing be made available on the standard IPTP stratification (month by 5 degree square) as far as possible, or on the finest strata available. Table 6 recapitulates the present status and characteristics (time-area stratification, type of size measure and interval, period available) of the IPTP size frequency database by gear and country.

Country	Gear	Time	Area	Interval	Measure	Years Data Available
Industrial Fisheries						
Japan	LL	Month	10°x20°	2 cm	FL	1952-1988
Korea	LL	-	-	2 cm	FL	1983-1985
Korea	LL	Quarter	-	2 cm	FL	1986-1989
Taiwan	LL	Month	5°x5°	2 cm	FL	1985-1988
Indonesia	LL	Month	-	1 kg	Weight	1987
France	PS	Month	5°x5°	2 cm	FL	1984-1990
Spain	PS	Month	5°x5°	2 cm	FL	1984-1990
Mauritius	PS	Month	5°x5°	2 cm	FL	1989-1990
U.S.S.R.	PS	(Raw Data)	-	-	FL	1986-1989
Coastal Fisheries						
SriLanka	Gill	Month	-	2 cm	FL	1983-1990
Indonesia	Trol,PS	Month	-	2 cm	FL	1981-1990
Maldives	P/L	Month	-	2 cm	FL	1983-1990
Pakistan	Gill	Month	-	2 cm	FL	1987-1990

LL = Longline, PS = Purse-seine, Gill = Gillnet, Trol = Trolling, P/L = Pole-and-Line
FL = Fork Length

Table 6: Present status and characteristics (time-area stratification, type of size measure and interval, period available) by gear and country of the IPTP size frequency database.

Quarterly yellowfin mean weights (estimated from size frequency data and length-weight relationships, as described under Agenda item 7) of the major fisheries (Japanese longline; purse-seine, log and school sets separated; artisanal fisheries of Maldives, Sri Lanka and Oman) are reported in Table 7.

6.3.1. Longline

IPTP has a complete set of size frequency data by 10 x 20 degree square from the Japanese longline fishery from 1952 to 1988. Data are available for the Taiwanese and Korean fisheries from 1985 and 1983 respectively, but these need either to be checked or entered. Some data from the Indian longline fishery were also made available to the meeting.

Size frequency distributions of the Japanese longline at the beginning of the exploitation (1952-60) and in a recent period (1975-88) are shown on Figure 7.

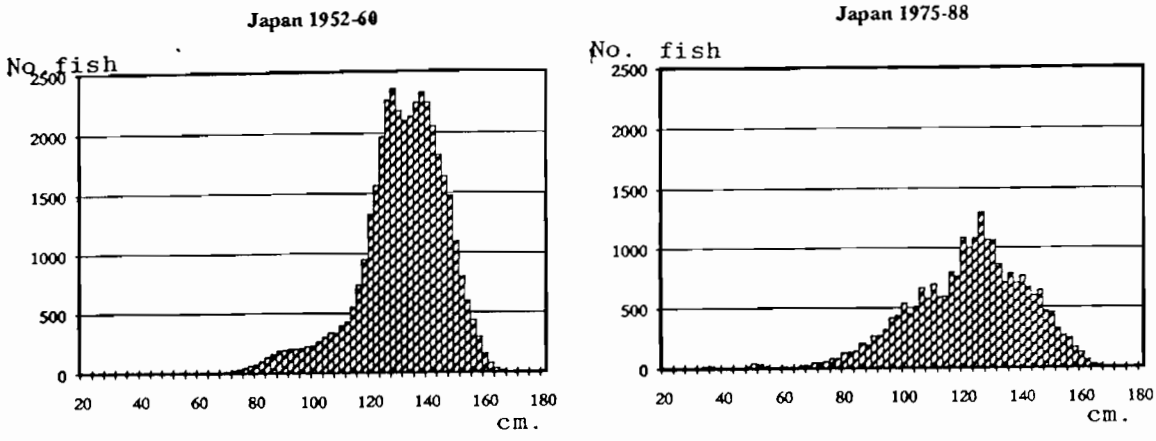


Figure 7: Mean size frequency distributions of Japanese longline catches at the beginning of the exploitation (1952-60, left) and in a recent period (1975-88, right).

6.3.2. Purse-seine

An almost complete set of length frequency data is now available for the western Indian Ocean purse-seine fishery, although it was noted that Spanish data for the period 1984-89 were obtained by strata substitution of French sampling. New data from USSR were made available to the meeting.

Purse-seine catches from free swimming and log schools show very different size distributions, the former having a larger proportion of large fish than the latter. Even fewer large fish are associated with artificial logs, which are perhaps not deployed long enough for such fish to aggregate. This phenomenon is clearly highlighted in Figure 8. Consequently, the importance of maintaining separate length frequency files for the different types of sets (as was recommended for catch-effort data) was recognized.

Mean size frequency distribution (log, free or combined schools) of the main purse-seine fleets (France, Japan, Mauritius and Spain) are shown on Figure 9, while Figure 10 exhibits the seasonal variations (by quarter, log and free schools separated) of the French purse-seine catch size composition.

LONGLINE

JAPAN					
YEAR	Q1	Q2	Q3	Q4	AVE
52			40.5	52.1	46.5
53	47.0	52.1	56.0	46.1	47.3
54	47.7	46.8	48.5	45.0	46.6
55	47.6	47.9	52.5	47.5	48.0
56	46.0	45.2	48.2	46.1	46.0
57	47.6	44.0	39.5	43.4	44.3
58	46.0	41.1	36.8	44.1	43.5
59	39.6	37.6	39.8	40.6	39.0
60	35.8	34.3	41.0	40.1	37.6
61	38.6	36.7	30.8	41.3	38.4
62	37.0	31.6	29.9	38.7	36.2
63	38.7	34.5	32.6	35.9	36.7
64	39.2	37.3	35.3	41.3	38.5
65	43.8	31.4	28.1	32.0	32.4
66	35.2	32.8	33.8	39.7	36.1
67	34.7	34.2	30.4	35.5	34.2
68	37.7	29.1	27.9	36.1	34.3
69	33.9	28.4	26.2	35.4	31.8
70	39.8	39.0	34.7	36.0	38.2
71	37.2	25.0	21.3	29.2	29.7
72	35.9	23.3	22.9	34.0	30.0
73	38.5	42.1	38.7	46.4	39.6
74	43.9	36.1	36.1	39.1	39.6
75	42.0	31.4	32.0	34.3	36.2
76	37.9	24.8	34.2	45.9	35.1
77	39.2	30.5	35.0	45.3	38.1
78	46.6	41.7	33.0	40.8	42.5
79	41.6	46.2	37.2	42.2	41.8
80	40.9	37.4	38.7	40.4	39.4
81	34.7	29.7	36.2	40.6	35.1
82	37.0	26.8	30.5	42.6	33.8
83	39.0	33.6	38.2	37.0	36.4
84	37.5	32.8	38.0	40.9	37.9
85	40.4	36.6	38.0	35.5	38.2
86	39.2	35.2	37.8	37.3	38.1
87	39.7	35.3	38.2	40.5	39.2
88	40.5	34.8	38.5	39.1	39.0

PURSE-SEINE

LOG SCHOOLS					
YEAR	Q1	Q2	Q3	Q4	AVE
82	4.8	5.4		4.7	4.7
83	4.1	7.5	4.7	7.6	5.9
84	9.7	28.4	8.7	5.7	8.0
85	11.5	11.3	5.9	3.5	5.2
86	9.3	7.0	11.9	9.3	9.3
87	16.9	9.0	10.0	12.8	11.1
88	5.7	5.3	5.9	4.6	5.4
89	6.4	9.4	7.3	6.9	7.5
90	4.8	8.5	5.6	7.8	6.5
PS FREE SCHOOLS					
YEAR	Q1	Q2	Q3	Q4	AVE
82		23.3	32.7	31.4	27.4
83	29.4	36.9	10.8	29.2	24.2
84	25.8	34.8	13.8	12.8	17.9
85	21.6	25.5	8.6	6.8	15.5
86	30.8	12.9	16.6	17.0	21.4
87	31.1	16.3	17.4	13.7	19.9
88	18.7	31.2	12.5	14.5	17.9
89	17.2	12.9	5.9	5.0	10.7
90	12.1	19.8	18.8	24.2	17.3

ARTISANAL FISHERIES

OMAN					
YEAR	Q1	Q2	Q3	Q4	AVE
89	20.7	9.5	12.3	9.5	13.7
SRI LANKA					
YEAR	Q1	Q2	Q3	Q4	AVE
85	5.8	7.1	7.1	11	7.4
86	16.4	8.5	7.2	12.1	8.1
87	16.5	8.6	7.6	8.0	8.3
88	11.9	12.2	6.7	8.7	9.1
89	9.1	4.6	6.9	11.3	7.4
90	16.9	10.5	10.3	10.8	11.6
MALDIVES					
YEAR	Q1	Q2	Q3	Q4	AVE
84	3.5	4.1	8.3	5.5	4.3
85	3.6	12.7	8.6	2.5	3.2
86	3.4	6.5	12.6	4.4	3.8
87	3.3	3.0	6.9	4.4	3.6
88	4.1	3.4	4.6	5.5	4.3
89	5.2	2.8	4.4	3.9	4.4
90	7.0	6.1	7.5	3.7	5.4

Table 7: Quarterly yellowfin mean weights in the main fisheries (Japanese longline; purse-seine, log and school sets separated; artisanal fisheries of Maldives, Sri Lanka and Oman).

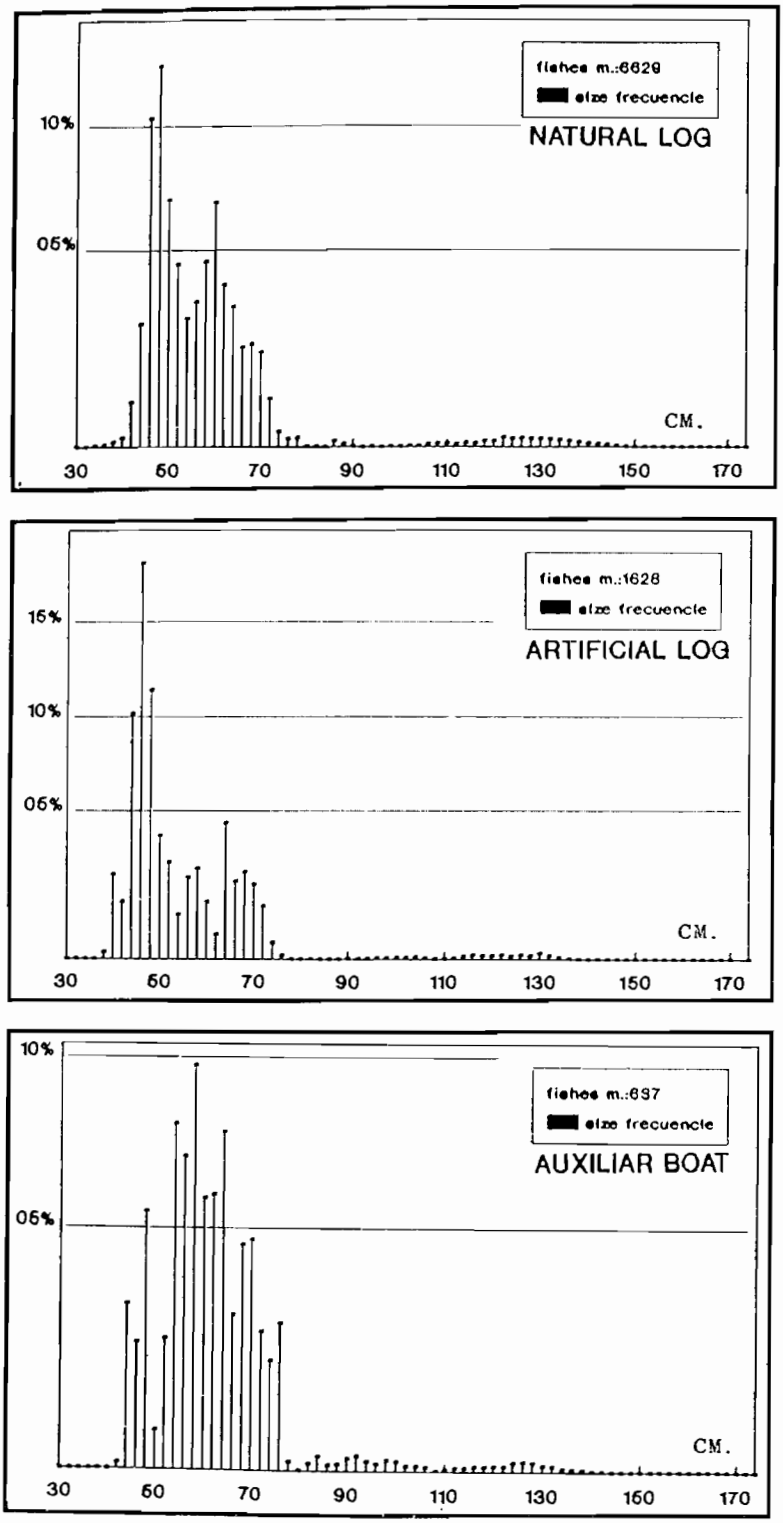


Figure 8: Mean size frequency distributions of Spanish catches on artificial logs (upper), natural logs (center) and auxiliary boats (lower), from January 1990 to June 1991.

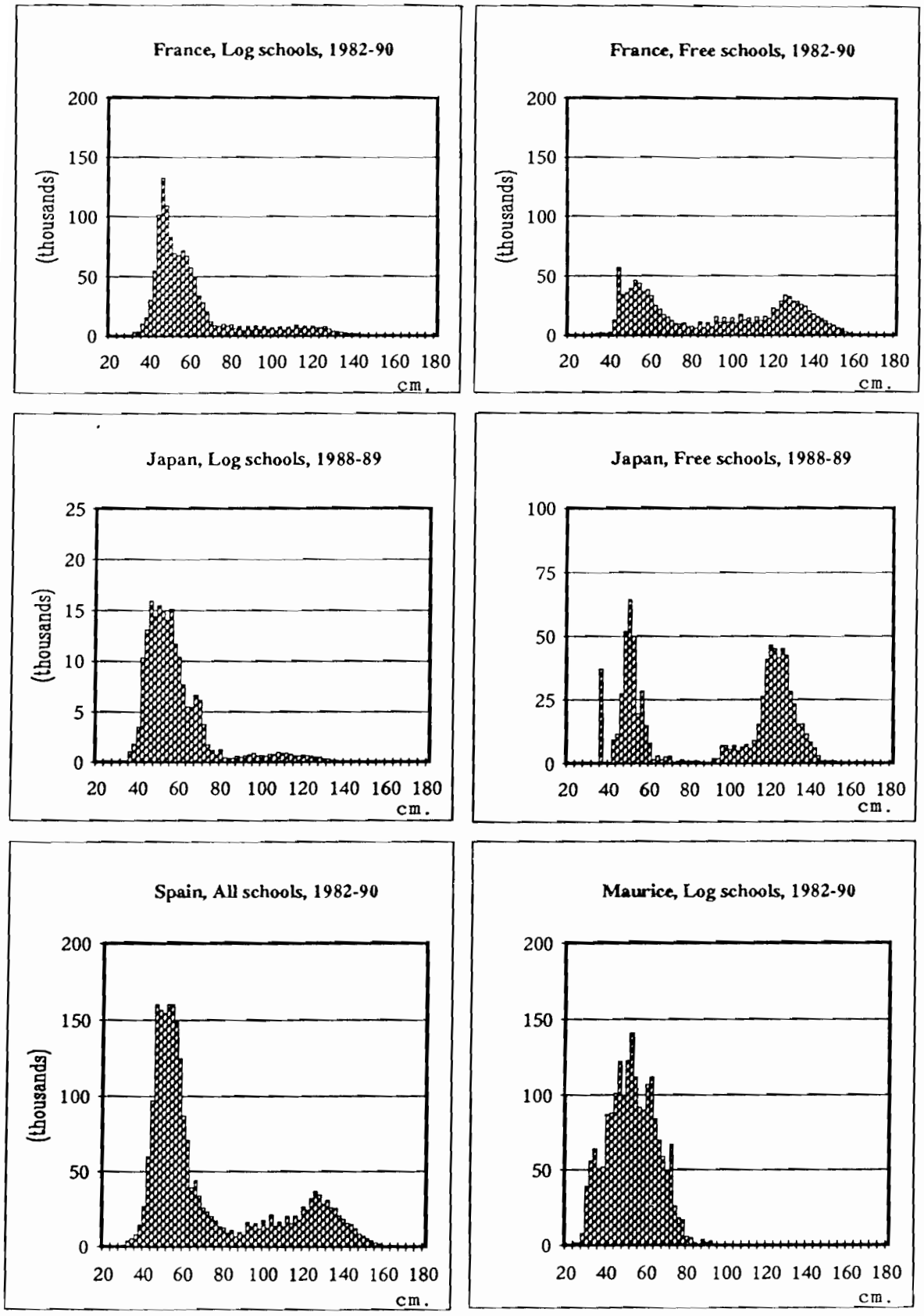


Figure 9: Mean size frequency distribution (log, free or combined schools) of the main purse-seine fleets (France, Japan, Mauritius and Spain).

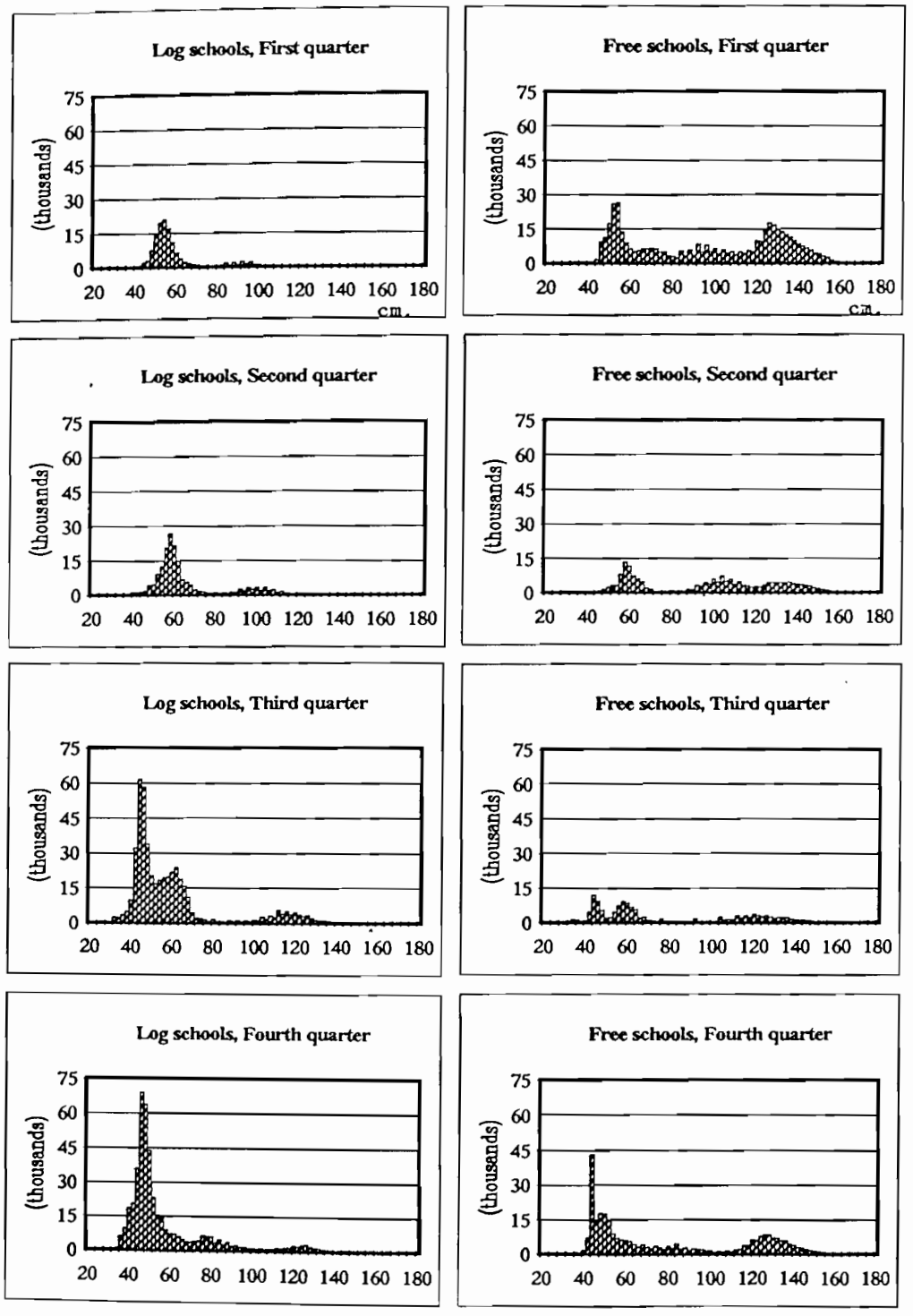


Figure 10: Seasonal variations by quarter of log associated (left) and free swimming (right) schools of the French-Ivory Coast purse-seine mean catch size composition, 1982-90.

6.3.3. Artisanal

Length frequency data from most of the major artisanal tuna fishing countries (Indonesia, Maldives, Oman, Pakistan, Sri Lanka) are available from the 80's in the IPTP database, although the variety of different gears may be difficult to handle. A limited (1984-90) set of size frequency data was made available on hardcopy to the meeting from India, but could not be used. Mean size frequency distribution of the main artisanal fisheries (Maldives, Oman and Sri Lanka) are shown on Figure 11. For stock assessment, artisanal fisheries size frequency data from recent years have to be substituted in the calculation of catch at length for earlier years.

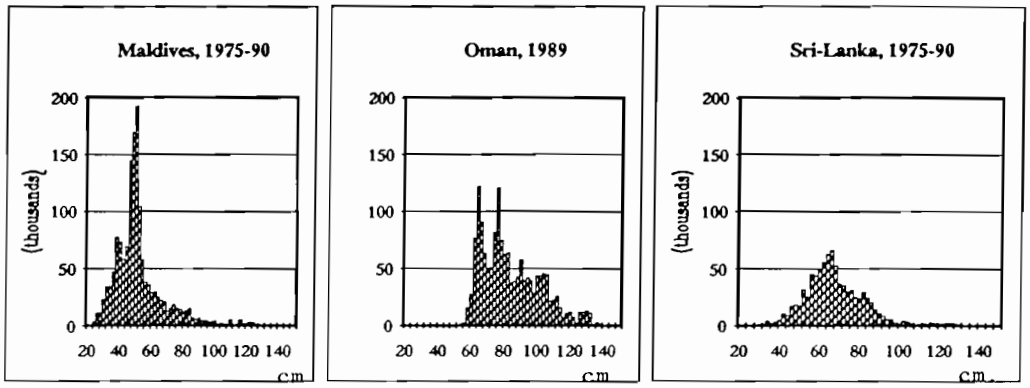


Figure 11: Mean size frequency distribution of the main artisanal fisheries (Maldives, Oman and Sri Lanka).

6.4. Tagging

During 1990, IPTP carried out a tuna tagging programme in the Maldives (TWS/91/08), in cooperation with the Ministry of Fisheries and Agriculture. Nearly 10,000 tunas were tagged, 1,907 of which were yellowfin. To date, 118 yellowfin have been recaptured, of which 12 were from outside the Maldives (more than 300 nautical miles from the release site). Release and recovery data are maintained by half degree square and month. Length at release and recapture are also available, but the length at recapture data are known to be of poor quality.

Other tuna tagging experiments had been conducted in the western Indian Ocean. These include tagging during Japanese research cruises (3,749 yellowfin tuna tagged from 1980 to 1990, 114 recaptures), by the "Commission de l'Océan Indien" (419 yellowfin tuna tagged in 1988-89, 8 recaptures) and by a cooperative USSR-Mozambique tagging programme (200 yellowfin tagged since 1990, no recaptures until now). Data from these experiments are not included in the IPTP database, but the necessity of maintaining a central file of all Indian Ocean tagging data at IPTP was noted. The importance of good fishing

effort (or at least catch) data for the interpretation of tag recovery information was emphasized.

7. REVIEW OF BIOLOGICAL PARAMETERS

7.1. Length-weight relationship

Document TWS/91/14 gives the calculation and equations describing different relationships between first dorsal length (FDL) - fork length (FL), FDL - weight (W) and FL - weight. The FL - W relationship adopted during the Mauritius Working Group (TWS/91/04) involves two relations depending on the size of fish considered:

Yellowfin with FL< 64 cm:
$W = a.FL^b$, where $a = 5.313 \times 10^{-5}$, $b = 2.753661$

Yellowfin with FL> 64 cm:
$W = a.FL^b$, where $a = 1.585 \times 10^{-5}$, $b = 3.044983$

The length-weight table calculated from these equations is given in Table 8. These relations were calculated from a large sample (n=2,242) including small and large yellowfin from 30 to 185 cm FL. Document TWS/91/21 present a length-weight relationship calculated from a much smaller sample (N=282) restricted to yellowfin caught in the Lakshadweep (India) area.

Table 8: Length-weight relationship of Indian Ocean yellowfin tuna as derived from the selected equations.

FL cm	W kg	FL cm	W kg	FL cm	W kg	FL cm	W kg	FL cm	W kg
21	0.2	51	2.7	81	10.3	111	26.8	141	55.5
23	0.3	53	3,0	83	11.1	113	28.3	143	57.9
25	0.4	55	3.3	85	11.9	115	29.8	145	60.4
27	0.5	57	3.6	87	12.8	117	31.4	147	63.0
29	0.6	59	4,0	89	13.7	119	33.1	149	65.7
31	0.7	61	4.4	91	14.6	121	34.8	151	68.4
33	0.8	63	4.8	93	15.6	123	36.6	153	71.2
35	0.9	65	5.3	95	16.7	125	38.5	155	74.1
37	1.1	67	5.8	97	17.8	127	40.4	157	77.0
39	1.3	69	6.3	99	18.9	129	42.3	159	80.0
41	1.5	71	6.9	101	20.1	131	44.4	161	83.1
43	1.7	73	7.5	103	21.3	133	46.5	163	86.3
45	1.9	75	8.1	105	22.6	135	48.6	165	89.6
47	2.1	77	8.8	107	24,0	137	50.9	167	92.9
49	2.4	79	9.5	109	25.3	139	53.1	169	96.4

Thus the participants agreed to use the length-weight and other relationships from document TWS/91/14 for all the fisheries (purse-seine, artisanal and longline fisheries). It was stressed that no significant difference could be detected between FL-weight relationships of males and females.

For Japanese longline data, such a length-weight relationship was used to estimate total catch in weight from recorded catch in number and size frequencies. Korea and Taiwan are using similar methods to estimate their longline catches in weight.

It was recommended to examine the consequences of using different length-weight relationships to estimate the total catch in weight in longline fisheries.

For the surface fisheries the length-weight relationship is used to draw up the catch at size data files (see 8).

7.2. Growth

Several documents dealing with growth estimates from different areas and using different techniques were presented: TWS/91/09, 11 and 17 present growth curves calculated from modal progressions of different sets of data; TWS/91/11 uses length frequencies of yellowfin tuna caught by longline in Indian seas; TWS/91/09 utilizes three different sets of length frequencies (French purse-seine, Japanese longline and Sri Lankan small scale fishery); TWS/91/17 uses size frequency samples from the French purse-seiners from 1984 to 1989.

The age at size resulting from the different growth curves are in relatively good agreement for fishes over 70 cm FL. The discussion was focussed on the growth and size at age of the small yellowfin tuna under 70 cm FL because of the diverging results presented in document TWS/91/09, using Sri Lankan small scale fisheries length frequencies, and in document TWS/91/17, using French purse-seiners data. The choice of a growth curve for these small fish may be of some importance for stock assessment, because they are (in term of number of fishes) a major component of the surface fisheries.

Document TWS/91/09 proposes a classic single von Bertalanffy growth curve which indicates a fast growth rate of 2.8 cm/month for yellowfin between 30 and 90 cm FL, while document TWS/91/17 proposes a linear slow growth rate (1.5 cm/month) for 40-70 cm FL yellowfin tuna, followed by a classical von Bertalanffy growth curve for larger fish (Figure 12).

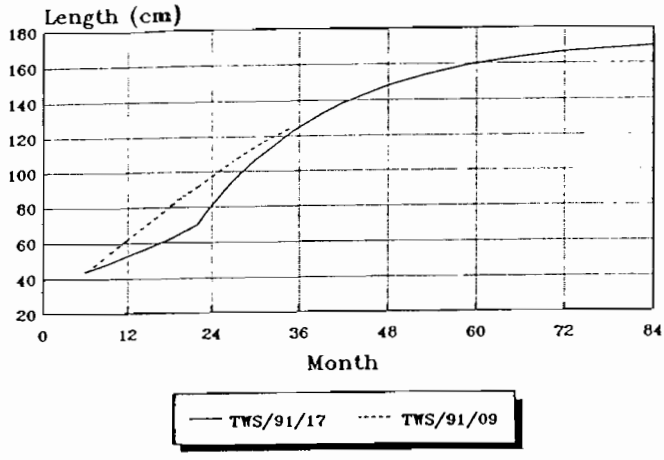


Figure 12: Comparison between the two main growth curves presented at the workshop (from documents TWS/91/09 and 17).

Discussions followed on the different arguments to be taken into account to make a choice between these two growth patterns. It was noted that an apparently slow growth of small yellowfin has already been observed in other areas, such as the Atlantic (1.5 cm/year, ICCAT) and the western Pacific (2.0 cm/year, SPC) Oceans. It was also pointed out that growth can be highly variable according to the time and area, this phenomenon being reflected in the increasing variance of length frequency modes with age.

As it was not possible to make a choice based on objective arguments, the participants agreed to use both growth curves as two different working hypotheses, and to build up two sets of catch at age tables for comparing the results. For that purpose, a composite growth curve combining those presented in document TWS/91/09 and including a fast growth rate for small fishes was drawn (Figure 13). The age at size deduced from this curve will be used and compared with those deduced from the growth curve presented in document TWS/91/17.

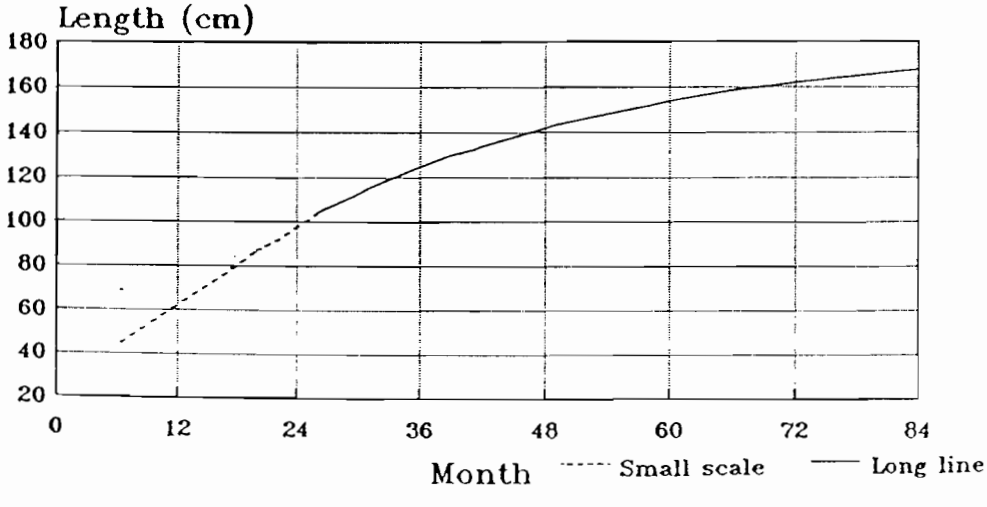


Figure 13: Composite growth curve used to derive the "fast" growth hypothesis.

Nevertheless, it was stressed that - whatever will be the final decision - the growth pattern which will be used must be considered as working hypothesis. It was strongly recommended to undertake yellowfin tuna growth studies by multiple methods (direct age reading, tagging ...) so as to be able to estimate the growth of small yellowfin tunas in the Indian Ocean and to assess the growth variability between area, seasons, sex and individual fish.

7.3. Natural mortality

Several documents (TWS/91/04, 09, 11, 21) give estimates of the apparent natural mortality factor (Table 9). It was pointed out that no new information exists which permit to reach any conclusion for a value of M differing drastically from the previous estimates from other oceans.

Table 9: Apparent yellowfin tuna natural mortality values available in the Indian Ocean.

Document	M Values
TWS/91/04	M = 0.8 (Fishes age 0+ and 1) M = 0.6 (fishes age 2 to 6)
TWS/91/09	M = 0.61 - 0.70
TWS/91/11	M = 0.74
TWS/91/21	M = 0.54

It appears from sex-ratio related to size of the fish (see paragraph 7.4) that males and females could have different natural mortalities and/or growth, and thus catch at age should be split by sex in order to use different M and growth coefficients in further stock analysis. Sensitivity analysis conducted on a theoretical basis shows that an over-estimate of M generally leads, for a given catch, to an over-estimate of the population and to an under-estimate of the fishing mortality, but that the extent of bias varies, depending on other factors such as trends in fishing mortality F and recruitment.

The participants agreed to adopt a moderate constant value (M=0.6) in order to remain conservative and prudent, although it was recognized that - for evident physiological and biological reasons - a natural mortality depending on age (as used in the Atlantic Ocean, where M=0.8 for yellowfin up to 80 cm LF, then M=0.6: TWS/91/04) should be considered in future work.

7.4. Stock structure and biological characteristic of the stock

Paper TWS/91/08 summarizes the results (tagging and recoveries) of the tagging operations conducted in Maldives under IPTP assistance as well as the long range recoveries of yellowfin tuna from other tagging programmes in the Indian Ocean (Table 10).

Table 10: Summary of yellowfin tuna tagged in the Indian Ocean (from TWS/91/08).

Year	Location	Number		Recovery rate (%)	Source
		Released	Recovered		
1980-1990	Indian Ocean	3749	114	3.04	Yano, 91 (SEAC/90/17)
1988-1989	Western Indian Ocean	419	8	1.91	Cayre, Ramcharrun, 91 (TWS/90/61)
1989	Java, Indonesia	6	0	0.00	Naamin, this meeting, 1991
1990	Maldives	1907	118	6.19	Yesaki & Waheed, 1991 (TWS/91/08)
1990	Mozambique	200	0	0.00	USSR Report, this meeting, 1991
1980-1990	Total	6081	240	3.95	

The Shimizu Working Group (TWS/91/05) suggested that the working hypothesis of a single yellowfin tuna stock in the Indian Ocean be adopted, as no evidence of multiple stocks can be drawn from the longline data. This hypothesis is confirmed by the preliminary results of the present tagging studies, as suggested on Figure 14 (TWS/91/08).

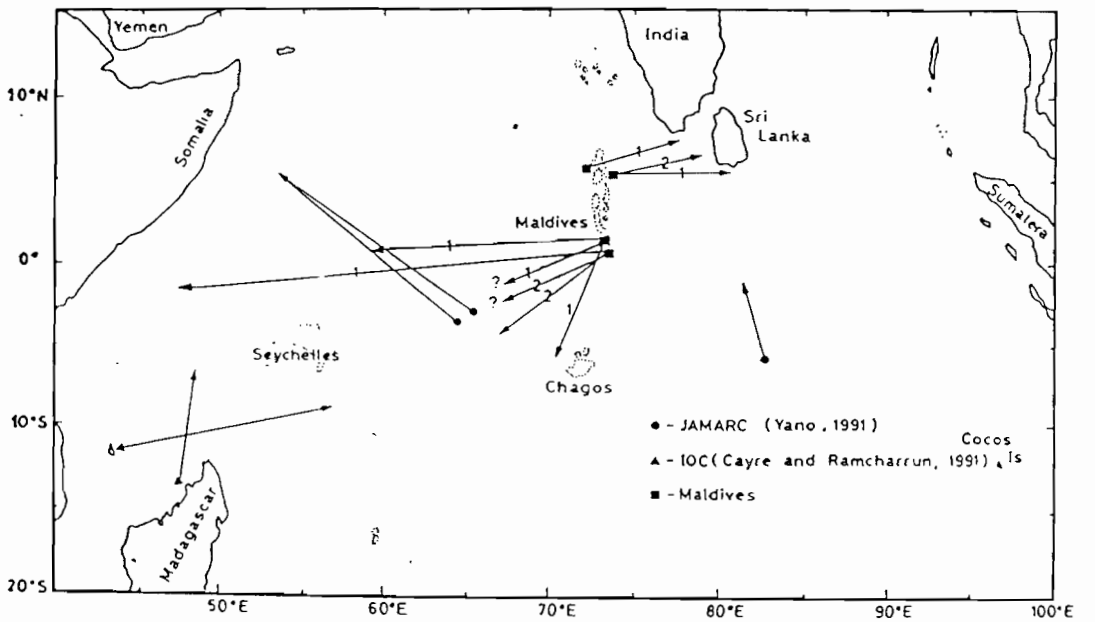


Figure 14: Long distance recoveries of yellowfin tuna in the Indian Ocean (from TWS/91/08)

Tuna larval distribution studies in the Indian Ocean are too patchy to be conclusive in any sense; moreover, larval distribution is generally a weak method to assess stock structure.

It was recommended that detailed analysis of the huge amount of catch by size/area/time data available from every fisheries be conducted to improve knowledge on stock structure. However,

it was also stressed that stock analysis should be conducted in the future taking into account many more environmental factors which obviously constrain yellowfin tuna distribution, as indicated by different studies in the Indian Ocean as well as in other oceans.

The catches of yellowfin observed off the southern part of Africa up to 15°E clearly belong to the Indian Ocean stock, as evidenced by the Japanese longline CPUE data distribution (Figure 15). Because of similar environmental and catch distribution evidence, it was suggested the eastward boundary of the Indian Ocean stock of yellowfin off the southern part of Australia be fixed at 140°E instead of 150°E. The South Pacific Commission (SPC) mentioned that tagging will be undertaken in the extreme western part of the Pacific Ocean which could allow the reality of this 140°E eastward boundary to be verified.

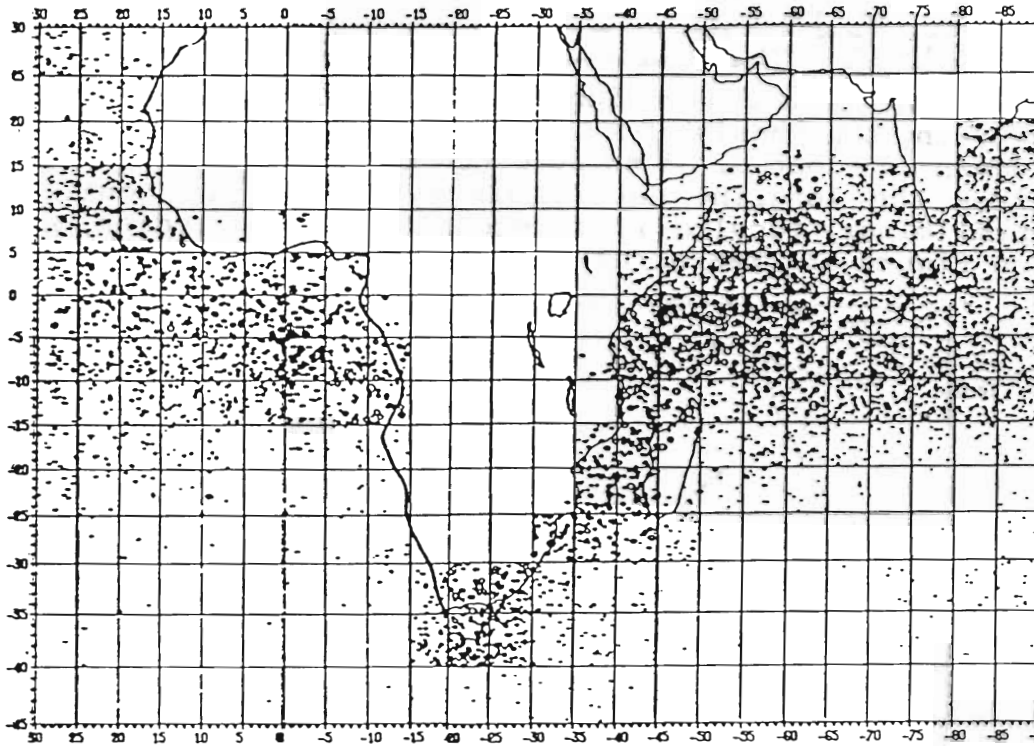


Figure 15: Monthly CPUE of Japanese longliners, first quarter all months during the period 1962-86 in Atlantic and Indian Ocean.

NB 1: Random positions of all monthly catches are calculated within each 5 degree square, which explains some catches appearing on land; the apparent weak gap in front of Mozambique coast is due to the reduced effort during this period, whereas the large one in front of Namibia and Angola is due to oceanographical conditions (cold waters of the Benguela current).

NB 2: The first quarter was chosen as an example as no notable seasonal variations take place in this area.

7.5. Size at first maturity

Document TWS/91/32 gives the results of research conducted by USSR from 1966 to 1990 in the western part of Indian Ocean (Seychelles EEZ and northern part of Mauritius EEZ); the mean size at which all the yellowfin tuna females found are mature is 120 cm LF, while the minimum size at maturity found was 52 cm LF.

A Sri Lankan paper presented at IPTP's 1986 session (Maldeniya and Joseph, 1987), showed the first size at maturity (50% maturity) was at 100 cm FL (Figure 16) while Hasani and Stequert at the 1990 IPTP meeting (TWS/90/68) presented a study setting the first size at maturity at 116 cm FL. All these results are in relative agreement.

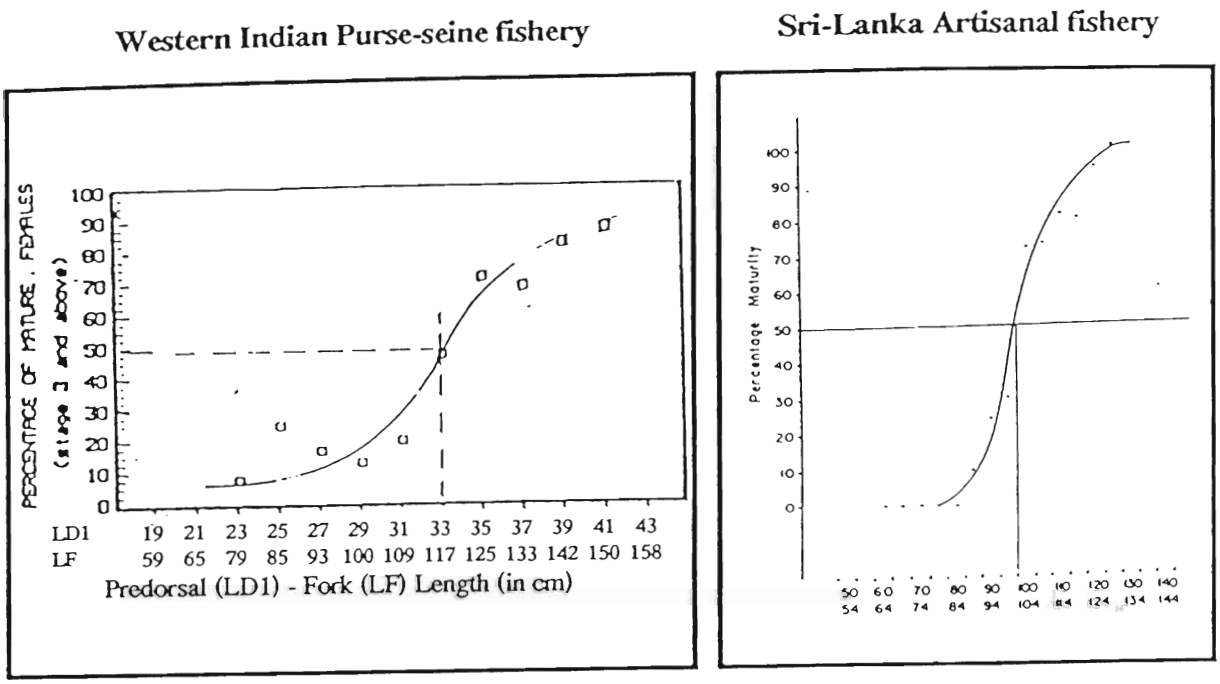


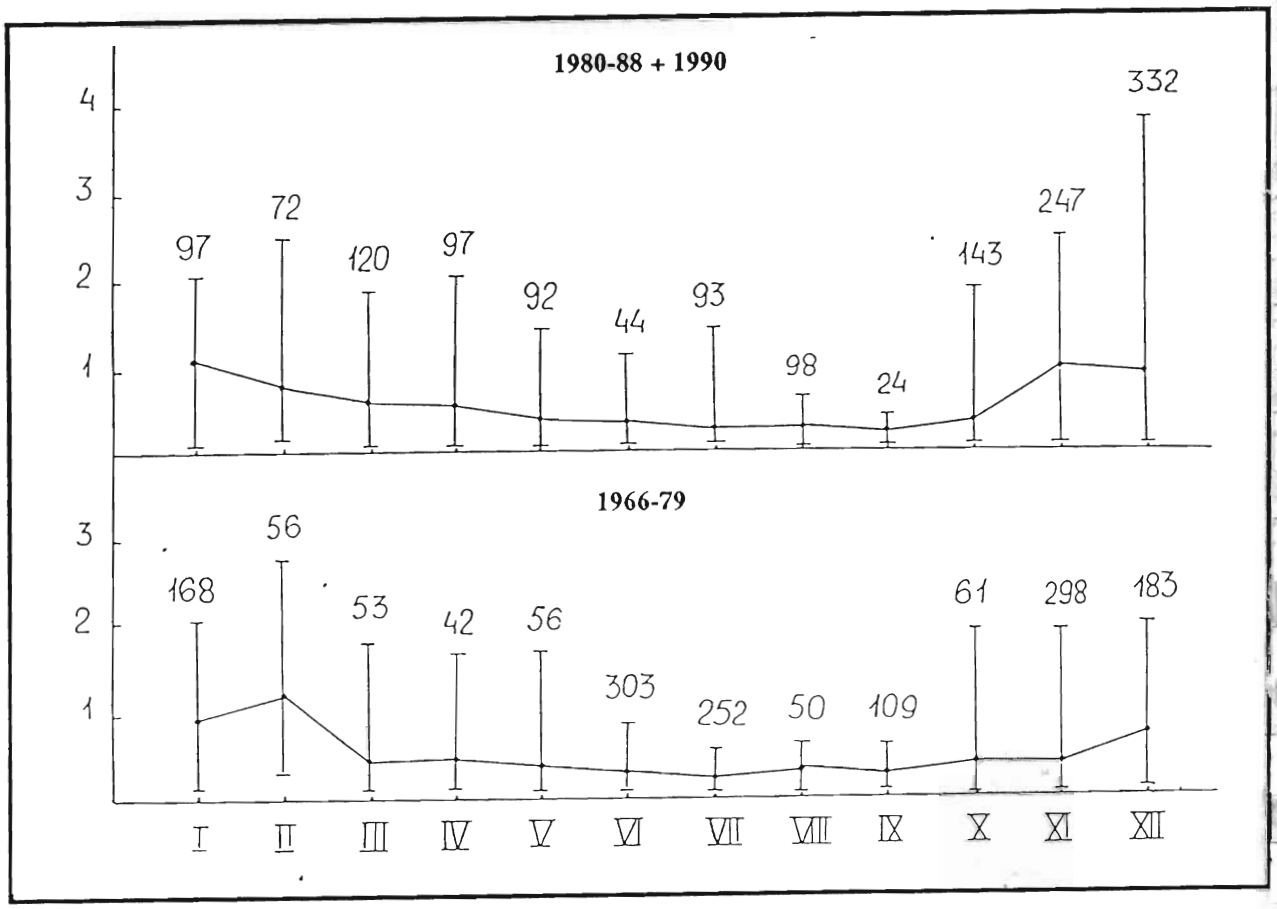
Figure 16: Size at maturity of yellowfin tuna: in the western Indian Ocean purse-seine fishery (left, from TWS/90/68) and in coastal waters of Sri Lanka (right, from TWS/86/18).

7.6. Spawning

Gonad index values calculated from a six month September -March sample collected on longline vessels operating in the Indian EEZ (TWS/91/11) indicate that higher values (GI>15) were observed in the February-March months.

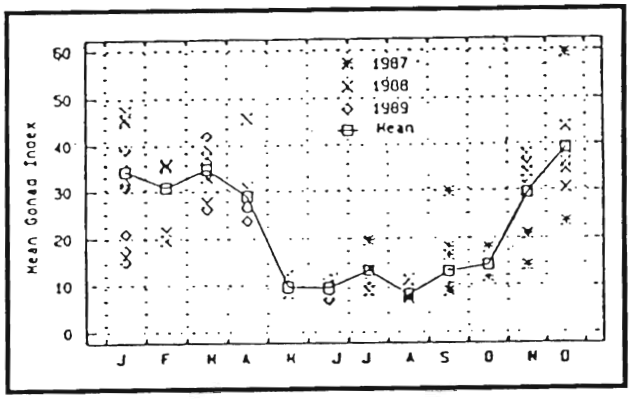
A substantial sample of gonads was collected from USSR longliners (TWS/91/34) operating in the western part of Indian Ocean (Seychelles EEZ) over the 1966-90 period. The analysis of these samples and maturity coefficient values indicates that, in the area sampled, the spawning season falls in the November-February period (Fig. 17A); it was also pointed out that the 3 month peak spawning period shifts from year to year within this period. All these results are in agreement with the results (TWS/90/68) previously updated at IPTP (Figure 17B).

A - USSR Longliners , western Indian Ocean (TWS/91/32)



B - French Purse-seiners, western Indian Ocean (TWS/90/68)

Females **Males**



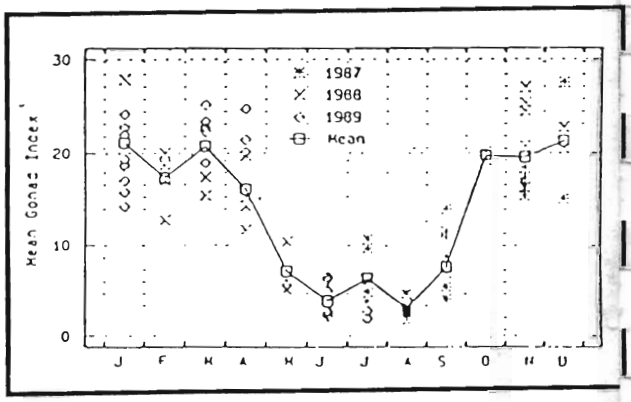


Figure 17: Seasonal variations of yellowfin tuna fecundity in the western Indian Ocean.

A Maturity coefficient changes by month for yellowfin tuna females from USSR longliners in the western Indian Ocean (from TWS/91/32; numerals is number of samples).

B Mean monthly variations of Gonad Index during 1982-89 for yellowfin tuna caught in the western Indian Ocean French purse-seine fishery (from TSW/90/68).

It was stressed during the meeting that reproduction indices should be gathered and assessed on a wide geographical scale covering in as much detail as possible the entire area of distribution of the yellowfin in the Indian Ocean; moreover, it was recommended that this index should be calculated as a routine activity to assess the variability of reproduction from year to year. The participants were informed that a preliminary analysis, which is being conducted by French and Seychelles scientists, seems to indicate from samples collected in the purse-seiners catches that a small second reproductive season could fall during the winter (July-August) in the western part of Indian Ocean (between Seychelles and Chagos Islands).

The results presented in document TWS/91/32, were discussed and it was stressed that high gonad indices and hydrated ovocytes were very rarely observed in the samples collected from longline catches in other oceans. Thus, these results, if confirmed, could indicate a particular reproductive habit of yellowfin tuna in the Indian Ocean.

7.7. Sex ratio

A study conducted from longline surveys in the Indian seas (TWS/91/11) indicated that males are predominant at all sizes sampled from 60 to 180 cm LF; their percentage increases drastically at sizes over 140 cm FL (Figure 18B).

A large sample of 3,309 yellowfin tunas collected from 1966 to 1990, during 13 research cruises aboard USSR vessels (Seychelles and northern part of Mauritius EEZ, TWS/91/32) indicates males are prevailing at all sizes from 70 to 200 cm FL (Figure 18A): the sex ratio is close to 50% for sizes comprised between 101 and 140 cm FL, but as, in the previously mentioned analysis, their proportion gradually increase for sizes over 140 cm FL; very big specimens (FL> 180cm) are exclusively males.

The predominance of males at large sizes observed in both documents is in agreement with previous results presented at IPTP (Maldeniya and Joseph, 1987; Hasani and Stequert, 1990: Figure 18C and D). Nevertheless, some discrepancies are observed comparing those results with others coming from other areas: in the Pacific Ocean, males become predominant from 125 cm FL, whereas in the Atlanic Ocean females are significantly dominant from 125 to 145 cm, males then becoming more numerous.

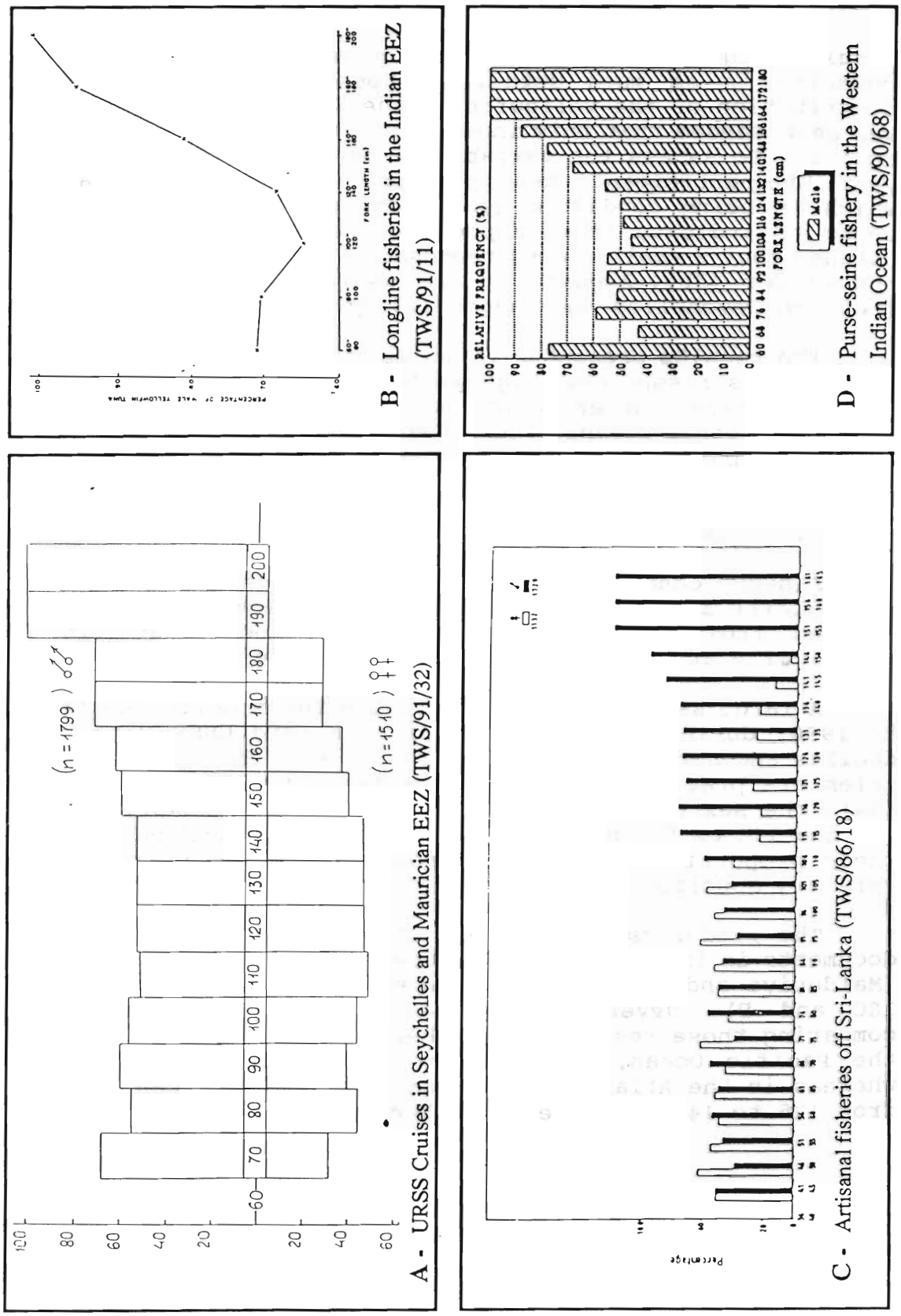


Figure 18: Indian Ocean yellowfin tuna sex ratio evolution with size:
A USSR cruises in Seychelles and Mauritian EEZ (from TWS/91/32)
B Longline fishery in the Indian EEZ (from TWS/91/11)
C Artisanal fisheries off Sri Lanka (from TWS/86/18)
D Purse-seine fishery in the western Indian Ocean (from TWS/90/68)

The different hypotheses which could explain this change of sex ratio with size were recalled: differences in growth and/or natural mortality between sexes, reduced catchability of large females. In the Pacific Ocean, a difference of growth between males and females was demonstrated. In the Indian Ocean there is no evidence on which hypothesis could explain this trend in the sex ratio.

It was recommended to check by statistical analysis the significance of the sex ratio at each size and to undertake physiological research on growth pattern, because this observed trend in the sex ratio could have important implications on stock assessment.

7.8. Feeding habits

Gut content study of yellowfin tuna from longline catches off the north-west coast of Indian as well as in Andaman sea (TWS/91/11) confirms the diversity and seasonal variability of prey organisms ingested (Figure 19). Document TWS/91/31 analyses and compares stomach contents of yellowfin tuna caught by purse-seine and by long-line in the western part of Indian Ocean, while document TWS/91/33 analyses the diet of yellowfin tuna from long line in the same area.

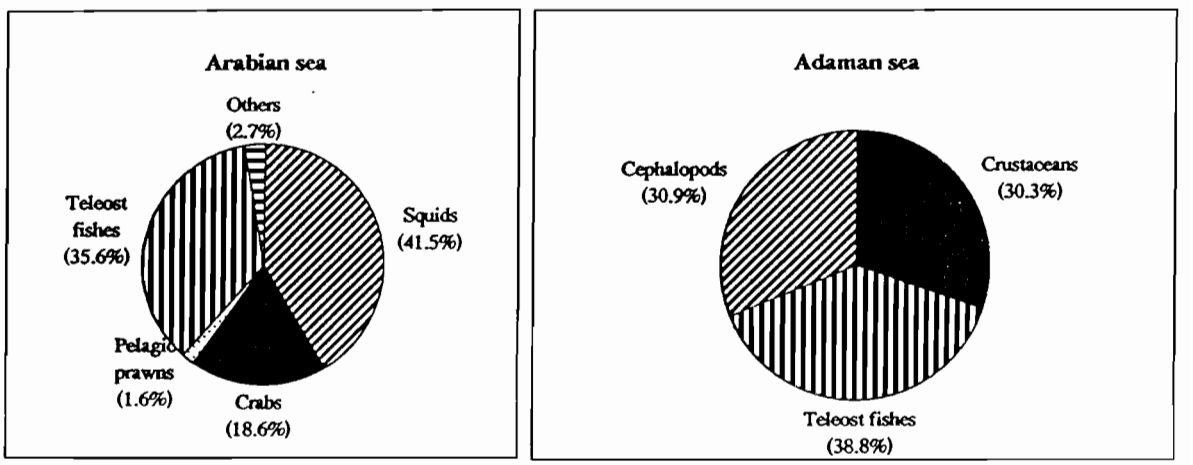


Figure 19: Gut contents of longline yellowfin tuna caught in the Indian Ocean : Arabian sea (left) and Andaman sea (right), from TWS/91/11.

Both documents indicate a significant seasonal change in the prey organisms ingested by yellowfin from the longline fishery: during the winter season (December-January) a large dominance of cephalopods and crabs (Charibdis edwardsi) was observed; on the opposite, during the summer season (April-July) Charibdis edwardsi was rare, and a great number of Auxis sp. were found in the stomachs. These observations are similar to those reported in the eastern Pacific, where the yellowfin tuna diet switches to the red crab Pleuroncodes

planipes during the upwelling season. In the winter season, pelagic fish species long-finned fathead (Cubiceps pauciradiatus) and Japanese anchovy (Engraulis japonicus) were the main objects of tuna diet in surface school (TWS/91/31).

It was observed (TWS/91/31) that stomachs of yellowfin tuna caught by purse-seine around logs are generally empty.

8. CREATION OF CATCH-AT-LENGTH DATA.

Catch at length tables are the basic data needed to run sequential population analysis. The goal is to estimate catch at size by unit of time, which is later converted into catch at age using the growth equation selected. The basic information is found in the length frequency samples relevant to each gear, combined and raised to total catch by area-time stratum. Since all the strata exploited by the fisheries are not sampled for sizes, some substitutions must be carried out, size composition of known strata being used to fill in gaps in the non sampled strata. This step - which is a sensitive one - is generally effected by national scientists who know their fisheries, because criteria and choices must be determined on a realistic basis.

8.1. Longline fisheries.

8.1.1. Japan, Korea and Taiwan.

The Shimizu meeting recognized that there were some differences in average size and size distribution patterns of longline catch between Japan, Korea and Taiwan. In general, Taiwanese catch showed smallest average size, followed by Japanese and Korean with approximately 10 cm difference between nations. While Japanese and Taiwanese data often showed distinct plural modes, Korean data always showed single mode distribution.

At the venue of the meeting, Korean size data were not available in computerized form, and could not be used; complete data will be sent soon to IPTP. Taiwanese monthly size data from 1985 to 1988 have been made available to the IPTP, but were expected to contain some errors since no confirmation was made. Therefore, the Japanese size data were used to create catch-at-size matrices for longline fleets of all three nations, in spite of the differences recognized at the Shimizu meeting.

All catch data were extrapolated on a quarterly basis. While the area strata by 10 x 20 degree were applied for 1975 to 1988, no area consideration was made for years before 1974, as the quarterly catch distribution from Japan - the only fishery then - was already extrapolated to the whole Indian Ocean. The substitution of time-area strata was prepared before the meeting by the NRIFSF scientists according to the rule agreed on at the Shimizu meeting. The substitution was made within the same time strata as long as possible, putting higher priority to substitution from the same latitude than from the same longitude.

Catches for Japan and Korea for 1990 were estimated. Catch-at-size for the last two years (1989 and 1990) were also extrapolated, assuming the same catch-at-size pattern by quarter as in 1988. However, this was done for provisional purposes only and will be substituted when estimates using standard time-area strata become available.

8.1.2. Indonesia

Monthly catches from the Japanese longline fishery during 1953 were used to proportion the Indonesian annual catches. Similarly, length frequencies for the Japanese longline fishery were substituted for all years.

8.1.3. Others

Countries included in this group were Australia, India, Iran, Kenya, Mauritius, Oman, Seychelles and the USSR. Monthly catches for the longline fishery based in Oman during 1990 were used to proportion total catches of this group. Quarterly length frequencies for the Japanese longline fishery were substituted for all years.

8.2. Purse-seine

One of the main characteristics of the purse-seine fishery is the wide range of sizes exploited and the dichotomy of fishing activity between log-associated and free swimming schools. Since the size distribution is quite different in these two types, each sample is clearly identified as a log or free school sample. The sampling unit is the hold on board vessels, holds containing a single set being preferred to those with multiple sets. In any case, sets in each hold had to belong to the same 5 degree -fortnight stratum.

To create the catch at length table, one starts with any 1 degree fortnight catch of a particular school type. All samples of each school type are summed up within 5 degree month strata. At this level, 90 % of the catch from French purse-seiners is already processed. If samples are missing in the fished strata, a second step is initiated: the 5 degree stratum is enlarged by 1 degree steps up to a maximum of 9 degree. If samples are not yet found, one comes back to the initial 5 degree square but search is made into the previous and following fortnight. This latter procedure allows catch at length for additional 8 % of the French catch to be obtained. The remaining catch is processed at a larger range of substitution. The number of fish which constitute the samples selected are extrapolated to the total catch of the strata.

Following the Mauritius preparatory meeting, Spanish samples were checked and compared with French samples. It was found that up to mid-90, these samples had to be rejected as unreliable. Therefore, all the Spanish catch from 1984 to 1989 were processed using the French size data set, using the method described in the preceding paragraph; at the first level, 80% of the Spanish catch

is already processed. For 1990, combined size samples from French and Spanish purse-seiners were used. The validity of such substitution is justified as both fleets operate on the same fishing grounds.

Since the Japanese purse-seiners are only operating on artificial logs, and as an insignificant number of samples were available, the French data relevant to log fishing were used for substitution.

The same situation prevails for Soviet purse-seiners, except that the break down of the catch between log and free schools was only available for 1990, after the introduction of new log books on these vessels by the Seychelles Fishing Authority. From 1987 to 1989, catch at length were obtained from the French samples without taking into account the type of schools. In 1990, the same substitution was carried out, but distinguished between log and free schools.

These results will soon be updated by using samples collected between November and April, from 1986 to 1989. As they were not on a computerized form, they could not be used for this meeting. In any case, the coverage will have to be completed by the French samples for the other months.

The Japanese scientist was asked to send to IPTP any available size samples collected on Japanese purse-seiners. It was also suggested that the few samples from Japanese purse-seiners obtained in Seychelles be compared with those from Mauritian vessels. Actually, it seems that size of YFT caught on artificial logs is smaller than on natural logs; since these two fleets have the same fishing strategy, it could be more relevant to substitute within this specific fishery instead of using the French log samples.

The size sampling intensity was checked by the French scientists. Despite the log/free stratification, it was found that the number of fish measured by 5 degree-fortnight stratum is proportional to the catch, as it should be in reliable sampling.

8.3. Small-scale fisheries.

8.3.1. Maldives

The 1987 length frequencies were substituted for the years 1975 to 1984. The highest number of fish were measured and all months were sampled during this year. In the future, it would be better to use separate eastern and western samples, as they are quite different; catches should also be distinguished.

8.3.2. Sri Lanka.

Length frequencies collected by the National Aquatic Resources Agency (NARA) during 1985 were substituted for the years 1975 to 1984. A handline fishery for yellowfin tuna

associated with porpoise developed along the west coast as from 1986, so length frequencies of recent years contain a relatively high proportion of large fish. The 1985 frequencies most probably better approximate the size compositions of the yellowfin catch of the seventies and early eighties. Monthly landings estimated during 1985 from the NARA sampling programme were used to proportion annual catches.

8.3.3. Others

Countries included in this category were Australia, Comoros, Iran, Mauritius, Mozambique, Oman, Pakistan, Seychelles, Somalia, South Africa, Tanzania and Yemen A.R. The 1989 length frequencies for Oman were substituted for all years. Monthly catches in Oman for 1990 were used to proportion annual catches.

9. STATUS OF STOCK

9.1. Trends of catch-per-unit of fishing effort

The catch-per-unit of fishing effort (CPUE) has been traditionally used as a measure of relative change to all stock abundance. The difficulty with the determination of such an index is in defining effective fishing effort in a way that would result in a linear relationship between CPUE and abundance. The indices presented during the Workshop are reviewed below.

9.1.1. Longline fisheries

Standardized CPUE for the Japanese, Korean and Taiwanese longline fisheries were estimated at the Shimizu meeting using the Honma method. The GLM method was then applied to determine standardized CPUE for the combined longline fisheries; both are shown on Figure 20 from TWS/91/05.

The obtained trends of standardized CPUE are similar. The initial rapid decline with large fluctuations until the mid 70's is characteristic of yellowfin in most tuna longline fisheries. It can be explained by fishing an accumulated stock, and extending fishing grounds to areas of less productivity: such an expansion is likely to significantly overestimate the initial decline in the abundance of age-classes (2.5 to over 5 year old) exploited by the longline fisheries.

The stabilization of CPUE from the mid 70's is also characteristic of many longline fisheries, suggesting that the catches in the corresponding period are sustainable, if CPUE is proportional during that period to the entire abundance of the age-classes exploited by longliners.

The assumption of proportionality between CPUE and abundance was questioned. The sharp increase in the purse-seine catch from 39,000 (1983) to 151,000 (1989) mt was likely to affect the abundance of fish available to longliners. However, longline CPUE

appeared not to be affected by this tremendous increase; possible explanation of this event were discussed.

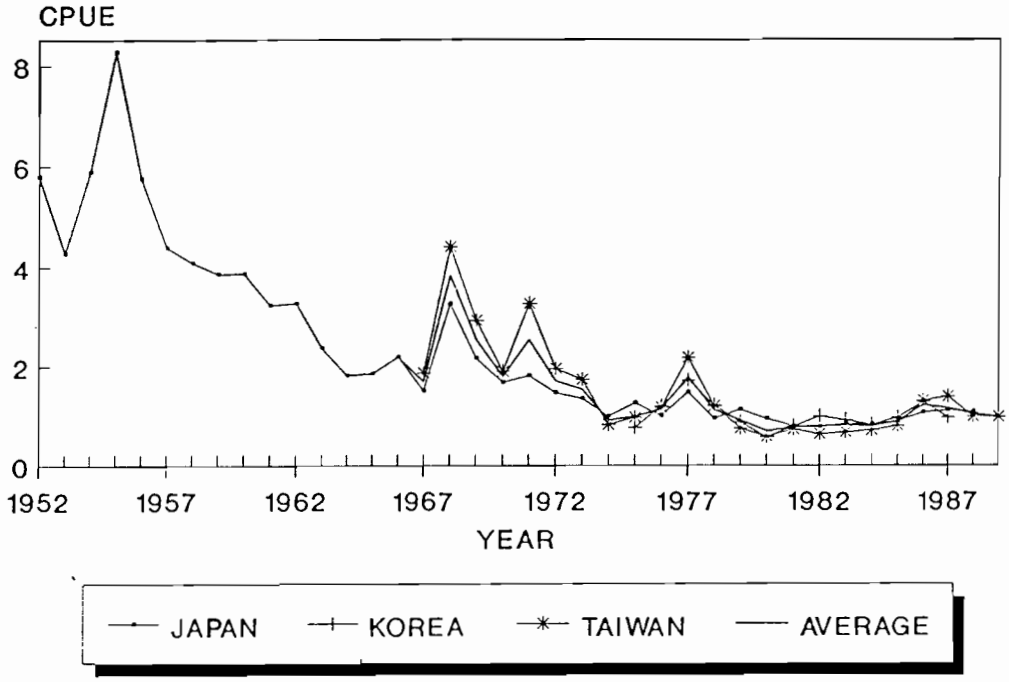


Figure 20: Standardized longline CPUE on yellowfin using Honma's method (Japan, Korea and Taiwan), 1967-89 and the General Linear Model (all fleets), 1975-89 (TWS/91/05)

Four alternative hypothesis were suggested for explaining the trends in standardized CPUE for the longline fisheries:

(1) only a part of the population - which is independent of the abundance of the earlier population - is available to the longline fisheries,
(2) an increased productivity of the stock,
(3) an extremely large population,
(4) a biased measure of fishing effort, or
(5) a combination of the above-mentioned factors.

The significant increase in longline fishing effort throughout the period of the fishery with the flattening annual catch, the five fold increase in the purse-seine annual catch from 1983 to 1989 as well as the lack of impact of the purse-seine fishery on the longline fishery suggested that hypothesis (1) or (3) may be valid. However, the relative likelihood of the four alternative explanations for the stabilization of CPUE was difficult to determine with any certainty, leaving the trend in the abundance of fish older than 2.5 years uncertain for the entire period of fishery operation.

9.1.2. Purse-seine fisheries.

Standardized CPUE for the French purse-seiners since the beginning of substantial operation in 1984 are reported in document TWS/91/18. The number of searching and fishing days (free schools) have been used as measures of fishing effort. In both cases, the CPUE trend was increasing throughout the period of operation of purse-seiners or increasing and, then, stabilizing (Figure 21). The participants concluded that the variability in the data is likely to prevent a statistical distinction between the two hypotheses.

Standardized CPUE for the Spanish purse-seiners are presented in Figure 22; they are similar in general to those of French purse-seiners. The differences between them are likely to be caused by the French purse-seiners targeting more for yellowfin tuna (and especially large ones) than skipjack, as compared to the Spanish purse-seiners.

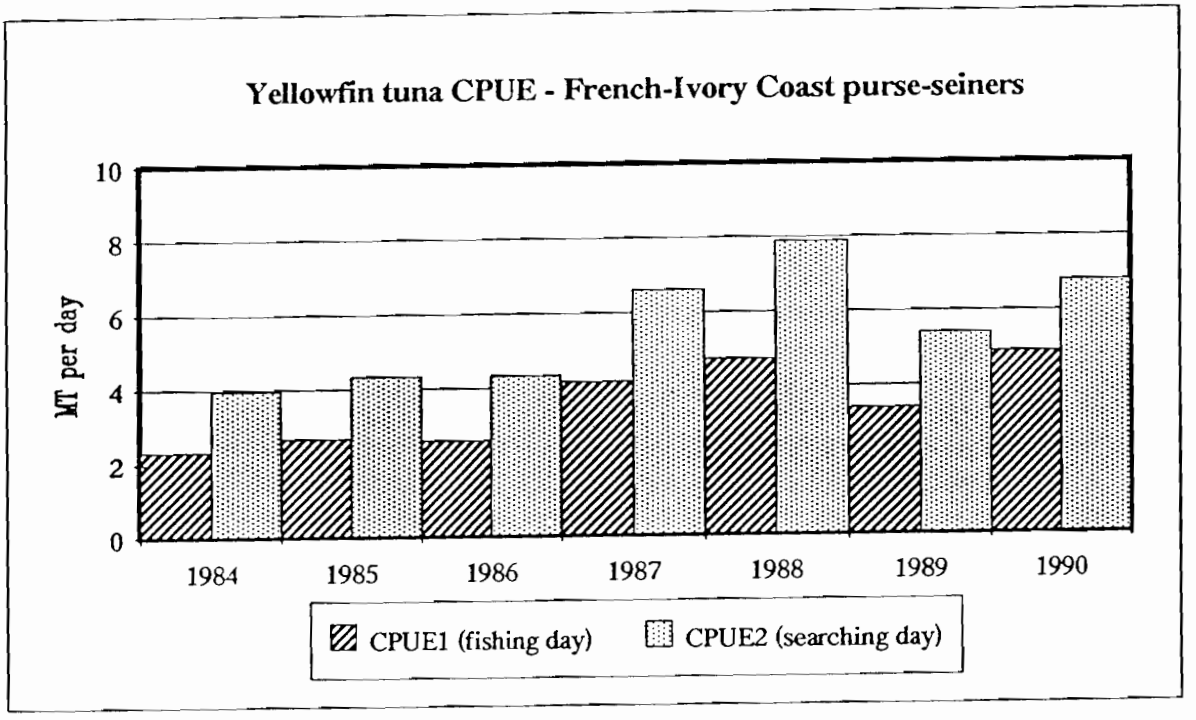


Figure 21: French-Ivory Coast purse-seine yellowfin CPUE (fishing and searching days), 1984-90.

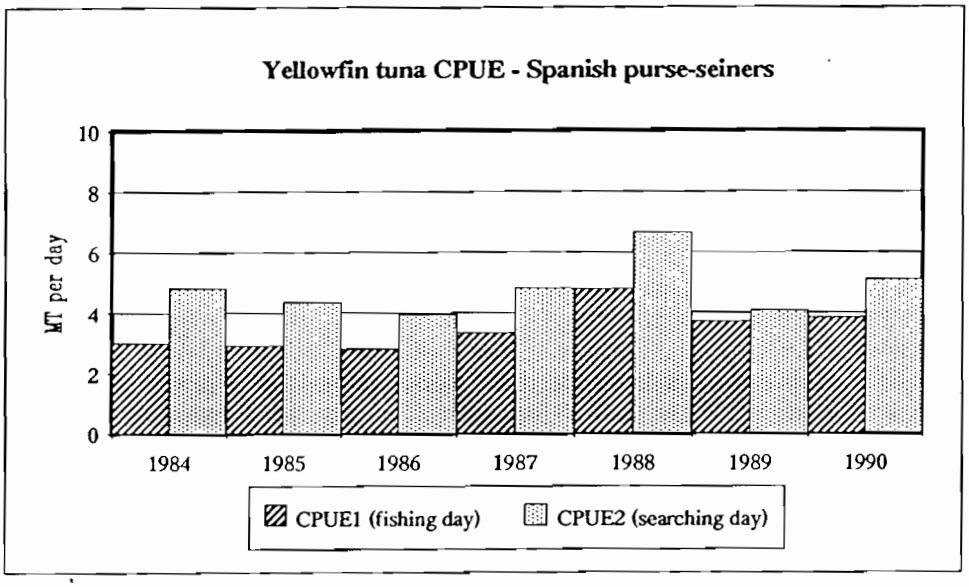


Figure 22: Spanish purse-seiners yellowfin CPUE (fishing and searching days), 1984-90.

The very significant gradual increase in the efficiency of purse-seining throughout the operation of the fishery was pointed out; this phenomenon can be attributed to:

(1) the introduction of sophisticated electronic equipment, including a radar for detecting birds usually associated with tuna schools,
(2) a reduced time of setting nets (resulting in more sets per day) and,
(3) other general ways of increasing fishing power as satellite information, improved nets, use of auxiliary boats, ...

With respect to item (1), the effect of introducing a radar has been examined by performing simulations. Their results, presented during the Workshop, demonstrated that the efficiency of purse-seining (compared with classic scouting using binoculars) might increase from 3 times for high school density up to 9 times for the most commonly occurring low school densities; the non-linearity of this relationship between biomass and efficiency is an important point to be taken in account in future studies.

With respect to item (2), the decreasing of the setting time observed since the beginning of the fishery was used as a corrective factor to the CPUE time series. Though not completely satisfactory, this corrected CPUE integrates at least part of the change in efficiency, and should be preferred to traditional fishing days.

This increased efficiency led the participants to believe that the rise in CPUE may be too small to be consistent with a constant abundance of the age-classes exploited by the purse-seiners (1 to 4 or even 5 year old), which suggests the

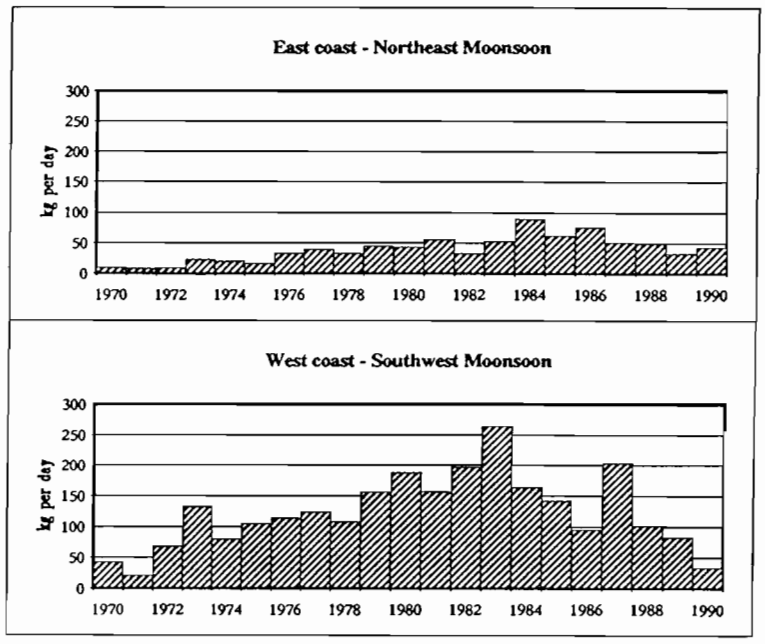


Figure 23: CPUE for the pole and line Maldivian fisheries: East coast during the northeast monsoon (upper) and West coast during the southwest monsoon (lower)

Table 11: Yellowfin tuna catch rates of the artisanal fisheries in Sri Lanka: 3,5 and 11 tons boats.

Boat Type	3.5 tons					11 tons	
Year	Area				CPUE	CPUE	CPUE
	NW	W	SW	S	kg/day	1	2
1967	-	-	-	-	41.8	-	-
1968	-	-	-	-	56.8	70.8	-
1969	-	-	-	-	51.8	-	-
1970	-	-	-	-	52.1	-	-
1971-82	-	-	-	-	-	-	-
1983	51.9	3.3	13.9	16.9	21.5	-	-
1984	56.7	7.1	13.3	14.1	22.7	-	-
1985	77.8	20.6	15.3	22.6	34.1	-	-
1986	50.9	18.2	9.1	19.3	24.4	-	-
1987	36.3	28.7	22.5	-	29.2	44.2	25.5
1988	43.8	28.7	22.4	10	26.2	38.9	20.2
1989	56.1	21.3	25	21.1	28.1	39.2	-
1990	33	17.5	20	14.4	21.3	25.3	-

Source : TWS/91/12 (- means no data)
11 tons boats : 1 = Artisanal fishery, 2 = Exploratory fishing

9.1.4. Conclusions

The analysis of CPUE trends for the above-mentioned fisheries led the participants to the conclusion that the structure and migration of the yellowfin tuna stock may be too complex to allow a simple traditional interpretation of CPUE. This, together with difficulties in determining effective fishing effort for the purse-seine fisheries, leaves trends in the population abundance unknown to a significant extent.

9.2. Relationship between Catch and Effort

Production models were useful in assessing levels of effort and catch for yellowfin tuna in Atlantic and Pacific Ocean. Early analyses of the yellowfin tuna fishery (1952-77, TWS/91/06) fitted production models to catch and effort data of the longline fishery in the Indian Ocean.

9.2.1. Local estimates

Recent investigations were made on catch and effort relationships for the live bait pole-and-line fishery of the Maldives and Lakshadweep, developing "Production function models" that incorporate interactions between boats, as the standard Schaefer and Fox models do not take into account such interactions. Another local analysis on the longline fishery in Indian waters (TWS/9/21) provides an example of techniques used in fitting production models to catch and effort data.

The workshop emphasized, however, that such analyses did not provide meaningful estimates of maximum sustainable yield (MSY) or other indications of total population size: production models should be applied to the entire stock, where immigration and emigration did not influence the biomass available to exploitation.

9.2.2. General considerations

Other limitations and assumptions of production models were discussed. It was particularly mentioned that

(1) productivity is not constant and might vary with environmental conditions: in this situation, production models would give variable estimates of MSY;
(2) production models overlooked important features of the stock, such as age structure; and
(3) effort observations above the optimum fishing effort (f_{opt}) are necessary for an accurate estimation of f_{opt} and MSY.

Considering the recent history of the fishery and its current structure, participants highlighted three specific

limitations of applying production models to the Indian Ocean yellowfin tuna fishery:

(1) it was difficult to obtain a single satisfactory estimate of effective effort because several types of gear were used to fish apparently different components of the yellowfin tuna population;
(2) the available measures of effort probably did not reflect the effective effort in any of the fisheries. For example, technological developments in purse-seining, such as "bird radar", had greatly improved efficiency, yet their affect on catch rates could not be quantified at this stage;
(3) during the late 80's there was a rapid and substantial increase in catches by purse-seine. The yellowfin tuna population was probably not in equilibrium, which may affect the relationship between the abundance index (i.e. CPUE) and effort. Nevertheless, some techniques allows to take in account such situations.

9.2.3. Calculation of the effective effort

The basic principle of the method consists in assuming that any reasonable estimate of abundance index (i.e. CPUE) is significant, and consequently has the same weight, whatever the importance of the fishery. This hypothesis results in the estimation of a standardized abundance index computed as the mean CPUE relatively to a selected "standard" gear; the total "effective" effort is then estimated as the total catch divided by this estimated global abundance index.

Longline catches:

Calculations are detailed in Table 12. For each fleet (Japanese, Korean and Taiwanese), annual CPUE during 1952-90 period was standardized by dividing them by their 1975-87 average (for example, the Japanese standardized CPUE in 1952 is 3.055/0.527 = 5.800). Then, the total effective effort was calculated as the total catch divided by the average adjusted CPUE.

All fleets:

Calculations are detailed in Tables 13 and 14. For five selected fleets (both east and west Maldivian pole-and-line fisheries, French purse-seiners, longline/driftnet fishery of Sri Lanka, and the combined Asiatic longline fishery), the respective raising factors were computed by dividing the mean French purse-seine CPUE (selected as the reference) during the 1984-89 period by their mean CPUE during the same period (Table 13: for example, the raising factor of the Mald-1 fishery is 3.56/130.5 = 0.0273). Next, each individual CPUE was raised by this factor, the standardized CPUE being the average of those five standard CPUE. Finally, the total effective effort was calculated as the total Indian Ocean catch divided by the resulting standardized CPUE.

Year	JAPAN				KOREA				TAIWAN				TOTAL		
	C(J)	U(J)	Us(J)	X(J)	C(K)	U(K)	Us(K)	X(K)	C(T)	U(T)	Us(T)	X(T)	Ctot	Uadj	Xtot
1952	8.9	3.06	5.80	1.5	0.0	0.00	0.00	0.0	0.0	0.00	0.00	0.0	8.86	5.80	1.5
1953	13.3	2.25	4.28	3.1	0.0	0.00	0.00	0.0	0.0	0.00	0.00	0.0	13.26	4.28	3.1
1954	24.9	3.11	5.90	4.2	0.0	0.00	0.00	0.0	0.2	0.00	0.00	0.0	25.09	5.90	4.3
1955	46.5	4.35	8.26	5.6	0.0	0.00	0.00	0.0	0.7	0.00	0.00	0.0	47.15	8.26	5.7
1956	64.4	3.03	5.75	11.2	0.0	0.00	0.00	0.0	1.1	0.00	0.00	0.0	65.49	5.75	11.4
1957	36.0	2.31	4.38	8.2	0.0	0.00	0.00	0.0	1.3	0.00	0.00	0.0	37.34	4.38	8.5
1958	25.7	2.15	4.08	6.3	0.0	0.00	0.00	0.0	1.8	0.00	0.00	0.0	27.61	4.08	6.8
1959	24.4	2.03	3.86	6.3	0.0	0.00	0.00	0.0	2.4	0.00	0.00	0.0	26.87	3.86	7.0
1960	40.3	2.04	3.87	10.4	0.0	0.00	0.00	0.0	2.2	0.00	0.00	0.0	42.60	3.87	11.0
1961	34.6	1.70	3.23	10.7	0.0	0.00	0.00	0.0	2.9	0.00	0.00	0.0	37.50	3.23	11.6
1962	51.7	1.72	3.27	15.8	0.0	0.00	0.00	0.0	3.5	0.00	0.00	0.0	55.20	3.27	16.9
1963	25.9	1.25	2.37	10.9	0.0	0.00	0.00	0.0	3.4	0.00	0.00	0.0	29.46	2.37	12.4
1964	24.8	0.95	1.81	13.7	0.0	0.00	0.00	0.0	2.9	0.00	0.00	0.0	27.99	1.81	15.5
1965	27.6	0.97	1.85	14.9	0.0	0.00	0.00	0.0	2.2	0.00	0.00	0.0	30.74	1.85	16.7
1966	44.1	1.15	2.18	20.2	0.1	0.00	0.00	0.0	4.4	0.00	0.00	0.0	51.25	2.18	23.5
1967	31.6	0.79	1.51	21.0	0.2	0.00	0.00	0.0	3.4	0.72	1.85	1.8	38.38	1.68	22.8
1968	50.5	1.72	3.26	15.5	4.0	0.00	0.00	0.0	22.7	1.70	4.40	5.1	79.91	3.83	20.9
1969	25.2	1.14	2.15	11.7	6.0	0.00	0.00	0.0	21.2	1.13	2.92	7.2	54.09	2.54	21.3
1970	14.5	0.88	1.67	8.7	7.0	0.00	0.00	0.0	11.1	0.73	1.89	5.9	34.68	1.78	19.5
1971	13.5	0.95	1.81	7.5	6.5	0.00	0.00	0.0	16.4	1.26	3.25	5.0	37.97	2.53	15.0
1972	8.8	0.77	1.46	6.0	9.6	0.00	0.00	0.0	8.9	0.75	1.94	4.6	28.99	1.70	17.0
1973	3.4	0.71	1.34	2.5	9.1	0.00	0.00	0.0	4.3	0.67	1.73	2.5	17.84	1.53	11.6
1974	4.4	0.52	0.99	4.4	11.6	0.00	0.00	0.0	3.3	0.32	0.82	4.0	19.92	0.91	22.0
1975	4.7	0.66	1.25	3.8	11.7	0.36	0.76	15.4	3.5	0.37	0.96	3.6	20.12	0.99	20.3
1976	2.7	0.52	0.99	2.8	12.8	0.57	1.20	10.7	2.5	0.45	1.16	2.2	19.18	1.12	17.2
1977	2.1	0.77	1.46	1.4	31.4	0.82	1.71	18.4	6.1	0.84	2.16	2.8	40.94	1.78	23.0
1978	4.0	0.50	0.94	4.3	25.2	0.58	1.21	20.8	3.2	0.46	1.19	2.7	33.86	1.11	30.4
1979	2.0	0.59	1.12	1.8	17.8	0.42	0.87	20.5	2.8	0.29	0.74	3.7	24.22	0.91	26.6
1980	3.3	0.49	0.93	3.5	12.8	0.27	0.56	22.6	2.9	0.22	0.57	5.0	20.79	0.69	30.2
1981	4.7	0.42	0.79	5.9	11.8	0.38	0.78	15.0	3.1	0.28	0.72	4.2	21.67	0.77	28.3
1982	6.4	0.41	0.77	8.2	18.7	0.47	0.99	18.9	3.5	0.24	0.63	5.6	30.78	0.80	38.6
1983	7.0	0.45	0.84	8.3	15.3	0.44	0.92	16.7	4.2	0.26	0.67	6.2	28.18	0.81	34.7
1984	7.5	0.44	0.83	9.0	9.9	0.39	0.82	12.1	4.4	0.27	0.71	6.2	23.76	0.78	30.3
1985	9.3	0.47	0.88	10.5	12.0	0.46	0.96	12.5	5.1	0.31	0.80	6.5	28.23	0.88	32.1
1986	11.0	0.56	1.06	10.3	14.9	0.61	1.27	11.7	12.1	0.50	1.30	9.3	40.05	1.21	33.0
1987	7.6	0.58	1.11	6.8	12.6	0.46	0.96	13.1	16.0	0.53	1.38	11.6	38.78	1.15	33.8
1988	8.6	0.57	1.08	7.9	13.4	0.00	0.00	0.0	14.4	0.38	0.98	14.7	39.09	1.03	38.0
1989	3.6	0.00	0.00	0.0	8.1	0.00	0.00	0.0	13.3	0.38	0.97	13.6	36.09	0.97	37.1
1975-87		0.53				0.48				0.39					

Individual Fisheries (i):

C(i) = Catch (1,000 MT); U(i) = annual CPUE; Us(i) = standardised annual CPUE (period 75-87); X(i) = effective effort (C/Ustd).

Total (tot):

Ctot = Total yellowfin catch in the Indian Ocean; Uadj = adjusted mean standardised CPUE; Xtot = total effective effort (Ctot/Uadj).

Table 12: Standardization of Japanese, Korean and Taiwanese longline CPUE and estimation of the total longline effective effort, 1952-89.

Table 13: Raising factors calculated for five selected fleets (both East and West coast Maldivian pole-and-line fisheries, French purse-seiners, longline/driftnet fishery of Sri Lanka, and the combined Asiatic longline fishery), 1981-90.

Year	Maldives-W		Maldives-E		France		Sri-Lanka		Longline		Total
	U	Ustd	U	Ustd	U	Ustd	U	Ustd	U	Ustd	Uadj
1977									1.78	6.31	6.31
1978									1.11	3.94	3.94
1979									0.91	3.23	3.23
1980									0.69	2.45	2.45
1981	157.80	4.30	55.30	3.35					0.77	2.73	3.46
1982	169.90	4.63	32.60	1.98					0.80	2.84	3.15
1983	263.90	7.20	51.40	3.12			21.50	2.79	0.81	2.87	3.99
1984	162.30	4.43	87.70	5.32	3.35	3.35	22.70	2.94	0.78	2.77	3.76
1985	142.20	3.88	60.20	3.65	2.54	2.54	34.10	4.42	0.88	3.12	3.52
1986	94.30	2.57	73.30	4.44	2.90	2.90	24.40	3.16	1.21	4.29	3.47
1987	201.10	5.48	49.40	2.99	4.18	4.18	29.20	3.79	1.15	4.08	4.10
1988	100.60	2.74	47.60	2.89	4.83	4.83	26.20	3.40	1.03	3.65	3.50
1989	82.50	2.25	34.00	2.06	3.55	3.55	28.10	3.64	0.97	3.44	2.99
1990	49.70	1.36	42.40	2.57	4.11	4.11	21.30	2.76			2.70
84-89	130.50		58.70		3.56		27.45		1.00		
RF	0.027		0.061		1.000		0.130		3.547		

U = annual CPUE for each fishery
Ustd = standardised CPUE (period 1984-89) for each fishery
Uadj = Adjusted mean standardised CPUE

9.2.4. Results

Longline catches

Standardized CPUE of the longline fleets plotted against year (Figure 20) and yellowfin tuna catch plotted against effective effort (Figure 24) provide graphical representations of trends in the longline fishery; because of the problems outlined above, a yield curve was not fitted to the data.

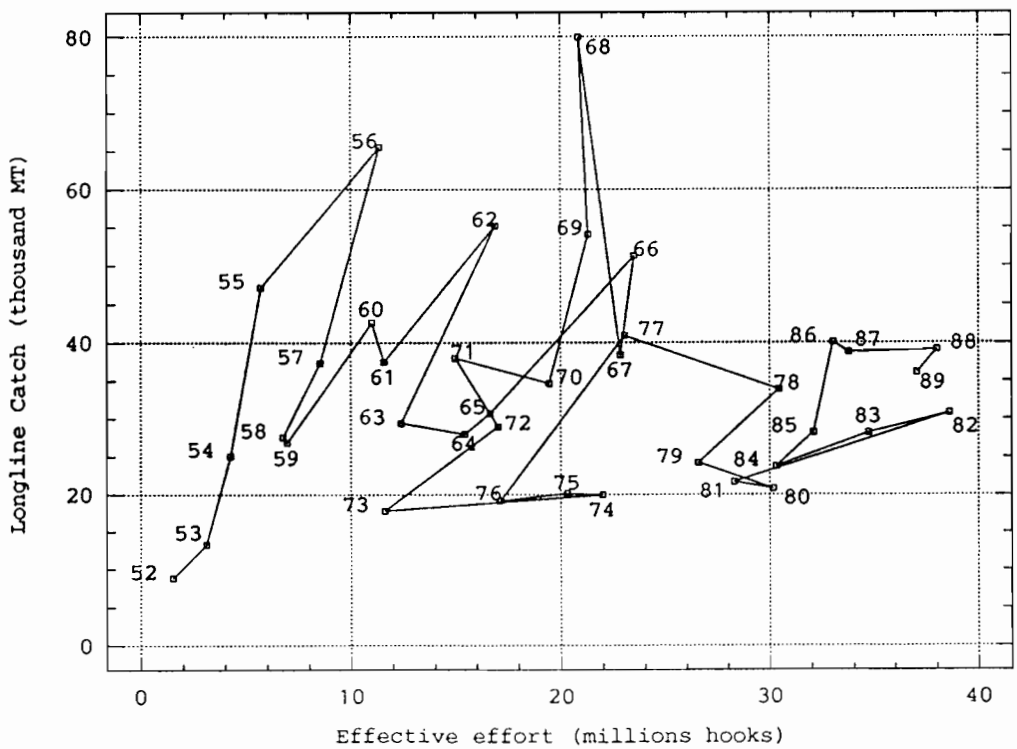


Figure 24: Relationship between yellowfin catch and standardized effort (see text) in the longline fishery, from 1952 to 1989.

Table 14: Standardized CPUE for five selected fleets (both East and West coast Maldivian pole-and-line fisheries, French purse-seiners, longline/driftnet fishery of Sri Lanka, and the combined Asiatic longline fishery) and estimation of the total Indian Ocean effective effort, 1952-91.

	Standardised CPUE					Total Indian Ocean		
Year	Mald-W	Mald-E	France	Sri-Lanka	Longline	Uadj	Ctot	Xtot
52					20.60	20.60	14.7	0.7
53					15.20	15.20	18.7	1.2
54					20.95	20.95	31.6	1.5
55					29.34	29.34	54.5	1.9
56					20.44	20.44	74.5	3.6
57					15.55	15.55	48.8	3.1
58					14.50	14.50	37.1	2.6
59					13.71	13.71	36.8	2.7
60					13.73	13.73	52.8	3.8
61					11.48	11.48	48.6	4.2
62					11.60	11.60	66.4	5.7
63					8.42	8.42	47.0	5.6
64					6.43	6.43	40.9	6.4
65					6.55	6.55	42.7	6.5
66					7.75	7.75	65.1	8.4
67					5.97	5.97	54.7	9.2
68					13.61	13.61	98.7	7.3
69					9.02	9.02	68.5	7.6
70					6.33	6.33	48.4	7.6
71					8.99	8.99	49.3	5.5
72					6.04	6.04	43.8	7.3
73					5.45	5.45	35.1	6.4
74					3.22	3.22	36.9	11.5
75					3.52	3.52	37.6	10.7
76					3.97	3.97	38.5	9.7
77					6.32	6.32	59.2	9.4
78					3.94	3.94	49.8	12.6
79					3.23	3.23	43.8	13.5
80					2.45	2.45	39.3	16.0
81	4.30	3.35			2.74	3.46	43.4	12.5
82	4.63	1.98			2.84	3.15	53.5	17.0
83	7.20	3.12		2.79	2.88	3.99	66.5	16.6
84	4.43	5.32	3.35	2.94	2.77	3.76	104.7	27.8
85	3.88	3.65	2.54	4.42	3.13	3.52	113.0	32.1
86	2.57	4.44	2.90	3.16	4.30	3.48	127.7	36.7
87	5.48	2.99	4.18	3.79	4.09	4.11	130.8	31.9
88	2.74	2.89	4.83	3.40	3.66	3.50	187.8	53.6
89	2.25	2.06	3.55	3.64	3.41	2.98	171.6	57.5
90	1.36	2.57	4.11	2.76		2.70	188.1	69.7

Uadj = Mean adjusted standardised CPUE (MT/standard searching day of FIS purse-seine)
Ctot = Total Indian Ocean yellowfin tuna catch (1,000 MT)
Xtot = Total effective effort in the Indian Ocean (1,000 FIS purse-seine standard searching days)

Longline effort has progressively increased throughout the history of the fishery: during 1952-74, both effort and catch increased significantly while CPUE declined greatly; then, during the 80's catches were less variable and, notably, did not decline during the late 80's following the spectacular growth of the purse-seine fishery and further expansion in longline effort.

According to Figure 24, the workshop concluded that large increases in longline effort above current levels would probably not significantly increase catch.

All catches

Standardized yellowfin tuna CPUE in five selected significant fisheries (the longline/driftnet fishery of Sri Lanka, the French purse-seiners, the combined Asiatic longline fishery and the two east and west Maldivian pole-and-line fisheries), as well as their mean resulting composite CPUE are presented in Figure 25.

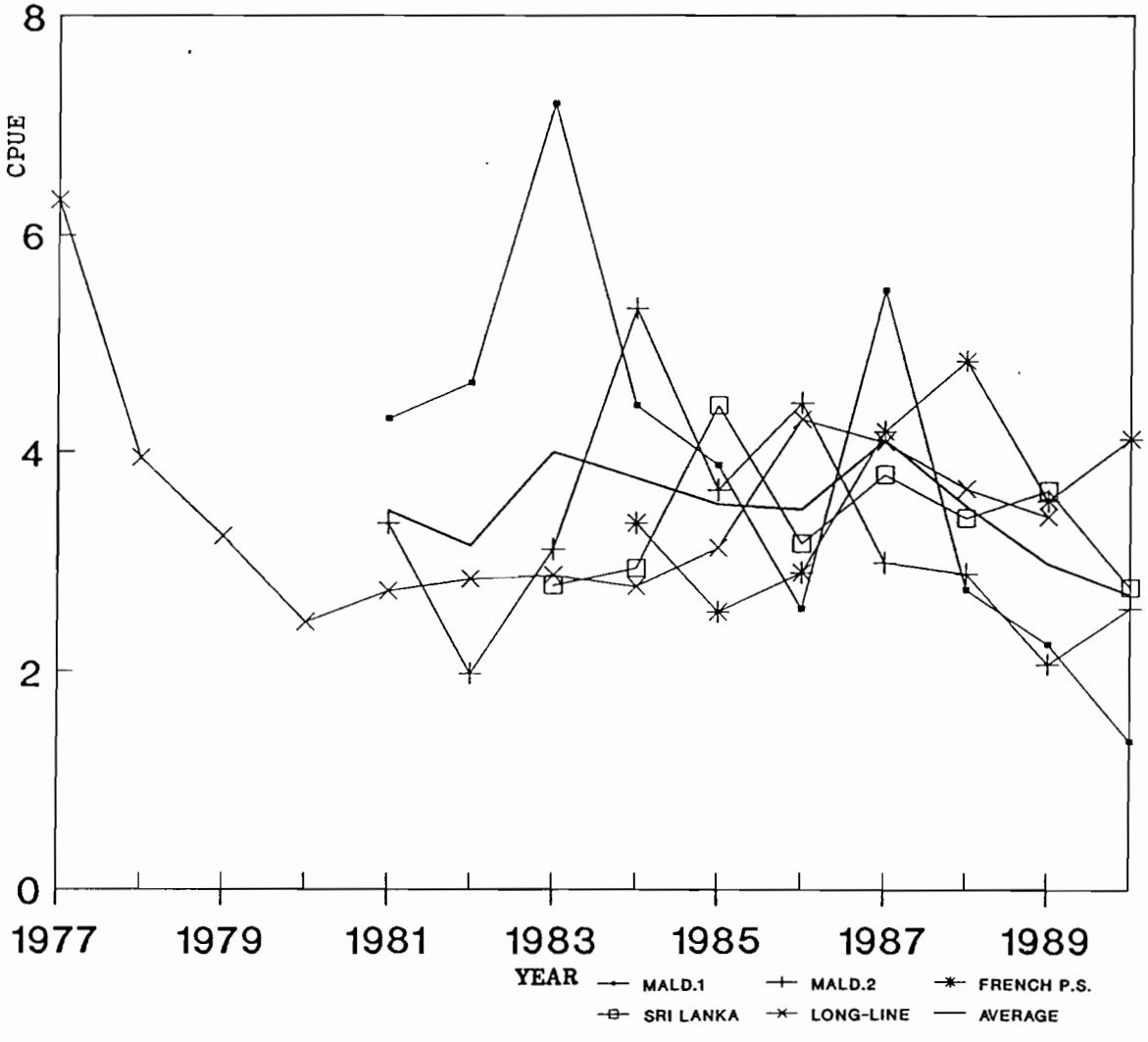


Figure 25: Standardized yellowfin tuna CPUE (abundance indices) in five selected fisheries, and mean composite standardized CPUE.

The abundance indices show wide variance between these five fisheries, but no trend is apparent in the data. When combined (Figure 26) the indices show small catch and very high CPUE in early years when the fishery was dominated by longline. Apparent abundance declined and then stabilized, as effort and catches grew due to further development of longlining and, later, the growth in purse seining.

Participants suggested that the apparent absence of a decline in longline catches and CPUE during the late 80's (Figures 20 and 24) might indicate that:

(1) environmental conditions have a significant positive effect on availability or abundance,
(2) the measures of effective effort or abundance were poor, or
(3) longline and purse-seine are exploiting two mostly independent components of the adult stock.

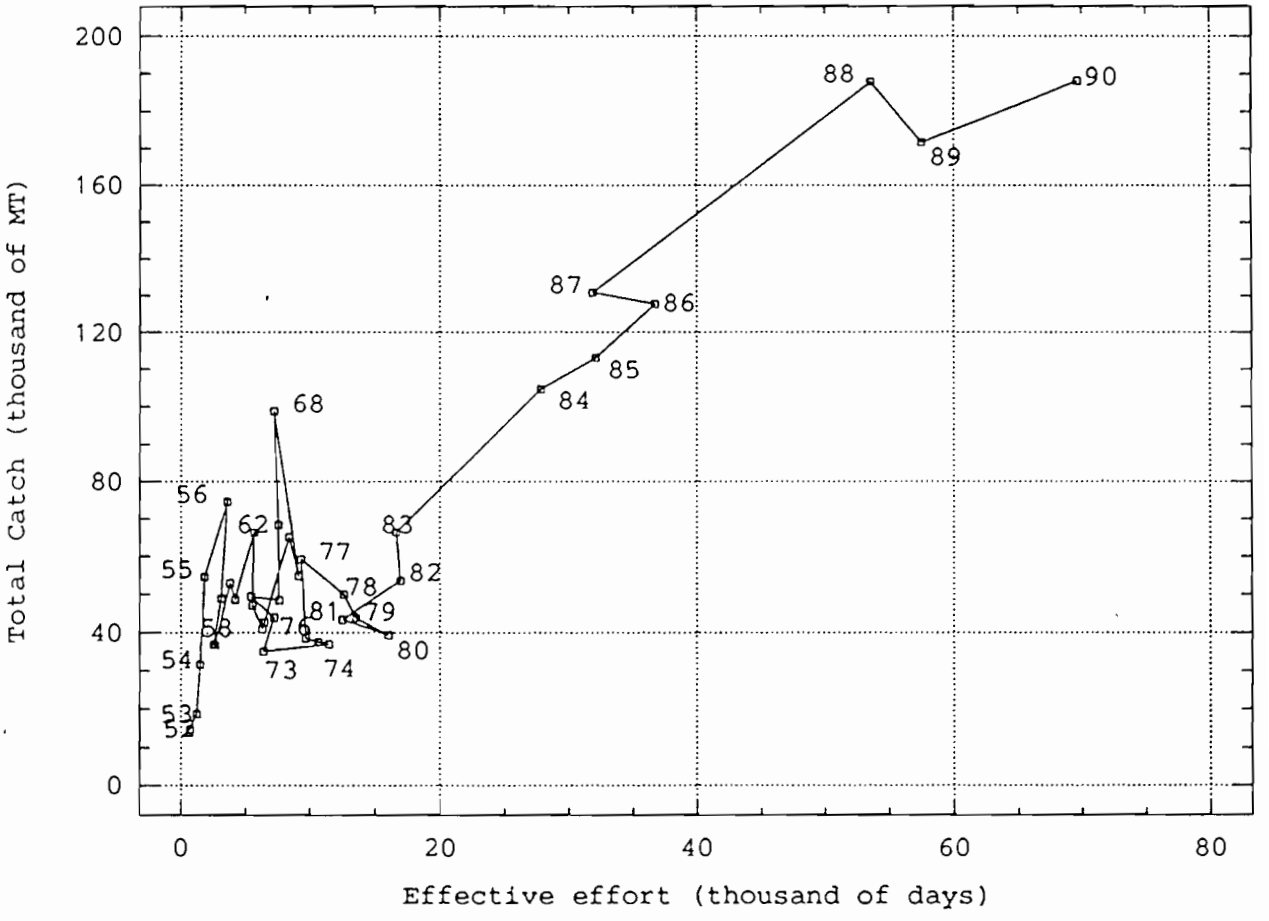


Figure 26: Relationship between yellowfin catch and standardized effort (see text) in the whole Indian Ocean fishery, from 1952 to 1990.

9.3. Catch at age table: calculation and discussion of trends

According to the discussion on growth (Chapter 7.2) the participants agreed to accept different growth curve hypothesis. Therefore, two catch at age tables have been calculated: one with a slow growth rate for juveniles, which is completely based on the French purse-seine data (TWS/91/17), the other with a faster growth rate for juvenile based on Sri Lanka size data for small fish and on Japanese longline data for larger yellowfin (TWS/91/09).

Both catch at age tables were calculated using the corresponding slicing tables coming from these two growth curves (Tables 15). Tables 16 and 17 give from 1952 to 1990 and by quarter the estimated number of yellowfin tuna caught by the whole fishery, in thousands of fish.

However the breaking down of these catch at age by gears is available on computer. Six gears were used:

* longline as a whole
* purse-seine log-associated school
* purse-seine free swimming school
* artisanal Maldives fisheries
* artisanal Sri Lanka fisheries
* all other artisanal fisheries in one group called "Oman type" fishery.

Table 15: "Slicing" tables (i.e. monthly sizes limits between successive ages, in cm LF) used to build the catch at age tables under both slow and fast growth hypotheses for juvenile yellowfin tuna.

Month	A: Slow Growth						A: Fast Growth					
	Length at Age						Length at Age					
	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5+	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5+
1		44-63	64-108	109-137	138-153	154-200		47-83	84-116	117-136	137-150	151-200
2		46-65	66-112	113-139	140-155	156-200		50-86	87-118	119-138	139-151	152-200
3		46-69	70-115	116-141	142-155	156-200		53-89	90-119	120-139	140-152	153-200
4		48-73	74-118	119-143	144-157	158-200		56-92	93-123	124-140	141-153	154-200
5		50-77	78-121	122-145	146-157	158-200		59-95	96-124	125-141	142-154	155-200
6	30-49	50-81	82-123	124-145	146-159	160-200	25-61	62-98	99-125	126-142	143-155	156-200
7	30-51	52-85	86-125	126-147	148-159	160-200	28-64	65-101	102-126	127-143	144-155	156-200
8	30-53	54-89	90-127	128-147	148-161	162-200	32-68	69-103	104-128	129-145	146-156	157-200
9	30-55	56-93	94-129	130-149	150-161	162-200	35-71	72-106	107-129	130-146	147-156	157-200
10	30-57	58-97	98-131	132-151	152-163	164-200	38-74	75-107	108-131	132-147	148-157	158-200
11	30-59	60-101	102-133	134-151	152-163	164-200	41-77	78-110	111-133	134-148	149-157	158-200
12	30-61	62-105	106-135	136-153	154-165	166-200	44-80	81-113	114-134	135-149	150-158	159-200

Data from the two tables are presented on Figure 27 for each of the 6 age groups (0-5) and both sets of data (fast and slow growth curves), showing results as could be expected: fast growth results in greater number for both younger (age 0) and older (age 4-5) fishes and, contrarily, lower number for intermediate ages (1-3), differences being low for ages 3 and 4.

This observation for age 5 may partly result from a slightly higher $L_{infinity}$ in the fast growth curve, based on longline data instead of purse-seine data. However, differences at all age remain, most of the time, minimal except for age 2 group.

Overall each age group show an important increase in the number of yellowfin caught starting at the beginning of the eighties. This is a direct consequence of the development of the purse-seine fishery, a very efficient fishing method whose catch covered the entire spectrum of sizes, from 40 to 170 cm FL. Artisanal fisheries are also partly responsible for this increase, especially for age groups 0 to 2 (for instance the recent important development of the Oman fishery on yellowfin tuna).

9.4. Estimates of population sizes and fishing mortality trends using Sequential Population Analysis

Sequential Population Analysis (SPA) is a powerful method commonly used to estimate population sizes and manage fisheries. This method, which rely on the availability of catch at age data, assume that some parameters (as natural mortality) are known, and needs a set of hypotheses to calibrate the fishing mortalities.

9.4.1. Tuning of the SPA

Consequently to the discussions held on indices of abundance trends, the Workshop decided not to use the traditional tuning of SPA, no acceptable indices being available. Nevertheless, it was decided to try to find a reasonable range of population sizes and exploitation rates, in order to evaluate the possible fishery and stock trends. In that aim, the following parameters and hypothesis were retained:

Growth: according to previous discussions (see 7.2 and 9.3), the catch by age matrix corresponding to the slow juvenile growth hypothesis (Table 16) was retained.

Natural mortality (M): as new estimates presented were consistent with results obtained on other yellowfin tuna stocks, the "traditional" value M=0.6 on an annual basis was taken for this first analysis, although it was stressed than an age vector (as developed in the Atlantic Ocean, see 6.7) may be more realistic.

Recruitment: as tuning the SPA was not possible, it was decided to run the analysis from a set of "credible" recruitments.

In a first step, minimal recruitment required to support the historical fishery was examined, using a backward cohort analysis and assuming a high fishing mortality (.40) at all terminal age. This analysis (Table 18) showed that a level of some 40-50 millions of recruits was necessary to explain the observed catch. It also resulted in a regular and strong increasing of estimated recruitment; as recruitment could not have increased in such a way during this time, the Workshop retained the hypothesis of a constant recruitment during the period 1952-90, even though it was recognized that some fluctuations (for example linked to oceanographical events such as the ENSO phenomenon) certainly occurred, but without any noticeable trend.

In a second step, it was decided to evaluate a range of reasonable recruitments. In that purpose, a set of VPA - assuming recruitments from 20 to 200 millions of fishes - was run, and the corresponding fishing mortalities (ages .5 to 5 years) were calculated for all cohorts born from 70 to 86 (Table 19). Examining these results, the value of 60 millions of fishes was retained as an example of low recruitment, and a doubling of this value considered as a reasonable example of high stock estimate.

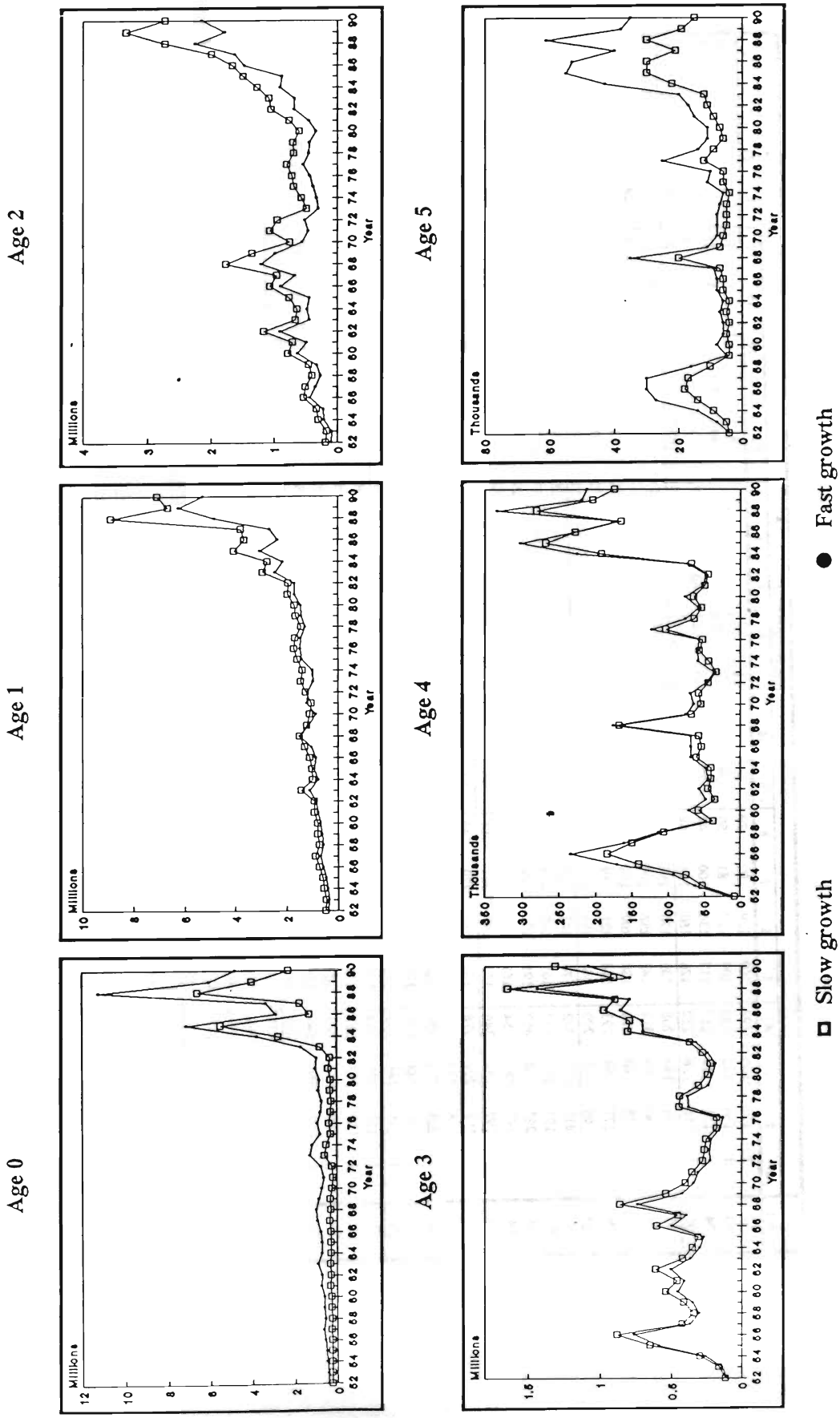
Table 16: Catch at age table of yellowfin tuna caught by all fisheries, in thousands of fish slow growth hypothesis, 1952-90.

Year	Age (by quarter)																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
52	1	90	37	109	71	137	150	121	64	51	21	56	9	3	11	91	1	1	1	5	1	1	1	1
53	1	90	37	110	72	132	144	125	68	45	11	47	69	26	10	57	38	4	2	9	2	1	1	1
54	1	90	38	119	74	158	177	138	85	78	52	85	49	107	83	57	32	27	12	4	6	1	1	1
55	1	90	38	120	75	171	194	163	103	80	29	119	174	244	117	117	79	40	11	11	11	1	1	1
56	1	91	39	128	77	206	238	204	133	137	95	169	322	267	175	118	116	42	15	11	15	1	1	1
57	1	91	39	132	79	245	288	263	160	150	79	116	176	148	44	58	113	32	2	3	14	1	1	1
58	1	90	38	125	76	209	241	208	135	143	39	85	150	134	11	46	83	19	1	3	7	1	1	1
59	1	100	43	140	85	226	261	230	138	149	64	100	158	170	41	45	25	6	2	5	1	1	1	1
60	1	95	40	133	81	224	260	233	208	278	83	213	232	184	63	62	33	10	6	9	1	1	1	1
61	1	118	50	167	100	257	311	265	160	145	161	241	195	107	32	125	25	4	2	5	2	1	1	1
62	1	100	44	154	89	260	325	263	212	293	300	350	307	121	71	111	32	4	7	2	1	1	1	1
63	1	101	46	178	97	395	474	465	229	202	90	147	212	106	32	69	31	6	1	3	2	1	1	1
64	1	100	44	152	90	284	338	293	180	181	157	122	130	107	61	50	32	6	1	2	1	1	1	1
65	1	100	44	156	90	276	338	308	157	207	193	201	152	90	36	32	53	4	2	2	3	1	1	1
66	1	92	41	153	85	305	376	334	261	311	210	278	288	127	77	112	39	7	3	5	3	1	1	1
67	1	106	48	188	102	370	451	387	291	274	169	218	236	152	33	37	42	11	1	4	4	1	1	1
68	1	84	41	182	92	425	529	464	435	647	379	294	487	233	69	72	139	20	3	6	17	1	1	1
69	1	106	48	173	98	343	425	346	404	328	299	315	321	107	56	57	56	7	3	2	4	1	1	1
70	1	69	62	112	84	277	413	329	183	171	223	178	173	93	83	51	39	9	4	3	3	1	1	1
71	1	47	33	104	55	244	432	300	185	391	281	200	182	96	54	23	42	11	3	2	2	1	1	1
72	1	68	80	94	84	320	520	331	221	321	246	159	179	52	19	27	38	4	1	2	2	1	1	1
73	1	167	163	256	200	346	590	313	213	126	83	69	110	65	30	62	27	3	1	3	2	1	1	1
74	1	131	114	273	130	354	536	377	182	165	87	132	110	56	32	55	30	7	3	4	1	1	1	1
75	20	129	62	77	352	377	463	398	211	193	133	156	80	48	34	19	36	14	4	3	3	1	1	1
76	25	96	73	178	410	368	494	454	242	214	156	102	87	40	22	30	28	8	5	12	3	1	1	1
77	39	75	62	111	505	318	421	424	269	200	194	130	98	88	90	167	34	21	24	25	6	3	2	1
78	27	62	56	138	397	288	369	379	218	156	116	203	243	95	30	74	42	12	4	6	6	1	1	1
79	21	124	67	122	355	383	454	473	241	199	153	109	151	79	35	41	31	12	3	8	3	1	1	1
80	28	99	72	105	438	367	458	431	220	171	129	83	105	69	31	39	42	9	6	8	4	1	1	1
81	40	136	68	168	560	429	479	494	265	184	170	141	86	57	30	48	25	11	7	7	4	3	1	1
82	21	52	79	172	473	389	542	531	297	279	212	256	120	59	31	69	28	6	3	8	8	1	1	1
83	33	243	185	341	800	681	685	757	343	274	201	257	140	94	62	72	42	8	6	12	9	1	1	1
84	53	197	636	1866	861	485	707	713	416	331	218	301	328	163	121	193	89	47	30	26	11	7	1	3
85	47	37	1361	4033	1071	872	1373	730	559	253	336	336	402	221	110	62	174	76	12	6	19	9	1	1
86	78	85	504	629	744	756	1232	921	495	356	432	371	596	167	137	71	193	19	12	5	25	3	1	1
87	47	270	601	843	533	779	1357	1131	542	483	500	459	525	113	147	113	129	7	6	23	14	1	1	5
88	150	141	2537	3756	2172	1813	2813	2069	788	721	622	600	759	463	169	252	165	80	13	22	18	8	3	1
89	6	357	1463	2180	1719	1746	1395	1793	1251	1064	457	558	588	140	60	117	165	23	4	13	14	3	1	1
90	18	86	825	1360	2411	1029	1571	2048	864	630	442	789	593	273	220	224	87	43	33	12	7	4	3	1

Table 17: Catch at age table of yellowfin tuna caught by all fisheries, in thousands of fish: fast growth hypothesis, 1952-90.

	Age (by quarter)																							
AN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
52	1	138	106	194	109	129	92	39	28	11	11	54	7	3	9	83	1	1	1	13	1	1	1	1
53	1	140	108	190	109	117	81	50	36	10	4	43	63	20	8	49	36	9	3	15	4	1	1	2
54	1	151	125	217	117	136	100	44	47	45	45	82	43	90	73	53	30	36	19	8	9	3	1	1
55	1	152	128	232	126	160	116	64	61	38	21	106	162	217	104	105	73	56	19	23	21	4	1	1
56	1	161	144	268	135	198	152	80	103	96	84	152	285	222	151	104	118	62	30	24	23	4	2	1
57	1	166	154	312	147	252	199	91	108	78	57	108	158	124	37	52	106	42	4	9	24	4	1	1
58	1	158	140	270	138	209	158	70	86	85	21	77	134	116	10	43	80	27	1	6	13	1	1	1
59	1	177	158	293	144	221	169	92	107	95	44	85	128	148	35	40	26	9	4	9	2	1	1	1
60	1	168	150	290	144	254	176	104	184	196	65	184	191	156	51	57	33	16	9	13	3	1	2	2
61	1	211	188	342	176	243	235	126	108	77	103	204	168	94	28	118	27	7	2	12	3	1	1	1
62	1	194	186	330	161	245	313	147	204	235	177	290	239	98	61	107	34	7	10	6	3	1	1	1
63	1	223	238	457	191	371	328	214	165	114	47	119	181	92	29	65	29	9	1	6	4	1	1	1
64	1	192	185	354	161	267	232	105	130	116	128	109	108	91	52	48	33	9	3	4	3	1	1	1
65	1	197	191	346	166	289	283	181	96	105	104	138	134	76	31	31	53	10	3	3	5	1	1	1
66	1	192	207	378	162	290	270	146	253	242	159	242	218	107	65	104	39	10	7	13	5	1	1	1
67	1	236	250	449	214	353	316	161	212	173	106	183	201	131	28	34	42	19	3	5	6	1	1	1
68	1	228	272	491	246	543	482	210	333	421	205	239	429	186	55	68	130	30	7	9	32	1	1	1
69	1	218	224	404	191	382	420	166	390	194	137	264	239	85	45	55	55	12	5	4	8	1	1	1
70	1	151	248	332	168	271	287	135	124	104	173	153	147	78	68	48	37	14	9	5	5	1	1	1
71	1	112	226	289	147	454	409	205	114	123	115	110	159	81	48	21	41	19	6	4	5	1	1	1
72	1	159	303	317	179	427	446	144	162	130	99	123	143	42	16	25	36	6	2	4	5	1	1	1
73	1	295	500	482	308	298	281	93	128	53	57	62	87	56	28	59	25	5	2	5	4	1	1	1
74	1	248	386	540	226	343	302	125	98	62	51	117	98	48	28	46	29	12	5	13	3	1	1	1
75	20	225	260	286	473	383	336	223	100	95	67	123	71	40	28	17	32	17	7	4	7	2	1	1
76	25	190	301	421	530	373	340	232	146	117	86	82	63	33	15	26	25	13	7	13	5	1	1	3
77	39	152	248	346	642	320	296	203	146	129	145	117	84	72	71	149	28	28	28	39	12	4	4	5
78	27	133	216	349	502	294	275	199	142	83	54	173	214	79	25	68	37	25	5	10	11	1	1	1
79	21	215	267	385	473	383	333	236	171	114	77	84	103	66	30	38	28	17	5	8	5	3	1	2
80	28	193	283	330	559	359	309	221	112	87	70	68	92	57	25	35	38	19	9	11	8	1	1	1
81	40	245	284	433	706	423	326	246	132	84	113	123	73	48	21	45	21	15	9	8	8	4	1	2
82	21	154	324	454	618	407	381	290	168	165	132	216	104	47	26	67	23	12	4	9	14	1	1	1
83	33	404	530	727	971	651	419	410	188	148	129	218	124	83	52	68	36	15	8	15	15	1	1	3
84	53	319	1053	2350	1019	504	376	257	286	199	145	273	297	132	98	173	83	64	37	42	20	12	4	7
85	47	237	2382	4459	1464	794	428	358	182	138	271	282	374	182	91	57	171	101	20	10	34	17	2	2
86	78	436	1200	1161	837	506	602	410	449	273	392	351	544	139	103	69	179	26	18	7	44	5	3	1
87	47	343	1481	1465	670	847	573	580	443	361	426	387	484	88	116	105	118	13	16	26	28	1	1	10
88	150	1089	4698	5299	2398	1100	759	571	642	518	533	556	670	384	143	236	157	121	19	36	36	15	5	5
89	6	582	2123	3338	2528	2116	882	717	500	480	317	475	519	115	51	110	162	34	6	18	27	6	2	3
90	18	352	1824	2612	2734	1022	644	890	646	411	395	695	485	211	175	211	81	62	47	23	17	8	8	2

Figure 27: Indian Ocean yellowfin tuna catch at age (in number, ages 0 to 5) of the whole fishery, according to both slow and fast growth curves hypotheses, 1952-90.



9.4.2. Results

According to these hypotheses, and assuming that all cohorts entering the fishery in 1952 were virgin, two sets of analyses have been run. The resulting fishing mortality vector by age Fi are shown in Tables 20 (low recruitment, R=60 millions) and 21 (high recruitment, R=120 millions) as well as in Figures 28-30:

Figure 28 shows, in the low recruitment case, the time series of mean Fi vectors for small (age 3-8 quarters), medium (age 9-12 quarters) and large (age 13-20 quarters) sized yellowfin tunas. Those series clearly demonstrate the tremendous increase of fishing mortalities since 1983, specially on the two first age groups.

Figure 29 exhibits mean Fi's vector for three reference periods, the two former with low (1955-60 and 1970-75), and the latter with high exploitation rates; this figure again demonstrates clearly the considerable change in the fishery which occurred since the beginning of the 80's.

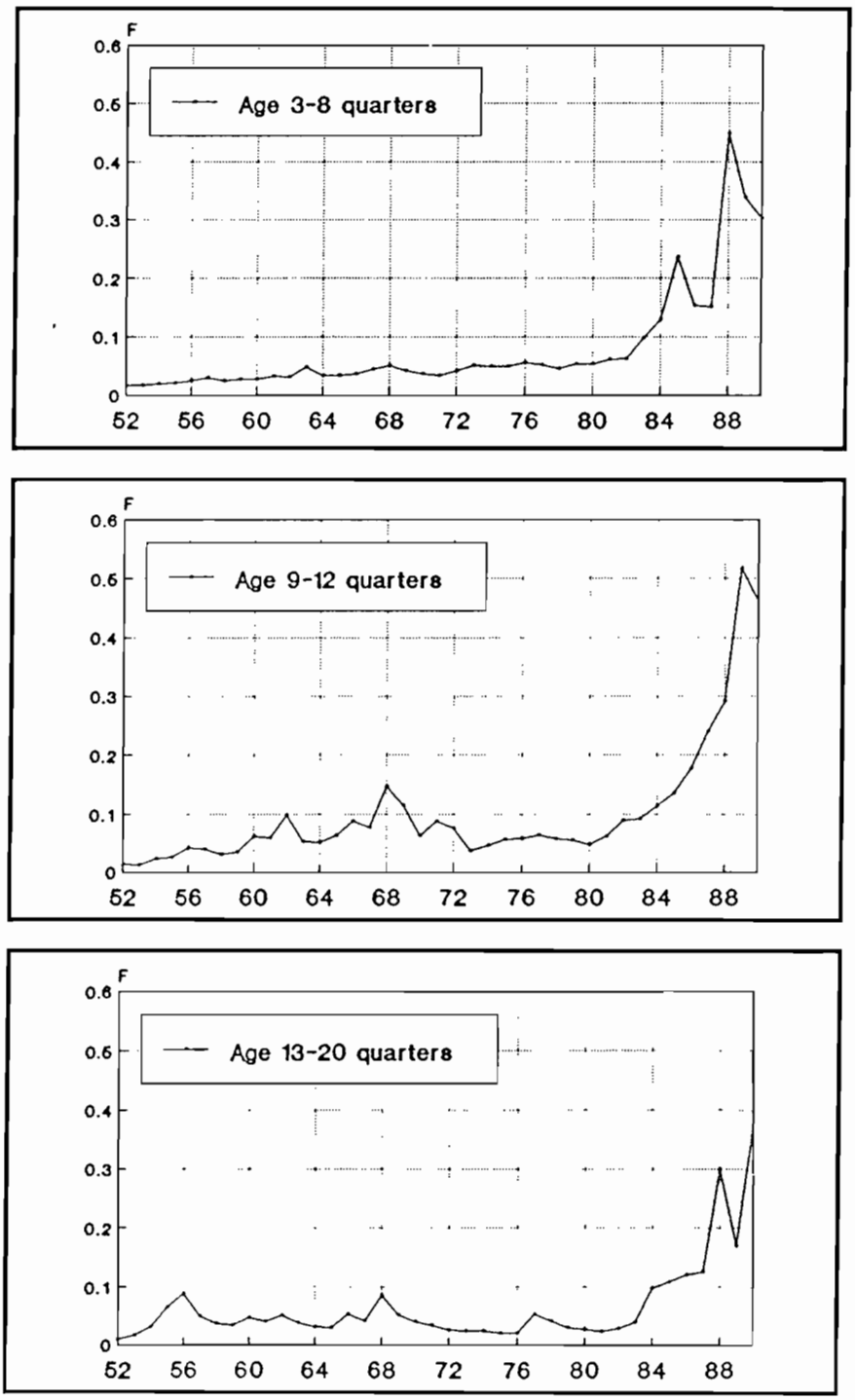
Figure 30 displays the detailed sharing out according to the main gears in the first and last periods, for both high and low recruitment hypothesis. The general shape of the two curves related to the same period are similar, but with some remarkable differences between both periods:

* during the period 1955-65, the bulk of the young fish catches was coming from artisanal fisheries, while the older fishes were exclusively caught by the longline fishery;

* during the period 1985-90, the situation is more complex: artisanal and longline fisheries continue to catch the same size pattern with changed exploitation rates (higher for artisanal fisheries and lower for longliners); the new purse-seine fishery exploits the complete range of sizes (with a notable discrepancy between logs and schools exploitation). The large mortality on large fish due to purse-seiners (much higher than longline's historical ones) should be noticed.

Finally, in the present situation of rapidly increasing fishing effort and in the absence of reliable index of abundance, it seems difficult to go further using this type of analysis, as the recruitment range may possibly be much different than what was chosen. It is also important to point out that the recruitment variability (relative to environment's one, and which may be important) could not be taken into account in this analysis.

Figure 28: Time series of average fishing mortality by age for small (age 3-8 quarters), medium (age 9-12 quarters) and large (age 13-20 quarters) sized yellowfin tunas under the low recruitment hypothesis, 1952-90.



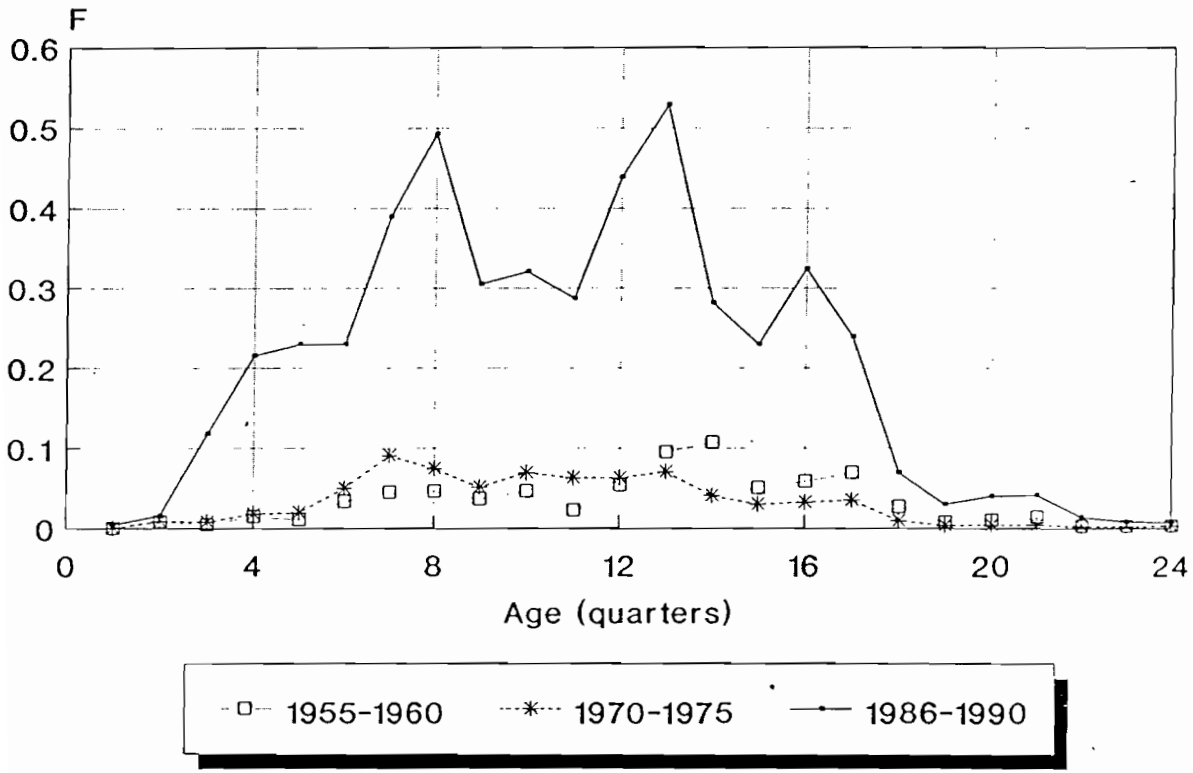


Figure 29: Average fishing mortality by age for three reference periods with low (1955-60 and 1970-75) and high (1986-90) exploitation rates under the low recruitment hypothesis.

Table 18: Quarterly fishing mortalities (F_i) and annual minimal recruitments estimated from SPA: slow growth, constant natural mortality (M=0.6), high constant $F_{terminal}$=0.40, cohorts born from 1952 to 1986.

Year	Recruitment (millions)	Age (by quarter)																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
52	17.79	0.000	0.025	0.042	0.042	0.041	0.094	0.123	0.119	0.160	0.154	0.076	0.244	0.030	0.012	0.051	0.522	0.014	0.016	0.019	0.400
53	13.95	0.000	0.032	0.054	0.054	0.033	0.070	0.091	0.094	0.080	0.062	0.018	0.090	0.378	0.178	0.082	0.589	0.280	0.036	0.021	0.400
54	10.91	0.000	0.042	0.076	0.076	0.043	0.109	0.146	0.137	0.076	0.082	0.065	0.126	0.112	0.298	0.289	0.247	0.437	0.481	0.273	0.400
55	10.84	0.000	0.042	0.077	0.077	0.056	0.153	0.211	0.217	0.123	0.114	0.049	0.242	0.317	0.576	0.361	0.465	0.432	0.278	0.093	0.400
56	14.29	0.000	0.032	0.062	0.062	0.058	0.186	0.264	0.282	0.217	0.277	0.238	0.541	0.871	1.068	1.061	1.087	0.613	0.289	0.126	0.400
57	12.14	0.000	0.038	0.075	0.075	0.045	0.166	0.238	0.269	0.275	0.323	0.212	0.389	0.769	0.928	0.379	0.660	1.704	0.771	0.062	0.400
58	11.48	0.000	0.039	0.075	0.075	0.051	0.168	0.236	0.252	0.170	0.219	0.072	0.188	0.665	0.832	0.089	0.464	1.412	0.479	0.031	0.400
59	12.96	0.000	0.039	0.075	0.075	0.061	0.193	0.274	0.302	0.206	0.274	0.144	0.275	0.440	0.627	0.195	0.264	0.324	0.095	0.038	0.400
60	13.19	0.000	0.036	0.070	0.070	0.051	0.168	0.239	0.265	0.344	0.600	0.231	0.780	0.851	0.986	0.472	0.618	0.239	0.088	0.062	0.400
61	10.62	0.000	0.056	0.110	0.110	0.062	0.190	0.284	0.303	0.225	0.251	0.349	0.690	1.040	0.840	0.339	2.041	0.326	0.064	0.038	0.400
62	13.37	0.000	0.038	0.080	0.080	0.070	0.246	0.386	0.400	0.303	0.541	0.755	1.321	1.303	0.778	0.663	1.487	0.886	0.147	0.317	0.400
63	14.62	0.000	0.035	0.084	0.084	0.059	0.293	0.448	0.580	0.450	0.521	0.299	0.636	1.288	0.999	0.420	1.294	0.634	0.158	0.031	0.400
64	17.28	0.000	0.029	0.061	0.061	0.050	0.190	0.278	0.301	0.291	0.370	0.411	0.411	0.780	0.921	0.753	0.879	0.923	0.233	0.047	0.400
65	15.96	0.000	0.031	0.067	0.067	0.042	0.154	0.230	0.258	0.200	0.327	0.387	0.525	0.680	0.546	0.282	0.313	1.438	0.155	0.093	0.400
66	18.21	0.000	0.025	0.058	0.058	0.043	0.185	0.281	0.313	0.272	0.410	0.354	0.613	1.060	0.677	0.557	1.161	0.490	0.110	0.056	0.400
67	15.63	0.000	0.034	0.083	0.083	0.045	0.197	0.296	0.319	0.344	0.413	0.325	0.542	0.713	0.631	0.177	0.242	0.636	0.216	0.023	0.400
68	15.56	0.000	0.037	0.109	0.109	0.048	0.268	0.423	0.482	0.458	0.940	0.795	0.883	1.879	1.624	0.758	1.166	1.269	0.259	0.047	0.400
69	12.56	0.000	0.042	0.096	0.096	0.070	0.298	0.471	0.503	0.555	0.605	0.759	1.180	1.501	0.778	0.560	0.782	1.458	0.265	0.139	0.400
70	12.61	0.000	0.027	0.061	0.061	0.055	0.218	0.408	0.419	0.344	0.410	0.715	0.800	0.989	0.771	0.995	0.901	0.753	0.229	0.124	0.400
71	10.34	0.000	0.023	0.019	0.069	0.035	0.188	0.416	0.370	0.299	0.845	0.875	0.903	1.220	0.987	0.808	0.470	1.106	0.409	0.139	0.400
72	16.62	0.000	0.021	0.028	0.039	0.066	0.306	0.650	0.559	0.346	0.662	0.698	0.618	1.221	0.515	0.241	0.432	1.093	0.157	0.047	0.400
73	27.04	0.000	0.031	0.035	0.066	0.098	0.204	0.437	0.295	0.476	0.364	0.303	0.316	0.577	0.451	0.265	0.717	0.568	0.080	0.031	0.400
74	16.47	0.000	0.040	0.041	0.116	0.039	0.227	0.233	0.201	0.213	0.237	0.152	0.284	0.660	0.449	0.329	0.749	0.468	0.137	0.070	0.400
75	17.54	0.005	0.037	0.021	0.030	0.180	0.236	0.363	0.399	0.136	0.150	0.124	0.176	0.213	0.155	0.132	0.088	0.681	0.351	0.124	0.400
76	16.27	0.007	0.030	0.026	0.076	0.192	0.211	0.352	0.414	0.308	0.343	0.315	0.257	0.118	0.065	0.042	0.067	0.156	0.053	0.039	0.400
77	14.22	0.012	0.027	0.026	0.054	0.260	0.202	0.332	0.426	0.312	0.291	0.355	0.300	0.308	0.349	0.458	1.211	0.090	0.066	0.089	0.400
78	14.87	0.008	0.021	0.022	0.064	0.232	0.207	0.329	0.431	0.278	0.247	0.227	0.504	0.741	0.389	0.153	0.472	0.437	0.157	0.062	0.400
79	19.10	0.005	0.033	0.021	0.044	0.197	0.262	0.391	0.531	0.352	0.369	0.361	0.326	0.493	0.333	0.183	0.263	0.252	0.119	0.035	0.400
80	32.75	0.004	0.015	0.013	0.022	0.189	0.193	0.297	0.352	0.320	0.312	0.295	0.236	0.399	0.334	0.186	0.289	0.337	0.089	0.070	0.400
81	24.02	0.007	0.028	0.017	0.048	0.138	0.127	0.171	0.216	0.272	0.234	0.267	0.276	0.304	0.251	0.162	0.319	0.229	0.123	0.093	0.400
82	25.36	0.004	0.010	0.018	0.046	0.162	0.161	0.275	0.338	0.158	0.180	0.166	0.244	0.293	0.177	0.112	0.306	0.232	0.060	0.035	0.400
83	39.02	0.004	0.031	0.028	0.060	0.261	0.276	0.348	0.496	0.274	0.272	0.247	0.398	0.163	0.132	0.104	0.145	0.231	0.053	0.047	0.400
84	46.69	0.005	0.021	0.081	0.287	0.183	0.124	0.220	0.273	0.353	0.356	0.296	0.525	0.673	0.448	0.431	0.945	0.218	0.140	0.107	0.400
85	50.72	0.004	0.004	0.159	0.602	0.204	0.203	0.399	0.268	0.267	0.148	0.239	0.297	0.981	0.782	0.534	0.393	1.308	0.875	0.184	0.400
86	40.94	0.008	0.010	0.073	0.108	0.142	0.174	0.352	0.333	0.225	0.198	0.297	0.320	0.691	0.254	0.258	0.164	1.857	0.281	0.220	0.400

Table 19: Annual fishing mortalities (F_i) for different levels of recruitment: slow growth, constant natural mortality (M=0.6), cohorts born from 1970 to 1986.

Recruitment (millions)	Birth date of cohort																
	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
200	0.011	0.009	0.010	0.012	0.014	0.014	0.012	0.011	0.011	0.013	0.018	0.023	0.026	0.028	0.039	0.053	0.040
150	0.015	0.013	0.013	0.016	0.019	0.019	0.017	0.014	0.015	0.017	0.024	0.032	0.035	0.038	0.053	0.073	0.055
100	0.023	0.019	0.020	0.024	0.029	0.029	0.026	0.022	0.022	0.026	0.037	0.049	0.055	0.060	0.086	0.121	0.089
80	0.029	0.024	0.025	0.031	0.037	0.036	0.032	0.028	0.028	0.033	0.048	0.064	0.072	0.078	0.113	0.166	0.118
70	0.034	0.028	0.029	0.035	0.043	0.042	0.037	0.032	0.032	0.038	0.055	0.074	0.084	0.091	0.136	0.205	0.141
60	0.040	0.033	0.034	0.042	0.051	0.050	0.044	0.038	0.038	0.045	0.066	0.090	0.102	0.111	0.169	0.269	0.177
50	0.049	0.040	0.042	0.051	0.063	0.062	0.054	0.047	0.047	0.055	0.082	0.113	0.129	0.142	0.227	0.410	0.239
40	0.063	0.052	0.054	0.066	0.082	0.080	0.071	0.060	0.060	0.072	0.109	0.154	0.178	0.199	0.360	0.386	
30	0.089	0.072	0.075	0.094	0.119	0.115	0.100	0.085	0.085	0.102	0.161	0.244	0.295	0.348			
25	0.112	0.090	0.094	0.119	0.153	0.148	0.127	0.106	0.107	0.130	0.215	0.358	0.474	0.666			
20	0.152	0.120	0.126	0.163	0.216	0.209	0.175	0.144	0.144	0.180	0.332						

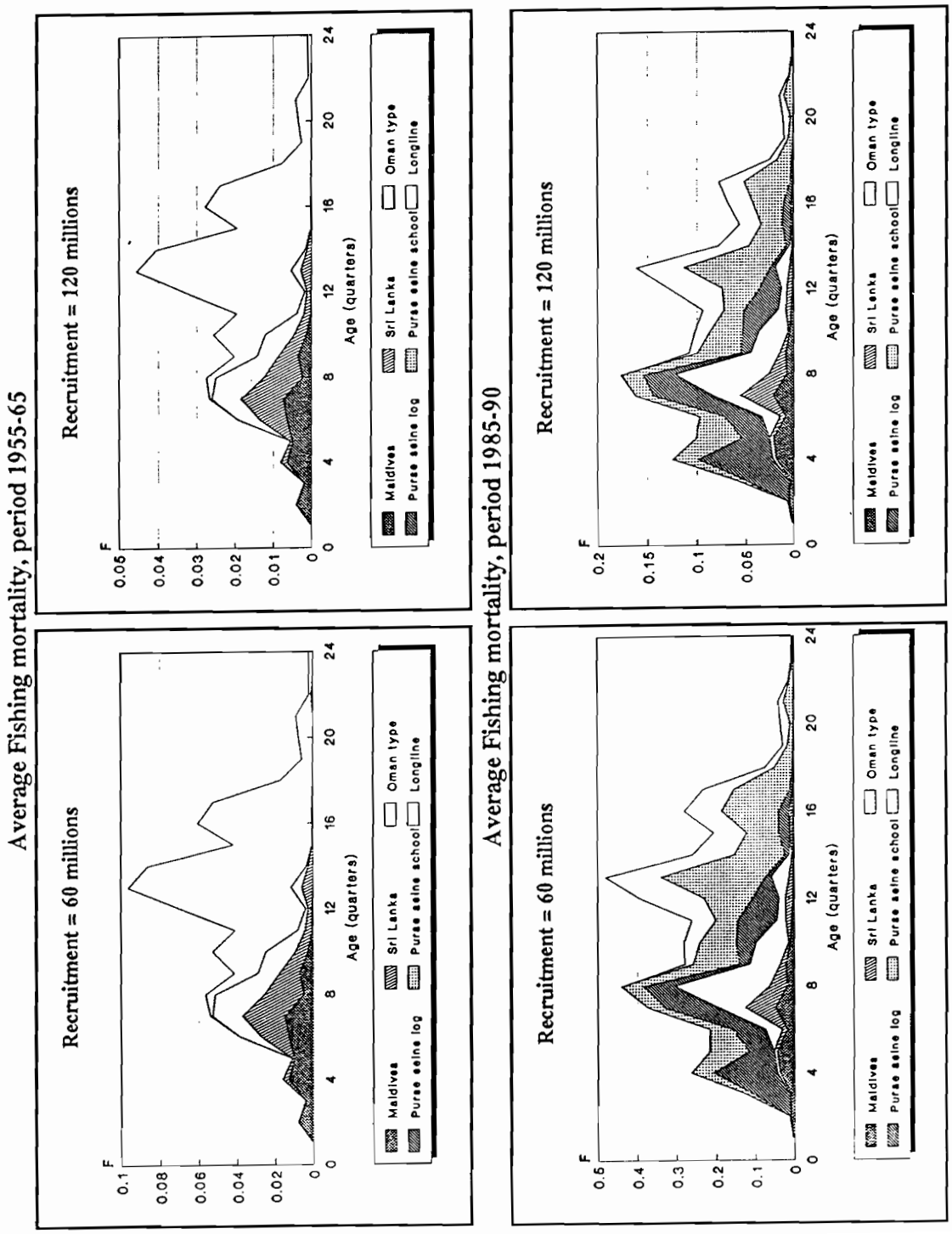
Table 20: Quarterly fishing mortalities (F_i) in the Indian Ocean yellowfin tuna fishery: low recruitment hypothesis (60 millions of fishes), slow growth, constant natural mortality (M=0.6), cohorts born from 1952 to 1990.

Year	Recruitment (millions)	Age (by quarter)																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
52	60077	.000	.008	.004	.012	.009	.021	.027	.025	.015	.014	.007	.021	.004	.002	.006	.063	.001	.001	.001	.006	.001	.002	.002	.002
53	60077	.000	.008	.004	.012	.009	.020	.026	.026	.017	.013	.004	.018	.030	.013	.006	.040	.031	.004	.002	.011	.003	.002	.002	.002
54	60077	.000	.008	.004	.013	.010	.024	.032	.029	.021	.022	.017	.033	.022	.056	.052	.042	.026	.026	.013	.005	.009	.002	.002	.002
55	60077	.000	.008	.004	.014	.010	.026	.035	.034	.025	.023	.010	.047	.080	.134	.077	.091	.068	.041	.013	.015	.017	.002	.002	.002
56	60077	.000	.008	.004	.014	.010	.032	.043	.043	.033	.040	.032	.067	.150	.150	.119	.095	.107	.046	.019	.016	.024	.002	.002	.003
57	60077	.000	.008	.004	.015	.010	.038	.052	.056	.040	.044	.027	.047	.083	.083	.029	.045	.109	.036	.003	.005	.025	.002	.002	.003
58	60077	.000	.008	.004	.014	.010	.032	.043	.044	.034	.042	.013	.034	.071	.075	.007	.035	.076	.020	.001	.004	.013	.002	.002	.003
59	60077	.000	.008	.004	.016	.011	.035	.047	.049	.034	.043	.022	.040	.075	.095	.027	.035	.022	.006	.002	.007	.002	.002	.002	.003
60	60077	.000	.008	.004	.015	.011	.034	.047	.049	.052	.082	.029	.087	.110	.104	.042	.049	.030	.011	.007	.013	.002	.002	.002	.003
61	60077	.000	.010	.005	.019	.013	.040	.056	.057	.040	.042	.055	.098	.095	.062	.022	.100	.023	.004	.002	.007	.003	.002	.002	.003
62	60077	.000	.008	.004	.017	.012	.040	.059	.056	.053	.087	.106	.148	.150	.071	.049	.090	.030	.004	.009	.003	.002	.002	.002	.003
63	60077	.000	.008	.004	.020	.013	.061	.087	.101	.058	.060	.031	.060	.108	.064	.023	.057	.030	.007	.001	.005	.003	.002	.002	.003
64	60077	.000	.008	.004	.017	.012	.044	.061	.063	.046	.055	.056	.051	.063	.061	.041	.039	.031	.007	.001	.003	.002	.002	.002	.003
65	60077	.000	.008	.004	.018	.012	.043	.061	.066	.040	.061	.068	.083	.075	.053	.025	.026	.049	.004	.003	.003	.005	.002	.002	.003
66	60077	.000	.008	.004	.017	.011	.047	.068	.072	.066	.093	.075	.118	.143	.075	.054	.093	.037	.008	.004	.007	.005	.002	.002	.003
67	60077	.000	.009	.005	.021	.013	.057	.082	.084	.074	.083	.060	.092	.120	.092	.024	.031	.041	.013	.001	.006	.007	.002	.002	.003
68	60077	.000	.007	.004	.021	.012	.066	.097	.101	.112	.202	.143	.134	.249	.145	.051	.063	.137	.023	.004	.010	.031	.002	.002	.003
69	60077	.000	.009	.005	.020	.013	.053	.078	.075	.105	.102	.111	.140	.176	.070	.043	.052	.058	.008	.004	.003	.007	.002	.003	.003
70	60077	.000	.006	.006	.013	.011	.043	.075	.071	.047	.051	.079	.075	.092	.059	.062	.045	.042	.011	.006	.005	.006	.002	.003	.003
71	60077	.000	.004	.003	.012	.007	.038	.078	.064	.047	.118	.101	.085	.090	.056	.037	.019	.043	.013	.004	.003	.004	.002	.003	.003
72	60077	.000	.006	.008	.011	.011	.049	.095	.071	.056	.096	.087	.067	.091	.031	.013	.022	.036	.004	.001	.003	.004	.002	.003	.003
73	60077	.000	.014	.016	.029	.026	.054	.108	.068	.054	.038	.029	.028	.055	.038	.021	.050	.026	.003	.001	.005	.003	.002	.002	.003
74	60077	.000	.011	.011	.031	.017	.055	.099	.083	.047	.050	.031	.055	.053	.032	.021	.043	.028	.008	.004	.006	.002	.002	.002	.003
75	60003	.001	.011	.006	.009	.047	.059	.086	.088	.055	.059	.048	.066	.039	.028	.023	.015	.033	.015	.005	.004	.005	.002	.002	.003
76	60003	.002	.008	.007	.020	.054	.057	.091	.100	.063	.066	.057	.044	.043	.023	.015	.024	.026	.009	.006	.017	.005	.002	.002	.003
77	60001	.003	.006	.006	.013	.067	.050	.078	.093	.070	.062	.071	.056	.049	.052	.063	.139	.032	.023	.031	.037	.010	.006	.005	.003
78	60001	.002	.005	.005	.016	.053	.045	.068	.082	.057	.048	.042	.086	.124	.058	.021	.062	.041	.014	.005	.009	.010	.002	.002	.003
79	60000	.002	.010	.007	.014	.047	.060	.084	.104	.062	.060	.055	.046	.076	.047	.024	.033	.030	.014	.004	.012	.005	.002	.002	.003
80	60002	.002	.008	.007	.012	.058	.057	.085	.095	.057	.052	.047	.035	.052	.040	.021	.031	.040	.010	.008	.012	.007	.002	.002	.003
81	60001	.003	.011	.007	.019	.074	.067	.089	.110	.069	.057	.062	.060	.043	.033	.020	.038	.023	.012	.009	.010	.007	.006	.002	.003
82	60000	.002	.004	.008	.019	.063	.061	.101	.118	.078	.087	.079	.113	.061	.035	.022	.056	.026	.007	.004	.012	.014	.002	.002	.003
83	60000	.002	.020	.018	.039	.107	.109	.131	.174	.091	.086	.075	.114	.074	.058	.045	.062	.040	.009	.008	.018	.015	.002	.002	.003
84	60000	.004	.016	.062	.220	.117	.078	.136	.165	.115	.110	.086	.142	.176	.105	.093	.178	.091	.057	.043	.043	.020	.015	.002	.008
85	60002	.003	.003	.134	.500	.154	.151	.292	.192	.157	.085	.135	.163	.231	.155	.092	.062	.195	.103	.019	.011	.037	.021	.003	.003
86	60001	.006	.007	.049	.073	.116	.141	.282	.262	.158	.137	.202	.212	.357	.124	.121	.075	.231	.027	.020	.010	.055	.008	.003	.003
87	60002	.003	.023	.059	.098	.073	.127	.269	.279	.190	.206	.263	.301	.374	.099	.155	.144	.163	.011	.010	.047	.032	.003	.003	.018
88	60000	.011	.012	.255	.480	.309	.324	.659	.665	.241	.273	.294	.357	.649	.534	.250	.474	.256	.152	.029	.058	.043	.023	.010	.004
89	60010	.000	.030	.145	.265	.281	.359	.365	.616	.544	.621	.350	.556	.450	.134	.068	.160	.402	.069	.014	.054	.044	.011	.004	.005
90	60002	.001	.007	.081	.160	.368	.196	.373	.640	.391	.364	.324	.768	.814	.515	.551	.767	.143	.085	.077	.033	.034	.023	.020	.008

Table 21: Quarterly fishing mortalities (F_i) in the Indian Ocean yellowfin tuna fishery: high recruitment hypothesis (120 millions of fishes), slow growth, constant natural mortality (M=0.6), cohorts born from 1952 to 1990.

Year	Recruitment (millions)	Age (by quarters) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
52	120322	.000	.004	.002	.006	.005	.010	.013	.012	.008	.007	.003	.011	.002	.001	.003	.031	.000	.000	.001	.003	.001	.001	.001	.001
53	120322	.000	.004	.002	.006	.005	.010	.013	.013	.008	.006	.002	.009	.015	.007	.003	.020	.015	.002	.001	.006	.001	.001	.001	.001
54	120322	.000	.004	.002	.007	.005	.012	.016	.014	.010	.011	.009	.016	.011	.028	.025	.020	.013	.013	.007	.003	.004	.001	.001	.001
55	120322	.000	.004	.002	.007	.005	.013	.017	.017	.012	.011	.005	.023	.039	.064	.036	.042	.032	.019	.006	.007	.008	.001	.001	.001
56	120322	.000	.004	.002	.007	.005	.016	.021	.021	.016	.019	.016	.033	.072	.071	.055	.044	.049	.021	.009	.007	.011	.001	.001	.001
57	120322	.000	.004	.002	.007	.005	.019	.026	.027	.019	.021	.013	.022	.040	.039	.014	.021	.049	.016	.001	.002	.011	.001	.001	.001
58	120322	.000	.004	.002	.007	.005	.016	.021	.022	.016	.020	.006	.016	.034	.035	.003	.017	.035	.009	.001	.002	.006	.001	.001	.001
59	120322	.000	.004	.002	.008	.006	.017	.023	.024	.017	.021	.011	.019	.036	.045	.013	.016	.010	.003	.001	.003	.001	.001	.001	.001
60	120322	.000	.004	.002	.007	.005	.017	.023	.024	.025	.040	.014	.042	.052	.049	.020	.023	.014	.005	.003	.006	.001	.001	.001	.001
61	120322	.000	.005	.002	.009	.007	.020	.028	.028	.019	.021	.027	.047	.045	.029	.010	.046	.011	.002	.001	.003	.002	.001	.001	.001
62	120322	.000	.004	.002	.009	.006	.020	.029	.027	.026	.042	.050	.069	.070	.033	.022	.041	.014	.002	.004	.001	.001	.001	.001	.001
63	120322	.000	.004	.002	.010	.006	.030	.042	.049	.028	.029	.015	.029	.050	.029	.010	.026	.013	.003	.001	.002	.002	.001	.001	.001
64	120322	.000	.004	.002	.009	.006	.022	.030	.031	.022	.026	.027	.024	.030	.029	.019	.018	.014	.003	.001	.001	.001	.001	.001	.001
65	120322	.000	.004	.002	.009	.006	.021	.030	.032	.019	.030	.032	.039	.035	.024	.011	.012	.023	.002	.001	.001	.002	.001	.001	.001
66	120322	.000	.004	.002	.009	.006	.023	.034	.035	.032	.045	.035	.055	.067	.035	.024	.042	.017	.003	.002	.003	.002	.001	.001	.001
67	120322	.000	.004	.002	.011	.007	.028	.040	.041	.036	.039	.029	.043	.055	.042	.011	.014	.018	.006	.001	.003	.003	.001	.001	.001
68	120322	.000	.003	.002	.010	.006	.033	.048	.049	.054	.095	.066	.060	.114	.065	.023	.028	.061	.010	.002	.004	.014	.001	.001	.001
69	120322	.000	.004	.002	.010	.006	.026	.038	.036	.050	.048	.051	.064	.078	.030	.019	.022	.025	.004	.002	.001	.003	.001	.001	.001
70	120322	.000	.003	.003	.006	.006	.021	.037	.034	.022	.025	.038	.035	.041	.026	.027	.019	.018	.005	.002	.002	.002	.001	.001	.001
71	120322	.000	.002	.002	.006	.004	.019	.039	.031	.023	.056	.048	.040	.042	.026	.017	.008	.019	.006	.002	.001	.002	.001	.001	.001
72	120322	.000	.003	.004	.005	.005	.024	.047	.035	.027	.046	.041	.031	.042	.014	.006	.010	.016	.002	.001	.001	.002	.001	.001	.001
73	120322	.000	.007	.008	.014	.013	.026	.053	.033	.026	.018	.014	.013	.025	.018	.009	.023	.012	.002	.001	.002	.002	.001	.001	.001
74	120322	.000	.005	.006	.015	.009	.027	.048	.040	.022	.024	.015	.026	.025	.015	.010	.020	.013	.003	.002	.003	.001	.001	.001	.001
75	120013	.001	.005	.003	.004	.023	.029	.042	.042	.026	.028	.023	.031	.018	.013	.011	.007	.015	.007	.002	.002	.002	.001	.001	.001
76	120012	.001	.004	.004	.010	.027	.028	.045	.048	.030	.031	.027	.020	.020	.011	.007	.011	.012	.004	.003	.008	.002	.001	.001	.001
77	120006	.001	.003	.003	.006	.033	.025	.038	.045	.034	.029	.033	.026	.023	.024	.029	.062	.015	.010	.014	.017	.005	.003	.002	.001
78	120000	.001	.003	.003	.008	.026	.022	.033	.040	.027	.023	.020	.040	.057	.026	.010	.028	.018	.006	.002	.004	.005	.001	.001	.001
79	120013	.001	.005	.003	.007	.023	.029	.041	.050	.030	.029	.026	.022	.035	.022	.011	.015	.014	.006	.002	.006	.002	.001	.001	.001
80	120001	.001	.004	.003	.006	.029	.028	.041	.046	.027	.025	.022	.016	.024	.019	.010	.014	.018	.005	.004	.005	.003	.001	.001	.001
81	120007	.001	.006	.003	.009	.037	.033	.043	.053	.033	.027	.029	.028	.020	.015	.009	.018	.011	.005	.004	.005	.003	.003	.001	.001
82	120013	.001	.002	.004	.010	.031	.030	.049	.057	.037	.041	.037	.052	.028	.016	.010	.026	.012	.003	.002	.005	.006	.001	.001	.001
83	120003	.001	.010	.009	.019	.053	.053	.063	.082	.043	.040	.035	.052	.033	.026	.020	.027	.018	.004	.004	.008	.007	.001	.001	.001
84	120001	.002	.008	.031	.108	.057	.038	.065	.078	.053	.050	.039	.063	.079	.046	.040	.076	.040	.025	.018	.018	.009	.006	.001	.004
85	120004	.002	.002	.067	.238	.073	.071	.133	.084	.072	.038	.060	.071	.099	.065	.038	.025	.081	.042	.008	.004	.016	.009	.001	.001
86	120001	.003	.004	.025	.036	.053	.063	.123	.110	.068	.057	.082	.084	.150	.050	.048	.029	.092	.011	.008	.004	.022	.003	.001	.001
87	120004	.002	.011	.029	.048	.036	.061	.127	.127	.077	.081	.100	.109	.142	.036	.055	.050	.063	.004	.004	.018	.012	.001	.001	.007
88	120000	.005	.006	.125	.225	.148	.149	.283	.259	.106	.115	.119	.138	.219	.163	.071	.126	.087	.050	.009	.019	.016	.008	.004	.001
89	120045	.000	.015	.072	.127	.125	.153	.147	.230	.193	.200	.104	.152	.163	.046	.023	.053	.099	.016	.003	.012	.014	.003	.001	.002
90	120014	.001	.004	.040	.078	.170	.087	.159	.253	.135	.118	.099	.213	.196	.109	.105	.127	.047	.027	.024	.010	.008	.005	.005	.002
		.002	.042	.059k	0.125	0.100	0.184	0.162	0.117	0.138	0.101	0.094	0.127	0.161	0.073	0.056	0.063	0.075	0.025	0.008	0.011	0.014	0.004	0.002	0.002

Figure 30: Average fishing mortality by age shared out according to the main gears for two reference periods with low (1955-65) and high (1985-90) exploitation rates, under both high and low recruitment hypotheses.



9.5 Yield-per-recruit analysis

Yield-per-recruit is a measure of the productivity that one can expect from a fish recruited into the fishery, depending on the level of the fishing effort and the type of gear used in the fishery (more specifically age or size at first capture).

The yield-per-recruit have been calculated using Ricker's model under the juvenile slow growth rate hypothesis, with resulting fishing mortalities for the two following periods:

* **1955-65** which corresponds to the early age of the fishery, when the longline method was by far the main fishing gear;
* **1985-90** which corresponds to the present situation of the fishery, with a major purse-seine fishery, active artisanal fisheries while longline fishery is still significant.

The two levels of recruitment retained from SPA (see 9.4) were used for the analysis: a low level of 60 million fish and a higher level (but not considered as a maximum level) of 120 million fish. On this basis, four figures have been produced to illustrate these results (Figure 31), which give the yield-per-recruit for both periods under the two levels of recruitment hypotheses.

When interpreting these results, it should be kept in mind that in the case of tuna fisheries, fishing effort can be easily changed (increased or decreased) through technical or political decisions, but it is much more difficult to change age at first capture: several attempts in other tuna fisheries at this level have shown that this type of action is difficult to put into practice.

For the 1955-65 period, figures are very similar, showing that an increased catch would result from an increased fishing effort. However, this was not observed in the longline fishery despite a low exploitation rate.

For the 1985-90 period, figures are of course very different from the previous ones; furthermore, the pattern is not similar according to the level of recruitment:

* Under the 60 million recruitment hypothesis, a substantial increase of the yield-per-recruit may result from an increased fishing effort. This is due to the fact that many small yellowfin are already caught, and that fishing mortality coefficients are quite high under this hypothesis: under this set of hypothesis (growth, natural mortality and recruitment), we might be close to full exploitation of the stock, and therefore an increase of fishing effort might induce overfishing.

* Under the 120 million recruitment hypothesis, an increased fishing effort will result in a substantial increase of yield-per-recruit, as overall fishing mortality coefficients are much lower under this hypothesis; however this

increase will not be tremendous, as many small yellowfin are already caught by the artisanal and purse seine fisheries.

It was suggested to produce this yield-per-recruit analysis using the faster juvenile growth curve hypothesis, and that a thorough examination of the pattern of yield -per-recruit between gears be conducted in order to have an inside view of gear interactions. Those analyses, which are supposed to take into account a larger set of hypotheses, were not possible during the remaining time of this meeting. Therefore, participants recommended to undertake such analyses for future meetings.

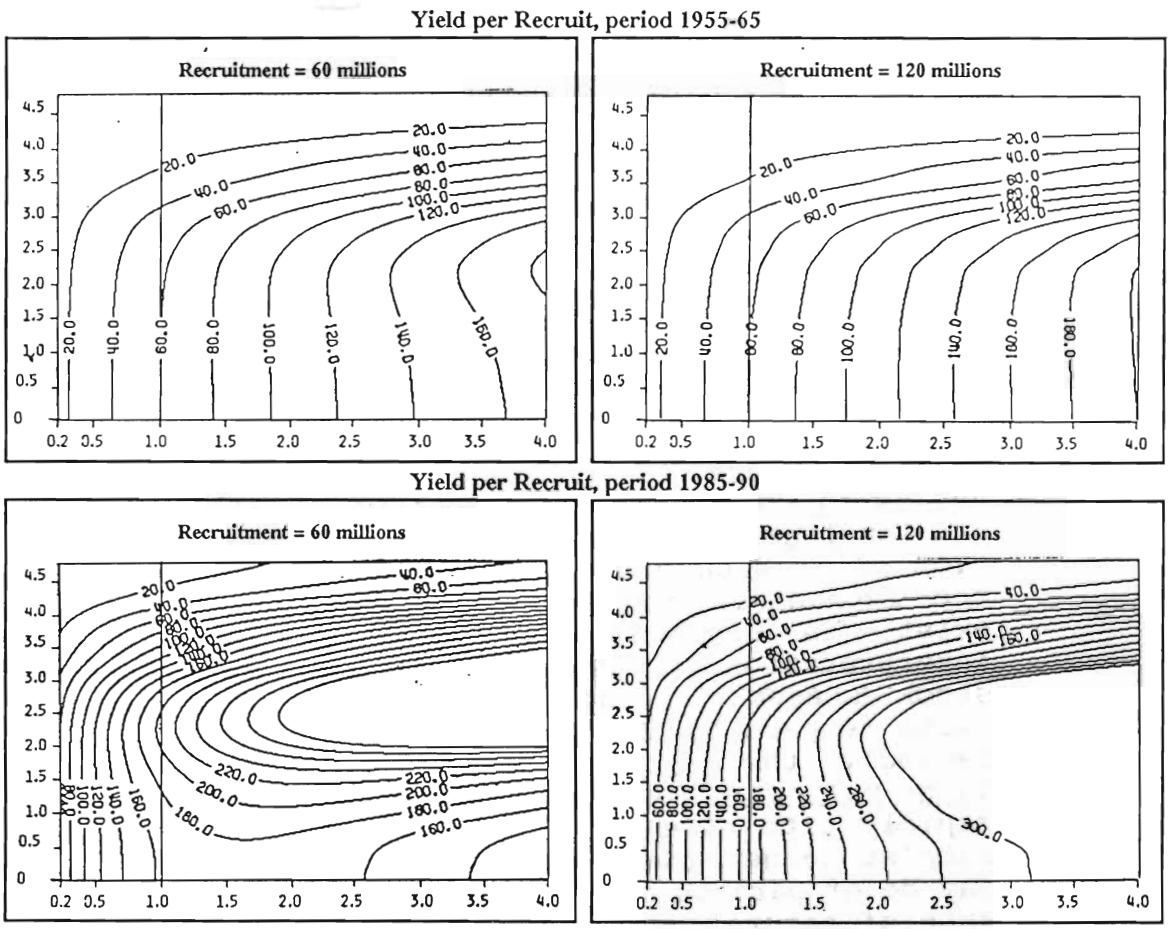


Figure 31: Yellowfin yield-per-recruit for two reference periods with low (1955-65) and high (1985-90) exploitation rates under both low (60 millions) and high (120 millions) level of recruitment hypotheses.

9.6 Review of results

Although great improvements have been made in the compilation of catch, effort and size composition data for Indian Ocean yellowfin fisheries, gaps in our understanding of key biological and fishing processes presently hinder the objective interpretation of these data.

The problem areas include:

(1) The nature of the relationship between CPUE from the various fisheries and yellowfin abundance, which remains generally unknown:
   * for the longline fishery, there is uncertainty as to how consistently the gear samples the adult population;
   * for the purse-seine fishery, the environmental effects on CPUE are still uncertain, and the effects of increased fishing power of the fleet through improvements in searching and catching technology have yet to be estimated, and are likely to be complex;
   * lastly, for the various coastal fisheries, the relationship between CPUE, local abundance and overall abundance in the Indian Ocean is unknown. For these reasons, none of the CPUE indices presented could be used as a thoroughly agreed indicator of relative abundance of Indian Ocean yellowfin.

(2) The stock structure - having a large bearing on stock assessment - two aspects of which are still unclear at this time:
   * firstly, there is evidence to suggest that large yellowfin are not equally available to the purse-seine and longline fisheries; however, the extent of separation of surface and subsurface "stocks", as well as the mechanisms mediating this separation, if they exist, is unknown. This further complicates the interpretation of CPUE trends, and casts doubt on stock assessment methods for which a homogeneous stock (with respect to the two gears) is assumed;
   * secondly, the strong disequilibrium in sex ratio for large yellowfin (over some 120 cm LF), which increases rapidly with size in favour of males (such that few females larger than 180 cm have ever been observed) may be of paramount importance: this implies a higher rate of natural mortality for larger females, and/or a sex-specific growth resulting in a smaller maximum size of females. No information is currently available for either alternative that would allow this structure to be incorporated into population models.

(3) The considerable uncertainty regarding several important biological parameters which still exists, including:
- growth rates (juveniles, male/females),
- natural mortality rates (global, by age and by sex),
- the pattern of reproductive maturity between surface and subsurface segments of the population.

Because of the difficulties all these problems raise for the interpretation of fishery trends and sequential age-structured population models, no firm conclusions on the status of the Indian Ocean yellowfin stock could be reached.

Several avenues of investigation, which may clarify or circumvent some of these problems, were discussed; they are recapitulated in the following section on recommendations.

10. RECOMMENDATIONS

10.1. Statistics

The Workshop was greatly impressed with the marked improvement in the yellowfin tuna statistics collected by IPTP during the past 10 years. They stressed the importance of IPTP bridging the interval until a permanent tuna body is established, to assure continuity in the statistical information: disruption of this statistical collection system would be disastrous for the scientific community, and extremely costly to all countries and organizations involved to implement another system to take its place.

The Workshop noted that the following recommendations made at the Expert Consultation on Tunas in the Indian Ocean held in Bangkok in 1990, were still relevant:

* countries should improve reporting of the main tuna species in catch statistics;
* countries should cross check catch statistics with landings for industrial longline fisheries, to improve its accuracy;
* Indonesia should introduce a log book systems for its industrial purse-seine and longline fisheries;
* IPTP should continues to assist coastal countries to maintain and improve sampling programmes;
* IPTP should, as ICCAT, report statistics corrected for inconsistencies between reporting countries in its data summaries, in lieu of official flag figures;
* every country should continue to collect reliable statistics in the smallest time-area strata possible, and to submit them to IPTP on a timely basis; the largest recommended strata is 5° square by month;
* countries with historical data sets that have not yet been submitted to IPTP should check those data and submit to IPTP in the required format as soon as possible;

* the recommendation to record separately free and log school catches made at the Expert Consultation has been implemented for the French and Spanish purse-seine vessels; this system should be continued and adopted by the other purse-seine fleets operating in the Indian Ocean.

The Workshop made the following additional recommendations:

* IPTP should encourage countries implementing statistical collection systems to adopt standard codes and recording forms as set up for the workshop to facilitate data exchange and analyses;
* the area of IPTP coverage should be extended from 30°E to 15°E to include yellowfin catches made off South Africa as these fish are part of the Indian Ocean stock; IPTP should also consider reducing the coverage area from 150°E to 140°E to exclude Pacific Ocean yellowfin tuna captured off the east coast and south-east corner of Australia;
* Maldives should expand their sampling programme to other sites to obtain size data for yellowfin tuna more representative of the catches;
* Indonesia should initiate a sampling programme to collect size data of catches made by national and foreign flags vessels based in Jakarta and Bali;
* India should investigate means of initiating a sampling programme to collect size data of catches made by chartered vessels operating in its EEZ;
* free and log school purse-seine size frequencies should be recorded separately in the same way as with catches.

10.2. Research

A large number of questions relative to yellowfin tuna biology, ecology and population dynamics are still to be solved. Pending questions and possible methods to give an answer are listed below, for the main subjects.

10.2.1. Stock structure

Ia. Determine the relationship between the pool of fish respectively available to longline and purse-seine fisheries, as well as with the entire stock; both horizontal and vertical heterogeneities should be investigated.

Methods:

* fine spatio-temporal analysis of historical longline CPUE;
* large scale tagging programme, including sonic and archival tags;
* developing of advanced mathematical integrated models, simultaneously utilizing all available data, to estimate parameters associated with

various sets of hypotheses, in association with statistical testing of their validity.

Ib. Determine sex ratio as a function of fish age, area, season and method of capture.
Methods:
* subsampling the measured fish to determine their sex.

10.2.2. Growth

II. Refine estimates of fish growth for both juvenile (slow/fast growth problem) and separately males and females adults (sex differential growth problem) fish.
Methods:
* tagging fish and marking their hard parts by tetracycline,
* aging fish by reading hard parts, including the validation of the method;
* statistically testing the improvements in the fit to data of Richards's function compared to von Bertalanffy's one, and using this function if desired.

10.2.3. Maturity and spawning

III. Improve the knowledge of yellowfin reproduction modes and variability.
Methods:
* Examine the variability in gonad indices among different geographical areas, seasons and years.
* biological studies, including behaviour and physiology.

10.2.4. Natural mortality

IV. Explore the possibility of estimating the rate of natural mortality, its changes with age and/or sex as well as its limits of uncertainty.
Methods:
* evaluate and test various methods to estimate the rate of natural mortality;
* sensitivity analysis;
* biological studies, including behaviour and physiology.

10.2.5. Oceanographic conditions

V. Examine the impact of oceanographical conditions on the availability of fish to different fishing gears as well as on the productivity of the stock.
Methods:
* collection of oceanographic data;
* determine their influence on fish availability to different gears;

* evaluate the impact of the interannual variability on the global productivity of the stock (mainly through recruitment).

10.2.6. CPUE

VI. To have a better understanding of the relationship between effort and fishing mortality, i.e. between CPUE and abundance.

Methods:

* estimate the improvements in fishing efficiency of purse-seiners, longliners and other vessels: new electronic equipment (bird radar, remote sensing facilities, ...), improved fishing gear (deeper nets, monofilaments lines, ...), changes in the fishing strategy (species targeting, ...), ...;
* examine the impact of environmental conditions on CPUE (catchability coefficient) and develop new models including non-linear effects;
* examine the effect of targeting at species other than yellowfin on CPUE calculated for yellowfin (purse-seiners as well as longliners);
* further attempts to develop general linear models of CPUE for the various fisheries, and in particular models of purse-seine CPUE (including non linear models) that account for the effect of environmental variation and increased fishing power.

10.2.7. Stock assessment

VII. In addition to better understanding the relationship between CPUE and stock abundance, other solutions should be investigated.

Methods:

* further apply traditional approaches to stock assessment with differentiation of life parameters between sexes;
* development of advanced integrated stock assessment models utilizing all available data simultaneously and testing various hypotheses;
* explore the feasibility, effectiveness and cost of aerial and fisheries observer surveys in order to have an independent index of abundance;
* collect regularly information on biological parameters, as a mean of monitoring stock condition;
* determine the resistance of the population to exploitation, using simulations.

10.2.8. Fisheries interactions

VIII. Determine the extent of interactions among the fisheries.
Methods:
* analyses of available data from past tagging.
* implementing a large-scale tagging programme in the Indian Ocean.

10.2.9. General

IXa. Complete the design of a large-scale tagging programme to satisfy recommendations Ia, II and VIII.

IXb. Formulate an Indian Ocean Yellowfin Year Programme for the consideration of the 1993 Expert Consultation on Stock Assessment of Tunas in the Indian Ocean.

10.3. Tagging

Tuna large-scale tagging programmes have already been conducted in all the major tuna fisheries, with the exception of Indian Ocean. It was outlined that tagging is - and specially with regards to tuna - one of the most powerful techniques to obtain - in a relative short term - information on biology, stock structure and fisheries interactions. It was also noted that such programmes efficiently complement and boost national capabilities in most of the fisheries concerns (improvement of fisheries statistics, national development and management of fisheries, ...).

The large set of questions relative to yellowfin tuna biology, ecology and population dynamics mentioned during previous discussion (see 9.6 and 10.2) led the Workshop to make numerous recommendations, including a large scale tagging programme and to propose an Indian Ocean Yellowfin Year Programme for the consideration of the 1993 Expert Consultation (recommendation IXa & b). Furthermore, the answers to several other recommendations (IV, VI, VII) would be strongly improved by the companion studies and the results of such a programme.

On a general basis, the importance for IPTP to work as a central point of all tagging experiments conducted in its area of competence was stressed, and led to the following recommendations:

I. IPTP should maintain a central file of all Indian Ocean tagging data; countries or organizations conducting tagging experiments should submit a complete copy of those data to IPTP;
II. IPTP should act as a channel through which countries and organizations conducting tagging experiments within the Indian Ocean can publicize their activities in order to maximize tag returns. IPTP should also continue to act as an inter-regional coordinator to ensure smooth transfer of

relevant tagging information with organizations in other Oceans, notably with SPC.

Although this Workshop was devoted to yellowfin tuna, it was then emphasized that the discussion should be extended, taking into account the more general conclusions of previous meetings such as the last Expert Consultation on Stock Assessment of Tuna in the Indian Ocean (Bangkok, 2-6 July, 1990): the determination of the objectives (stock structure, biological parameters, stock management, fisheries interactions) of the tagging experiment which is essential and will determine the strategy (time-area strata, species, sizes) to be put into action, the expected number of returns, the type of vessel to be used.

The three major problems raised on yellowfin tuna (the nature of the relationship between CPUE and abundance, the stock structure and migration pattern and the uncertainties in most of the biological parameters) are also valid for skipjack and bigeye. A fourth capital issue - with less scientific impact but of considerable interest for all the concerned parties - is the problem of interactions between fisheries and species (on "local", "regional" and "species" bases) also needs to be examined.

Although the Workshop did not give any firm advice considering the proposed large-scale tagging programme to be implemented, several general guidelines were outlined:

Area and species:

* The general area of operation will be the western Indian Ocean (west of 80Ê), where the surface fisheries are well developed for both industrial and artisanal fisheries;
* Yellowfin should be the target species; other species - mainly skipjack and bigeye tuna - will be tagged as far as possible on an opportunistic basis;

Objectives:

* The programme should focus as first priority on stock structure and biological parameters, which are the most critical uncertainties for future stock assessment;
* Given the paramount and rather unique importance of artisanal coastal fisheries (which represent nearly 30% of the total Indian Ocean tropical tuna catch) and the variety of gears used (pole-and-line, gillnets, troll, purse-seine, handlines, ...), fisheries interactions should be the second priority;
* The tagging strategy should take into account the order of these priorities; however, the possibility of achieving other objectives for yellowfin and/or other tuna species without significantly increasing the cost of the programme should be explored.

Type of boat:

* This point was thoroughly examined; as it is essential to be able to tag in the main fishery (i.e. the large purse-seine fishery) all year round, a sufficiently large tagging boat is absolutely necessary. However, complementary tagging from small scale artisanal fisheries (as done in Maldives for example) should be integrated in the programme as often as possible;
* As it is an essential element of the success of the programme, due consideration should be given to carefully choose the type of vessel to be used.

Budget:

* Of course, it will include all expenses directly linked to the programme (vessel chartering, scientific staff, travels, equipment and supplies, rewards and lotteries, ...);
* It was also stressed that obtaining information on recapture as well as the thorough analysis of resulting data are integral parts of the programme and should be included in the budget; specially, the importance of advertising (administrations, fishermen, canneries, ...) as well as collecting and checking of all the returns needs special attention.

The programme will be prepared on such a basis, and submitted for funding at the beginning of next year (EEC or any other source).

10.4. Management

No recommendation were made by the Workshop on management.

However, it was not evident to participants that the stock is now threatened by exploitation, despite the tremendous increase of the catch these last 10 years. Nevertheless, participants pointed out numerous uncertainties that are detailed in the previous sections; they concluded that significantly more research is needed as recommended above, before the status of the stock can be more precisely determined.

11. ADOPTION OF THE REPORT

The report of the Workshop on Stock Assessment of Yellowfin Tuna in the Indian Ocean was adopted on 12 October 1991.

Appendix 1

INAUGURAL ADDRESS OF THE HON. JOSEPH MICHAEL PERERA MINISTER OF FISHERIES AND AQUATIC RESOURCES AT THE WORKSHOP ON STOCK ASSESSMENT OF YELLOWFIN TUNA IN THE INDIAN OCEAN, COLOMBO, SRI LANKA
7-12 OCTOBER, 1991

Distinguished Participants, Ladies & Gentlemen,

In view of the emphasis placed on exploitation of tuna species world over, I consider this Workshop on Stock Assessment of Yellowfin Tuna in the Indian Ocean to be an extremely important one and I am happy to be associated with you to share a few thoughts this morning.

I understand that this Workshop is organized based on a recommendation made at the Expert Consultation on Stock Assessment of Tunas in the Indian Ocean held in Bangkok, Thailand, in July 1990. Tuna fisheries is of paramount importance for my country as well as other countries in the region. Tuna fisheries in Sri Lanka is artisanal and small scale fishing communities are engaged in exploitation of this resource. The present production is in the region of 25,000 metric tons and Yellowfin tuna contributes substantially to this catch.

As you are aware, UNDP/FAO is committed to develop fisheries in our region. Under the policy guidance of the Indian Ocean Fishery Commission and Indo-Pacific Fishery Commission, Indo--Pacific Tuna Programme (IPTP) was established in 1982 in Colombo. The broad obejctive of the IPTP is to assist the governments in the long-term management and development of fisheries for tuna and tuna-like species. Within this framework, technical objectives like compilation and dissemination of regional statistics, coordination of research, regular review of status of tuna stocks was undertaken under the important database building objective. A self-sustaining data centre funded by coastal countries, distant water fishing countries, EEC and FAO is proposed.

I am happy to note that the IPTP has successfully achieved its objective of establishing a regional tuna information centre to compile and disseminate regional tuna statistics, coordinate research and arrange for regular reviews on the status of tuna stocks and their exploitation. However, due to constraints on funds and manpower, limited work on stock assessment has been done.

Although exploitation of tuna stocks is important for the improvement of nutritional standards of our people, it has to be undertaken on a sustainable basis. Conservation-oriented exploitation is possible only with reliable information on stocks and therefore this Workshop is timely. With the deliberations

of the Scientists gathered here, the status of tuna stocks in the Indian Ocean would be better known.

The excellent work done by the IPTP has to be continued. The proposed Indian Ocean Tuna Commission is the logical evolution of the IPTP and I wish to reiterate our committment to management of Indian Ocean Tuna by providing host facilities to the Commission in Sri Lanka.

In conclusion, I wish to take this opportunity to thank UNDP for the assistance and the Organisers for the invitation extended to me to inaugurate this Workshop. I am sure that your deliberations will assist the countries in the region in conservation-oriented exploitation of tuna for the provision of much needed animal proteins for our people and socio-economic improvement of small-scale fishing communities. I am sure you will have sometime off from your busy schedules to enjoy the Sri Lankan hospitality. I wish you success.

Thank you.

Appendix 2

AGENDA

1. OPENING OF THE MEETING
2. ADOPTION OF THE AGENDA AND MEETING ARRANGEMENTS
3. REVIEW OF WORKING PAPERS
4. REPORTS OF THE WORKING GROUP MEETINGS
5. REVIEW OF NATIONAL YELLOWFIN TUNA FISHERIES IN THE INDIAN OCEAN
6. REVIEW OF THE DATABASE
   (1) Nominal catch statistics
   (2) Catch and effort statistics
   (3) Size frequency data
   (4) Tag release and recapture data

7. REVIEW OF BIOLOGICAL PARAMETERS
   (1) Length-weight relationship
   (2) Growth
   (3) Natural mortality
   (4) Stock structure and biological characteristics of the stock
   (5) Others: size at first maturity, sex ratio by sizes, etc

8. CREATION OF CATCH-AT-LENGTH DATA
9. STATUS OF STOCK
   (1) Trends of stock abundance
   (2) Production model analysis
   (3) Catch at age table: calculation and discussion of trends
   (4) Estimates of population sizes and fishing mortality trends using Sequential Population Analysis
   (5) Yield-per-recruit analysis
   (6) Review of results

10. RECOMMENDATIONS
    (1) Statistics and research
    (2) Tagging
    (3) Management

11. ADOPTION OF THE REPORT

Appendix 3

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Appendix 4

LIST OF DOCUMENTS

TWS/91/01 Provisional agenda.
TWS/91/02 Provisional list of participants.
TWS/91/03 Provisional list of documents.
TWS/91/04 Report of the Mauritius Working Group (preparatory Working Group for the IPTP Workshop on Stock Assessment of Yellowfin Tuna in the Indian Ocean) to be held in Colombo, October, 1991, Mauritius, 17-23 May 1991.
TWS/91/05 Report of the Working Group Meeting of longline fishery for stock assessment of yellowfin tuna in the Indian Ocean, 24-28 June, 1991, Shimizu, Japan.
TWS/91/06 An extract on Indian Ocean yellowfin tuna from the report on State of Selected Stocks of Tuna and Billfish in the Pacific and Indian oceans (FAO Fisheries Technical Paper No 200 : FIRM/T200 1980).
TWS/91/07 Review of the database - IPTP.
TWS/91/08 Preliminary results for yellowfin tuna (Thunnus albacares) from the Maldivian Tuna Programme - M. Yesaki and A. Waheed.
TWS/91/09 Population parameter estimates of Indian Ocean yellowfin tuna based on length data - M. Yesaki.
TWS/91/10 Trends in tuna longline fishery in Indian seas with particular reference to exploitation of yellowfin tuna - M. E. John, D. Sudarsan & A. K. Bhargava.
TWS/91/11 Some biological considerations of yellowfin tuna, Thunnus albacares (Bonnaterre) taken by longline gear in the Indian EEZ - D. Sudarsan, M. E. John & K.N.V. Nair.
TWS/91/12 Present status of the yellowfin tuna fisheries in Sri Lanka - P. Dayaratne & R. Maldeniya.
TWS/91/13 Spanish status report of yellowfin tuna fishery, 1984 - 1990 - J.I. Parajua.
TWS/91/14 Yellowfin length-weight relationships from western Indian Ocean purse-seine fisheries - J. P. Hallier.
TWS/91/15 Artisanal and industrial (Surface and longline) fisheries of yellowfin tuna in Mauritius from 1987 - 1990 - D. Norungee & A. Venkatasami.
TWS/91/16 Status report of the Korean tuna longline fishery for yellowfin tuna in the Indian Ocean - Y. C. Park, W. S. Yang and T. I. Kim.
TWS/91/17 Growth of Indian Ocean yellowfin tuna estimated from size frequencies data collected on French purse-seiners - F. Marsac.
TWS/91/18 French and Ivory Coast yellowfin purse-seine fishery of the western Indian Ocean (1984-1990) - J. P. Hallier.
TWS/91/19 National report of Taïwan - Institute of Oceanography, National Taïwan University.
TWS/91/20 Present status of yellowfin tuna fishery in Indonesia - N. Naamin & B. Gafa.

TWS/91/21 Fishery biology and status of stock of yellowfin tuna - P. P. Pillai, K.P. Said Koya & T. M. Yohannan.

TWS/91/22 Yellowfin tuna fishery in India: National Status Report - P.S.B.R. James & P. P. Pillai.

TWS/91/23 On the occurence of yellowfin tuna (Thunnus albacares) in the drift gillnet catch at Cochin P.S.B.R. James & A. A. Jayaprakash.

TWS/91/24 How much bigeye in Maldivian Tuna Catches - R. C. Anderson & A. Hafiz.

TWS/91/25 Status report of Japanese longline fishery with respect to yellowfin tuna in the Indian Ocean - National Research Institute of Far Seas Fisheries.

TWS/91/26 Regional Tuna Tagging Project - Monthly tagging summary, September 1991 - South Pacific Commission.

TWS/91/27 Yellowfin tuna fisheries of the western Australian fishery zone - P. Ward.

TWS/91/28 Yellowfin tuna in Oman: A status report - T. Zahran Al-Abdisalaam.

TWS/91/29 Tuna Bulletin - First Quarter 1991 - Seychelles Fishing Authority.

TWS/91/30 Tuna Bulletin - Second Quarter - 1991 - Seychelles Fishing Authority.

TWS/91/31 Diet composition of tunas caught with longlines and purse-seines in the western Indian Ocean - YugNIRO.

TWS/91/32 Notes on reproductive biology of yellowfin tuna in the western Indian Ocean - V. F. Bashmakar, V. V. Zamorov & E. V. Romanov.

TWS/91/33 On the role of the swimming crab Charybdis smithi McLeay in the feeding habit of yellowfin tuna Thunnus albacares (Bonnaterre) - V. V. Zamorov, V.A. Spiridonov & G.V. Napadovsky.

TWS/91/34 Status of yellowfin tuna (Thunnus albacares) fishery in Pakistan - A. Majid & J. Ahmed.