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Special Report 9

PROCEEDINGS OF THE

FIRST WORLD MEETING ON BIGEYE TUNA

Edited by

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La Jolla, California
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TABLE OF CONTENTS

INTRODUCTION

The first world meeting on bigeye tuna, *Thunnus obesus*, was held in the Southwest Fisheries Science Center, U.S. National Marine Fisheries Service, La Jolla, California, USA, on November 11-15, 1996. The meeting included participants from the Food and Agriculture Organization of the United Nations (FAO), the Indian Ocean Tuna Commission (IOTC), the Institut Français de Recherche Scientifique pour le Developpement en Coopération (ORSTOM) of France, the Instituto Español de Oceanografía (IEO) of Spain, the Inter-American Tropical Tuna Commission (IATTC), the National Research Institute of Far Seas Fisheries (NRIFSF) of Japan, the South Pacific Commission (SPC), the U.S. National Marine Fisheries Service (NMFS), the University of the Azores, and the University of Hawaii. These are listed on pages 291-292. Richard B. Deriso of the IATTC served as convenor of the meeting. A contribution from FAO paid for the printing of this report and for some other costs of the meeting.

The annual catches of bigeye are exceeded by those of only two other species of tuna, skipjack, *Katsuwonus pelamis*, and yellowfin, *Thunnus albacares*. However, because most of the bigeye caught are consumed fresh, whereas most of the skipjack and yellowfin caught are canned, the economic value of bigeye exceeds that of any other species of tuna. Despite its importance, less is known of the biology of bigeye than of the biology of any of the other principal market species of tunas. Historically, bigeye have been harvested mostly by longlines, which take only medium to large fish. During recent years, however, greater amounts of small bigeye have been caught by purse seines and other surface gear. This is a matter of concern for several reasons. First, longline fishermen are concerned that the harvesting of small bigeye will decrease the amounts of medium to large bigeye available to them. Second, since small bigeye are canned, rather than eaten fresh, consumers are concerned about the possible decrease in the supply of high-quality fresh fish. Third, economists are concerned about the possible economic loss associated with harvesting fish at less than their maximum economic value. Fourth, biologists are concerned about the possibility that harvesting of small bigeye could decrease the overall catches of that species. These concerns cannot be properly addressed until more knowledge of the biology of bigeye is available. The purposes of the meeting were to review and discuss the information available and to make recommendations for further research.

The following sessions were held: (1) discussion of review papers prepared for the Atlantic, Indian, and Pacific Oceans; (2) review of basic data; (3) review of parameter estimates; (4) review of stock assessment; (5) suggestions for future research. The rapporteurs' reports for all but the first session are included in the next section of this report.

RAPPORTEURS' REPORTS

BASIC DATA

Chairman: Antony D. Lewis

Rapporteurs: David Itano and Naozumi Miyabe

The session chairman introduced the topic of basic data currently available on bigeye tuna and fisheries. The meeting agreed to discuss and compare bigeye data pertaining to the following categories: catch and effort statistics, size-frequency data, sex ratio information, maturity indices, species composition and tagging data. The discussion objectives were further defined to discuss and assess the utility of basic data collection in these categories to the stock assessment of bigeye tuna resources. The quality and accuracy of available data (especially species composition) and the importance of technological changes in bigeye fisheries were also discussed.

Total catch, logsheet data and species composition

Atlantic Ocean

The collection of logsheet data and the determination of species composition of the catch were discussed by ocean basin. The status of Atlantic catch statistics (landings) was stated as being relatively good with total landings reported by country and gear, catch and effort reported by $1°^2$/month/fleet for purse seine and baitboat vessels and by $5°^2$ for longliners. Problems with non-reporting or mis-reporting of juvenile bigeye tuna as other tuna species were highlighted from the purse-seine catches for which a specific meeting had been convened (Anon., 1984). Procedures for adjusting logsheets to match species composition sampling were also discussed.

The majority of purse-seine port sampling is conducted in Tema and Abidjan at a reasonable level. Length-frequency and species composition data are collected from the wells for large- and small-sized fish, but sampling is not stratified by school type. This data are used to adjust logbooks by fish size categories.

Discards on the fishing grounds in the absence of at-sea observer programs and the side-marketing of "black market" fish were noted as two sources of unrecorded tuna catch in Atlantic purse-seine fisheries. However, bigeye were noted to constitute only 2% of black market fish by weight (Amon Kothias *et al.*, 1993). In the future, the loining and processing of whole tuna at sea was noted as a potential problem, and it was suggested that conversion factors for loined weight to whole weight of tuna species should be developed. The IATTC noted that length/weight conversions for a wide range tuna species and dressed condition would be included in a soon-to-be-published IATTC Bulletin on the EPO Japanese longline fishery.

The Atlantic longline fishery was described as predominantly a Japanese fishery that submits high-quality logsheet data. However, a potential problem may exist for recent Taiwanese longline data in the Atlantic, since the Taiwanese fishery reportedly increased substantially after 1990. This year, the Taiwanese fleet reported landings of 10,000 mt for the past four years, and it is not certain what level of accuracy these figures represent. It was suggested that reported catches could be compared to bigeye landings in Japan from the Atlantic Taiwanese fleet as a way to grossly estimate the accuracy of logsheet data from this fleet.

The lack of a vessel registry system for ICCAT was highlighted as a major problem in the Atlantic and Indian Oceans.

Indian Ocean

The main problems of catch reporting in the Indian Ocean were stated as under-reporting, non-reporting or lack of timely submission of catch data by distant-water Taiwanese longline vessels and the lack of a vessel registry system to monitor participation in the fishery. It was recommended that a longline port sampling program be re-established in southern Indonesia to record catch and effort for smaller Taiwanese "offshore" class longliners. The possibility of expanding an ongoing CSIRO southern bluefin tuna sampling program in Bali was discussed. Data collection from artisanal fisheries of the Indian Ocean are not well established, with the exception of Sri Lanka and the Maldives. The representative of the IPTP stated that the duties and responsibilities of his office will be assumed by the IOTC, and endorsed the establishment of a vessel registry system to be administered by this organization.

Sampling of purse seiners unloading in the Seychelles and Madagascar is relatively good, but the program needs to be significantly expanded to sample vessels now unloading in other ports. The increasing trend to transshipment at sea will pose additional problems. Basically, an increased level of sampling is required to allow more accurate adjustments of logsheet data to reflect true catches and landings.

The port sampling procedures to record length frequencies and determine species composition of the catch by time/area strata were described in detai, and appear very thorough. Sampling is conducted by size class of tuna species and related to original school type. The Seychelles no longer conducts an observer program, and discards at sea are not recorded unless reported by fishermen.

The meeting recommended that bigeye catches by gear type be reported in the text of this report, with some indication of the level of confidence of the estimate.

Eastern Pacific Ocean

A representative of the IATTC reviewed logsheet data collection and adjustment procedures. Basically, purse-seine logsheet data are adjusted to reflect port sampling of the catches, if necessary, with the total weights adjusted to reflect cannery unloading totals. The IATTC conducts a large at-sea observer program, but observers do not take at-sea length-frequency measurements, and their other data are not used to determine species composition of the catch.

Western Pacific Ocean

A representative of the NMFS reviewed data collection and logsheet procedures for the US western Pacific fleet. Logsheets are submitted from all vessels licensed under the South Pacific Tuna Treaty that is monitored by an at-sea observer program of the Forum Fisheries Agency, with approximately 20% coverage of the fleet. Port sampling of vessels unloading in Pago Pago is conducted to obtain species composition data and total catch for the trip, using a stratified sampling protocol by area and month. Sampling continues until all areas have adequate sampling by species, size and set type for a given month. It was noted that FFA observers on these vessels also conduct species composition and length-frequency sampling of every set. This information is used to refine logsheet data onboard the vessel, but is not used or normally compared to the NMFS port sampling data. It was suggested that a comparison of this nature should be done to assess the accuracy of both sampling programs and eliminate unnecessary duplication of effort.

For Japanese purse-seine vessels, data previous to 1994 are derived completely from logsheet data submitted by the commercial fleet. It is likely that landings of juvenile bigeye were not accurately recorded during this period. Beginning in 1994, the NRIFSF began a sampling program at two ports (Yaizu, Makuzaki) to better define species composition, length frequencies and catch by time/area strata at a coverage rate of 10% of all unloadings. Sampling is conducted within the commercial market categories. The agency has also instituted an at-sea observer program.

Problems with reported catch and data from the Japanese purse-seine fishery include: sorting and high grading (discards) at sea which are not reported, the mixing of catches during well transfers at sea which make the determination of catch by time/area strata impossible for many sets and opposition to sampling high grade (PS grade) tuna by the fishermen.

The representative of the NRIFSF estimated that reported bigeye landings of 2,000 mt by the Japanese purse-seine fleet should be raised to 2,800 mt.

Landings by other DWFN and Pacific Island domestic or joint venture purse-seine and longline fleets are compiled by the South Pacific Commission from logsheet data, and are regularly reported in the quarterly SPC Tuna Bulletin and the annual SPC Fishery Yearbook. Current estimates of bigeye bycatch in the western Pacific purse seine fishery (1989-1995) range from 11,105 to 19,197 mt per year. These rough estimates are based on port sampling data of US purse seiners by set type applied to the total yellowfin catches by set type for other fleets. These estimates make numerous assumptions, and should be regarded as preliminary. No data or estimates are available from Indonesia and the Philippines, where yellowfin catches by various gears are approximately 120,000 mt per year.

The representative of the SPC stated that separate estimates of bigeye catch that have been previously combined with yellowfin landings will be reported in future issues of the SPC Tuna Yearbook. The estimates will use the best estimates of bigeye bycatch by set type that are currently available. Total bigeye catches in the western Pacific may exceed 70,000 mt per year, but have been relatively stable in recent years.

Japanese longline

Japanese longline tuna fisheries consist of three vessel classes operating in different areas. The distant-water fleet is composed of large-sized boats, and operates mostly in the eastern Pacific. The second fleet consists of medium-sized vessels whose operational area is limited to western Pacific. The third category are small-scale longliners fishing in the coastal waters of Japan. Landing have been well covered by the statistical procedures which include conversion of fish in number to weight. Except for the coastal longliners, data are collected and coverage exceeds 85%. Starting in 1993, several improvements to data collection have been instituted; logbook coverage has been expanded to include coastal longliners with daily catch information in weight by species and data on the number of fish caught included in the new logbooks.

Japan also has distant-water and coastal pole-and-line fisheries targeting skipjack and, to a lesser extent, albacore. Bigeye landings in these fisheries are considered to be relatively insignificant.

Effort

A round-table discussion was held on the type and detail of fishery data necessary to define effort in bigeye tuna fisheries. For longline fisheries, it was agreed that the most important gear and operational aspects to record are the number of hooks per basket, the length of the floatline, the total number of hooks per set and the time of setting and hauling. This information allows the rapid categorization of a longline fishery as to fishing strategy, *e.g.* traditional daytime and deep-set bigeye gear or shallow night-set gear that usually targets bigeye during new moon periods. Additional gear details of secondary importance were listed, such as type of bait (live or dead), mainline type, use of lightsticks, *etc.*

The definition of effort in the purse-seine fisheries is far more complex, and a consensus was difficult to achieve. Active discussion on the efficiency of purse-seine gear over time ensued, with the majority in agreement that purse-seine fleets continue to improve their fishing power over time, which can confound CPUE analyses. No clear consensus was reached on this topic, with catch per set, catch per successful set and catch per fishing day given as typical examples. The comparison of purse-seine CPUE among years will always be confounded by possible changes in fishing power or efficiency of different fleets, which led the meeting to endorse the importance of recording and documenting changes in gear technology and methodology over time that can influence catches and CPUE, *i.e.* use of drifting FADs, bird radar, more powerful hydraulic systems, deeper nets, *etc.*

Sex ratios

The sex ratio of bigeye tuna appears to approach 1:1 for fish less than approximately 120 cm FL. The pattern is not so uniform for larger fish, although a trend toward a predominance of males in larger length classes is apparent in the larger data sets available to the group (Pallarés *et al.*, 1998). Yellowfin tuna exhibit a definite shift in sex ratio toward males in sizes over approximately 110 cm FL, and females virtually drop out of the population at sizes over 150 cm FL. Many researchers have postulated that this is due to the onset of sexual maturity and a slowing of growth rates of females due to the energetic demands of daily spawning, leading eventually to a higher natural mortality rate. It was proposed that if this theory holds true for bigeye tuna a less definite change in sex ratio could be explained by a higher average length at sexual maturity and a lower cost of spawning (*i.e.* lower spawning rate or shorter seasons). Further studies and data collection on the sex ratio of bigeye by size class are needed.

Tagging

Atlantic Ocean

Two tagging projects in the Atlantic were described. The first has released approximately 1,000 small bigeye in the Gulf of Guinea region during the International Skipjack Year Program, with bigeye exhibiting the most directed movements out of tropical areas to possible sub-tropical feeding areas. Another Atlantic tagging project on Senegal baitboats is ongoing, and has released 300 bigeye with 60% recapture rates. The high recapture rate is a consequence of this fishery operating on tuna schools maintained in long term associations with the capture vessels.

Indian Ocean

Some opportunistic tagging of bigeye has taken place in the Maldives during a small-scale skipjack tagging project, but no recoveries were recorded. Research cruises of the Japanese purse seiner, RV *Nippon Maru*, have tagged approximately 1,300 bigeye during the period 1980-1990, with a recovery rate of 3%.

Pacific Ocean

Some general cautions and requirements for the design of tuna tagging programs were discussed. It was agreed that tagging programs are vital but expensive projects to run, and that it is desirable to collect as much information as possible during the field component of a tagging project that may later be useful for the robust analysis of recapture data. In particular, methods to estimate tag shedding and under-reporting of recaptures are necessary. Of course, the most important aspect of tag recapture programs is a strong and continuing publicity campaign.

The Hawaii Seamount Tagging Project (ongoing) was described, which has currently released over 1,600 bigeye and yellowfin tuna in the outer Hawaii EEZ, with 5% recaptures from handline, troll and longline gear. This small scale project is examining fishery interaction, retention rates of tuna on seamounts and anchored FADs and movement of tunas within and around the Hawaii region. The project is collaborating with the IATTC on an age validation study of bigeye tuna, and over 600 bigeye have been OTC injected to date, with a target release number of 1,000. Some OTC recaptures have already been made, but reading and analysis will not occur until 1997.

The NMFS (Honolulu Laboratory) has been conducting conventional tagging of large, longline-caught bigeye tuna during research cruises in and north of the Hawaii EEZ. Sixty bigeye have been tagged to date, with three recaptures. Comments were made to the effect that bigeye tunas are distinct from other tropical tunas in having higher survival rates on longlines, as determined by TDR-equipped gear, and appear to make good candidates for longline tagging.

The IATTC stated its aspirations to mount a large-scale bigeye tagging project in the EPO to address interaction concerns in the face of a rapidly-expanding surface fishery west of the Galapagos Islands. Its proposal has been in limbo for two years, as a major source of funding has yet to be identified.

The representative from the SPC presented tagging information specific to bigeye tuna from the large-scale Regional Tuna Tagging Project. Yellowfin tuna were the target of this project, but 8,074 bigeye were tagged, with a current recapture rate of 11.5%. Most of these releases were made in the Coral Sea of Australia on medium- and large-sized fish (6% return), in the southern Philippines on small fish (28% return) and the remaining number of releases spread out along the equatorial fishery on small and medium-sized fish (13% return). Coral Sea recaptures exhibit an interesting seasonal pattern of continuing recaptures of up to five years at liberty in the area of release, in contrast to Philippines recaptures which occurred very quickly in the area of release to a very high level and stopped after a year. The remaining recaptures are spread across the area of the western Pacific fishing grounds in a pattern similar to yellowfin recaptures. However, a few recaptures of Coral Sea releases have been made in the Hawaii EEZ or as far east as 130°W in the main area of the Japanese longline fishery for bigeye (over 4,000 nm displacement). Bigeye are clearly capable of considerable long-distance movement throughout their life history, although many long-term recaptures show minimal displacement.

References

Amon Kothias, J. B., J.P. Hervé, and F.X. Bard. 1993. Updates of quantities of minor tunas (*Auxis*, *Euthynnus*) and small tunas (skipjack, yellowfin, bigeye) landed as market fish in Abidjan, 1981-1993. ICCAT Col. Vol. Sci. Pap. 42 (2): 377-380.

Anon. 1984. Report of the data preparatory meeting for the working group on juvenile tropical tunas. February 3-9, 1984. CRODT, Dakar, Senegal. ICCAT Redbook, Appendix 2. pp 28-54.

Pallarés, P., J. Pereira, N. Miyabe, and A. Fonteneau. 1998. Atlantic bigeye tuna: overview of present knowledge (November 1996). Inter-Amer. Trop. Tuna Comm. Spec. Rep., 9: 20-80.

PARAMETER ESTIMATES

Chairman: Alain Fonteneau

Rapporteurs: François X. Bard and Francis Marsac

The session chairman emphasized the key importance of the biological parameters for realistic stock assessment leading to efficient fishery management. The main parameters were reviewed as follows.

Growth

Pacific Ocean

An analysis was undertaken by SPC from tag recoveries of the Regional Tuna Tagging Project, for the western and central Pacific. A von Bertalanffy model integrating measurement errors and individual variability in L_∞ was used on a data set of 254 reliable returns. The best fit between the length increment and the time at liberty was obtained through a segmented model, with linear growth for the data set with less than 500 days at liberty, and a von Bertalanffy model for time a liberty > 500 days (size range of 40-110 cm FL). The annual K and L_∞ of this second segment are 0.4272 and 156.82 cm, respectively. However, the estimates can be improved with a complementary analysis of daily rings on otoliths which is underway.

Another study based on otolith microstructure is in progress from fish caught by Japanese purse seiners in the western Pacific (Matsumoto, 1997). The total sample consisted 160 individuals, ranging from 27 to 67 cm FL, but only 9 have been analyzed so far (35-60 cm FL). Assuming daily deposits, the growth would be 40 cm in six months and 55 cm in one year. Otoliths from larger fish will be processed by this technique.

Modal progressions were used in the eastern Pacific (Tomlinson, 1998). Two cohorts appear yearly in the fishery. The distinction between modes is reliable for fish smaller than 130-140 cm, but it becomes increasingly difficult beyond this size, where the individual variability generates a smoothing of the size distribution.

In Hawaii, OTC tagging for validation of hard-part readings has been recently initiated (600 fish so far).

Atlantic Ocean

Three techniques were used: spines, tagging and modal progression. ICCAT has used tagging data to study the growth of bigeye (size range: 38-92 cm, sample size: 139 fish). The curves are similar for juveniles, but diverge for large fish, which is likely to be due to sexual dimorphism. The growth of juveniles is well known, but such is not the case for adults, so studies should be focused on these.

Indian Ocean

There have been no recent studies in this ocean. The past analyses used modal progressions on juveniles (Mozambique Channel) and reading of hard parts for fish of a wider size range. The latter, which did not provide reliable results, produced estimates of 59 cm/yr. during the first year and 24 cm during the second year. Estimates on young fish (40-70 cm) are 16 to 18 cm/yr.

These studies need to be completed: actually, the large number of length-frequency samples available in the purse-seine fishery and those which have just been released in the longline fishery should be analyzed, using Petersen modal structure and progression.

Discussion

The growth might be described by other models (Richards function, or polynomial fit) depicting different stanzas or aging segments, in relation with the ecology and the life cycle of the fish. It should be kept in mind that the growth estimated at the level of the population is likely to be underestimated, compared to the individual pattern.

At the present stage, it remains difficult to compare statistically the different growth curves presented, due to the various size spans used, and the time basis of the *K* (month, quarter, year). For clarification, a comprehensive analysis of the growth rates in the three oceans, using original data, should be undertaken.

Natural mortality

There is still little knowledge of this parameter.

Pacific Ocean

The SPC tagging program produced estimates of *M* for juvenile bigeye (25-40 cm, tagged in Philippines) and bigger fish (55-105 cm, Coral Sea). Different estimates of *M* were obtained, according to the reporting rate. For a rate of 0.5, the *M* for juveniles would be 0.34 on a monthly basis, and 0.46 on an annual basis for the second group. These estimates support the hypothesis of an age-specific *M*, which is still challenged. The very high *M* on juveniles could also be an "apparent *M*" due to a strong migration pattern away from the Philippine fishery.

Atlantic Ocean

The *M* vector used in the ICCAT analyses is 0.8 for ages 0 and 1, and 0.4 for older fish. It was hypothesized that *M* is high when the small bigeye are intermingling with skipjack and yellowfin of similar sizes, and then decreases when the bigeye become larger and no longer school with skipjack and yellowfin. Nevertheless, reliable estimates of *M* are still not available.

Indian Ocean

The values used in past analyses were either the Atlantic vector or different levels of constant *M* (0.2, 0.4, 0.6).

Discussion

It was stressed that uncertainties concerning *M*, especially for the juvenile component, have important consequences on the yield per recruit. Greater Y/Rs are available from an exploited stock with a relatively low *M* if the age at first capture is delayed. Conversely, a high *M* would make possible a high exploitation rate on juveniles without significantly affecting the Y/R (as juvenile *N* is very large). However, it has been hypothesized that the older fish become senescent, at which time *M* increases.

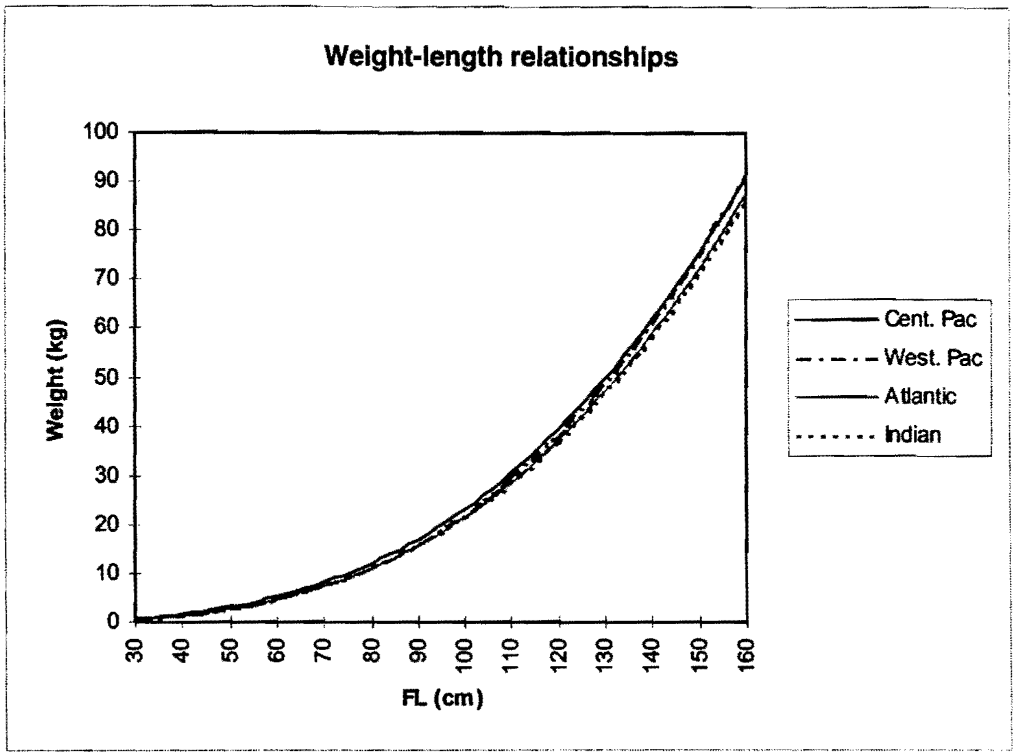
It is agreed that a better assessment of the transfer rates between the surface fisheries catching a high proportion of juveniles (*e.g.* the payao fishery in the Philippines) and offshore longline fisheries is one of the ways to improve the estimates of *M* for juvenile fish. Tagging remains the appropriate technique to meet this goal.

Weight-length relationships

In the Pacific, two WL relationships are used, namely from the central and western Pacific data sets (9,144 and 481 individuals, respectively). In the Atlantic, one relationship was adopted by ICCAT. In the Indian Ocean there are two data sets obtained from purse-seine samples (Arabian Sea and western basin). However, the Arabian Sea data set, whose quality is questionable, is not currently used.

The combined plot of these curves (Figure 1) does not show great differences for fish under 130 cm FL. Beyond 130 cm, however, the divergence of the curves is more significant. The difference in weight at 160 cm FL is around 6 kg.

The hypothesis of different WL relationships for the sub-equatorial spawning areas and the feeding zones in temperate waters was discussed. Therefore, effort should be made to check if such differences are real. It is also recommended that an analysis of variance of estimators (*a* and *b*) between sexes and among gear types, areas and seasons be undertaken for the three oceans.



Central Pacific: Nakamura and Uchiyama (1966) - longline
Western Pacific: Morita (1973) - longline
Atlantic: Parks *et al.* (1982) - bait boat and purse seine
Indian: Cort (1986) - purse seine

Swim bladder

An interesting finding was made recently in the Atlantic (Azores) by Pereira regarding the swimming bladder of juvenile bigeye tunas. Those which associate with skipjack do not fully develop their swimming bladder: only the front part is functional, and the rear part displays a ribbon-like shape. This is probably explained by the fact that the bigeye are feeding in the surface layers. So far, it has not been observed in the Pacific (Hawaii and Tahiti), where young bigeye have a fully-developed swim bladder, which makes possible longer dwelling times in deep waters to feed.

Photographs of these half-developed bladders would be helpful in carrying out comparative surveys in the other oceans. A relationship with the size of the pectoral fins may exist, since a greater fin size can provide a better hydrostatic equilibrium to balance the adverse effect of a reduced swim bladder. The different swimming behavior may result in a catchability specific to each type. In addition, there might be a genetic dimension to this characteristic which would be interesting to investigate.

Length-age conversion

It is rather easy to assign ages to bigeye in accordance with their lengths during the first five years or so of life, but after that it becomes more difficult. The basic problem is the overlap between modes, which is caused by the variability in growth of individual fish and on the protracted periods of spawning and recruitment.

The slicing method, which is used in the western Pacific, the Indian Ocean, and the Atlantic Ocean is easy to implement, but not entirely satisfactory. Probabilistic methods, such as Multifan (Fournier *et al.*, 1990), might produce better estimates, particularly when consecutive weak and strong cohorts are observed.

Sex ratio

The observations available indicate that males are more numerous than females among the larger fish (>150 cm), except off southern Brazil. However, this sexual dimorphism is not as marked as in yellowfin or albacore, for which it occurs at earlier life stages.

Explanation of this phenomenon could partly involve sexual growth dimorphism (*e.g.* females growing more slowly) and differential *M*. It was pointed out that the variations on *M* and growth could be linked together, particularly at the level of the individuals: those which grow more rapidly will die sooner that those having a slower growth rate.

Extensive sampling could be carried out from longliners, when the fish are gutted, to provide more reliable estimates of the sex ratio by size.

Movements

The debate was focused on the alternative "oriented" *versus* "random" movements. Maps of the distribution of catches by ocean (Fonteneau 1998: Figures 4-6) show two major areas of concentration: an equatorial area, where spawning occur, and temperate areas where sub-adults congregate probably for feeding. In the Pacific and the Atlantic, the feeding zones are located mainly in the northern portion of the ocean, from 30°N to 40°N. A secondary zone is also found in the South Atlantic, off Uruguay, and to a lesser extent off South Africa. In the Indian Ocean there is only a southern feeding area, between 30°S and 40°S from South Africa to Australia.

The meaning of the movements between these two areas was much discussed. Are there directed migrations from spawning to feeding areas or only random movements bringing only a part of the population spending its life stage in the temperate waters to the equatorial spawning grounds? The biological and evolutionary meanings of the second hypothesis were discussed without reaching any definite conclusions.

Another common feature shared by the Atlantic and Pacific is the meridian equatorial "gap" due to low densities of the longline catches. Several explanations, such as lower biomass or heterogeneity in of the distribution of the fishing effort, have been given. Such heterogeneity could be related to shear currents that could prevent successful setting of the longlines or a poorer quality of the flesh for those equatorial fish, making them less suitable for the high-grade *sashimi* market.

In the Pacific, the IATTC staff has postulated that the bigeye movement pattern is very similar to the yellowfin model, *e.g.* two components separated by 150°W. This hypothesis is presently supported by a lack of transoceanic tag returns, but this result might not be significant because of the very small number of releases.

The development of the log fishing has increased the levels of catch of juvenile bigeye in the eastern Pacific, eastern Atlantic and Indian Oceans. This may lead to a new interpretation on the geographical extension of the nursery grounds.

It was concluded that further information on movements and stock structure is needed, and that this can be obtained from large scale tagging experiments initiated in various areas and directed at a wide size range of fish. Another field of investigation is the reproductive biology. The fact that longliners seek to catch fish which will bring high prices because of the quality of the flesh was stressed and, consequently, relationships between the physiological status of the fish *versus* commercial quality should be investigated according bench marks. A Hawaii-based consulting firm has been investigating tuna quality issues relevant to the equatorial purse seine and longline fisheries of the western Pacific. Its findings indicate an inverse relationship between flesh quality of skipjack and yellowfin tuna and increased spawning activity. Further studies in this area are recommended.

Two major objectives were identified: 1) better assessment of the spatial variation of the longline effort, and 2) knowledge of the physiological status at the different stages of the life cycle, *i.e.* migration, nutrition, pre and post-spawning, and its relation with natural mortality.

Other topics

Reports from the Atlantic (Bard *et al.* 1996) mention the unusual occurrence of "green bigeye" observed in 1993 and 1994 among large individuals (> 60 kg), due to bones stained by biliverdine. This phenomenon has not been observed in other areas. No physiological explanation has yet been proposed.

Literature cited

Bard, F. X., J.B. Amon Kothias, J. Panfili, and A. Hervé. 1996. Unusual occurrence of "green tunas" in Abidjan landings, 1993-1995. Inter. Comm. Cons. Atlan. Tunas, Coll. Vol. Sci. Pap., 45 (3): 126-129.

Cort, J.L. 1986. Data on tuna fishing by Spanish vessels in western Indian Ocean. In Expert Consultation on Stock Assessment of Tunas in the Indian Ocean IPTP Coll. Vol. Work. Doc., 1: 165-167.

Fonteneau, A. 1998. A comparison of bigeye stocks and fisheries in the Atlantic, Indian, and Pacific Oceans. Inter-Amer. Trop. Tuna Comm., Spec. Rep., 9: 190-211.

Fournier, D. A., J. R. Sibert, J. Majkowski, and J. Hampton. 1990. MULTIFAN a likelihood-based method for estimating growth parameters and age composition from multiple length frequency data sets illustrated using data for southern bluefin tuna (*Thunnus maccoyii*). Canad. Jour. Fish. Aquatic Sci., 47 (2): 301-317.

Matsumoto, T. 1998. Preliminary analysis of age and growth of bigeye tuna, *Thunnus obesus*, in the western Pacific Ocean based on otolith measurements. Inter-Amer. Trop. Tuna Comm., Spec. Rep., 9: 238-242.

Morita, Y. 1973. Conversion factors for estimating live weight from gilled-and-gutted weight of bigeye and yellowfin tunas. Far Seas Fish. Res. Lab., Bull., 9: 875-913.

Nakamura, E. L., and J. H. Uchiyama. 1966. Length-weight relations of Pacific tunas. *In* Manar, Thomas A. (editor), Proceedings of the Governor's [Hawaii] Conference on Central Pacific Fishery Resources: 197-201.

Parks, W., F. X. Bard, P. Cayré, S. Kume, and A. Santos. 1982. Length-weight relations for bigeye tuna captured in the eastern Atlantic Ocean. Inter. Comm. Cons. Atlan. Tunas, Coll. Vol. Sci. Pap., 17 (1): 214-225.

Pereira, J. G. 1998. Bigeye tuna: the access to deep waters. Inter-Amer. Trop. Tuna Comm., Spec. Rep., 9: 243-249.

Tomlinson, P. K. 1998. Assessment studies of bigeye tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Spec. Rep., 9: 250-290.

STOCK ASSESSMENT

Chairman: Alejandro A. Anganuzzi

Rapporteurs: Jacek Majkowski and Pilar Pallarés

The Chairman of the session suggested that the discussions be structured according to the following topics: stock structure, indices of abundance, non age-structured models, VPA, and yield-per-recruit analysis.

Stock structure

Most aspects of the topic were comprehensively addressed within Agenda Item 3 (Parameter estimates). Therefore, during discussion of this Agenda Item, only the usefulness of genetic methods for the determination of the most appropriate management units of the population were considered. Genetic mutation rates were not regarded to be relevant criteria for identifying stock structure. It was concluded that the potential usefulness of genetic methods is limited to the rejection of the hypothesis that fish are from the same stock.

It was pointed out that when two genetically-separate stocks occupy the same area they should be managed separately. This is required in the light of recently-formulated requirements for fisheries management.

Indices of abundance

Longliners

The Japanese longline fishery has been operatinglonger than that of any other nation, and covers the largest geographical area. Data from that fishery were considered particularly suitable for developing an index of abundance because the way of setting the gear doesnot vary much.

Detailed information on the operation of fisheries (including the setting of longlines) and on oceanographic conditions was regarded as necessary for the estimation of effective fishing effort and the standardization of CPUE. In particular, information is needed on:

- the number and position of hooks on which fish were caught;
- the temperature at the depths at which hooks were set; and
- the time of day the longlines are set,

potentially allowing the determination of depths at which fishing is most effective. Such information could be obtained by observers. It was pointed out that such information has been actually collected for longline fisheries operating off the Federated States of Micronesia (FSM).

Due to logistic difficulties, two observers are required for collection of all the necessary data. Time-depth recorders might be used for recording the temperature at the depths at which hooks are set, but the cost of such equipment is considerable.

Various problems with the development of abundance indices were considered. One of them is local depletion, due the operation of many fishing vessels, in areas where initially the density of fish was very high . This phenomena makes the identification of areas with a high density of fish nearly impossible if the data are aggregated over longer periods.

It was felt that with the development of other longline fisheries catching bigeye (*e.g.*, from Korea and Taiwan), abundance indexes from these fisheries might provide useful supplementary information, particularly when these fisheries operate in areas and periods different from those for the Japanese fishery. It was suggested that detailed information from the Korean and Taiwanese fisheries which is required for the determination of effective fishing effort and the standardization of CPUE from the different fisheries be obtained. A recommendation that steps be taken to facilitate the collection of such data was made to various international tuna institutions.

Purse seiners

The presently-available data do not allow determination of abundance indices from purse-seine fisheries because the mechanisms of fish aggregation around logs and the effectiveness of searching for fish are poorly understood. One of the unknown relationships is that between school sizes and the local density and/or abundance of the stock. The extrapolation of mechanisms of fish aggregation from skipjack and yellowfin to bigeye tuna was seen as not necessarily appropriate.

It was suggested that modeling studies should be initiated to explore various hypotheses regarding fish aggregation and to determine the most suitable abundance indexes associated these hypotheses. Most data necessary for carrying out this task are already available.

It was pointed out that environmental effects should be accounted for in the development of abundance indices, as they may affect the catchability coefficient. In particular, the depth of net and its relationship with the depth of thermocline may critically influence the effectiveness of fishing.

The feasibility of obtaining fishery-independent indices of abundance was considered. It was concluded that the chances of obtaining useful information are not high and that the cost of surveys would be very high.

Production models

The participants discussed the disadvantages of applying fitting procedures based on an equilibrium assumption to the estimation of parameters of production models in tuna stocks and, in particular, to bigeye tuna. The conclusion was that the use of equilibrium-based methods, which assume that the population reaches a new equilibrium level immediately after any change in fishing mortality, should be discouraged. The reason is that they might introduce serious biases in the parameter estimates even if, in some cases, their results might be close to the ones obtained by non-equilibrium methods.

In the case of analyses carried out on bigeye tuna stocks, it was noted that the use of the program PRODFIT (Fox, 1970) to estimate the parameters actually includes a procedure to correct for deviations from the equilibrium assumption.

The main issue discussed under this subject was the applicability of production models, considering the recent increases in fishing mortality on small bigeye tuna by the purse-seine fisheries. If these increases are important, then the pattern of age-specific selectivities will change significantly, with subsequent changes in the yield per recruit and productivity of the population. Production models, in general, do not take into account these changes, as they assume that the selectivity pattern remains constant through time.

In general, it was agreed that when there are changes in the fisheries, especially if the fishing grounds are changing, the results of analyses using production models might indicate discrepancies with previous estimations. The cases of the eastern Pacific or the Atlantic show how expansions in the fishing grounds might result in increases in the estimates of the stock productivity.

Actually, important changes are taking place in the bigeye fisheries of the Pacific, Atlantic and Indian Oceans. In addition to the traditional longline fisheries, still the predominant gear in bigeye tuna fisheries, the purse-seine fleets are developing fishing strategies which result in significant increases in bigeye catches.

The large development of the FAD-associated fishery and the use of sonar in the identification of schools have increased the catchability of the purse-seine gear on the juvenile bigeye tuna. The fishing grounds have expanded as the fleet follows the drifting FADs, and the use of the sonar has resulted in the access to a possibly new component of the stock. Recent estimates of the MSY have been greater than previous ones. However, there is not enough information to determine whether the current level of catches is sustainable, especially taking into account that the increase in fishing mortality is, fundamentally, on juveniles and that production models cannot predict the consequences of this increase on the spawning stock.

In summary, it was agreed that the production models do not offer a good assessment of the current status of the bigeye stocks.

Cohort analyses

The discussion was focused on the convenience of utilizing VPA models tuned with indices of abundance and on the indices to use. It was agreed that the main problem was that the appropriate indices were not always available and that the quality of the available indices was questionable. In all cases, the only indices available for large fish are from catch rates of Japanese longline vessels. These indices are assumed to represent the relative abundance of the adult stock.

It was mentioned that the tuning could be focused on the age groups that contribute the most to the stock biomass. However, the absence of indices for the younger ages is an important problem because it does not allow the tuning of the estimates of recruitment. Along the same lines, the fact that the indices are limited to a few age classes forces the assumption of constant selectivity patterns, with problems when the partial recruitments are variable. This situation occurs frequently in tuna fisheries in general, and in bigeye tuna in particular. Under this issue, it was suggested that models based on broader age categories, each including more than one age, be used. The advantage of these models would be that the problems related with the assignment to ages could be avoided, although it would be necessary to include new assumptions about the selectivity among groups, and the results could be very dependent upon the values for the terminal fishing mortality.

There was consensus that, while the minimum abundance is relatively easy to estimate, there are many uncertainties in the estimates of the actual abundances, independent of the VPA model utilized.

Another issue discussed was the significance of the abundance indices, considering that, in many cases, the longline indices represented at best the local abundance. If we consider that the tuna "viscosity" is relatively low, changes in the abundance on the fishing grounds could have little effect on other fishing grounds. In such cases, the trend in the local abundance (measured by changes in the CPUE) will be different from the trends in total stock abundance. It was mentioned that it was important to differentiate between stock and exploitable stock and between the range of the stock and the fishing area.

The effects of errors in the age assignment, especially for older fish, were again discussed. It was considered that the extent of this effect might depend on the longevity of the species, on the ages present in the fishery and on the exploitation pattern. Taking into account the fact that the stock dynamics is dominated by the biomass of the first age groups when growth is rapid, if the catch is dominated by these classes ageing errors might have little effect on the estimates of recruitment and mortalities. This situation cannot be extrapolated to other stocks, such as bluefin tuna with a different exploitation pattern and an important fishing mortality on older ages.

The possibility of using other types of models was discussed. The first model considered was the spatially-disaggregated model used in the assessment of the South Pacific albacore tuna, which is being tested with other tuna stocks (yellowfin). The model requires estimates of density-dependent growth, movement, mixing rates, and catchability (mostly from the tagging studies). The applicability of this model to bigeye tuna is low, first because the structure of the bigeye stock is more complex than that of albacore, with a poorly-defined distribution and movements. Another significant problem is the large number of parameters in the model and the lack of data, especially from tagging studies, to estimate mixing rates. Nevertheless, it was agreed that this is an interesting model that should be tested for bigeye as specific research programs provide the information required.

The possibility of running VPA analyses for each ___ was discussed. Pope's (1972) method could be applied on a monthly or quarterly basis, which would produce independent estimates of recruitment and mortalities for the purse-seine and longline data, assuming, in each of the analyses, that the whole stock had been caught.

Yield per recruit

The importance of natural mortality in the results from yield-per-recruit analyses was again discussed. It is essential to have accurate estimates of this parameter to determine the effect of increases in juvenile fishing mortality on recruitment to the longline fishery, yields of the surface and longline fisheries, and the status of the stock. The need for tagging programs that would furnish the data necessary to estimate this parameter was emphasized. The tagging program should be extensive, covering the geographic range of the fishery and the range of sizes of fish taken by the surface and longline fisheries. The problem of tag recovery in all the fisheries, and the longline fisheries in particula,r was discussed. Only a continuous effort to improve communication between scientists and fishermen will be able to solve this problem. In addition to traditional tags, other types of tags, such as archival and pop-up tags, should be considered. Archival tags were considered to have interesting possibilities, and it was reported that the project for Atlantic bigeye tuna includes the release of 400 bigeye tuna with archival tags. Pop-up tags were also considered of potential interest, although they have not been developed yet. Along the same lines, it was suggested that studying physical factors might make it possible to assess natural mortality.

Literature cited

For, W. W., Jr. 1970. An exponential surplus-yield model for optimizing exploited fish populations. Amer. Fish. Soc., Trans., 99 (1): 80-88.

Pope, J. G. 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. Inter. Comm. Northwest Atlan. Fish., Res. Bull., 9: 65-74.

FUTURE RESEARCH

Chairmen: Richard B. Deriso and Christofer H. Boggs

Rapporteurs: William H. Bayliff and Hiroaki Okamoto

At the start of this session Dr. Boggs stated that scientists working on bigeye in a particular ocean area should be aware of work carried out in other ocean areas, and use information from other areas to evaluate their own work or, when appropriate, use parameter estimates from other areas when they have been unable to calculate such estimates for their own areas.

Dr. Fonteneau called attention to the fact that scientists' interpretations of their findings can be affected by the types of maps and charts (type of projection, features shown, *etc.*) that they use, so they should be aware of this and, if appropriate, plot their data on more than one type of map or chart.

Species identification

Bigeye, particularly the smaller ones, are frequently recorded as yellowfin, or even as skipjack. Bigeye are quite different in appearance from skipjack, and reliable criteria for distinguishing bigeye and yellowfin exist. Sampling to determine the species composition of the catches should be done for all areas, seasons, gear types, and sizes of fish, and the catch and effort statistics should be adjusted accordingly. This work should include catches from all oceans, and should rate high priority. (In some areas such sampling is already being done, and the catch and effort data are already being adjusted.) The IATTC is preparing an improved guide to diagnostic characters of bigeye and yellowfin, which it can make available to other organizations.

Statistics

ICCAT has published catch statistics for the Atlantic Ocean in its annual Statistical Bulletins. The IATTC and the SPC should either publish a single volume for the Pacific Ocean or publish separate volumes for the regions east and west of 150°W in the same format so that scientists are able to combine the data for the two areas easily when necessary. (Catch and effort statistics for the eastern Pacific have been published in the IATTC Annual Reports. More detailed statistics for the surface fishery and for the Japanese longline fishery of the eastern Pacific have been published by Hinton and Ver Steeg (1994) and Uosaki and Bayliff (1997), respectively, and previous papers cited therein. The SPC publishes catch and CPUE statistics for the SPC area in its quarterly Regional Tuna Bulletins and its annual Tuna Fishery Yearbooks. Parts of the western Pacific Ocean are not covered in the SPC reports, and parts of the eastern Pacific Ocean are covered by both the IATTC and SPC reports.) These data could be made available on the Internet.

More at-sea observer programs are needed, and greater rates of coverage are needed for many of the existing programs. A notable exception is the fleet of large purse seiners which fishes in the eastern Pacific Ocean.

Gillnet fisheries should be more closely monitored to determine how much bigeye they catch.

Attempts should be made to obtain electronic monitoring data on vessel positions to use for scientific purposes.

All of the above work should include fish from all oceans, and should rate high priority.

Effort should eventually be devoted to investigating methods of monitoring longline and purse-seine catches automatically, *e.g.* with video cameras, "black boxes," *etc.* This work should include fish from all oceans, and should rate medium priority.

Tagging

Tagging frequently provides better information on stock structure, movements, mixing rates, interactions among different fisheries, growth, mortality, and behavior than do any other techniques, and it should be vigorously pursued in all oceans on fish of a wide range of sizes.

Some form of estimating the amount non-reporting of recaptures of tagged fish should be incorporated into the design of any tagging experiment.

Archival tagging would provide useful information on behavior, but it should be conducted in circumstances for which the probability of recapture of the tagged fish is high. The use of pop-up tags should also be considered, as these would provide extremely valuable information on mortalities.

Consideration should be given to tagging longline-, purse seine-, baitboat-, troll-, and handline-caught fish. Trolling and handline fishing might be conducted in deep water near FADs and natural aggregators, such as islands and seamounts. The IATTC should conduct a pilot study to investigate the possibility of tagging bigeye aboard purse-seine vessels which fish for tunas associated with FADs and other floating objects. (These vessels usually make one set each day, early in the morning, and then drift the rest of the day near the same object, or travel to a nearby object marked with a radio beacon. When such is the case, tagging 100 or so bigeye before brailing commences would not usually cost the vessel any searching time.) Group purse seining, as practiced by some Japanese vessels (Itano, 1991), produces fish in better condition for tagging than those caught by conventional purse seining. Undersized bigeye caught by Ecuador-based longliners could be tagged by observers aboard these vessels. In the Atlantic *mancha* fishing, in which a fishing boat is used as a floating object, and is replaced by an empty vessel when it gets a load of fish (Fonteneau and Diouf, 1994), might produce fish for tagging.

The Indian Ocean Tuna Commission should devote more effort to tagging of bigeye and analyzing the data.

If and when tagging is conducted, considerable effort should be devoted to publicizing the program, canvassing the ports where fish are landed, encouraging the fishermen to provide accurate data on locations and dates of recapture and sizes of the fish, paying the rewards promptly, creating and maintaining an adequate data base, *etc.*

Estimates of parameters

Growth

Separate growth rates and weight-length relationships should be estimated for fish of different putative stocks, for males and females, and for fish caught in feeding and spawning areas. This work should include fish from all oceans, and should rate high priority. The growth rates of the older fish should be validated. If otoliths of fish caught within a few years of atmospheric testing of nuclear weapons during the 1950s and 196s are available, these might be useful for age validation, as was the case for southern bluefin tuna (Kalish *et al.*, 1996). The California Department of Fish and Game might be a source of these. The search for such otoliths should include fish from all oceans, and it should rate medium priority.

Modeling should be carried out to estimate the effects of biased estimates of the age of the fish on stock assessments; this should also rate medium priority.

Bigeye are currently being tagged and marked with oxytetracycline near Hawaii, and this work should produce some data useful for age validation.

Natural mortality

The natural mortality is almost certainly greater for young fish than for those of medium age, and it may be greater for mature females than for mature males (Pallarés *et al.*, 1997: Figure 8).

Separate vectors of natural mortality should be estimated for fish of different putative stocks, for males and females, and for fish caught in feeding and spawning areas. This work should include fish from all oceans, and should rate high priority.

An attempt should be made to find the original data of Shomura and Keala (1963) so that they could be used to attempt to determine whether the mortality rates of males and females differ.

Fishing mortality

Estimates of fishing mortality should include all fish which die due to fishing, *e.g.* fish which are retained for sale through normal channels, fish which are landed, but are not in good enough condition for sale through normal channels, fish which are discarded at sea, fish which are hooked by longlines, but "stolen" by other fish or by marine mammals, fish which drop off longlines before they can be brought aboard the vessels, *etc.* This work should include fish from all oceans, and should rate high priority.

Movements

The tagging experiments mentioned above should produce estimates of directional movements and diffusion, which are necessary for estimating mixing rates, interactions, *etc.* This work should include fish from all oceans, and should rate high priority.

Maturity

Gonadosomatic indices are not accurate indicators of spawning activity (de Vlaming *et al.*, 1982), but nevertheless they will continue to be calculated and used because it is much easier to employ gonadosomatic indices than to conduct histological studies. Fish from the same samples should be used for histological studies of maturity and for calculations of various gonadosomatic indices. The data should be compared, so as to ascertain which gonadosomatic indices give results which are closest to the truth, as measured from histological studies. The maturity indices should be correlated with such things as condition factors and ocean temperatures. This work should include fish from all oceans, and should rate medium priority.

Indices of abundance

In general, indices of abundance are more useful for stock assessment of longer-lived species. Bigeye are longer lived than skipjack and yellowfin, but shorter lived than albacore and bluefin. It is easy to calculate indices of abundance, but difficult to determine what they are measuring, since vulnerability to capture is not necessarily constant Since the longline and purse-seine fisheries exploit bigeye of different ages, there is probably no point in attempting to standardize either of these to the other. Some participants expressed the opinion that it is not necessary that indices of abundance be precise, nor is it even necessary that they be accurate (unbiased), provided the biases are constant from year to year. Others said that, although precision and accuracy may not be necessary for stock assessment, these are important for studies of some aspects of biology, such as detecting movements and making inferences about habitat preferences. Studies of indices of abundance should be conducted for the fisheries of all oceans, and should rate high priority.

Indices of abundance from purse seining

Calculation of meaningful indices of abundance from a purse-seine fishery on tunas associated with floating objects will not be possible until a better understanding of this fishery is obtained; this would be a good subject for a doctoral dissertation. In the meantime, catch per day's fishing (catch/(days absent - days traveling through areas devoid of fish, days lost due to bad weather or mechanical problems, *etc.*)) is probably the best index of abundance of the fish.

Indices of abundance from longlining

Longline catches are recorded as numbers of fish, and these are converted to weights before performing some types of stock assessment. Different scientists use different methods to determine the average weights of the fish, however, and this results in disagreement as to the catches.

It is common for the longline CPUEs to be extremely high in newly-exploited areas, followed by declines in the CPUEs to less than half the original rates, but increasing catches. Nobody knows the reason(s) for this, although it has been hypothesized by Nakano and Bayliff (1992) that in a virgin stock there are accumulations of fish which are highly vulnerable to capture by longlining and which are decimated within a few years.

Hook saturation can be a problem in the analysis of longline CPUE data. The catch per baited hook provides a better index of abundance than the catch per total number of hooks. When the longline is first placed into the water all the hooks are baited, but by the time it is removed from the water many of the hooks are occupied by fish or have lost their bait. The average number of baited hooks available is less than the number of baited hooks placed into the water, but more than the number of baited hooks removed from the water (but not necessarily the arithmetic or geometric mean of these). Adjustments to compensate for different levels of hook saturation in different area-time strata should be made.

Sometimes the CPUEs are high in areas with little fishing effort; these data should not be considered to be as significant as data for areas with high CPUEs and substantial amounts of effort.

Most studies of longline fishing have used only data for Japanese vessels, but in the future, as more vessels of other nations enter the fishery, more attention should be directed to data for these.

More attention should be directed to peripheral fisheries, *e.g.* those of Hawaii and the Azores Islands.

Attempts to standardize effort data by comparing the CPUEs of different gear configurations in the same area-time strata, *e.g.* Punsly and Nakano (1992), should continue. Also, attempts should be made to standardize the effectiveness of single gear configurations with different environmental conditions, *e.g.* temperature, depth of thermocline, *etc.* (Punsly and Fiedler, 1996).

Production modeling

In general, the results of production modeling are not very satisfactory. It is difficult or impossible to use production modeling with all the data for a fishery which consists of significant catches of both younger fish taken by the purse-seine fishery and older fish taken by the longline fishery.

Although production modeling is traditionally performed with catch data for all fisheries combined, it is possible to carry out the analyses with catch and CPUE data for the longline fishery alone. The removals by the purse-seine fishery can be regarded as reductions in recruitment to the longline fishery. The maximum sustainable yield (MSY) for the longline fishery estimated for a period of low catches by purse seiners should be greater than that for a period of high catches by purse seiners. In fact, if adequate data are available, the effect of the purse-seine fishery on the longline fishery can be evaluated in this manner.

Cohort analyses

Cohort analyses have considerable promise, but the results of such analyses are highly dependent on the assumptions which are made. The results of cohort analyses are always algebraically correct; the problem is to select a solution which is also biologically correct, or nearly so.

As a first step, estimates of age-specific abundance, from which age-specific total mortality can be estimated, are necessary. The estimates of age-specific abundance are almost always obtained from fishing data, and if the vulnerability to capture varies among fish of different ages the abundance indices will be biased. Even if the estimates of age-specific abundance are abundance are unbiased, there still remains the problem of partitioning the total mortality into natural and fishing mortality. Information from other sources, such as tagging, can be useful in selecting input for cohort analyses which are likely to provide solutions which are biologically reasonable.

Spawner-recruit relationships

The available data on relative abundance of bigeye spawners and recruits are poor, and no relationships between spawners and recruits have not been detected for other tropical tunas, so this type of study should be given low priority.

A workshop on stock assessment of bigeye involving about four to eight participants, all with experience and expertise in stock assessment, should be held in the near future. The emphasis of the workshop should be on evaluation of concepts, rather than on techniques.

A workshop on bigeye similar to that of 1996 should be held in about 5 to 10 years.

Literature cited

Fonteneau, Alain, and Taib Diouf. 1994. An efficient way of bait-fishing for tunas recently developed in Senegal. Aquatic Living Resources, 7 (3): 139-151.

Hinton, Michael G., and Gayle Ver Steeg. 1994. Statistics of the eastern Pacific Ocean tuna fishery, 1979 to 1992. Inter-Am. Trop. Tuna Comm., Data Rep., 8: ii, 96 pp.

Itano, David G. 1991. Tuna tagging and observations on a Japanese group purse seine vessel. South Pacif. Comm., Tuna and Billfish Assessment Programme, Tech. Rep., 23: vii, 31 pp.

Kalish, John M., Justine M. Johnston, John S. Gunn, and Naomi P. Clear. 1996. Use of the bomb radiocarbon chronometer to determine age of southern bluefin tuna (*Thunnus maccoyii*). Mar. Ecol. Prog. Ser., 143 (1-3): 1-8.

Nakano, Hideki, and William H. Bayliff. 1992. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1981-1987. Inter-Amer. Trop. Tuna Comm., Bull., 20 (5): 183-355.

Pallarés, P., J. Pereira, N. Miyabe, and A. Fonteneau. 1998. Atlantic bigeye tuna: overview of present knowledge (November 1996). Inter-Amer. Trop. Tuna Comm., Spec. Rep., 9: 20-80.

Punsly, R. G., and P. C. Fiedler. 1996. Purse-seiner catch rates of yellowfin tuna >7.5 kg, with and without dolphins, in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Internal Rep., 25: 41 pp.

Punsly, Richard, and Hideki Nakano. 1992. Analysis of variance and standardization of longline hook rates of bigeye (*Thunnus obesus*) and yellowfin (*Thunnus albacares*) tunas in the eastern Pacific Ocean during 1975-1987. Inter-Amer. Trop. Tuna Comm., Bull., 20 (4): 165-184.

Shomura, Richard S., and Betty Ann Keala. 1963. Growth and sexual dimorphism in growth of bigeye tuna (*Thunnus obesus*) a preliminary report. FAO Fish. Rep., 6 (3): 1409-1417.

Uosaki, Koji, and William H. Bayliff. 1998. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1988-1992. Inter-Am. Trop. Tuna Comm., Bull., 21 (6): in preparation.

de Vlaming, Victor, Gary Grossman, and Frank Chapman. 1982. On the use of the gonadosomatic index. Comp. Biochem. Physiol., 73A(1): 31-39.

ATLANTIC BIGEYE TUNA:
OVERVIEW OF PRESENT KNOWLEDGE (NOVEMBER 1996)

by

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1. FISHERIES

1.1. Description

Atlantic bigeye has been widely fished between 50°N and 50°S by surface fleets (live-bait and purse-seine) and particularly by longliners (Figure 1).

1.1.1. Baitboat fisheries

The live-bait fisheries, the first bigeye fisheries to be developed, are artisanal and operate locally. The fleet based in Tema (Ghana) is composed of boats from Ghana, Japan and Korea, and targets juvenile bigeye (average weight 2.5 kg) in the Gulf of Guinea area. The fleet based in Dakar (Senegal) includes boats from Senegal, France, Spain and Cape Verde which fish for preadult bigeye (average weight 18 kg) seasonally in the coastal area north of Senegal and Mauritania. In temperate waters, close to the Canary Islands, Madeira and the Azores, there are local fleets targeting preadults and adults between 100 and 180 cm (average weight 30 kg). Figure 2 shows the size distribution of the catches by gear.

Since the mid-1980s, the live-bait fleets based in Dakar have fished on *manchas*, a mode of fishing in which a vessel will follow a single school of fish and fish on it repeatedly throughout the fishing season (Fonteneau and Diouf, 1994). Since 1994, the live-bait fleet based in the Canary Islands also fishes on *manchas* (Ariz, 1995). This new fishing mode has increased the catches of the boats, and has also extended the fishing season.

Another important change in the baitboat fishery has been the introduction of fishing on floating objects fitted with radio beacons. The fleet based in Tema has used this mode of fishing since the early 1990s, and it has led to an important increase in the fleet's performance.

1.1.2. Purse-seine fisheries

The purse-seine fishery catches juvenile bigeye incidentally in eastern coastal areas, where they appear in mixed schools with small skipjack and yellowfin; the average weight in the purse-seine catch is 5.5 kg. This fishery, initiated in the eastern Atlantic the early 1960s, is currently composed of the French, Spanish and the so-called NEI (not elsewhere included) fleets. The NEI fleet includes all vessels operating under flags of convenience. The U.S., Japanese, Russian and other fleets have left the fishery.

Recently, the fleets have developed new fishing methods which have led to a large increase in the catches of juvenile and preadult bigeye. Since 1990 the purse-seine fleet has fished on floating objects fitted with radio beacons. This new fishing method has led to radio beacons being fitted to many natural or, more frequently, artificial floating objects (fish-aggregating devices, or FADs), allowing them to be tracked and monitored (Ariz, 1993, 1996; Fonteneau, 1993; Anon., 1993).

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Fishing on floating objects, or "logs," has taken place since the beginning of the purse-seine fishery, but is limited to specific zones and seasons (Fonteneau and Marcille, 1991). Previous to the development of fishing on beacon-equipped logs, about 20% of the sets were made on log-associated fish (Bard *et al.* 1985; Stretta and Slepouka, 1986). Since then nearly half of the purse-seine catches have been made in sets on logs.

Ariz *et al.* (1993) indicate that sets on logs are directed primarily toward skipjack (76% by weight), but the catches also include juvenile yellowfin (17%; average weight 5.3 kg) and bigeye (7%; average weight 4.5 kg). Comparison of the size distributions of the bigeye catches on logs and in free-swimming schools (Figure 3) shows that the ranges of sizes are very similar, being mostly juveniles. In contrast, yellowfin caught in free-swimming schools are large, while those caught on logs are exclusively juveniles.

The new fishing mode on logs takes place primarily in the equatorial zone during the first and fourth quarters, and in the Dakar, Cape Lopez and Abidjan areas during the third quarter; during the second quarter this type of fishing is less important (Figure 4).

The increase of fishing on logs has had two important consequences: a) it has enlarged the area of exploitation toward the west and toward the area to the south of theequator, following the shift of the logs caused by the equatorial currents (north and south) (Figure 5), and b) it has probably led to an increase in fishing power, producing greater catches than in 1990 with a similar presence in the fishing area. Catches on logs are greater, around 40 MT per set, while catches on free schools are between 17 and 28 MT per set (Pallarés *et al.*, 1995; Ariz *et al.*, 1996).

1.1.3. Longline fisheries

The greatest catches of bigeye (over 60% of the total) are made by longliners, which fish for the species in a wide area along the equator between 15°N and 15°S. This fishery catches adult bigeye, weighing, on average, about 40 kg.

The longline fisheries began to develop in the Atlantic Ocean in the 1950s. The main fleet, the Japanese, began its activities in 1956 in the equatorial zone, targeting yellowfin. From 1970, the fleet expanded the area of fishing toward temperate zones and the high seas, and introduced deep longlines (170 to 300 m depth), directing its effort toward bigeye, more valuable after the development of the Japanese *sashimi* market.

The Taiwanese longline fleet began to operate in the Atlantic Ocean in 1962, and, like the Japanese fleet, began fishing for yellowfin and later albacore. Since 1990, it has fished for bigeye, using deep longlines.

The Korean fleet, the third longline fleet in the Atlantic Ocean, initiated its activities in 1963, fishing for albacore and, since the beginning of the 1970s, yellowfin. In 1980 it began to use deep longlines, targeting bigeye.

Other less important longline fleets that operate or have operated in the Atlantic Ocean are those of Brazil, Brazil-Japan, Cuba, and the United States.

Since the change of target species to bigeye, the fleets fish in an extensive area, showing a strong seasonality. Figure 6 shows the quarterly distribution of the longline catches. During the first quarter two areas are observed, south and north of the equator and around 40°N. The equatorial fishing areas become less important, and are centered further to the west, later in the year. Catches in the northern area continue during the second and third quarters, but are less important. After the second quarter, the fishery moves southward along the African coast (Angola and South Africa) and to the south of Brazil.

1.2. Available data

The data available for bigeye are those in the data base of the International Commission for the Conservation of Atlantic Tunas (ICCAT): catches and effort by gear and 1° x 1° area and month for purse-seine and live-bait vessels, and 5° x 5° area and month for longliners, for the 1950-1995 period, and length-frequency distributions by 5° x 5° area (purse seine and live bait) and 5° x 10° area (longline) area and month. The longline length-frequency data start in the 1960s, and those for the surface fleet toward the end of the 1970s.

The data for the purse-seine and live-bait fleets operating in the Gulf of Guinea area are estimates, which since 1984 have been based on samples obtained from a multispecies sampling program (Bard, 1985) in effect since 1980. The sampling coverage of bigeye for the main purse-seine fleets of the eastern Atlantic is shown in Table 1.

The species composition recorded in vessel logbooks is adjusted by a method developed by the Working Group on Juvenile Tropical Tunas at a meeting in Brest (France) in 1994, which is designed to correct errors detected in the records of catches by species. Basically, the group found biases in the records of catch by species in the logbooks, and especially large ones for small fish. Two sources of bias were identified: misidentifying bigeye as yellowfin, arising from difficulty in distinguishing the two species in their juvenile phase and from the greater quantity of the yellowfin catch; and recording small bigeye and yellowfin as skipjack in sets on mixed schools in which skipjack clearly predominate. In both cases the result was an underestimate of the catches of juvenile bigeye.

Figure 7 shows the percentages of bigeye recorded in the logbooks and those obtained from multispecies sampling, by type of association. Figure 8 shows the same percentages for fish of less than 10 kg (Category 1). The percentages obtained in the samples are more than double those recorded in the logbooks. For small fish these differences are considerably greater, due to the fact that the greatest biases detected come from this category, as mentioned above. This means that using the figures recorded in the logbooks can lead to the bigeye catches being underestimated by 60%.

The method of adjustment for species composition was developed by taking into account the realities of the fishery in the 1980s. The application of this adjustment procedure has allowed us to reconstruct the catch-at-age matrix for juvenile bigeye, which has led to a clear improvement in the estimates of population parameters made using analytical models, especially yield-per-recruit (YPR) models. Since the current adjustment method was developed, the surface fishery (purse seiners and part of the live-bait fishery) has undergone major changes in fishing strategy, which might affect the species composition of the catch and reduce the value of the estimates obtained with the traditional adjustment method. The introduction of fishing on beacon-equipped FADs would be one of the most significant changes affecting the species composition of the catch. Similarly, analyses of the species and length-frequency composition (Fonteneau, 1991) show other important effects, such as distance from the coast or from islands, seamounts (around which bigeye tend to congregate), *etc.*

For all these reasons, it is important that the current method be thoroughly reviewed and that a procedure be developed that will provide better estimates of the catches by species, while taking into account the current realities of the fishery. This task is the aim of a special program initiated in 1995, with funding from the European Union.

1.2.1. Catches

Table 2 and Figure 9 show the evolution of total catches and catches by gear during the 1950-1995 period. A first stage, in which the longline and live-bait fisheries predominate, can be seen, followed by an increase in the longline catch from the early 1980s after the introduction of deep longlines targeting bigeye, as a result of the rise in the value of bigeye in the Japanese market. Since the early 1990s there has been an increase in the purse-seine catches of bigeye, as a result of the expansion of the fishery on beacon-equipped FADs. The catches in the live-bait fishery remained constant, although in recent years they have also increased due to the introduction of fishing on beacon-equipped FADs from the baitboat fleet based in Tema and of fishing on *manchas*, introduced by the live-bait fleets operating near Dakar and in the Canary Islands.

The total catch has generally shown an increasing trend. It was below 40,000 MT during the period before 1971, rose to 64,000 MT in 1974, and then remained around that level, with considerable fluctuation. In 1991 it exceeded 80,000 MT, and increased further during the following two years, reaching a historic high of 107,000 MT in 1994. This increase in recent years is attributable to increases of 20,000 MT in the purse-seine catch and 14,000 MT in the longline catch. Except for the most recent years, the fluctuations in the catch were caused mostly by the longline fishery, whose catches accounted for 60 to 70% of the total catch.

The purse-seine catch was less than 10,000 MT in the years before 1991, except for 1977 and 1981-1984. It has been reported that the increased use of artificial FADs in purse-seine operations in tropical areas was a primary cause of this increase, since young bigeye often form mixed-species schools associated with FADs.

The total longline catch has been fairly stable, fluctuating between 27,000 and 50,000 MT. However, it has exceeded 50,000 MT in the three most recent years. The 1995 catch was close to 60,000 MT. This increase was due to a sudden increase in the catch of the Taiwanese fleet, when it shifted its effort from albacore in temperate waters to bigeye in tropical waters, and a gradual increase in the Japanese catch.. In the western Atlantic, the U.S. longline fleet has recorded fairly stable catches (500-1,000 MT) over the past 10 years.

The decline of the longline catch observed in 1986 and 1987 was caused by the decrease in the numbers of boats of the Japanese and Korean fleets. While the Korean fleet continued to decrease in size, the Japanese fleet recovered and reached its highest level in 1993. In addition, the number of Taiwanese longliners has increased considerably since 1993.

The total baitboat catches have remained relatively stable between 12,300 and 17,600 MT since 1985, except for 1988. The annual variation observed in the catch is due mostly to the fluctuation in the catches of the baitboat fisheries around islands (Canary Islands, Madeira and the Azores). The major baitboat fisheries recorded relatively greater catches in 1995. Catches by Portuguese baitboats in 1995 showed a sharp increase from the very low level of 1994, due probably to favorable environmental conditions.

1.2.2. Effort

Day's fishing standardized to French purse seiners (Category 5) is used as a measure of purse-seine effort. Figure 10a shows the evolution of effort. There are two series of effort since 1981. One does not take into account the changes in fishing power of the newest purse seiners resulting from newly-introduced technological improvements such as bird radar, larger nets, and more powerful engines, and especially the introduction of fishing on beacon-equipped FADs which, as an examination of the catches of bigeye shows, has apparently led to a large increase in the catchability of that species. Likewise, the probable greater use of sonar could lead to further increases in catchability.

The other series of effort incorporates a constant annual increment of 3% in the fishing power of the purse seiners. This approximation of the effective effort is based on analyses of the evolution of the fishing power of the tropical purse-seine fleets (Gascuel *et al.,* 1993), which estimated an average increase of over 20% during the 1980-1990 period. These analyses did not take into account the effect of fishing on floating objects on the efficiency of the boats, since this fishing mode was introduced subsequent to the study. As a preliminary estimate, the 3% increase has been maintained for the years after 1990.

Days at sea is used as a measure of live-bait fishing effort. As with the purse-seine fleet, this measure does not take into account changes in fishing power which the live-bait fishery has experienced as a result of the expansion of fishing on FADs and the development of the technique of fishing on *manchas*.

Number of hooks is used as a measure of longline effort. Figure 10b shows the evolution of effective longline effort, based on standardized catch rates for Japanese longliners.

1.2.3. Catch rates and indices of abundance

Catch rates are available for most surface fisheries. Figure 11 shows the evolution of the unstandardized CPUEs by baitboats (Azores and Dakar) and purse seiners; however, they are not considered to be representative of abundance. Since changes have occurred in the school types targeted by the tropical purse-seine and island baitboat fisheries, and this information has not yet been incorporated into the effort standardization process, it is not possible at this time to develop a standardized catch per unit of effort (CPUE) for these fisheries. It should be noted that in the island baitboat fisheries, which exploit the marginal areas of the geographical distribution of this species, CPUE tends to vary with environmental factors, rather than as a reflection of abundance.

Fishing on beacon-equipped FADs has introduced new components, both in the structure of the schools which aggregate around the floating objects and in the concept of effective effort, which forces us to reconsider, at least in part, the hypotheses underlying the procedures for standardizing effort and calculating indices of abundance from catch rates in the fishery. Concepts such as catchability (a parameter which links effective effort with fishing mortality and catch rates with stock abundance) and stock density need to be revised.

For the purse-seine fisheries, time spent searching for schools is considered to be the unit which best links effort and fishing mortality, assuming that the search is random and the catchability constant; however, when fishing is conducted on a FAD which carries a beacon the concept of searching disappears, and the catchability increases greatly.

As regards the abundance of a stock in a certain area, when objects which encourage the formation of schools are deployed, we can assume that this has an effect on the natural behavior of the species and that the density of the stock by geographic unit is being modified, partly because the presence of an object can cause individuals to aggregate and increase the density in a certain area, and partly because the object's drift could move the schools into areas in which density was formerly low. In this respect, we must ask ourselves what catch rates on beacon-equipped FADs represent, to what extent they are indices of stock abundance, or whether they are essentially indicators of the number of objects deployed.

A similar situation arises when pole-and-line fishermen fish on *manchas*, and we would therefore appear to be a long way from having indices of abundance for the juvenile and preadult components of the stock.

Standardized CPUE for the entire Atlantic, by month and 5° square, are available for the Japanese longline fishery, for the 1961-1974 period. For more recent years (1975-present), information on the number of hooks between floats is available, and since 1994 information on the construction of the main and branch lines is incorporated. Factors included in the analysis were month, area, hooks between floats, and construction of the main and branch lines. CPUEs of other species were dropped from the analysis because CPUE of some species, such as yellowfin and albacore, showed a negative correlation with bigeye CPUE. Annual abundance was estimated by two models, which have different error structures: lognormal distribution for the general linear model (GLM) and Poisson distribution for the general model (GM). All zero-catch observations were incorporated into both models in 1996, although the number of such observations was negligible. For the GM, a small constant (10% of average CPUE) was added. The central area, where the major bigeye fishing grounds are located, was considered (Figure 12).

Since the data series was split because of the difference in the data included (no information on number of hooks between floats prior to 1975), the indices estimated had to be combined at some year to make them comparable throughout the whole period. It was noticed that differences in the abundance indices became apparent, depending on which year was used to combine the two series. A single series was developed for the whole period by assuming five hooks between floats for pre-1975 data.

Figure 13 shows the trend in the abundance index. Both models show a similar decreasing trend for years after the mid 1970s, but the GM shows a more precipitous decline than does the GLM.

The GM was considered better for the central area, because it can handle zero observations appropriately and because examination of the relationship between catch (GM) or catch rate (GLM) indicates that the error structure of the former is more believable. This index was used to tune the production model and the virtual population analyses (VPAs).

Data on Taiwanese longline CPUE for bigeye have recently become available for the first time. The standardization was made with the GLM, taking into account fishing season and area, for the 1968 1995 period. This fishery originally targeted albacore exclusively, but as boats with deep-freezing facilities joined the fishery, the target shifted to bigeye tuna. The recent increase in catch, starting in 1990, corresponds to this shift in target species. As information on target species is not available, this index has not been used in the analysis.

2. BIOLOGY

2.1. Age and growth

The age and growth of Atlantic bigeye tuna have been studied by several authors using different methods, such as modal analysis of length frequencies in the catches (Champagnat and Pianet, 1974; Marcille *et al.*, 1978; Weber, 1980; Pereira, 1984), the deposition of rings in hard parts (Gaikov *et al.*, 1980; Dragnik and Pelczerski, 1984; Delgado de Molina and Santana, 1986), and the analysis of tagging data (Cayré and Diouf, 1984). There are also differences in the origin and the number of fish sampled, and in the range of the sizes analyzed in each case.

The results obtained in these studies are presented in Table 3, and the corresponding growth curves are shown in Figure 14.

The estimates of bigeye growth based on size-frequency samples from the intertropical Atlantic surface fisheries were analyzed for the first time by Champagnat and Pianet (1974), who worked with data for fish measured from the tip of the snout to the insertion of the first dorsal spine (predorsal length). The corresponding size range, in fork length, of the fish used was 60 to 140 cm. Marcille *et al.* (1978) also used measurements of predorsal length from the surface fleets of France, Ivory Coast, and Senegal (FIS) for a larger size range, from 45 to 150 cm.

Weber (1980) also analyzed fork-length size-frequencies of bigeye, using samples from the Japanese longline fishery and some surface fisheries, on a quarterly basis.

The same method was later applied by Pereira (1984) to the overall size samples from the surface and longline fisheries for the 1975-1982 period. This analysis was conducted on a bimonthly basis, separately for the fork-length and predorsal-length samples. It emphasizes the irregular representation of large individuals in the samples and the difficulty in locating the modes for individuals over 150 cm.

The growth equations calculated by these authors describe the growth of bigeye in a similar way, mainly for sizes under 140 cm. The use of the modal-progression method presents some difficulties, mainly for fish over 150 cm, due to the small size of the samples and to the confusion of the modes that are not clearly seen (Pereira, 1984).

Direct age readings from the first dorsal fin spine have been used to determine age by Gaikov *et al.* (1980) for bigeye tuna samples from longliners ranging from 30 to 200 cm, by Dragnik and Pelczerski (1984) for a size range from 100 to 165 cm, also from longline-caught tuna, and by Delgado de Molina and Santana (1986), who used fish from the Canary Islands baitboat fishery ranging from 58 to 187 cm. The main problems with the use of dorsal fin spines are the absence of validation of the periodicity of growth marks, the difficulty in reading the spine sections of large fish because of the bony redeposition that occurs in the center of the spine, rendering the central part unreadable, and the subjectivity of the interpretation of growth checks.

Data from 130 recoveries of bigeye tuna tagged in the eastern Atlantic have been used by Cayré and Diouf (1984) to analyze bigeye growth. The value of 285.37 cm for L_∞ estimated by Cayré and Diouf is less than the values estimated by other authors, which can be explained by the size range of the fish used (38 to 110 cm).

The growth of large bigeye is still problematic. The different equations proposed to describe the growth of bigeye should be applied only within the size limits observed, as it is dangerous to extrapolate a growth curve that follows the von Bertalanffy equation outside the observed size range. All authors who have studied the growth of bigeye agree on the need for further studies on larger sizes of fish. In the absence of direct observations of the growth of large bigeye, growth curves deduced from small and intermediate sizes have been adopted as a working hypothesis.

It is likely that the growth rates of males and females at larger sizes are different, which could explain the difficulty in following the modes of large fish. Delgado de Molina and Santana (1986) did not find a significant difference in the growth curves of male and female bigeye tuna caught in the Canary Islands, but the number of large fish used by them is too small to provide evidence of differential growth between males and females.

2.2. Reproduction

Very few studies have been done on the reproduction of Atlantic bigeye tuna, so this is one of the less-known aspects of the biology of this species.

Male and female bigeye tuna cannot be distinguished by external characteristics.

2.2.1. Spawning areas and seasons

Present knowledge of the areas and seasons of reproduction is based on the study of the macroscopic aspects of the maturity of the gonads, gonadosomatic indices (GSIs), and the presence or absence of larvae.

Studies of bigeye reproduction in the Atlantic are based mostly on observations of fish captured by longliners (Sakamoto, 1969; Kume and Morita, 1977; Alekseev and Alekseeva, 1980; Gaikov, 1983; Gaikov and Fedoseev, 1986). Some studies of surface-caught bigeye have been conducted by Pereira (1985, 1987) on catches from the Azores baitboat fishery.

According to these investigators, the bigeye spawning area is located around the equator, between 15°N and 15°S, from the coast of the Americas to the Gulf of Guinea. Sakamoto (1969) observed higher values of the GSI, between 3.58 and 6.57, along the equator, mainly in the western Atlantic. Gaikov (1983) found only immature or sexually-inactive fish in the areas north of 15°N and south of 15° S. Spawning takes place throughout the year, with a peak in the northern hemisphere between May and August, with the spawners concentrated in the area between 3°N and 10°N from 30°W to 40°. In the southern hemisphere the peak is from December to April between 3°S and 10°S from 5°W to 15°W. Alekseev and Alekseeva (1980) stated that the sexual cycles of bigeye are in opposite phases in the northern and southern hemispheres, which may indicate the existence of two separate populations in the Atlantic. Accordingly, the spawning areas would be in the Gulf of Guinea and in the western tropical Atlantic, with spawning occurring during the respective summer in each hemisphere.

2.2.2. Larvae

The presence of larvae is usually considered to be evidence of recent spawning activity. Kume (1962) demonstrated that the time between fertilization and hatching in bigeye is 21 hours at temperatures of 28.1 to 29.4°C. Rudomiotkina (1983), on the basis of the distribution of bigeye larvae, indicates that the spawning areas are located in the eastern central Atlantic north of 5°N and northwest and south of the Gulf of Guinea. Spawning is limited to the warmer season, with sea-surface temperatures of 24.3 to 28.8°C, and salinities of 33.8 to 36.0‰. Caverivière *et al.* (1976) state that bigeye larvae are most abundant in waters with temperatures greater than 28°C, and that they are more tolerant to lower salinities, since they found larvae in waters with a salinity of 31‰. Those observations are in agreement with those of Richards and Simmons (1971), who indicated the presence of bigeye larvae in water temperatures greater than 26°C and salinities greater than 31.8‰. The area of distribution of bigeye larvae indicated by Caverivière *et al.* (1976) and Caverivière and Suisse de Sainte Claire (1980) includes all the equatorial area, with larvae present throughout the year, with peaks off the Brazilian coast from January to June and in the Gulf of Guinea from December to April. They also refer to the presence of an important zone of larval concentration off the coast of Venezuela and northeast of Brazil during the third quarter of the year. The results of Japanese research on larval distribution, presented by Nishikawa *et al.* (1985), indicate that in the Atlantic Ocean bigeye larvae occur in the equatorial area, from the Caribbean to the Gulf of Guinea, from October to March, and off the east coast of Brazil from January to March.

2.2.3. Maturation

The size of first maturity of Atlantic bigeye tuna is not known.

Kume and Morita (1977) proposed a maturity index for Atlantic bigeye which separated the fish into three categories: immature (GSI<1.5), beginning of maturation (1.6<GSI<3.0), and advanced maturation (GSI>3.1).

Gaikov (1983) proposed a six-stage scale of maturity for Atlantic bigeye tuna.

The maturation of the gonads of bigeye caught by longliners in the entire Atlantic has been studied by Sakamoto (1969), who observed higher GSI values, between 3.58 and 6.57, along the equator, mainly in the western Atlantic (Figure 15a).

For bigeye caught by purse seiners, Pereira (1995) indicates that, for the majority of a sample of 103 females, the GSI calculated by length classes was less than 3, and only two fish captured in December and January had GSI values greater than 3 (Figure 15b).

Pereira (1995) did not find any evidence of sexually-mature fish n the baitboat fishery of the Azores. All the bigeye observed in this northeast Atlantic fishery were immature or resting. The maximum GSI value of 1.20, observed for fish larger than 100 cm, provides no evidence of spawning activity in this area (Figure 15c).

2.3. Sex ratio

The sex ratio of Atlantic bigeye has been studied by several investigators, mainly on the basis of longline samples (Sakamoto, 1969; Zavala-Camin, 1978; Gaikov, 1983), but Pereira (1985b, 1987b, 1995) analyzed the bigeye sex ratio from the Azores baitboat fishery.

For bigeye caught by longlines, which catch mainly large fish, Sakamoto (1969) calculated a male-to-female ratio of 1.39: 1 from a sample of 5,404 fish caught in areas covering the entire Atlantic. Gaikov (1983) found that in the spawning areas the male-to-female ratio varied from 1.35: 1 to 1.88: 1, whereas in the feeding areas it ranged from 0.89: 1 to 1.67: 1.

The bigeye caught by longliners southwest and south of Brazil have been studied by Zavala-Camin (1978), who found the proportion to be 37% males and 63% females in a sample of 324 individuals, with a predominance of females in almost all size classes, but mostly among the larger individuals. These values contradict those calculated by Sakamoto (1969) for the areas off Brazil, 42.1% females in the coastal sectors and 25% females in the offshore areas.

Concerning bigeye caught by surface fisheries, Pereira (1995), gives an overall male-to-female ratio of 0.91: 1 for the Azores baitboat fishery, which corresponds to 47% males and 53% females, in a sample of 1,587 fish. This ratio is not significantly different from 1: 1, but the distribution of sexes by size class shows a greater proportion of females for sizes under 160 cm (Figure 16a). For fish with fork lengths under 70 cm, the number of males is slightly greater than the number of females, which may be explained by the difficulty in distinguishing the sexes at smaller sizes. The sex ratio of bigeye in the same schools has also been studied by Pereira (1985b), who observed greater numbers of females within schools of bigeye. For a small sample of 67 bigeye caught by purse seiners in the Azores, Pereira (1995) found a high proportion (70.2%) of males, ranging from 58 to 174 cm, while the females ranged from 58 to 140 cm. The dominance of males is also apparent in bigeye caught by the baitboat fishery of Madeira, where an overall male-to-female ratio of 1.5: 1 has been observed in a sample of 2,297 fish between 50 and 190 cm. In these samples the males dominate all size classes, and females are absent at lengths greater than 160 cm (Figure 16b). In the case of bigeye caught by purse seiners in the Gulf of Guinea, Pereira (1995) found an equal sex ratio in a sample of 229 individuals, with 52% males, but with males dominant for fish of lengths greater than 150 cm (Figure 16c).

2.4. Weight-length relationship

The weight-length relationship currently used for Atlantic bigeye tuna is that calculated by Parks *et al.* (1982) from samples covering a wide area of the Atlantic and caught by different fishing gears:

$$W = 2.396 \times 10^{-5} * L^{2.9774},$$

where W = weight in kilograms and L = length (tip of snout to fork of tail) in centimeters

2.5. Other biometric relationships

A relationship between predorsal length (tip of snout to insertion of first dorsal spine) and fork length (DL_1-FL) was established by Champagnat and Pianet (1974) from samples of bigeye caught by surface fisheries off the African coast, using observations from 2,858 fish of predorsal length ranging from 13 to 48 cm:

$$FL = (DL_1 + 21.45108)^2 / 5.28756^2$$

Another relationship between predorsal length and fork length was calculated by Pereira (1995) for bigeye tuna caught by the Azores baitboat fishery, based on a sample of 858 fish, of predorsal length ranging from 15.5 to 58 cm, for a range of fork lengths from 48 to 189 cm:

$$FL = 0.6221427\ DL_1^{0.851482}$$

2.6. Natural mortality

The rate of natural mortality (*M*) of Atlantic bigeye tuna, like that of other tuna species, is not well known. Murphy and Sakagawa (1976), in a review of the values of natural mortality calculated by different authors for tropical tunas, said that the value of *M* for bigeye in the Pacific is probably in the lower portion of the range of 0.35 to 0.73. Values of *M* of 0.45 and 0.55 were used by Kume (1978b) in a preliminary cohort analysis of Atlantic bigeye.

It is generally thought that *M* varies with the age of the individuals. As a working hypothesis, ICCAT (1984a) has adopted a rate of natural mortality for bigeye tuna which varies with age, being higher (0.8) for juveniles during the two first years and lower (0.4) in the following years. This hypothesis takes into account the different habitats of bigeye during their life cycle, and also changes in metabolism and physiology at different ages.

The assumption that the natural mortality is greater for juveniles is justified by the fact that during their juvenile phase bigeye live in mixed schools with young yellowfin and skipjack in the Gulf of Guinea, and *M* is assumed to be the same for the three species, since they live in the same environment and have the same predators. After the second year, at which time the small bigeye migrate from the Gulf of Guinea and cease to school with yellowfin and skipjack, the rate of natural mortality is believed to be lower and a value of 0.4 is adopted.

The use of a lower *M* for adults is also suggested by Suda and Kume (1967) for Pacific bigeye, based on their estimated annual value of $M = 0.361$ for fish 5 years of age and older.

3. STOCK STRUCTURE

It is generally assumed that there is a single stock of bigeye in the Atlantic Ocean. This hypothesis is based essentially on data from the fisheries, the extent of the fishing areas, and analyses of the size structure of fish in the catches, together with some tagging data, studies of sexual maturity and reproduction, and ichthyoplankton data.

Based on these various analyses, a hypothesis for the structure of the stock was developed which assumes a wide area of distribution in the intertropical and temperate zones (from 45°N to 45°S), a wide and continuous spawning area along both sides of the equator, and a single area for juveniles in the Gulf of Guinea, in which small bigeye occur in mixed schools with young yellowfin and skipjack. During the juvenile stage, bigeye live in surface waters, changing their habitat to deeper waters under the thermocline as they grow.

From the sparse tagging data available, all from the surface fishery, if was hypothesized that the juvenile and preadult fish migrate northward (to Senegal, the Canary Islands, Madeira, and the Azores) and southward (to Angola) along the western coast of Africa and later, when they reach the adult stage, move toward the equatorial spawning areas. However, the fact that there are no recaptures from the longline fishery and that no large fish have been tagged make the assumptions about the structure of the stock, especially those regarding the adult stage, highly questionable.

Figure 17 shows the longline catches of bigeye as a function of sea-surface temperature (SST), defining a spawning area as one with catch and with SSTs greater than 27°C. Two separate spawning areas, north and south of the equator, can be clearly seen, with movements toward the feeding areas at the north and south of the area of distribution and a well-defined juvenile area (Figure 18) in the Gulf of Guinea, with northward and southward movements along the coast. This pattern could correspond to a structure with two stocks, north and south (Figure 19), similar to that of albacore; in the early years of the fishery. Japanese scientists (Sakamoto, 1967, Hayasi, 1970, Kume, 1976) considered this to be possible, based on an analysis of data for the Japanese longline fishery and the identification of areas of strong seasonal density of bigeye north and south of the equator and a continuous area of low density in the central region of the equatorial area. Also, the data of Alekseev and Alekseeva (1980) indicate the possibility of northern and southern stocks.

4. ASSESSMENT

The Atlantic bigeye stock has traditionally been assessed using the PRODFIT production model (Fox, 1975), assuming that the stock is in equilibrium, and the forward application of virtual population analysis (VPA), using the method developed by Fox (1976) and adapted by Fonteneau (1981) to moderately-exploited stocks. This method, based on the assumption of stable recruitment common to most tuna species, uses constant recruitment values, set at levels which explain the catch-at-age matrix, on a quarterly basis.

The stability of the fisheries at moderate levels of exploitation meant that for many years the assessments of the status of the stock produced by these models were robust and in agreement with the situation in the fisheries.

In recent years major changes have occurred in both the surface and the longline fisheries. Since 1991 the live-bait and purse-seine fleets have begun to develop fisheries on beacon-equipped FADs, which has led to a large increase in the catches of juvenile bigeye in mixed schools, in which skipjack is the dominant species, aggregated around floating objects. In the years during which this type of fishing has been expanding, the catches of age-0 to -2 bigeye have risen from 75% to 87% of the total catches, in numbers of fish. Together with this increase in the surface catches, the longline effort has increased in the last three years, due basically to the change in target species from albacore to bigeye by the Taiwanese fleet; the result has been a 35% increase in the longline catches in the last two years over the average of the previous period (1988-1992).

The large increase in effort, on juveniles as well as on adults, has had an immediate effect on the stock, which has gone from a situation in which the catches and effort had increased coherently until they reached a situation of apparent full exploitation with a relatively stable exploitation pattern, to a situation of evident imbalance, with catches, effort, and fishing mortality much greater than the levels corresponding to maximum sustainable yield (MSY).

4.1. Production models

The stock of Atlantic bigeye has traditionally been assessed with production models, such as the PRODFIT equilibrium model (Fox, 1975), adjusted so that the shape parameter (m) equals 1 or 2 and, more recently, the ASPIC model (Prager, 1994), which is applicable to non-equilibrium conditions, developed from the Schaefer (1954) model. Until 1993, the results of the production models indicated a situation close to full exploitation, with catches slightly below the MSY. The increase in the total catches in 1993, 1994 and 1995 has raised the level of catches to well above the MSY, and has introduced considerable uncertainty into the results of the models. The current assessment is one of overexploitation, and the predictions for the future of the stock and the catches are very imprecise, showing a wide range of possible situations, more or less pessimistic depending on the model (Fonteneau, in press).

In 1996, ICCAT's Standing Committee on Research and Statistics (SCRS) has used various production models to evaluate the bigeye stock.

4.1.1. Equilibrium production model

The equilibrium production model (PRODFIT) (Fox, 1975) was run with 32 years of catch data, using, a CPUE biomass index from the Japanese longline fishery, standardized by the GM. The three most recent years (1993-1995) were excluded from the analysis, since the estimated parameters for those years were not in a realistic range when all data points were included, probably because the PRODFIT model uses the least-squares method and does not take into account the very high catch and effort values for 1993-1995, which are far greater than the rest of the data points. The number of significant year classes in the fishery (k) was set at 6, and the shape parameter (m) at 1 and 0. For $m = 1$ (Fox model) the estimate of MSY was 66,300 MT, with an optimum fishing effort (F_{MSY}) of 102 million hooks (Figure 20). When m was searched for in the model, the best fit was obtained for $m = 0$ and MSY = 92,800 MT. Since F_{MSY} approaches infinity when $m = 0$, the estimate of MSY may be misleading and should be interpreted with caution. The total catches after 1992 are apparently greater than the upper boundary of the estimated MSY range. The current F (195 million hooks) is also greater than the estimates of F_{MSY}.

4.1.2. Non-equilibrium production model (ASPIC)

ASPIC (Prager, 1994) is a non-equilibrium production model increasingly used by SCRS for several species. For bigeye, the data used for ASPIC modeling were the total Atlantic catch from 1960 to 1995 and a CPUE biomass index from the Japanese longline fishery for 1961-1995, standardized in two ways: first, assuming a Poisson error distribution (GM standardization), and second, assuming a lognormal error (GLM standardization). In addition, GM and GLM standardizations were conducted separately for the CPUE time series split at 1976. The GM standardization applied to the entire series showed little trend for the first few years of the fishery, followed by a moderate declining trend in the later years, whereas the GLM standardization showed less trend overall (Figure 13).

All four alternative treatments of the CPUE series (entire series, split series; GM standardization and GLM standardization) led to biologically-unreasonable results when all ASPIC parameters were freely estimated. In particular, the intrinsic rate of increase (r, which is 2 x F_{MSY}) was estimated to be either unreasonably low (<0.08) or unreasonably high (>2.5). In addition, estimates of the biomass (B) in 1960 were often unrealistically low (*e.g.* $<B_{MSY}$), given that fishing was relatively light prior to 1960.

Therefore, for illustrative purposes, the ASPIC model was run by fixing the initial biomass at the level of the carrying capacity (K) and fixing r between 0.2 and 1.0, a range judged to be biologically realistic. The results are shown in Table 4. Estimates of MSY for the GM standardization ranged between 44,000 and 78,000 MT, and for the GLM standardization between 60,000 and 94,000 MT. For the GM standardization, the ASPIC model was also run, using a range of initial biomass ratios (initial biomass as a fraction of K). The resulting estimates of MSY were remarkably insensitive to the initial biomass (Figure 21).

4.1.3. Non-equilibrium production model (GENPROD)

This model (Pella and Tomlinson, 1969) was applied to updated bigeye data with shape parameters between 0.4 and 2.0. The MSYs estimated with the GM were around 50,000 MT, and those estimated with the GLM were slightly higher (Table 5).

4.1.4. Age-structured production model (ASPM)

Preliminary ASPM (Punt *et al.*, 1992; Punt, 1996) runs were made with catch data for 1960 to 1995, divided into five fisheries with distinctly-different selectivities. Selectivities by age, for ages 0 to 7+, were based on the previous year's VPA. Only one index of abundance, from the Japanese longline fishery from 1961 through 1995, was used in the analyses.

Beginning-of-the-year input weights at age were 0.1, 2.4, 8.5, 18.8, 33.6, 51.6, 72.2, and 101.3 kg for ages 0 to 7+, respectively; and the corresponding middle-of-the-year weights were 0.9, 5.0, 13.3, 26.0, 42.0, 61.3, 83.5, and 101.3 kg. M was assumed to be 0.8 for ages 0 and 1 and 0.4 for ages 2 to 7+.

The underlying relationship between spawning stock biomass and recruitment was assumed to follow a Beverton and Holt (1957) function. The objective function of the fit was assumed to have a lognormal error structure, with equal weighting.

The results were similar to those of other production model analyses.

4.1.5. Summary of production model analyses.

In applying some of the models, it was found that the estimated parameters were not in realistic ranges. To solve this problem, either the values of certain parameters were fixed or data points from the most recent years were excluded, in order to identify the possible range of the MSY. The relationship between the abundance of the fish and the CPUE is not necessarily linear, since the size of the fish caught has changed considerably in recent years, *i.e.*, large amounts of small fish are being caught. It will take several years for this change to be reflected in the abundance index for adult fish. It is possible that the change in the size of fish caught may change the population parameters, such as r, which may result in different stock parameters (MSY, F_{MSY} and B_{MSY}).

4.2. Analytical models

In view of the uncertainty of the results of traditional methods of stock assessment, the SCRS, at its 1995 meeting, carried out trial assessments with virtual population analysis (VPA) techniques, calibrated with external indices.

The only standardized indices available for calibrating the VPAs were for Japanese longliners, and these are representative only of the relative abundance of the adult stock (ages 4-7+), a major limitation in the application of the models, as these required many assumptions about the juvenile and preadult stock, for which no indices of relative abundance could be estimated. Trials were made with ADAPT (Adaptive Framework: Gavaris, 1988; Conser and Powers, 1990; Powers and Restrepo, 1992 and 1993) and XSA (Extended Survivors Analysis: Doubleday, 1981; Shepherd, 1992; Darby and Flatman, 1994). These first trials were inconclusive, and their results were not included in the Committee's report.

Subsequent to the SCRS meeting, work has continued on the use of these models in the assessment of this stock. The results of this work were presented to the Committee in 1996 (Pallarés, in press).

The analysis was carried out on the catch-at-age (0-7+) matrix for the 1970-1994 period, for which more reliable data were available. The indices used for calibration were those obtained with GMs, covering the central area of the Atlantic. Observations with zero catches were excluded from the calculations. The indices of age-specific abundance were obtained from the catch ratio for ages 4 to 7.

A natural mortality value of 0.8 was selected for age 0-1 fish, and 0.4 for fish of other ages. A knife-edge ogive was assumed for maturity at age 4.

The first trials with ADAPT used fishing mortality values for the last age equal to those of the previous age. For the last year, with no calibration indices available for ages under 4, the fishing mortalities (F) for those ages were estimated from the partial recruitments obtained with separable VPA (Pope, 1977 and 1979; Pope and Shepherd, 1982), using age 4 as the reference age and allowing the program to estimate directly the values corresponding to ages 4 to 6. No reliable estimates of the parameters were obtained, since the program did not find minimum values for the target function. The estimates of F were lowered for ages 4 and 5, but no reliable values were obtained because the fit of the index for age 5 was very poor. Finally we decided to estimate age 4 only, and calculate the mortalities for the other ages from the partial recruitments, using age 4 as the reference age.

The XSA analyses were carried out with the same criteria used by the SCRS in 1995. The entire series of indices was included, using, by default, the weighting criterion which weights the indices according to their distance from the last year. In all the trials, the average values of the earlier estimates of abundance and fishing mortality were included during the iterative process, assigning them a certain weight, using the program's "shrinkage to the mean" option. As with ADAPT, the fit of the indices for age 5, and especially age 6, were very poor.

In parallel with the calibrated VPA, other trials of uncalibrated VPA were carried out, based on the *F* values and partial recruitments estimated by SVPA, using estimates of the total *F* for the last year obtained from the effort data of the historical series. Four periods of relative stability of the fisheries (1975-1980, 1980-1985, 1985-1990 and 1991-1994) were studied, and exploitation patterns were estimated for each period. The vectors of fishing mortality for the last age and year were estimated from the results of the various SVPAs and used as input for a VPA.

At the same time the longline effort series was calculated from the standardized Japanese catch rates and the total longline catches. The regression of calculated effort versus average fishing mortalities of fish of ages 4 to 6, estimated with VPA, allowed us to estimate the fishing mortality for the last year, for fish of those ages, from the corresponding effort. With the new estimated value of *F* and the exploitation pattern, the fishing mortalities for fish of all ages were recalculated from the last year, and the VPA was run again, taking into account two options for the fishing mortalities of the last age group: the option considered in the first VPA run, and the backward solution, assuming a ratio of 1 between the *F* of the last age group and the average *F* of the two previous age groups.

When the results obtained with the various methods were compared, it was seen that the estimates of both fishing mortalities and abundance were very close when the uncalibrated VPA was used, applied under the conditions described above, and when XSA was applied.

The average values for fishing mortality for fish of ages 4-6 estimated by both methods were consistent with the evolution of longline effort (Figure 22).

A comparison of the values obtained with these two methods with those obtained with ADAPT reveals remarkable differences in the estimates. Figure 23 shows the average fishing mortalities (all ages) from the three procedures; the values of *F* estimated by ADAPT are always higher, although the evolution is similar for the historical series (1970-1990). For recent years (1991-1994), the growing trend of fishing mortality is much steeper, especially in the last two years, for the ADAPT estimates than for those of the other models used. The "shrinkage to the mean" option selected when running the XSA, which to an extent forces the estimates to move in a more limited range of values, would probably explain part of the differences in the estimates for the last year.

Consistent with the results obtained for the fishing mortalities, the recruitments estimated with ADAPT (Figure 24) are about 30% lower than those estimated using other methods, with a similar tendency for the historical series and marked discrepancies in the estimates for the last three years.

The evolution of the recruitment shows three well-defined periods, a central period (1977-1990) of variable recruitment with no trends, as is expected in the case of bigeye in particular and of most tuna species in general, an early period (1971-1976) with average recruitments 25% less than those estimated for the following period, and a recent period (1991-1994), in which the estimates diverge.

The values estimated for recent years can be related to problems with calibration, lack of indices, poor fits, *etc*. As regards the estimates for the historical series, the two apparent levels of average recruitment could be related to the introduction of deep longlines and problems related to the introduction of this variable into the procedure for standardizing the catch rates. If we take into account the fact that deep longlines gave access to a component of the stock inaccessible to conventional longlines, the difference in the recruitment levels in the historical series would not be real, and would be masking changes in the total estimated biomass.

In 1996, the SCRS, rather than applying the variety of models used for last year's analyses, has focused attention on two approaches: ADAPT VPA (FADAPT program, Restrepo, in press) and forward VPA (COHORT program, Fox, 1976).

In the ADAPT VPA method, selectivity in the final year was estimated by SVPA (Table 6). The only available index, developed from the Japanese longline fishery in the central area using the GM procedure, was used and tuned with the partial population, which was calculated by the partial selectivity shown in Table 7. This fishery targets primarily bigeye of age 4 and older, and seems to best reflect the abundance of the adult bigeye stock.

Three base cases were examined: Case 1, catches from ages 7 and above were combined to form a plus group, so that ages were defined as 0 through 7+; Case 2, ages defined as 0 through 6+; and Case 3, ages defined as 0 through 5+. The inputs used for the final runs of each case are summarized in Table 6. Partial recruitment was estimated by SVPA.

Successive runs of FADAPT were performed for each case. As in the previous year, runs in which more than one terminal-year *F* was estimated resulted in modest coefficients of variation (CVs) for the terminal-year *F* estimated for one age and extremely high CVs for all other terminal-year *F*s estimated. This suggests that the data are inadequate for estimating more than one terminal-year *F*. Therefore, the final runs for each case included the estimation of terminal-year *F* values for age 4, which is highly selected for in the longline fishery from which the abundance index is derived.

The numbers of annual recruits estimated by FADAPT for Cases 1-3 are shown in Figure 25. For Cases 1 and 2, recruitment trends showed increasing recruitment from a low of about 9-10 million fish in 1960 to a peak of around 30 million fish around 1989, before declining in recent years. Results for Case 3 showed fluctuations between about 20 and 30 million recruits during the 1960-1981 period, followed by levels fluctuating in the narrower range of about 28 to 32 million recruits during 1982-1990, peaking at around 35 million fish in 1991-1992 before also declining in recent years.

The values of overall *F*, calculated as the arithmetic mean of the *F*s of each age, estimated by FADAPT for Cases 1-3, are shown in Figure 26. For all cases, the *F* s showed increasing trends throughout the time series, differing only in scale. The overall *F* values estimated for 1995 were 1.37, 1.51 and 0.55 for Cases 1-3, respectively.

The results of Cases 1-3 for recent years were quite variable, and indicate that recruitment and *F* trends during that period are greatly influenced by the availability of indices for tuning. Assumptions made regarding the exploitation profile in the terminal year may also have had an influence. The fit of Case 3 appeared to be best in terms of diagnostic statistics, and also the most realistic approach.

Forward VPA (FVPA), using a quarterly age matrix and constant recruitment, was carried out for two base cases: (1) recruitment = 30 million fish and (2) recruitment = 40 million fish. Natural mortality rates were set at 0.8 for fish of ages 0 and 1 and 0.4 thereafter. The level of recruitment was in the range of values estimated by XSA for 1995. The abundance trends for ages 5+ estimated by this method are compared to those estimated by the FADAPT Case 3 in Figure 27. FVPA Cases 1 and 2 both showed declining abundance trends, differing only in scale. For FVPA Case 1, estimates declined from about 4 million to about 1.8 million fish of ages 5+ during the 1960-1991 period, and then declined dramatically in recent years. For FVPA Case 2, estimates declined from about 5.3 million to about 3 million fish of ages 5+ during the 1960-1991 period, and then also declined dramatically in recent years. The abundance trend estimated by FADAPT Case 3 generally fell between the results from FVPA, with the exception that a slightly increasing number of fish of ages 5+ was estimated during the 1980s.

The overall *F* trends estimated by FVPA are compared to those estimated by the FADAPT Case 3 in Figure 28. FVPA Cases 1 and 2 both showed increasing fishing mortality trends through time, differing only in scale, with FVPA Case 1 estimating higher overall *F* values. The fishing mortality trend estimated by FADAPT Case 3 generally fell above the results from FVPA until 1981, and then fell between the estimates from FVPA Cases 1 and 2 thereafter. Overall *F* values estimated for 1995 were about 1.1 for FVPA Case 1, 0.6 for FADAPT Case 3, and 0.3 for FVPA Case 2.

Figure 29 shows a bimodal exploitation pattern by age, with high fishing mortalities for juveniles due to purse-seining, and for adults due to longlining.

All VPA methods produced results which generally agreed that abundance levels have experienced a considerable decline and that *F* values have been increasing dramatically. However, concerns about the inherent assumptions and the limitations of the available abundance index prevent definitive conclusions, particularly with regard to the scales of these trends and the values for the most recent years.

4.3. Conclusions

The various attempts at stock assessment for Atlantic bigeye show clearly that none of the methods used, whether analytical or global, is capable of interpreting the tremendous increase in the catches in the last three years, nor of producing an adjusted estimate of the status of the stock and developments in the near future. Problems related to the availability of indices of abundance suitable for a wide range of sizes of fish, together with other problems related to the models and their application to the tuna stocks, prevent a good calibration of the estimates for the most recent years.

To sum up, Figure 30 shows clearly the condition of the stock since the beginning of its exploitation and possible future developments. It shows a first period of low exploitation (1960-1968), with catches of less than 25,000 MT and low levels of effort, a period of moderate exploitation (1969-1974), with catches around 40,000 MT, a period of full exploitation (1975-1992) resulting from the development of the purse-seine fleets and the introduction of deep longlines, and a period of apparently heavy overexploitation (1993-1995) with catches well above the MSY estimated for this stock and effort more than 50% greater than the MSY level. The future status of the stock, and therefore of the catches, lies somewhere within a wide range of possible situations, from the highly improbable and biologically unrealistic one defined by the solution $m = 0$ of the PRODFIT model to the collapse of the stock predicted by the Schaefer model, which can likewise be considered improbable. In between is the situation, predicted by the exponential model, of a rapid drop in catches, with the current high levels of effort, to equilibrium levels of around 60,000 MT in 4-6 years. This situation may be considered more likely. The most prudent approach is the one which involves reducing the effort values to the levels of MSY.

4.4. Projections

4.4.1. Yield-per-recruit and spawning stock biomass-per-recruitment analyses

Inputs from the base-case FADAPT (with 5+ grouping) were used to define two alternative scenarios for analyses of yield per recruit (YPR) and spawning biomass per recruit (SPR): (1) YPR and SPR under average 1992-1994 conditions; and (2) YPR and SPR under "optimistic" conditions, where the partial recruitment (PR) is the same as the 1992-1994 average, except that it is set at zero for age 0 and halved for age 1 to approximate the values that would result from perfect implementation of the recommended minimum size of 3.2 kg. Two additional scenarios were based on results from forward VPA analyses, one assuming a constant recruitment of 30 million fish (Case 3) and the other assuming a constant recruitment of 40 million fish (Case 4). Recent fishing mortalities calculated from FADAPT ($F_{93} = 0.53$, $F_{94} = 0.58$, and $F_{95} = 0.86$) are all appreciably greater than common reference points such as $F_{0.1}$ and F_{max}. In addition, YPR and SPR estimates for the current fishing mortality are much less than the corresponding estimates for $F_{0.1}$ and F_{max}. Figure 31 shows that if age-1 fish could be avoided completely, and if the partial recruitment of age-2 fish could be halved, there would be a moderate gain in SPR and a substantial gain in YPR, particularly at current and higher levels of fishing mortality. However, substantial overall reductions in current fishing mortality are required to achieve appreciable increases in SPR.

Approximate equilibrium estimates of MSY and B_{MSY} can be obtained by multiplying average recruitment by the YPR and SPR estimates, respectively, for either $F_{0.1}$ or F_{max}, giving estimates of MSY corresponding to $F_{0.1}$ and F_{max} of 54,200 and 55,100 MT, and estimates of B_{MSY} of 141,100 and 101,600 MT.

Estimates of the long-term SPR that would be attained by maintaining recent fishing mortalities and fishing patterns indefinitely ranged from about 2.5 to 8.8% of the maximum SPR (attained at $F = 0$). These estimates of SPR percentages are low relative to the commonly-used recruitment overfishing threshold of 20%. While large pelagic species with high fecundities, such as tunas, may be more resistant to fishing than other species, it is unlikely that a level as low as 2.5% is sustainable.

Multi-gear YPR analysis was undertaken based on the quarterly catch-at-age, using the *F* vector from FVPA. The results suggests that a reduction of *F* in the small-fish fishery will result in an increase in the YPR, but increasing *F* in the large-fish fishery will bring very little gain or even a slight decline in the very high *F* for that fishery (Figure 32).

4.4.2. VPA

Some projections have been made, assuming recent fishing mortality rates and selectivities, recent estimated or assumed recruitment levels, and other biological parameters (notably *M*, which is assumed to be 0.8 for ages 0 and 1 and 0.4 for older ages). The resulting estimates of equilibrium yield ranged from 54,000 to 66,000 MT. Figure 33a shows the projected equilibrium yields and stock biomasses for the base-case FADAPT in relation to historical levels. A similar historical pattern, but with a steeper decline, was estimated by the forward VPA with 30 million recruits (Figure 33b).

The implication of these results is that, unless fishing mortality rates or selectivity patterns change in the future, and/or natural mortality or other population parameters have been incorrectly estimated or assumed, and/or recruitment has increased or is about to increase substantially, recent yields cannot be sustained indefinitely. In fact, it appears that large changes in population parameters are required to sustain catches in excess of 100,000 MT. For example, if recruitment is the only variable modified, then recruitment must increase for the forward VPA to about 60 million fish with a past constant recruitment of 30 million fish, and to about 65 million fish with a past constant recruitment of 40 million fish. Although changes of this magnitude are not impossible, the SCRS believes that a risk-averse or precautionary approach dictates that long-term sustainable yields of the order of 60,000-70,000 MT should be considered more probable than those exceeding 100,000 MT.

4.5. Management

The minimum size limit for bigeye of 3.2 kg, adopted to reinforce the same regulation for yellowfin, has been in effect since 1980. It is clear that the equatorial surface fleets (baitboat and purse-seine) continue to land large quantities of juvenile bigeye smaller than 3.2 kg: in 1995, about 70% of the total fish caught, in number, were below this minimum size. According to YPR analysis, a perfect implementation of this regulation could result in an increase of almost 30% in YPR at F_{max}.

Given the fact that the minimum size limit has never been observed in practice, that considerable catches of small fish have been made and those catches are still increasing, and that the detrimental effects of taking juvenile bigeye tuna are evident in terms of YPR and spawning biomass-per-recruit, in 1996 the SCRS considered implementing this minimum size regulation in such a way as to reduce the catch of small fish. Such a reduction can be undertaken by limiting fishing for schools associated with floating objects by the tropical surface fisheries.

The French and Spanish fleets agreed, at the request of the European Union, to refrain from using FADs in a large area of the eastern Atlantic from November 1, 1997, through January 31, 1998. This was done to reduce the mortality of small bigeye.

Since 1993, the total bigeye catch has substantially surpassed all presently-estimated levels of MSY. In 1994, the SCRS recommended reducing the fishing mortality rate to the 1989-1992 level, but despite this recommendation, catches have remained above 100,000 MT. Projections made in 1996 indicate that the 1994 level of fishing will reduce not only the population size to far below the MSY level, but also catches in the near future due to overfishing.

For these reasons, the Committee has strongly recommended, as in previous years, reducing the total catch to less than the most-likely MSY level (60,000-70,000 MT).

5. Bibliography

ABDON (M.M.), 1984. Maps of favorable areas for tuna fishing in the southwestern Atlantic prepared from satellite data. *ICCAT, Rec. Doc. Sci.*, **20** (2): 523-537.

AHLSTROM (E.H.), 1971. Kinds and abundance of fish larvae in the eastern tropical Pacific based on collections made on EASTROPAC I. *Fish. Bull. U.S.*., **69** (1): 3-77.

AHLSTROM (E.H.), 1972. Kinds and abundance of fish larvae in the eastern tropical Pacific on the second multivessel EASTROPAC survey, and observations on the annual cycle of larval abundance. *Fish. Bull. U.S.*, **70** (4): 1153-1242.

ALEKSEEV (F.E.) & ALELSEEVA (E.I.), 1980. Some problems of reproductive biology of oceanic and neritic tunas of the tropical Atlantic. *ICCAT, Rec. Doc. Sci.*, **9** (3): 695-703.

ALONCLE (H.) & DELAPORTE (F), 1978. Information sur les captures de petits patudos (*Thunnus obesus*) effectuées par "La Pelagia" dans les parages des Açores. *ICCAT, Rec. Doc. Sci.*, **7** (1): 94-96.

ALONCLE (H.) & DELAPORTE (F), 1980. Reprise des thonidés marqués par l'ISTPM en Atlantique nord (*T. alalunga - T. obesus – T. thynnus*). *ICCAT, Rec. Doc. Sci.*, **9** (3): 677-679.

ALVERSON (F.G.) & PETERSON (C.L.), 1963. Synopsis of the biological data on the bigeye tuna *Parathunnus sibi* (Temminck and Schlegel) 1894. *FAO Fish. Rep.*, **6** (2): 482-514.

AMON KOTHIAS (J.B.) & BARD (F.X.), 1984. Cartographie des mélanges d'espèces de thons de moins de 3 kg et de moins de 10 kg dans le golfe de Guiné. *ICCAT, Rec. Doc. Sci.*, **21** (2): 123-141.

AMON KOTHIAS (J.B.) & BARD (F.X.), 1984. Étude de l'influence des diverses rélations tailles-poids pour le thon obèse (*Thunnus obesus*) sur les estimations des structures démographiques. *ICCAT, Rec. Doc. Sci.*, **20** (1): 188-191.

AMON KOTHIAS (J.B.) & BARD (F.X.), 1986. Taux de mélange des listaos et des juveniles d'albacore et de thon obése à partir des captures de la flotille FISM. *Proceedings of the ICCAT Conference on the International Skipjack Year Program,* edited by P.E.K. Symons, P.M. Miyake and G.T. Sakagawa. Madrid, ICCAT, pp 160.

AMON KOTHIAS (J.B.) & HERVE (A.), 1996. Augmentation des captures de patudo (*Thunnus obesus*): senneurs français débarquant à Abidjan. *ICCAT, Rec. Doc. Sci.*, **45** (3): 224-226.

AMON KOTHIAS (J.B.); HERVE (A.) & BARD (F.X.), 1994. Update of quantities of minor tunas (*Auxis*, *Euthynnus*) and small tunas (skipjack, yellowfin, bigeye) landed as market fish in Abidjan, 1981-93. *ICCAT, Rec. Doc. Sci.*, **42** (2): 377-380.

AMORIM (A.F.) & ARFELLI (C.A.), 1994. Revision on statistical data of the Brasilian longliners based in Santos-SP (1971-90). *ICCAT, Rec. Doc. Sci.*, **16**: 169-179.

ANONYMOUS, 1980. List of the yellowfin, bigeye, skipjack data which were processed by the ICCAT Secretariat for the working group on juvenile tropical tunas, 1980. *ICCAT, Rec. Doc. Sci.*, **13**: 132-135.

ANONYMOUS, 1980. Report of the joint CECAF/ICCAT working group on juvenile tropical tunas (Abidjan, September 17-21, 1979). *ICCAT, Rec. Doc. Sci.*, **10**: 1-72.

ANONYMOUS, 1980. Working group on juvenile tropical tunas, May 28-30 and June 4-7, 1980, Brest, France. *ICCAT, Rec. Doc. Sci.*, **13**: 1-130.

ANSA-EMIN (M.), 1977. Landings and length composition of yellowfin, skipjack and bigeye tunas caught in the eastern tropical Atlantic by the Tema-based tuna fleet, 1975. *ICCAT, Rec. Doc. Sci.*, **6** (1): 56-61.

ARIZ (J.); DELGADO DE MOLINA (A.) FONTENEAU (A.); GONZÁLEZ COSTAS (F.) & PALLARÉS (P.), 1993. Logs and tunas in the eastern tropical Atlantic: a review of present knowledges and uncertainties. *ICCAT, Rec. Doc. Sci.*, **40** (2): 421-446.

ARIZ (J.); DELGADO DE MOLINA (A.); SANTANA (J.C.) & DELGADO DE MOLINA (R.), 1995. Datos estadísticos de la pesqueria de túnidos de las Islas Canarias durante el período 1975 a 1993. *ICCAT, Rec. Doc. Sci.*, **44** (2): 256-261.

ARIZ (J.); DELGADO DE MOLINA (A.); SANTANA (J.C.); PALLARÉS (P.) & DELGADO DE MOLINA (R.), 1996. Capturas de atunes, por tipo de asociación y estratos espacio-temporales, de la flota de cerco española en el Océano Atlántico (1990-93). *ICCAT, Rec. Doc. Sci.*, **45** (3): 130-154.

ARIZ (J.); PALLARÉS (P); DELGADO DE MOLINA (A.) & SANTANA (J.C.), 1991. Analisis de los datos obtenidos en campañas de observadores en el Atlántico intertropical durante el Programa Año del Rabil. *ICCAT, Rec. Doc. Sci.*, **36**: 109-157.

ARIZ (J.); PALLARÉS (P.); DELGADO DE MOLINA (A.); SANTANA (J.C.); & DELGADO DE MOLINA (R.), 1996. Estadísticas españolas de la pesqueria atunera tropical en el Océano Atlántico (1969-1994). *ICCAT, Rec. Doc. Sci.*, **45** (3): 161-168.

ARIZ (J.); PALLARÉS (P.); SANTANA (J.C.); & DELGADO DE MOLINA (A.), 1994. Estadísticas españolas de la pesqueria atunera tropical en el Océano Atlántico. *ICCAT, Rec. Doc. Sci.*, **42** (2): 422-427.

ARIZ (J.); SANTANA (J.C.) & DELGADO DE MOLINA (A.), 1993. Variación de las capturas de túnidos tropicales y túnidos templados en las Islas Canarias desde 1975 a 1991. *ICCAT, Rec. Doc. Sci.*, **40**(2): 144-148.

ARIZ (J.); SANTANA (J.C.); DELGADO DE MOLINA (A.) & DELGADO DE MOLINA (R.), 1995. Estudio de la modalidad de pesca sobre "manchas" de túnidos en las Islas Canarias. *ICCAT, Rec. Doc. Sci.*, **44** (2): 262-271.

ASAKAWA (S.) & SUDA (A.), 1957. Degenerate meat of tuna and marlins - I. Observations and statistical analysis on the meats collected in the Solomon Sea during the summer, 1953. *Nankai Reg. Fish. Res. Lab. Rep*, **5**: 169-178.

AZEVEDO (M.A.), 1983. Management of the population of bigeye tuna (*Thunnus obesus*) of the Atlantic. *ICCAT, Rec. Doc. Sci.*, **18** (2): 363-375.

BAGES (M.) & FONTENEAU (A.), 1980. Prises de la flottille thonière franco-ivoiro-sénégalaise et témperature de surface en 1977. *ICCAT, Rec. Doc. Sci.*, **9** (1): 180-198.

BARD (F.X.), 1980. Étude de la composition spécifique des bancs de thonidés tropicaux pêchés par la flotille FISM en 1978-79. *ICCAT, Rec. Doc. Sci.*, **13**: 220-231.

BARD (F.X.), 1984. Étude de l'adequation des échantillonnages de la flottille FISM d'aprés les données recueilliés en mer par des observateurs (1981-1983). *ICCAT, Rec. Doc. Sci.*, **21** (1): 82-90.

BARD (F.X.) & AMON KOTHIAS (J.B.), 1984. Classification des bancs the thons du golfe de Guiné d'après les échantillonnages multispécifiques 1980-84. *ICCAT, Rec. Doc. Sci.*, **20** (2): 115-122.

BARD (F.X.) & AMON KOTHIAS (J.B.), 1986. Résultats des campagnes de marcages de thonidés tropicaux menées par la Côte-d'Ivoire 1983-84. *ICCAT, Rec. Doc. Sci.*, **25**: 30-36.

BARD (F.X.); AMON KOTHIAS (J.B.); PANFILI (J.) & HERVÉ (A), 1996. Unusual occurrence of "green tunas" in Abidjan landings, 1993-1995. *ICCAT, Rec. Doc. Sci.*, **45** (3): 126-129.

BARD (F.X.); CAYRÉ (P.) & DIOUF (T.), 1988. Les migrations. *In*: Ressources, pêche et biologie des thonidés tropicaux de l'Atlantique centre-est. Fonteneau A. et Marcille J. (eds.). *FAO doc. techn. pêches,* **292**, pp 111-156.

BARD (F.X.) & VENDEVILLE (P.), 1986. Note sur l'échantillonnnage plurispécifique des thons tropicaux au port d'Abidjan. *ICCAT, Rec. Doc. Sci.*, **25**: 37-45.

BARRETT (I.) & KUME (S.), 1965. Observations on bigeye tuna caught in the surface tuna fishery in the eastern Pacific Ocean. *Calif. Fish Game,* **51** (4): 252-258.

BARRETT (I.) & WILLIAMS (A.A.), 1965. Hemoglobin content of the blood of fifteen species of marine fishes. *Calif. Fish Game,* **51** (3): 216-218.

BARTOO (N.) & SAKAGAWA (G.T.), 1978. Size frequency of bigeye tuna (*Thunnus obesus*) in the catch of the Atlantic surface fishery, 1967-1975. *ICCAT, Rec. Doc. Sci.,***7** (1): 97-104.

BATALYANTS (K.Y), 1992. On the study of spawning frequency for bigeye (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*), based on the Atlantic longline fishery data. *ICCAT, Rec. Doc. Sci.*, **39** (1): 31-38.

BEVERTON, (R.J.H.) & HOLT (S.J.) 1957. On the dynamics of exploited fish populations. Minis. Agri. Fish. Food, Fish. Inves., Ser. 2, 19: 533 p.

BETTENCOURT (M.L.), 1975. A pesca do atum e alguns aspectos da interacção oceano-atmosfera nos Açores. *Serviço Meteorológico Nacional,* MEM 221, RT 1222, 64 p.

BLACKBURN (M.), 1965. Oceanography and the ecology of tunas. *Oceanogr. Mar. Biol. Ann. Rev.*, **3**: 299-322.

BLUNT (C.E.) JR, 1960. Observations on the food habits of longline caught bigeye and yellowfin tuna from the tropical eastern Pacific 1955-1956. *Calif. Fish Game,* **46** (1): 69-80.

BOGGS (C. H.), 1990. Longline research on tuna and marlin. *Relatório, X Semana das Pescas dos Açores*: 249-252. Sec. Regional Agric. Pescas, Horta, Açores.

BOGGS (C.H.), 1992. Depth, capture time, and hooked longevity of longline-caught pelagic fish: timing bites of fish with chips. *Fish. Bull. U. S.* **90** (4): 642-658.

BORODULINA (O.D.), 1974. The feeding of the bigeye tuna (*Thunnus obesus*) in the Gulf of Guinea and its place in the trophic system of the pelagic zone. *J. Ichthiol.* **14** (5): 765-775.

BOUR (W.) & GALENON (P.), 1979. The development of tuna fisheries in the western Pacific. *South Pacific Comm., Occas. Pap.*, **12**: 34 pp.

BRUN (M.) & KLAWE (W.L.), 1968. Landing of skipjack and yellowfin tuna at Papeete market (Tahiti). *Com. Fish. Rev.*, **30** (4): 62-65.

BUSHNELL (P.G.), BRILL (R.W.) & BOURKE (R.E.), 1990. Cardiorespiratory responses of skipjack tuna (*Katsuwonus pelamis*), yellowfin tuna (*Thunnus albacares*), and bigeye tuna (*Thunnus obesus*) to acute reductions of ambient oxygen. *Canad. Jour. Zool.*, 68(9): 1857-1865.

CALKINS (T.P.), 1980. Synopsis of biological data on the bigeye tuna (*Thunnus obesus* Lowe, 1839), in the Pacific Ocean. *Spec. Rep. IATTC*, **2**: 213-260.

CALKINS, (T.P.), YAMAGUCHI (M.) & MIYABE (N.), 1993. Some observations on bigeye tuna (*Thunnus obesus*) caught by the surface and longline fisheries for tunas in the eastern Pacific Ocean. *Bull. IATTC*, **20** (8): 441-499.

CAREY (F.G.), 1983. Experiments with free swimming fish. *In* Brewer, P. G. (ed), *Oceanography, the present and future*. Springer-Verlag, NY., pp 58-68.

CAREY (F. G.) & LAWSON (K. D.), 1973. Temperature regulation in free-swimming bluefin tuna. *Comp. Biochen. Physio*l., **44** (2A): 275-292.

CAREY (F.G.) & OLSON (R.J.), 1982. Sonic tracking experiments with tunas. *ICCAT, Rec. Doc. Sci.*, **17**: 458-466.

CAREY (F. G.) & TEAL (J.M), 1966. Heat conservation in tuna fish muscle. *Nat. Acad. Sci.,Proc..*, **56** (5): 1464-1469.

CAREY (F. G.) & TEAL (J.M), 1969. Regulation of body temperature by the bluefin tuna. *Comp. Biochen. Physio*l., **28** (1): 205-213.

CAREY (F. G.); TEAL (J.M.); KANWISTER (K.D.); LAWSON (K. D.) & BECKETT, (J.S.), 1971. Warm-bodied fish. *Amer. Zool.* **11** (1): 135-143.

CARVALHO (D:), GOUVEIA (L:), ORNELAS (J) & GOMES (R:), 1983. Tuna fisheries and research in Madeira. *ICCAT, Rec. Doc. Sci.*, **18** (3): 725-746.

CAVERIVIERE (A.), CONAND (F.) & SUISSE DE SAINTE CLAIRE (E.), 1976. Distribution et abondance des larves de thonidés dans l'Atlantique tropico-oriental. Etude des données de 1963 à 1974. *Doc. Scient. Centre Rech. Océanogr. Abidjan., ORSTOM*, **7** (2): 49-70.

CAVERIVIERE (A.) & SUISSE DE SAINTE CLAIRE (E.), 1980. Recherche des larves de thonidés dans l'Atlantique tropical oriental. Campagnes effectuées en 1976-1977 par le N.O. Capricorne. *Doc. Scient. Centre Rech. Océanogr. Abidjan, ORSTOM*, **11** (1): 37-72.

CAYRÉ (P), 1984. Procédure suivie pour la révision de la composition spécifique des statistiques thonières FISM (France, Côte d'Ivoire, Sénégal et Maroc). *ICCAT, Rec. Doc. Sci.*, **21** (2): 102-107.

CAYRÉ (P.); AMON KOTHIAS (J.B.); STRETTA (J.M.) & DIOUF (T.), 1988. Biologie des thons, *In*: Fonteneau A. et Marcille J. (eds.). *Ressources, pêche et biologie des thonidés tropicaux de l'Atlantique centre-est. FAO doc. techn. pêches*, **292**, pp 157-268.

CAYRÉ (P.) & DIOUF (T.), 1984. Croissance du thon obèse (*Thunnus obesus*) de l'Atlantique d'après les résultats de marquage. *ICCAT, Rec. Doc. Sci.*, **20** (1): 180-187.

CAYRÉ (P.) & DIOUF (T.), 1987. L'exploitation du patudo (*Thunnus obesus*) dans l'Atlantique tropical nord-est de 1969 à 1985 et rélation pêche-température de surface. *ICCAT, Rec. Doc. Sci.*, **26**(1): 127-140.

CAYRÉ (P.) & FONTENEAU (A.), 1984. Perspectives d'aménagement des pêcheries d'albacores et patudo juveniles. *ICCAT, Rec. Doc. Sci.*, **21** (2): 64-79.

CHAMPAGNAT (C.) & PIANET (R.), 1974. Croissance du patudo (*Thunnus obesus*) dans les régions de Dakar et de Pointe Noire. *ICCAT, Rec. Doc. Sci.*, **2**: 141-144.

CHOO (W.I.), 1976. Relationship between length and weight of yellowfin and bigeye tuna from the eastern Atlantic ocean. *ICCAT, Rec. Doc. Sci.*, **5** (1): 72-81.

CHUR (V.N.), 1973. On the use of mean index of stomach filling in short-term forecasts of bigeye tuna, *Thunnus obesus* catches. *ICES*,C.M.1973/j: 14.

CHUR (V.N.) & KRASOVSKAYA (N.V.), 1980. Dependence of the mass of bigeye tuna (*Thunnus obesus*) of the tropical part of the Atlantic Ocean on the length. *ICCAT, Rec. Doc. Sci.*, **9** (2): 291-293.

COLLETTE (B.B.), 1978. Adaptations and systematics of the mackerels and tunas. *In* The physiological ecology of tunas, edited by G.D. Sharp and A.E. Dizon. Academic Press, N.Y., pp 7-39.

COLLETTE (B.B.) & CHAO (L.N.), 1975. Systematics and morphology of the bonitos and their relatives (Scombridae, Sardini). *Fish. Bull.*U.S., **73** (3): 516-625.

COLLETTE (B.B.) & NAUEN (C.E.), 1983. FAO species catalog. Scombrids of the world. *FAO Fish. Synop.*, **125** (2): 137 p.

COMPEAN (J.), 1980. Comparaison de techniques de détermination de l'age chez les principales espéces de thonidés de l'Atlantique. *Université Aix-Marseille.2* - Thèse 3éme cycle, 6/8, 158 p.

CONSER, (R.J.), & POWERS (J.E.), 1990. Extensions of the ADAPT VPA tunning method designed to facilitate assessment work on tuna and swordfish stocks. ICCAT, Rec. Doc. Sci., **32**: 461-467.

CUEVAS (A.) & HORRA (J.), 1996. Tuna fisheries in eastern Atlantic: some stastistical aspects. *ICCAT, Rec. Doc. Sci.*, **45** (3): 87-115.

CUEVAS (A.); HORRA (J.) & ROMO (J.), 1994. Statistical analisis of tuna fisheries in eastern Atlantic. A preliminary report. *ICCAT, Rec. Doc. Sci.*, **44** (2): 218-241.

DARBY, (C.D.), & FLATMAN, (S.), 1994. Virtual population analysis: Version 3.1 (Windows/DOS) user guide. Min. Agric. Fish., and Food (MAFF). Dir, Fish. Res. Info. Tech. Ser. No. 1. Lowestoft, U.K.

DELGADO DE MOLINA (A.); PALLARÉS (P.); SANTANA (J.C.); DELGADO DE MOLINA (R.) & ARIZ (J.), 1996. Estadísticas españolas de la pesqueria atunera tropical en el Océano Atlántico. *ICCAT, Rec. Doc. Sci.*, **44** (2): 249-255.

DELGADO MOLINA (A.) & SANTANA (J.C.), 1986. Estimation de la edad y crecimiento del patudo (*Thunnus obesus* Lowe, 1933) capturado en las Islas Canarias. *ICCAT, Rec. Doc. Sci.*, **25**: 130-137.

DELGADO DE MOLINA (A.); SANTANA (J.C.); ARIZ (J.) & DELGADO DE MOLINA (R.), 1996. Seguimento de la modalidad de pesca sobre "manchas" de túnidos en las Islas Canarias. *ICCAT, Rec. Doc. Sci.*, **45** (3): 215-223.

DELGADO DE MOLINA (A.); SANTANA (J.C.); DELGADO DE MOLINA (R.) & ARIZ (J.), 1994. Datos estadísticos de la pesqueria de túnidos de las Islas Canarias durante el período 1975-1992. *ICCAT, Rec. Doc. Sci.*, **42** (2): 417-421.

DELGADO DE MOLINA (A.); SANTANA (J.C.); DELGADO DE MOLINA (R.) & ARIZ (J.), 1996. Datos estadísticos de la pesqueria de túnidos de las Islas Canarias durante el período 1975 a 1994. *ICCAT, Rec. Doc. Sci.*, **45** (3): 169-174.

DIAS (M.L.) & BARRACA (I.F.), 1971. Sobre a pesca de tunídeos nas costas de Portugal continental e ilhas da Madeira e Açores. *Bol. inform. Inst. Biol. marit.*, Lisboa, **2**: 14 p.

DIOUF (T.) & FONTENEAU (A.), 1994. Statistiques de la pêche thonière FIS durant la période de 1969 à 1992. *ICCAT, Rec. Doc. Sci.*, **42** (2): 401-407.

DOUBLEDAY, (W.G.), 1981. A method for estimating the abundance of survivors of an exploited fish population using commercial catch-at-age and research vessel abundance indices. Can. Spec. Pub. Fish. Aquat. Sci., **58**: 164-178.

DRAGANIK (B.) & PELCZARSKI (W.), 1984. Growth and age of bigeye and yellowfin tuna in the central Atlantic as per data gathered by R/V "Wieczno." *ICCAT, Rec. Doc. Sci.*, **20** (1): 96-103.

EVANS (R.), 1981. Comments on the use of water temperature to delimit tropical tuna distributions. *ICCAT, Rec. Doc. Sci.*, **15** (1): 49-56.

FEDOSEEV (Y.P.), 1974. Feeding of bigeyed tuna (*Thunnus obesus* Lowe) in the eastern central Atlantic. *ICES, C.M.* 1974/j: 12.

FEDOSEEV (Y.P.) & CHUR (V.N.), 1980. Relationship between feeding of bigeye tuna (*Thunnus obesus*) of the Gulf of Guinea and their catches in the day time. *ICCAT, Rec. Doc. Sci.*, **9** (2): 287-290.

FERREIRA (E.), 1932. La pesca dell' "Albacora" nelle Azzorre. *Note dell'Instituto Italo-Germanico di Biologia Marine di Rovigno d'Istria*, **1**, 15 p.

FERREIRA (E.), 1937. Escombridas dos Açores. *Açoreana*, **1** (4): 129-134.

FERREIRA (E.), 1940. A pesca da "Albacora" em 1938 e 1939 e "Pediculados" dos Açores. *Açoreana*, **2** (3): 129-134.

FONTENEAU (A.), 1975a. Note sur les problèmes d'identification du patudo dans les statistiqies de pêche. *ICCAT, Rec. Doc. Sci.*, **5** (1): 168-171.

FONTENEAU (A.), 1984. Modélisation de l'aménagement des pêcheries de thonidés tropicaux de l'Atlantique est. *ICCAT, Rec. Doc. Sci.*, **21** (2): 34-37.

FONTENEAU (A.), 1987. Composition spécifique des captures des thons de petite taille (albacore, listao et patudo) par les senneurs et les canneurs dans le secteur du Cap des Trois Pointes. *ICCAT, Rec. Doc. Sci.*, **26** (1): 310-215.

FONTENEAU (A.), 1988. Modelisation, gestion et amenagement des pêcheries thonières de l'Atlantique centre est. *In*: Fonteneau A. et Marcille J. (eds.). *Ressources, pêche et biologie des thonidés tropicaux de l'Atlantique centre-est. FAO doc. techn. pêches*, **292**, pp 317-355.

FONTENEAU (A.), 1989. Environnement et thons tropicaux de l'Atlantique. Introduction au problème. *ICCAT, Rec. Doc. Sci.*, **30** (1): 104-117.

FONTENEAU (A.), 1991a. La concentration plurispécifique exploité par 3° Sud et 15° Ouest en décembre 1983 et janvier 1984: caractéristiques biologiques et de l'exploitation. *ICCAT, Rec. Doc. Sci.*, **36**: 326-347.

FONTENEAU (A.), 1991d. Monts sous-marins et thons dans l'Atlantique tropical est. *Aquat. Living Resour.*, **4** (1): 13-25

FONTENEAU (A.), 1991e. Modélisation des pêcheries thonières. *In* Actes de la Conférence thonière régionale pour l'Océan Indien sud-ouest, Antenarivo, Madagascar 9-12 mai 1990. LeGall (J.-Y.); Reviers (X.) & Roger (C.) (Eds.), *Colloques et séminaires de l'ORSTOM*, **144**, 91-100.

FONTENEAU (A.), 1992 Pêche thonière et objects flottants: situation mondiale et perspectives. *ICCAT, Rec. Doc. Sci.*, **40**: 459-472.

FONTENEAU (A.), 1994. La zone Liberia: quelques elements statistiques et de reflexions halieutiques. *ICCAT, Rec. Doc. Sci.,* **42** (2): 408-416.

FONTENEAU (A.), in press.

FONTENEAU (A.) & DIOUF (T.), 1994. An efficient way of bait-fishing for tunas recently developed in Senegal. *Aquat. Living Resour.*, 7 (3): 139-151.

FONTENEAU (A.) & PALLARES (P.), 1991. Evolution récente des pêcheries thonières à la senne dans le Golfe de Guiné. *ICCAT, Rec. Doc. Sci.,* **36**: 427-478.

FONTENEAU (A.), & SANTOS (A.), 1980. Catches by ages to be used in cohort analysis and yield per recruit of bigeye tuna for the whole Atlantic. *ICCAT, Rec. Doc. Sci.,* **13**: 212-214

FOX (W.W., JR.), 1975. Fitting the generalized production model by least squares and equilibrium approximation. *Fish Bull., US.* **73** (1): 23-36.

FOX (W.W., JR.), 1976. Program documentation for COHORT (a Fortran VI computer program). *NODC/NMFS/SFC,* 17 p.

FRADE (F.), 1927. Sur la vessie natatoire du *Thunnus obesus* Lowe (Le "Patudo" des pêcheurs de Madère). *Bull. Soc. Port. Sc. Nat.*, 10 (7): 83-85.

FRADE (F.), 1960. Le thon patudo, *Parathunnus obesus* (Lowe) et sa pêche. *Est. Ens. Doc. 69.* Junta Invest. Ultramar, Lisboa.

FRADE (F.) & POSTEL (E.), 1955. Contribution à l'etude de la reproduction des scombridés et thonidés de l'Atlantique tropical. *Rapp. et Proc.-Verb.*, **134**, Cons. Int. Expl. de la Mer, Copenhague, 137: 34-35.

FRANCA (M.L.P.) & COSTA (F.C.), 1979. Quelques informations sur la pêcherie de thonidés dans l'archipel de Madeira et dans l'archipel de Açores. *Bol. Inst. Nac. Invest. Pescas*, Lisboa, **2**: 55-65.

GAERTNER (D.); MARCANO (J.); SALAZAR (H.) & ASTUDILLO (L.), 1996. El problema de las correcciones multiespecíficas de las capturas atuneras. aplicación de un modelo log-lineal iterativo a las capturas Venezoelanas de superficie (1087-03). . *ICCAT, Rec. Doc. Sci.,* **45** (3): 116-125.

GAIKOV (V.Z.), 1983. The dynamics of maturation and sex ratio of bigeye tuna (*Thunnus obesus* Lowe) in the Atlantic Ocean. *ICCAT, Rec. Doc. Sci.,* **18** (2): 347-354.

GAIKOV (V.Z.), 1984. Feeding intensity of bigeye tuna, *Thunnus obesus* (Lowe), in the Atlantic Ocean. *ICCAT, Rec. Doc. Sci.,* **20** (1): 175-179

GAIKOV (V.Z.); CHUR (V.N.); ZHAROV (V.L.) & FEDOSEEV (YU.P.), 1980. On age and growth of the Atlantic bigeye tuna. *ICCAT, Rec. Doc. Sci.,* **9** (2): 294-302.

GAIKOV (V.Z.) & FEDOSEEV (YU.P.), 1986. Comparision between the indices of stomach fullness of living and distressed specimens of bigeye tunas. *ICCAT, Rec. Doc. Sci.,* **25**: 110-112.

GAIKOV (V.Z.) & FEDOSEEV (YU.P.), 1986. The influence of temperature and biotic factors on vertical distribution of bigeye tuna (*Thunnus obesus*) in the Atlantic Ocean. *ICCAT, Rec. Doc. Sci.,* **25**: 113-118.

GASCUEL (D.), FONTENEAU (A.) & FOUCHER (E.), 1993. Analyse de l'évolution des puissances de pêche par l'analyse des cohortes: application aux senneurs exploitant l'albacore (*Thunnus albacares*) dans l'Atlantique est. *Aquat. Living Resour.*, **6**(1): 15-30.

GIBBS (R.H.) & COLLETTE (B.B.), 1967. Comparative anatomy and systematics of the tunas, genus *Thunnus*. *Fish. Bull., U.S.*, **66** (1): 65-130.

GOUVEIA (L.), 1986. Length composition of bigeye tuna caught by Madeira baitboat fishery, 1979-1984. *ICCAT, Rec. Doc. Sci.*, **25**: 119-129.

GRAHAM (J.B.), 1975. Heat exchange in yellowfin tuna, *Thunnus albacares* and skipjack tuna, *Katsuwonus pelamis*, and the adaptative significance of elevated body temperatures in scombroid fishes. *Fish. Bull.* U.S. **73** (2): 219-229.

GRANDPERRIN (R.), 1975. Structures trophiques aboutissant aux thons de longue ligne dans le Pacifique Sud Ouest. *Thèse Doc. Etat. Université de Marseille*, 295 p.

HALLIER (J.P.), 1985. Purse seining on debris-associated schools in the western Indian Ocean. *I.P.T.P. Coll. Vol. Work. Doc.* TWS/85/30: 150-156.

HALLIER (J.P.), 1991. Tuna fishing on log-associated schools in the western Indian Ocean: an aggregation behaviour. *I.P.T.P. Coll. Vol. Work. Doc.*, **4**: 325-342.

HALLIER (J.P.) & DIOUF (T.), 1996. Statistiques de la pêche thonière FIS durant la période de 1969 à 1994. *ICCAT, Rec. Doc. Sci.*, **45** (3): 155-160.

HANAMOTO (E.), 1974. Fishery oceanography of bigeye tuna -I. Depth of capture by tuna long-line gear in eastern tropical Pacific Ocean. *La mer*, **12** (3): 128-136.

HANAMOTO (E.), 1975. Fishery oceanography of bigeye tuna II. Thermocline and dissolved oxygen content to tuna long-line fishing grounds in eastern tropical Pacific Ocean. *La mer*, **13** (2): 58-71.

HANAMOTO (E.), 1976. The swiming layer of bigeye tuna. *Bull. Soc. Fish. Oceanogr.* **29**: 41-44. [Engl. transl. No. 21 by T. Otsu, 1977, 7p; NMFS Honolulu Lab. Honolulu].

HANAMOTO (E.), 1987. Effect of oceanographic environment on bigeye tuna distribuition. *Bull. Jpn. Soc. Sci. Fish.*, **51** ( ): 203-216

HAYASHI (S.), 1958. A review on age determination of the Pacific tunas. *Indo-Pacific. Fish. Coun., Proc.*, 7 (2-3): 53-64.

HAYASHI (S.) & KIKAWA (S.), 1970. A comparative study on efficiency of the surface and longline fisheries for exploitation of tuna and related species. *Far Seas Fish. Res. Lab., S Series*, **3**: 97-114.

HIGGINS (B.E.), 1967. The distribution of juveniles of four species of tunas in the Pacific Ocean. *Indo-Pacific. Fish. Coun., Proc.*, **12** (2): 79-99.

HIGGINS (B.E.), 1970. Juvenile tunas collected by midwater trawling in Hawaiian waters, July-September 1967. *Amer. Fish. Soc. Trans.*, **99** (1): 60-73.

HISADA (K.), 1973. Investigation on tuna hand-line fishing ground and some biological observations on yellowfin and bigeye tunas in the notthwestern Coral Sea. *Far Seas Fish. Res. Lab., Bull.*, **8**: 35-69.

HISADA (K.), 1979. Relationship between water temperature and maturity status of bigeye tuna caught by longline in the central and eastern tropical Pacific Ocean. *Far Seas Fish. Res. Lab., Bull.*, **17**: 159-175.

HOLLAND (K.N.); BRILL (R.W.) & CHANG (R K.), 1990. Horizontal and vertical movements of yellowfin and bigeye tuna associated with fish aggregation devices. *Fish Bull. US.* **88** (3): 493-507.

HOLLAND (K.N.); BRILL (R.W.); CHANG (R.K.); SIBERT (J.R.) & FOURNIER (D.A.), 1992. Physiological and behavioural thermoregulation in bigeye tuna (*Thunnus obesus*). *Nature*, **358** (6385): 410-412

HOLLAND (K.N.) & SIBERT (J.R.) 1994. Physiological thermoregulation in bigeye tuna, *Thunnus obesus. Envir. Biol. Fish.*, 40 (3): 319-327.

HONMA (M.); WARASSHINA (Y.) & SUZUKI (Z.), 1973. Identification of young yellowfin and bigeye tunas in the western Pacific Ocean. Examination of pratical standards based on external characteristics and the reliaability in field survey. *Far Seas Fish. Res. Lab., Bull.*, **8:** 1-23.

HSU (C.C.) & LIU (H.C.), 1992. Status of Taiwanese longline fisheries in the Atlantic. *ICCAT, Rec. Doc. Sci.*, **39**(1): 258-264.

ICCAT, 1980a. Working group on juvenile tropical tunas, May 28-30 and June 4-7, 1980, Brest, France. *ICCAT, Rec. Doc. Sci.*, **12**: 1-25.

ICCAT. 1980b. Rapport de la réunion sur les thonidés tropicaux juvéniles. *ICCAT, Rec. Doc. Sci.*,**13:** 231 p.

ICCAT 1982a . Historical statistical bulletin. Vol.**1** (1950-59). *International Commission for the Conservation of Atlantic Tunas*, Madrid, 79 p.

ICCAT 1982b . Historical statistical bulletin. Vol.**2**, (1960-69). *International Commission for the Conservation of Atlantic Tunas*, Madrid, 109 p.

ICCAT, 1984a. Meeting of the working group on juvenile tropical tunas. COB, Brest, France, July 12-21, 1984). *ICCAT, Rec. Doc. Sci.*, **21** (1): 1-55.

ICCAT, 1984b. Report of the data preparatory meeting for the working group on juvenile tropical tunas, February 3-9, 1984, CRODT, Dakar, Senegal. *ICCAT, Rec. Doc. Sci.*, **21** (1): 28-51.

ICCAT, 1988a. Report of the meeting of the Working Group on Juvenile Multi-species Statistics. *ICCAT, Rec. Doc. Sci.*, **28**: 1-25.

ICCAT, 1988b. Statistical bulletin, Vol. 18 - 1987

ICCAT 1988c. Historical statistical bulletin. Vol.**3**, (1970-79). *International Commission for the Conservation of Atlantic Tunas*, Madrid, 180 p.

ICCAT, 1989. Report of the data preparatory meeting for the Yellowfin Year Program. *ICCAT, Rec. Doc. Sci.*, **29**: 1-56.

ICCAT, 1993. Statistical Bulletin. Vol. **23**-1992. *International Commission for the Conservation of Atlantic Tunas*, Madrid, 184 p.

ICCAT, 1994. Rapport de la Période Biennale 1992-93, IIe Partie, 1993, *International Commission for the Conservation of Atlantic Tunas*, Madrid, 435 p.

IVERSEN (E.S.), 1955. Size frequencies and growth of central and western Pacific bigeye tuna. *Spec. Sci. Rep. U. S. Fish Wildl. Serv. (Fish.)*, **162**: 1-40.

JAGER (B.), 1963. Synopsis of biological data on bluefin tuna *Thunnus thynnus orientalis* (Temminck and Schlegel) 1842, longfin tuna *Thunnus alalunga* (Bonnaterre) 1788, yellowfin tuna *Thunnus albacares* (Bonnaterre) 1788 and bigeye tuna *Thunnus obesus* (Lowe) 1839 (South Africa*). FAO, Fish. Rep.* , **6**(2): 588-607.

JUHL (R.), 1955. Notes on the feeding habits of subsurface yellowfin and bigeye tunas of the eastern tropical Pacific Ocean. *Calif. Fish Game*, **41**(1): 99-101.

KIKAWA (S.), 1953. Observations on the spawning of the big-eyed tuna (*Parathunus mebachi* Kishinouye) near the southern Marshall Islands. *Nankai Reg. Fish. Res. Lab., Contr.*, **1** (42): 10 p.

KIKAWA (S.), 1961. The group maturity of bigeye tuna *Parathunus mebachi* (Kishinouye) in the spawning areas of the Pacific. *Rep. Nankai Reg. Fish. Res. Lab.*, **13**: 35-46.

KIKAWA (S.), 1962. Studies on the spawning activity of the Pacific tunas *Parathunus mebachi* and *Neothunus macropterus,* by the gonad index examination. *Occas. Rep. Nankai Reg. Fish. Res. Lab.*, **1**: 43-56.

KIKAWA (S.), 1966. The distribution of maturing bigeye and yellowfin and an evaluation of their spawning potential in different areas in the tuna longline grounds in the Pacific. *Nankai Reg. Fish. Res. Lab. Rep.*, **23**: 131-208.

KING (J.E.) & IKEHARA (I.I.), 1956. Comparative study of the food of bigeye and yellowfin tuna in central Pacific. U.S. Fish Wild. Serv., *Fish Bull., US.* **57** (108): 61-85.

KISHINOUYE (K.), 1923. Contributions to the comparative study of the so-called scombriod fishes. *J. Coll. Agric. Imper. Univ. Tokyo* **8**(3): 293-475.

KOBAYASHI (H.), 1982. Observation upon the swimming layer of the bigeye tuna, *Thunnus obesus*, caught by deep longline. *Bull. of Faculty of Fish. Mie Univ.* **9**: 89-99.

KONAGAYA (S.); YAMABE (K.) & AMANO (K.), 1969. On body temperatures of the tunas at the time of haulage. *Jap. Soc. Sci. Fish. Bull.*, **35** (4): 410-416.

KUME (S.), 1962. A note on the artificial fertilization of bigeye tuna, *Parathunnus mebachi* (Kishinouye). *Rep. Nankai Reg. Fish. Res. Lab.*, **15**: 79-84.

KUME (S.), 1967. Distribution and migration of bigeye tuna in the Pacific Ocean. *Rep. Nankai Reg. Fish. Res. Lab.*, **25**: 75-80.

KUME (S.), 1969. Ecological studies on bigeye tuna. V. A critical review on distribution, size composition and stock structure of bigeye tuna in the North Pacific Ocean (north of 16° N). *Bull. Far Seas Fish. Res. Lab.*, **1**: 57-75.

KUME (S.), 1969. Ecological studies on bigeye tuna. VI. A review on distribution and size composition of bigeye tuna in the equatorial and south Pacific Ocean. *Bull. Far Seas Fish. Res. Lab.*, **1**: 77-98.

KUME (S.), 1974. Tuna fisheries and their resources in the Pacific Ocean. *Indo-Pacif. Fish. Coun., Proc.*, **15**(3): 390-423.

KUME (S.), 1976. Present status of the bigeye tuna in the Atlantic Ocean. *ICCAT, Rec. Doc. Sci.*, **5** (1): 172-175.

KUME (S.), 1977. Recent status of the bigeye tuna in the Atlantic Ocean. *ICCAT, Rec. Doc. Sci.*, **6** (1): 162-167.

KUME (S.), 1978a. Age composition of the Atlantic bigeye tuna, 1965-75. *ICCAT, Rec. Doc. Sci.*, **7** (1): 107-109.

KUME (S.), 1978b. Recent status of the bigeye tuna stocks in the Atlantic Ocean. *ICCAT, Rec. Doc. Sci.*, **7** (1): 114-119.

KUME (S.), 1979. A note on the present status of Atlantic bigeye tuna. *ICCAT, Rec. Doc. Sci.*, **8** (1): 251-256.

KUME (S.), 1980. A production model approach to evaluate recent bigeye stock conditions in the Atlantic. *ICCAT, Rec. Doc. Sci.*, **9**(2): 312-316.

KUME (S.), 1981. An approach to evaluate the stock status of Atlantic bigeye tuna by production model. *ICCAT, Rec. Doc. Sci.*, **15** (1): 171-186.

KUME (S.), 1985. An analysis on the stock abundance of Atlantic bigeye tuna caught by Japanese longline fishery. *ICCAT, Rec. Doc. Sci.*, **23** (2): 248-253

KUME (S.), 1986. Species composition and some features of surface tuna school caught by baitboat fishery in the Gulf of Guinea. *in Proceedings of the ICCAT Conference on The International Skipjack Year Program*, edited by P.E.K. Symons, P.M. Miyake and G.T. Sakagawa. Madrid, ICCAT, pp 122-126.

KUME (S.) & JOSEPH (J.), 1966. Size composition, growth and sexual maturity of bigeye tuna, *Thunnus obesus* (Lowe), from the Japanese long-line fishery in the eastern Pacific Ocean. *Bull. IATTC*, **11** (2): 47-99.

KUME (S.) & JOSEPH (J.), 1969. The Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean east of 130°W, 1964-1966. *Bull. IATTC*, **13** (2): 275-418.

KUME (S.) & MORITA (Y.), 1966. Ecological studies on bigeye tuna-III. On bigeye tuna, *Thunnus obesus*, caught by "nighttime longline" in the north Pacific Ocean. *Rep. Nankai Reg. Fish. Res. Lab.*, **24**: 21-30.

KUME (S.) & MORITA (Y.), 1967. Ecological studies on bigeye tuna-IV. Size composition of bigeye tuna, *Thunnus obesus* (Lowe), caught by pole-and-line fishery in the north-western Pacific Ocean. *Rep. Nankai Reg. Fish. Res. Lab.*, **25**: 81-90.

KUME (S.) & MORITA (Y.), 1977. On the stock structure of bigeye tuna in the Atlantic Ocean. *ICCAT, Rec. Doc. Sci.*, **6** (1): 149-155.

KUME (S.); MORITA (Y) & OGI (T), 1971. Stock structure of the Indian bigeye tuna, *Thunnus obesus* (Lowe), on the basis of distribution, size composition and sexual maturity. *Bull. Far Seas Res. Lab.*, **4**: 141-164.

LE GALL (J.Y.); LAUREC (A.) & CHARDY (P.), 1975. Mise en évidence des relations phénotypiques et phylogénétiques à l'intérieur du genre *Thunnus* par une analyse multicritères. *Bull. Mus. Nat. Hist. Nat. 3ème série*, **339**, zoologie, 241 p.

LEGENDRE (R.), 1936. Presence de *Parathunnus obesus* dans le Golfe de Gascogne. *C. r. somm. Scienc. Biogeog. Paris*, **113**: 66-67

LENARZ (W.H.), 1975. Length weight relations for five eastern tropical Atlantic scombrids. *Fish. Bull. U.S.* **72** (3): 848-851.

LENARZ (W.H.) & SAKAGAWA (G.T.), 1973. A review of the yellowfin tuna fishery of the Atlantic Ocean. *ICCAT, Rec. Doc. Sci.*, **1**: 5-58.

LOWE (R.T.), 1839. A supplement to a synopsis of the fishes of Madeira. *Proc. Zool. Soc. Lond.*, **7**: 76-92.

MAGNUSON (J.J.), 1973. Comparative study of adaptations for continuous swimming and hydrostatic equilibrium of scombroid and xiphoid fishes. *Fish. Bull. U.S.*, **71** (2): 337-356.

MAGNUSON (J.J.), 1978. Locomotion by scombrid fishes: hydromechanics, morphology and behaviour. *In* Hoar (W.S.) & Randall (D.J.) (eds), 1978. Fish Physiology, Volume VII, Academic Press, New York: 239-313.

MAGNUSON (J.J.) & HEITZ (J.G.), 1971. Gill raker apparatus and food selectivity among mackerels, tunas and dolphins. *Fish. Bull.U.S..*, **69** (2): 361-370.

MAGNUSON (J.J.) & WEININGER (D.), 1978. Estimation of minimum sustained speed and associated body drag of scombrids. *In* SHARP (G.D.) & DIZON (A.E.) (eds.), 1978. *The physiological ecology of tunas.* Academic Press, New York.: 293-311.

MARCILLE (J.), 1979. Niveau d'exploitation du patudo Atlantique (années 1969 à 1976). *ICCAT, Rec. Doc. Sci.,* **8** (1): 241-250.

MARCILLE (J.) & ARMADA (N.), 1979. Les prises de jeunes albacores et patudos dans l'Atlantique oriental tropical. Consequences en matière d'aménagement. *ICCAT, Rec. Doc. Sci.,* **8** (1): 108-119.

MARCILLE (J.); CHAMPAGAT (C.) & ARMADA (N.), 1978. Croissance du patudo (*Thunnus obesus*) de l'Océan Atlantique intertropical oriental. *Doc. Sci. Cent. Rech. Océanogr. Abidjan ORSTOM,* **9** (1): 73: 8 1.

MATHER (F.J., III), 1963. Tunas (Genus *Thunnus*) of the western North Atlantic. Part III. Distribution and behavior of tuna species. *In Proc. World Scient. Meet Biol. Tunas and rel. spec., La Jolla, Calif.,*1962 (FAO, Rome,1963) Vol. 3: 1159-1161.

MATHER (F.J., III), 1964. Tunas (Genus *Thunnus*) of the western North Atlantic. Part III. Distribution and behavior of tuna species. *In Symposium on Scombroid fishes, Part I, Mar. Biol. Assoc. of India, Mandapam Camp,* 1963: 411-426.

MATHER (F.J., III), & GIBBS (R.H.), 1958. Distribution of the Atlantic bigeye tuna, *Thunnus obesus,* in the western North Atlantic and the Caribbean Sea. *Copeia 3*: 242-244.

MENDOZA (J.); ROY (C.) & JEZEQUEL (M.), 1983. Résultats préliminaires de l'étude des données historiques concernant l'hydrologie et la pêcherie thonière de surface de l'Atlantique est. *ICCAT, Rec. Doc. Sci.,* **18** (1): 1-49.

MIYABE (N.), 1984. On the growth of yellowfin and bigeye tunas estimated from the tagging results. *ICCAT, Rec. Doc. Sci.,* **20** (1): 117-122

MIYABE (N.), 1989. An updated production model analysis on Atlantic bigeye tuna as of 1986. *ICCAT, Rec. Doc. Sci.,* **30** (1): 1-5

MIYABE (N.), 1996. Standardized bigeye CPUE from the Japanese longline fishery in the Atlantic. *ICCAT, Rec. Doc. Sci.,* **45** (3): 208-214.

MIYABE (N.) & BAYLIFF (W.H.) 1987. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1971-1980. *Bull. IATTC,* **19**(1): 1-163.

MIYAKE (P.M.), 1990. Field manual for statistics and sampling Atlantic tunas and tuna-like species. *International Commission for the Conservation of Atlantic Tunas*, Madrid, 184 p.

MIYAKE (P.M.) & HAYASI (S.), 1978. Manuel d'opérations pour les statistiques et l'échantillonnage des thonidés et espèces voisines dans l'océan Atlantique. *International Commission for the Conservation of Atlantic Tunas*, Madrid, 149 p.

MURPHY (G.I.) & SHOMURA (R.S.), 1953. Longline fishing for deep-swimming tunas in the central Pacific, January-June 1952. *U.S. Fish. Wild. Serv., Spec. Sci. Rep. Fish.*, **108**: 32 p.

MURPHY (G.I.) & SHOMURA (R.S.), 1955. Longline fishing for deep-swimming tunas in the central Pacific, August-November 1952. *U.S. Fish. Wild. Serv., Spec. Sci. Rep. Fish.*, **137**: 42 p.

MURPHY (G.I.) & SHOMURA (R.S.), 1972. Pre-exploitation abundance of tunas in the equatorial central Pacific. *Fish. Bull.U.S.*, **70** (3): 875-913.

MURPHY (T.C.) & SAKAGAWA (G.T.) , 1976. A review and evaluation of estimates of natural mortality rates of tunas. *ICCAT, Rec. Doc. Sci.*, **6** (1): 117-123.

NAKAMURA (E.L.) & MATSUMOTO (W.M.), 1967. Distribution of larval tunas in Marquesan waters. *Fish. Bull. U.S.*, **66** (1): 1-12.

NAKAMURA (H.), 1969. Tuna distribution and migration. *Fishing News (Books) Ltd.*, London: 76 p.

NAKANO (H.) & BAYLIFF (W.H.), 1992. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1981-1987. *Bull. IATTC*, **20**(5): 183-355.

NIKAIDO (H.); MIYABE (N.) & UEYANAGI (S.), 1991. Spawning time and frequency of bigeye tuna, *Thunnus obesus*. *Bull. Nat. Res. Inst. Far Seas Fish.*, **28**: 47-73.

NISHI (T.), 1990. The hourly variations of depth and hooking depth of yellowfin tuna (*Thunnus albacares*), and bigeye tuna (*Thunnus obesus*), of tuna longline in the eastern region of India Ocean. *Mem. Fac. Fish. Kagoshima Univ.* **39**: 81-89.

NISHIKAWA (Y.); HONMA (M.); UEYANAGI (S.) & KIKAWA (S.), 1985. Average distribution of larvae of oceanic species of Scombroid fishes, 1956-1981. *Far Seas Fish. Res. Lab., S Series* **12**, 99 p.

NISHIKAWA (Y.); KIKAWA (S.), HONMA (M.) & UEYANAGI (S.), 1978. Distribution atlas of larval tunas, billfishes and related species - results of larval surveys by R/V Shunyo Maru and Shoyo Maru, 1956-1975. *Far Seas Fish. Res. Lab., S Series* **9**, 99 p.

NOSE (Y.); KAWATSU (H.) & HIYAMA (Y.), 1957. Age and growth of Pacific tunas by scale reading. *In* Collection of Works on Fisheries Science, Jubilee Publication of professor I. Amemiya, *Univ. Tokyo Press*: 701-716.

ORSTOM, 1993. Rapport du Grupe de Travail ORSTOM Thon-Liberia. *ICCAT, Rec. Doc. Sci.*, **40** (2): 483-490.

OSIPOV (V.G.), 1968. On the vertical distribution of the yellowfin *Neothunnus albacora* and bigeye *Parathunnus obesus* tunas. *Zoologicheshii Zhurnal*, **47** (8): 1192-1197 (in Russian; English abstract).

OTSU (T.) & UCHIDA, (R.N.), 1956. Tagged bigeye tuna recovered. *Pacif. Sci.*, **10** (2): 236.

OVCHINNIKOV (V.V.), 1983. Pecularities of vertical distribution and migration of tunas in the Gulf of Guinea. *ICCAT, Rec. Doc. Sci.*, **18** (3): 719-224.

PALLARÉS (P.); in press.

PALLARÉS (P.); ARIZ (J.); DELGADO DE MOLINA (A.) & SANTANA (J.C.; 1996. Análisis de la composición específica de las capturas de cerco de túnidos tropicales en el Atlántico Oriental. *ICCAT, Rec. Doc. Sci.*, **45** (3): 182-197.

PALLARÉS (P); DELGADO DE MOLINA (A.); SANTANA (J.C.) & ARIZ (J.), 1994. Muestreo multiespecífico: efectos sobre el tamaño muestral y las distribuciones de tallas resultantes. *ICCAT, Rec. Doc. Sci* **42** (2): 133-137.

PALLARES (P.); DELGADO DE MOLINA (A.); SANTANA (J.C.); DELGADO DE MOLINA (R.) & ARIZ (J.), 1994. Evolución de la pesca al objecto y sobre bancos libres de la flota de cerco española en el Océano Atlántico (1990-1993). *ICCAT, Rec. Doc. Sci.*, **44** (2): 287-295.

PALLARES (P.); GARCIA MAMOLAR (J.M.) & FERNANDEZ (A.M.), 1983. Estimation de la proporcion rabil-patudo en las capturas de la flota tropical española (1979-81). *ICCAT, Rec. Doc. Sci.*, **18** (2): 343-346.

PALLARÉS (P); SANTANA (J.C.); ARIZ (J.) & DELGADO DE MOLINA (A.), 1990. Explotation durante una semana de los tunídos asociados a un objecto flotante en el Atlántico intertropical. *ICCAT,* SCRS/89/38 YYP/89/4

PARKS (W.); BARD (F.X.); CAYRÉ (P.); KUME (S.) & SANTOS (A.), 1982. Length-weight relations for bigeye tuna captured in the eastern Atlantic ocean. *ICCAT, Rec. Doc. Sci.*, **17** (1): 214-225

PELLA (J.J.) & TOMLINSON (P.K.), 1969. A generalized stock production model. *Bull. IATTC*, **13** (3): 419-496.

PEREIRA (J.), 1983. Pêche et recherche thonières aux Açores. *ICCAT, Rec. Doc. Sci.*, **18** (3): 747-753

PEREIRA (J.), 1984. A safra do atum nos Açores em 1983. *Relatório da 4ª Semana das Pescas dos Açores*, Horta, Açores, 12 a 16 de Março de 1984, pp 119-142.

PEREIRA (J.), 1984. Croissance du patudo (*Parathunnus obesus*) de l'Atlantique. *ICCAT, Rec. Doc. Sci.*, **20** (2): 143-154

PEREIRA (J.), 1984. Etat des stocks du patudo de l'Atlantique par analyse de cohortes, analyse de production par recrue et par le modèle global. *ICCAT, Rec. Doc. Sci.*, **20** (2): 155-183.

PEREIRA (J.), 1985. Analyse de la PUE dans la pêcherie de patudo en surface aux Açores. *ICCAT, Rec. Doc. Sci.*, **23** (2): 221-223.

PEREIRA (J.),1985. Observations sur le sex ratio du patudo (*Thunnus obesus*) aux Açores. *ICCAT, Rec. Doc. Sci.*, **23** (2): 237-241.

PEREIRA (J.), 1985. Procédures suivis aux Açores pour la collecte des statistiques thonières. *ICCAT, Rec. Doc. Sci.*, **23** (2): 437-438.

PEREIRA (J.), 1986. Composition spécifique des bancs de thonidés pêchés à la senne aux Açores. *ICCAT, Rec. Doc. Sci.*, **25:** 395-400.

PEREIRA (J.), 1987 . Analyse de l'état du stock de patudo Atlantique. *ICCAT, Rec. Doc. Sci.*, **26** (1): 141-167.

PEREIRA (J.), 1987. Maturité sexuelle et sex ratio des patudos capturés aux Açores. *ICCAT, Rec. Doc. Sci.*, **26** (1): 168-173.

PEREIRA (J.), 1987. Situation actuelle de la pêche du patudo aux Açores. *ICCAT, Rec. Doc. Sci.*, **26** (1): 174-183.

PEREIRA (J.), 1989. Etat du stock de patudo (*Thunnus obesus*) de l'Atlantique. *ICCAT, Rec. Doc. Sci.*, **30** (1): 173-202.

PEREIRA (J.), 1990. Analyse de l'abondance de patudo Atlantique en 1973-1975. *ICCAT, Rec. Doc. Sci.*, **32** (1): 73-82.

PEREIRA (J.), 1990. Etat du stock du patudo Atlantique au 30 Septembre 1989. *ICCAT, Rec. Doc. Sci.*, **32** (1): 83-110.

PEREIRA, (J.), 1991. Statistiques de la pêche thonière açorienne. *ICCAT, Rec. Doc. Sci.,* **35** (1): 184-191.

PEREIRA, (J.), 1991. Indices de détection et taille des thons dans les bancs associés a objets flottants. *ICCAT, Rec. Doc. Sci.,* **35** (1): 192-195.

PEREIRA, (J.), 1992. Statistiques de la pêche thonière açorienne, années 1979-1990. *ICCAT, Rec. Doc. Sci.,* **39** (1): 88-95

PEREIRA, (J.), 1992. Etat du stock de patudo de l'Atlantique. *ICCAT, Rec. Doc. Sci.,* **39** (1): 96-112.

PEREIRA, (J.), 1993. Etat du stock de patudo de l'Atlantique au 30 Septembre 1992. *ICCAT, Rec. Doc. Sci.,* **40** (2): 174-184.

PEREIRA, (J.), 1993. Statistiques de la pêche thonière açorienne, années 1979-1991. *ICCAT, Rec. Doc. Sci.,* **40** (2): 185-190.

PEREIRA, (J.), 1994. Analyse de l'état du stock de patudo de l'Atlantique. *ICCAT, Rec. Doc. Sci.,* **42** (2): 279-289.

PEREIRA, (J.), 1994. Statistiques de la pêche thonière açorienne, années 1979-1992. *ICCAT, Rec. Doc. Sci.,* **42** (2): 428-435.

PEREIRA, (J.), 1995. Etat d'exploitation du stock de patudo. *ICCAT, Rec. Doc. Sci.,* **44** (2): 272-280.

PEREIRA (J.), 1996. Tuna schools in the Azores. *ICCAT, Rec. Doc. Sci.,* **45** (3): 236-247.

PEREIRA (J.) & BARD (F.X.), 1986. Distribution, migrations et structure de stock du patudo Atlantique. *ICCAT. SCRS/86/63,* 29 p.

PEREIRA (J.) & MIYABE (N.), 1990. Production model analysis on Atlantic bigeye tuna as of 1987. *ICCAT, Rec. Doc. Sci.,* **32** (1): 67-72

PEREIRA, (J.) & MIYABE (N.), 1991. Production model analysis on Atlantic bigeye tuna as of 1988. *ICCAT, Rec. Doc. Sci.,* **35** (1): 22-27.

PEREIRA, (J.) & MIYABE (N.), 1993. Production model analysis on Atlantic bigeye tuna as of 1990. *ICCAT, Rec. Doc. Sci.* **40** (2): 169-173.

PIANET (R.), 1995. Statistiques et indices de pêcheries thonières tropicales à la senne. Compte rendu de la réunion du Groupe de Travail ORSTOM, Paris du 2 au 5 juillet 1991. *ORSTOM, Collection Colloques et Seminaires, Paris.*

PINHO (M.R.), 1995. Application of an integrated version of the Fox's model to the yellowfin and bigeye tuna fisheries. *ICCAT, Rec. Doc. Sci.,* **44** (2): 281-286.

POPE, (J.G.), 1977. Estimation of fishing mortality, its precision and implications for the management of fisheries. pp. 63-76 *In*: J.H. Steele. (ed) Fisheries Mathematics. Academic Press, London, New York.

POPE, (J.G.), 1979. Population dynamics and management: current status and future trends. Invest. Pesq., **43** (1): 199-221.

POPE, (J.G.), & SHEPHERD, (J.G.), 1982. A simple method for the consistent interpretation of catch-at-age data. J. Cons. Int. Explo. Mer, **40** (2): 176-184.

POSTEL (E.), 1969. Répartition et abondance des thons dans l'Atlantique Tropical. *Actes du Symposium Océanographie et ressources halieutiques de l'Atlantique Tropical. Abidjan, 1966, UNESCO*, pp 109-138.

POTIER (M.) & FONTENEAU (A.), 1982. Aménagement de la population de patudo (*Parathunnus obesus*) de l'Atlantique. *ICCAT, Rec. Doc. Sci.*, **17** (1): 234-247.

POWERS, (J.E.), & RESTREPO, (V.R.), 1992. Additional options for age-sequenced analysis. *ICCAT, Rec. Doc. Sci.* **39**: 346-354.

POWERS, (J.E.), & RESTREPO, (V.R.), 1993. Evaluation of stock assessment research for Gulf of Mexico king mackerel: benefits and cost to management. *N. Amer. J. Fish. Manag.* **13**(1): 15-26.

PUNT, (A.E.), 1996. A multi-component variant of the ASPM approach for use in the assessment of North Atlantic albacore (*Thunnus alalunga*). *ICCAT Col. Vol. Sci. Pap.*, **43**: 347-360.

PRAGER, (M.H.), 1994. A suite of extensions to a nonequilibrium surplus-production model. *Fish. Bull. U.S.*, **92** (2): 374-389.

PUNT, (A.E.), PENNEY, (A.J.) & WILKE, (C.G.), 1992. Stock assessment of south Atlantic albacore using an age-structured production model. *ICCAT, Rec. Doc. Sci.*, **34**: 215-224.

RAMOS (A.); DELGADO DE MOLINA (A.); ARIZ (J.); SANTANA (J.C.); GARCIA-WEILL (L.) & CANTON (M.), 1996. Agregaciones de rabil (*Thunnus albacares*, BONATERRE 1788) y patudo (*Thunnus obesus*, LOWE 1839) en eventos oceanográficos submesoescalares del área de Canarias observados mediante teledetección infrarroja. *ICCAT, Rec. Doc. Sci.*, **45** (3): 175-181.

RESTREPO (V.), in press.

RICHARDS (W.J.), 1969. Distribution and relative apparent abundance of larval tunas collected in the tropical Atlantic during Equalant surveys I and II. *Proc. symp. oceanography and fisheries resources of the tropical Atlantic*. UNESCO, pp 289-315.

RICHARDS (W.J.) & KLAWE (W.L.), 1972. Indexed bibliography of the eggs and young of tuna and other scombrids (Pisces, Scombridae), 1880-1970. *U.S. Nat.Mar.Fish.Sev., NOAA Tech.Rep. NMFS SSRF*-652: 107 p.

RICHARDS (W.J.) & SIMMONS (D.C.), 1971. Distribution of tuna larvae (*Pisces*, Scombridae) in the northwestern Gulf of Guinea and off Sierra Leone. *Fish. Bull. U.S.*, **69** (3): 555-568.

RUDOMIOTKINA (G.P.), 1983. Areas, periods and conditions of bigeye tuna, *Thunnus obesus* (Lowe), spawning in the tropical parts of the Atlantic Ocean. *ICCAT, Rec. Doc. Sci.*, **18** (2): 355-362.

SAITO (S.), 1973. Studies on fishing albacore, *Thunnus alalunga*, (Bonnaterre) by experimental deep longline. *Mem. Fac. Fish. Hokkaido Univ.*, **21**: 107-841.

SAITO (S.), 1975. On the depth of capture of bigeye tuna by further improved vertical longline in the tropical Pacific. *Bull. Jpn. Soc. Sci. Fish.*, **41** (8): 831-841.

SAITO (S.); ISHII (K.) & YONETA (K.), 1970. Swimming depths of large sized albacore in the South Pacific Ocean.-I. Fishing of albacore by a newly designed vertical longline. *Bull. Jpn. Soc. Sci. Fish.* **36** (6): 578-584.

SAITO (S.) & SASAKI (S.), 1974. Swimming depth of large sized albacore in south Pacific ocean - II. Vertical distribuition of albacore catch by an improved vertical longline. *Bull. Jpn. Soc. Sci. Fish.* **40** (7): 643-649. [Engl. Transl. No. 9 by Tamio Otsu, 1974, 12 p.; NMFS Honolulu Lab.]

SAKAMOTO (H.), 1967. Regional change in the age composition of bigeye caught by longline gear in the Indian Ocean. *Rep. Nankai Reg. Fish. Res. Lab.,* **25**: 59-66.

SAKAMOTO (H.), 1967. Distribution of bigeye tuna in the Atlantic Ocean. *Rep. Nankai Reg. Fish. Res. Lab.,* **25**: 67-73.

SAKAMOTO (S.), 1969 - Preliminary review on the regional change in size composition, sex-ratio and gonadal index on the Atlantic bigeye caught by tuna longline fishery. *Bull. Far Seas Res. Lab.*, **1**: 49-56.

SCHAEFER (M.B.), 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. *Bull. IATTC*, 1 (2): 25-56.

SHARP (G.D.), 1969. Electrophoretic study of tuna hemoglobins. *Comp. Biochem. Physiol.*, **31**(5): 749-755.

SHARP (G.D.), 1973. An electrophoretic study of hemoglobins of some scombrid fishes and related forms. *Comp. Biochem. Physiol.*, **44**(2B): 381-388.

SHARP (G.D.) & DIZON (A.E.) (eds.), 1978. *The physiological ecology of tunas.* Academic Press, New York., 485 p.

SHEPHERD, (J.G.), 1992. Extended survivors' analysis: an improved method for the analysis of catch-at-age data and catch-per-unit-effort data. Working paper No.11 ICES Multispecies Assessment Working Group, June 1992, Copenhagen, Denmark. 22 p (mimeo).

SHIMADA (B.M.), 1951. Contributions to the biology of tunas from the western equatorial Pacific. *Fish. Bull. U.S. Fish. Wildl. Serv.*, **52** (62): 111-119.

SHOMURA (R.S.) & KEALA (B.A.), 1963. Growth and sexual dimorphism in growth of bigeye tuna (*Thunnus obesus*), a preliminary report. Proc. of the World Scientific Meeting on Biology of Tunas and Related Species. *FAO Fish. Rep.*, **6**(3): 1409-1417.

SHOMURA (R.S.) & MURPHY (G.I.), 1955. Longline fishing for deep-swimming tunas in the central Pacific, 1953. *U.S. Fish. Wildl. Serv., Spec. Sci. Rep. Fish.*, **157**: 70 pp.

SILVA (J.N.A.), 1994. Tuna fishery by leased Japanese longliner fleet from 1977 to 1991. *ICCAT, Rec. Doc. Sci.,* **41**: 180-188.

STRETTA (J.M.), 1988. Environment et pêche thonière en Atlantique tropical oriental. *In* Fonteneau, A. et Marcille, J. (eds.). *FAO doc. techn. pêches,* **292**, pp 269-316.

STRETTA (J.M.) & SLEPOUKHA (M.), 1986. Analyse des facteurs biotiques et abiotiques associés aux bancs de thons. *in Proceedings of the ICCAT Conference on The International Skipjack Year Program,* Symons, P.E.K.; Miyake, P.M. & G.T. Sakagawa (eds). Madrid, ICCAT, pp 161-169.

SUDA (A.) & KUME (S.), 1967. Survival and recruit of bigeye tuna in the pacific Ocean, estimated by the data of tuna longline catch. *Rep. Nankai Reg. Fish. Res. Lab.,* **25**: 91-104.

SUDA (A.); KUME (S.) & SHIOHANA (T.), 1969. An indicative note on a role of permanent thermocline as a factor controlling the longline fishing ground for bigeye tuna. *Bull. Far Seas Fish. Res. Lab.*, **1**: 99-114 .

SUDA (A.) & SCHAEFER (M.B.), 1965. General review of the Japanese tuna long-line fishery in the eastern Pacific Ocean 1956-1962. *Bull. IATTC.*, **9**(6): 307-462.

SUND (P. N.), BLACKBURN (M.) & WILLIAMS (F.), 1981. Tunas and their environment in the Pacific Ocean: a review. *Oceanogr. Mar. Biol. Ann.Rrev.*, **19**: 443-512.

SUZUKI (Z.), 1980. An aspect on catch of three major species, skipjack, yellowfin and bigeye tunas, taken by the Japanese baitboat fleet based in Tema, 1969-78. *ICCAT, Rec. Doc. Sci.*,**9** (1): 255-262.

SUZUKI (Z.), 1981. A preliminary analysis on mixing of species within schools fished by Tema-based Japanese baitboat fleet during 1979 and 1980. *ICCAT, Rec. Doc. Sci.*,**15** (1): 91-98.

SUZUKI (Z) & KUME (S.), 1982 Fishing efficiency of deep longline for bigeye tuna in the Atlantic as inferred from the operation in the Pacific and Indian oceans. *ICCAT, Rec. Doc. Sci.*, **17**(2): 471-486.

SUZUKI (Z.); WARASHINA (Y.) & KISHIDA (M.), 1977. The comparation of catches by regular and deep tuna longline gears in the western and central equatorial Pacific. *Bull. Far Seas Fish. Res. Lab.*, **15**: 51-89

TALBOT (F.H.) & PENRITH (M.J.), 1963. Synopsis of biological data on species of the genus *Thunnus* (sensu lato) (South Africa). *FAO, Fish. Rep.*, **6**(2): 608-646.

TORIN (Y.A.), 1969. Vertical distribuition of bigeye tuna, *Thunus obesus* (Lowe) and thermal condition in their habitat in Southeast Atlantic. *Trudy AtlantNiro*, **25**: 115-119.

UEYANAGI (S.), 1971. Larval distribution of tunas and billfishes in the Atlantic ocean. *FAO, Fish. Rep.*, **71**(2): 297-305.

UEYANAGI (S.); Mori (K.) & Nishikawa (Y.), 1969. Research on distribution of larvae. *Far Seas Fish. Res. Lab.*, S Series, **1**: 12-17.

UEYANAGI (S.); Mori (K.) & Nishikawa (Y.), 1969. Tuna spawning grounds and potential resources of pelagic fishes based on distribution of larvae. *Far Seas Fish. Res. Lab., Tuna Fisheries Research Conference for Fiscal Year of 1968*: 7 pp.

UOZUMI (Y.), 1996. A historical review of Japanese longline fishery and albacore catch in the Atlantic Ocean. *ICCAT, Rec. Doc. Sci.*, **43**: 163-170.

VALLE (S.), 1980. Analisis de cohortes de la pesqueria del atún ojo grande (*Thunnus obesus*) en el Océano Atlantico. *ICCAT, Rec. Doc. Sci.*, **9** (2): 317-322.

VALLE (S.); MEZENTSEVA (N.) & RODRIGUEZ (A.), 1980. Nota sobre el contenido estomacal del atun ojo grande (*Thunnus obesus*) en el Atlantico centro oriental. *ICCAT, Rec. Doc. Sci.*, **9** (2): 282-286.

WATANABE (H.), 1958. On the difference of the stomach contents of the yellowfin and bigeye tunas from the western equatorial Pacific. *Rep. Nankai Reg. Fish. Res. Lab.*, **7**: 72-81.

WATANABE (H.), 1960. Regional differences in food composition of the tunas and marlins from several oceanic areas. *Rep. Nankai Reg. Fish. Res. Lab.*, **12**: 75-84.

WHITELAW (A.W.) & UNNITHAN (V.K.). 1997. Synopsis of the distribution, biology and fisheries of the bigeye tuna (*Thunnus obesus*, Lowe) with a bibliography. *Rep. CSIRO Mar. Lab.*, 228: 62 pp.

WEBER (E.), 1980. An analysis of Atlantic bigeye tuna (*Thunnus obesus*) growth. *ICCAT, Rec. Doc. Sci.*, **9** (2): 303-307.

YAMAGUCHI (Y.), 1989. Tuna longline fishing IV: Fish ecology in the context of tuna longline fishing. *Mar. Behav. Physiol.* **15**: 45-73.

YANG (W.S) & GONG (Y), 1987. The vertical distribution of tunas and billfishes, and fishing efficiency between Korean regular and deep longlines in the Atlantic Ocean. *ICCAT, Rec. Doc. Sci.*, **26** (1): 184-187.

YANG (W.S) & GONG (Y.), 1988. The vertical distribuition of tunas and billfishes, and fishing efficiency between Korean regular and deep longlines in the Atlantic oceans. *Bull. Natl. Fish. Res. Dev. Agency* **42**: 39-42.

YASUTAKE (H.); NISHI (G.) & MORI (K.), 1973. Artificial fertilization and rearing of bigeye tuna (*Thunnus obesus*) on board, with morphological observations on embrionic through to early post-larval stage. *Bull. Far Seas Fish. Res. Lab.*, **8**: 71-78.

YOSHIARA (T.), 1954. Distribution of catch of tuna longline-IV. On the relation between K and L_∞ with a table and diagram. *Bull. Jpn. Soc. Sci. Fish.* **19** (10): 1012-1014.

YUEN (H.S.), 1955. Maturity and fecundity of bigeye tuna in the Pacific. *Spec. Sci. Rep. U. S. Fish. Wild. Serv. (Fish.)*, **150**: 30 pp.

YUEN (H.S.), 1979. A night handline fishery for tunas in Hawaii. *Mar. Fish.Rev.*, 41(8): 7-14.

YONEMORI (T.), 1982. Study of tuna behavior, particulary their swimming depths, by use of sonic tags. *Far Seas Fish. Res. Lab (Shimizu) Newsletter* **44**: 1-5. [Engl. Transl. No. 70 by Otsu, T., 1982, 7 p; Honolulu Lab, Southwest Fish Cent., Natl. Mar. Fish. Serv. NOAA, Honolulu].

YUKINAWA (M.) & YABUTA (Y.), 1963. Age and growth of bigeye tuna, *Parathunnus mebachi* (Kishinouye). *Rep. Nankai Reg. Fish. Res. Lab.*, **19**: 103-118.

YUWAKI (Y.); HIGASHI (M.); SHIMADA (K.) & HENMI (T.), 1985. Studies on depth of longline hook. *Mem. Fac. Fish. Kagoshima Univ. Suisangakubu Kiyo,* **34** (1): 21-26.

ZAVALA-CAMIN (L.A.), 1978. Frequencia mensal de tallas y sex ratio del patudo (*Thunnus obesus*) capturado en el sudeste y sur del Brasil (1976-Agosto 1977). *ICCAT, Rec. Doc. Sci.*, 7(1): 105-106.

ZAVALA-CAMIN (L.A.), 1982. Distribucion vertical y estacional de tunidos y otros especies pelagicas en el sudeste y sur del Brasil, obtenida por medio de analysis de contenido estomacal. *ICCAT, Rec. Doc. Sci.*, **17**: 439-443.

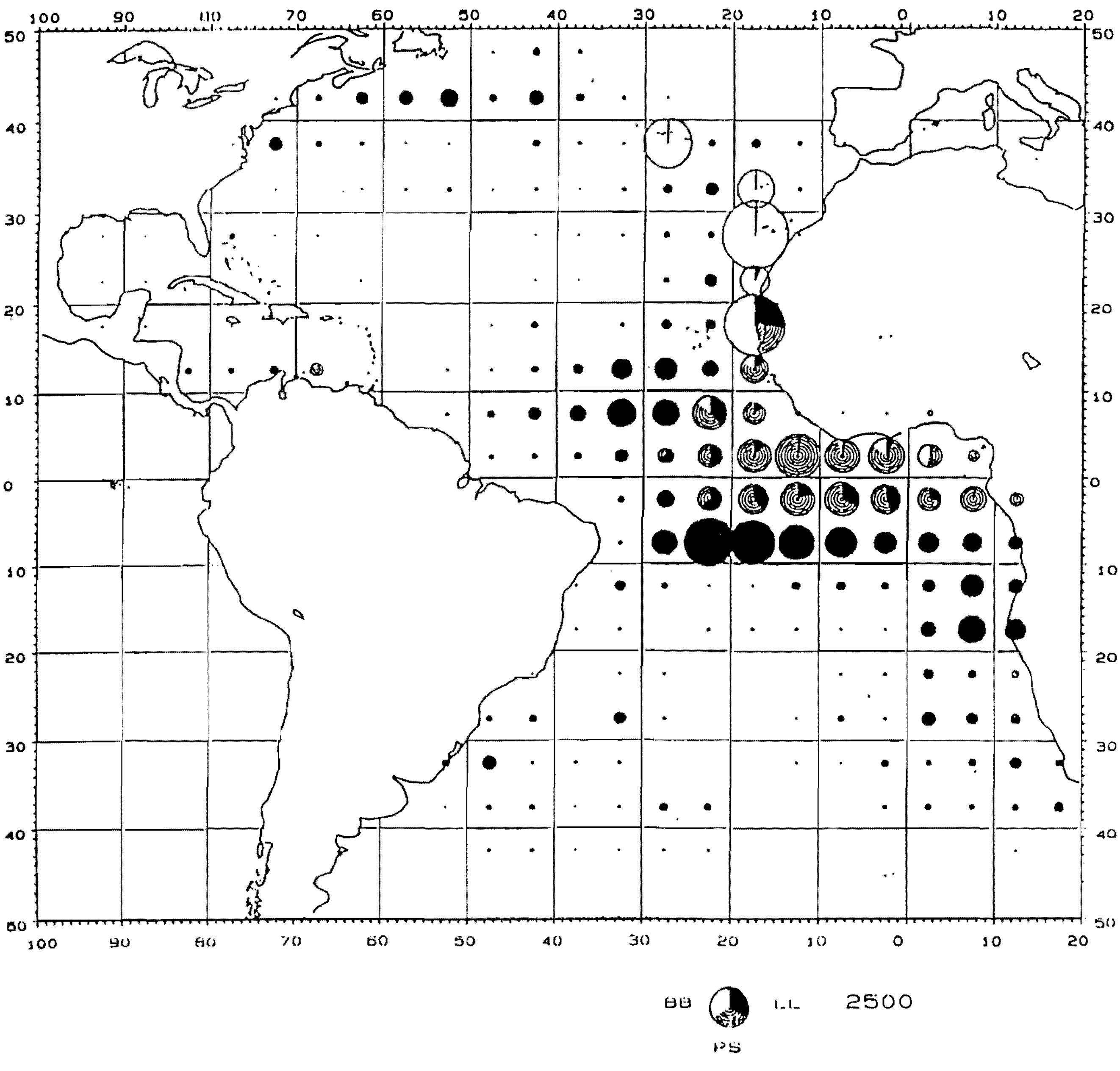

FIGURE 1. Distribution of catches of bigeye, by gear, during 1993-1995.

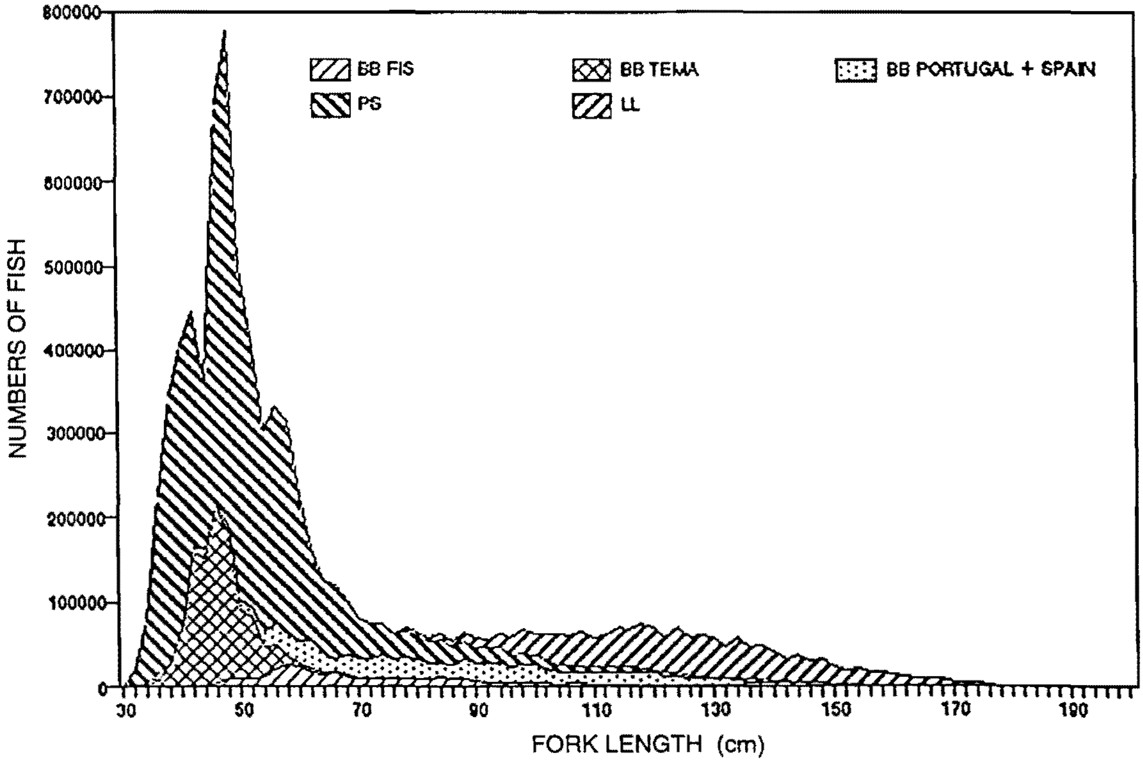

FIGURE 2. Size distributions of the catches of bigeye, by major gear types, during 1995. FIS stands for France, Ivory Coast, and Senegal. Tema is in Ghana.

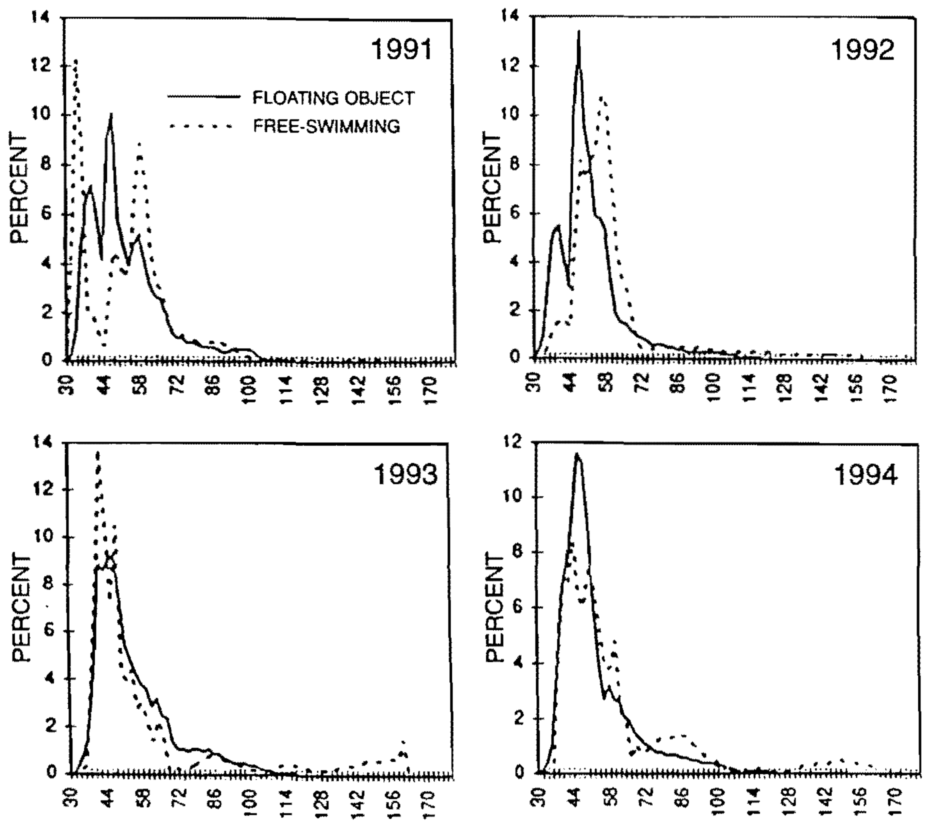

FIGURE 3. Length distributions of catches of bigeye in free-swimming and floating object-associated schools.

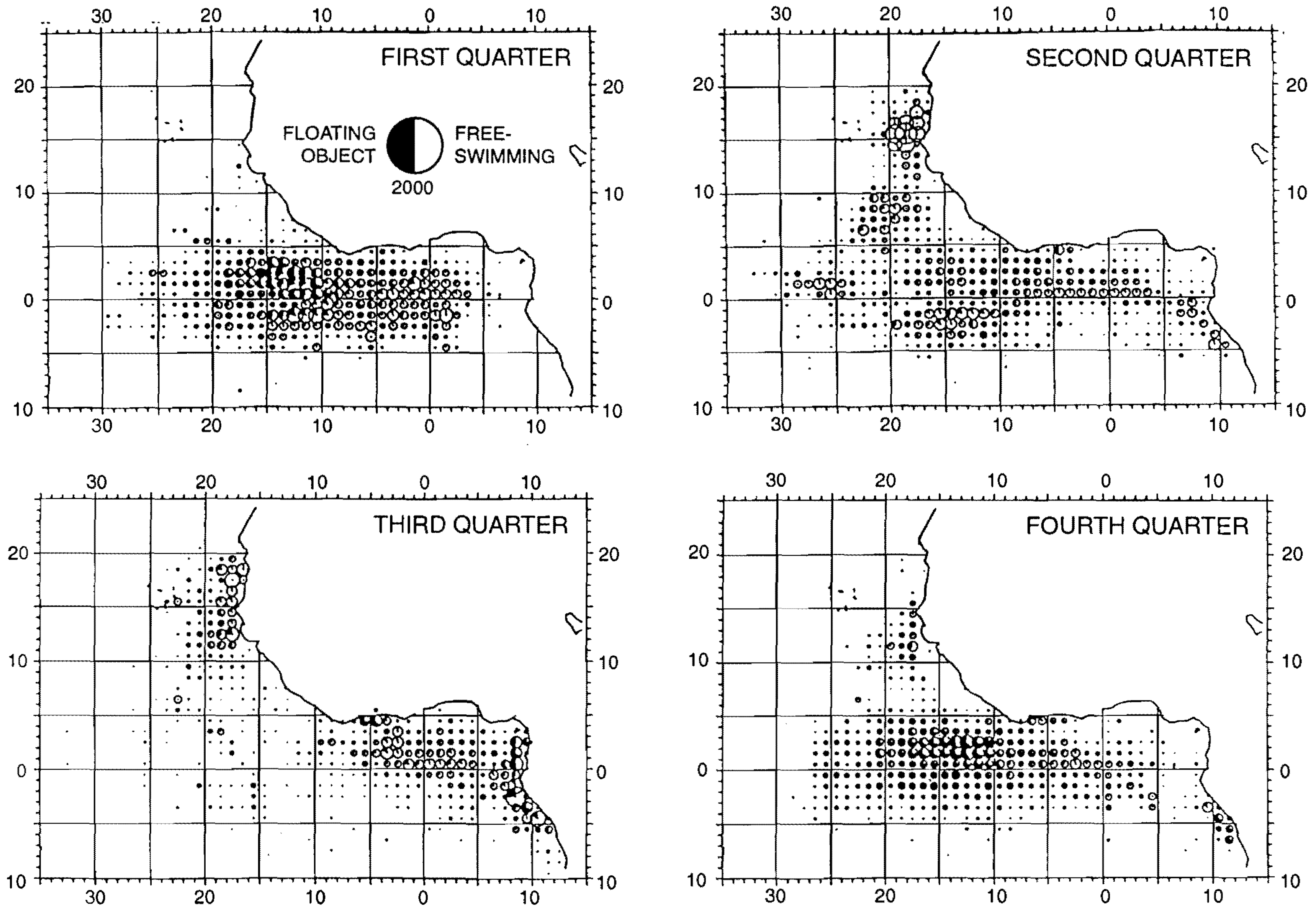

FIGURE 4. Quarterly distributions of catches of bigeye, by French and Spanish purse-seine vessels, in free-swimming and floating object-associated schools, during 1991-1994.

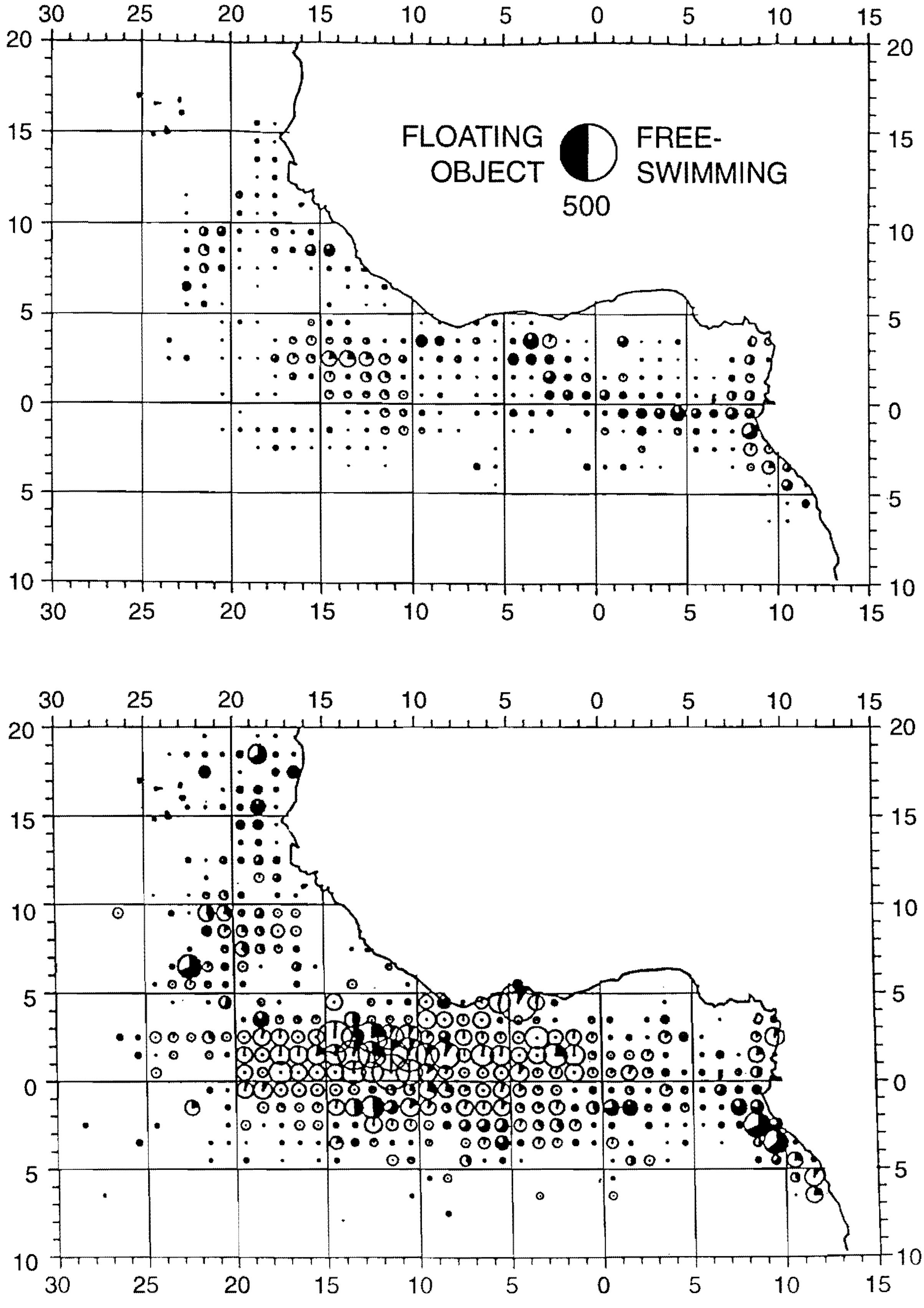

FIGURE 5. Catches of bigeye, by purse-seine vessels, in free-swimming and floating object-associated schools during 1990 (upper panel) and 1994 (lower panel).

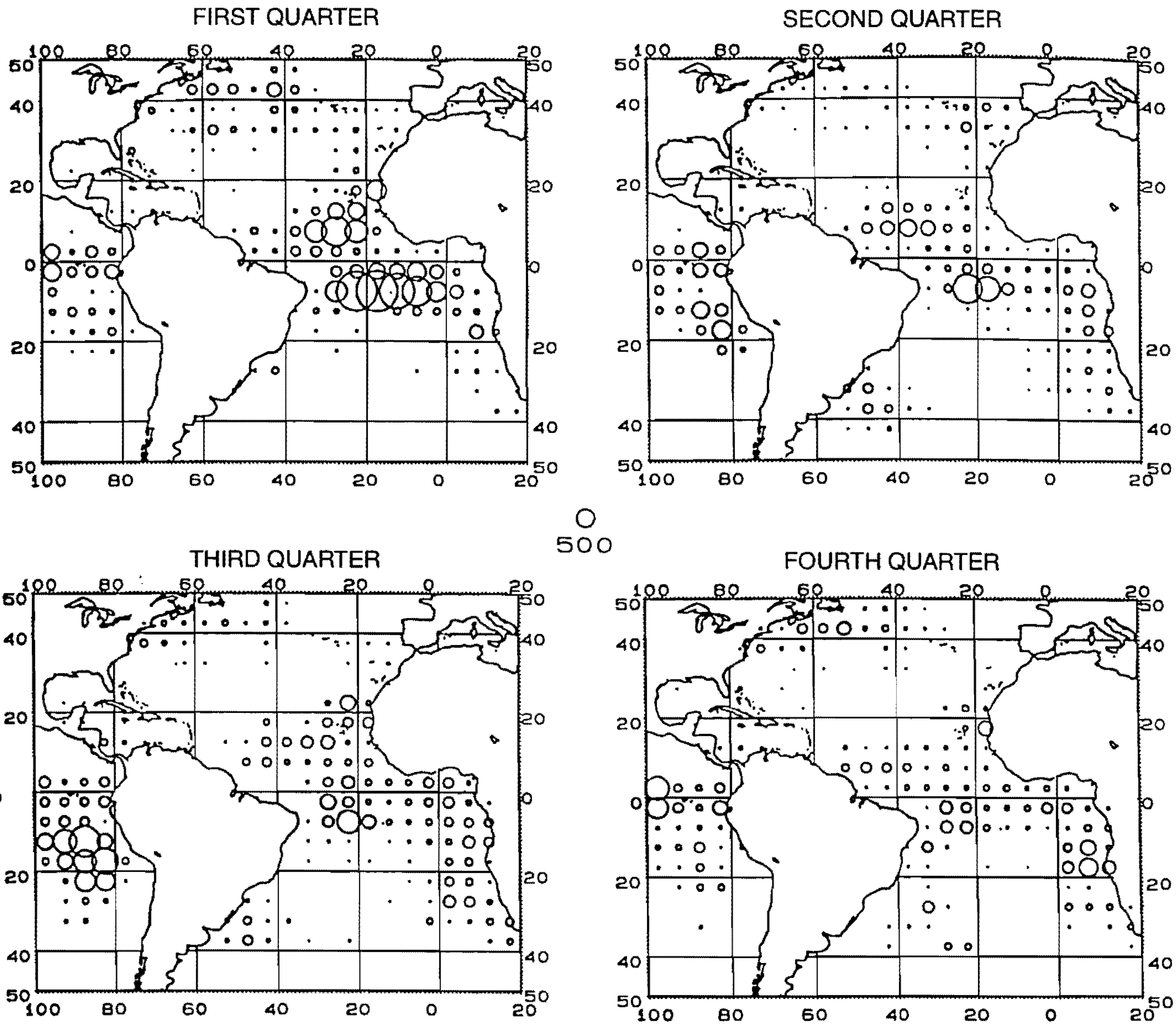

FIGURE 6. Quarterly distributions of longline catches of bigeye.

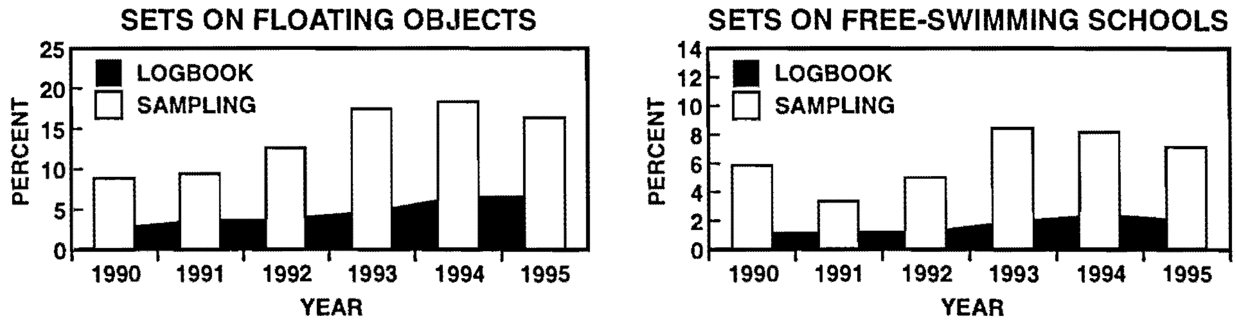

FIGURE 7. Percentages of bigeye recorded in the logbooks and obtained from multispecies sampling, by type of association.

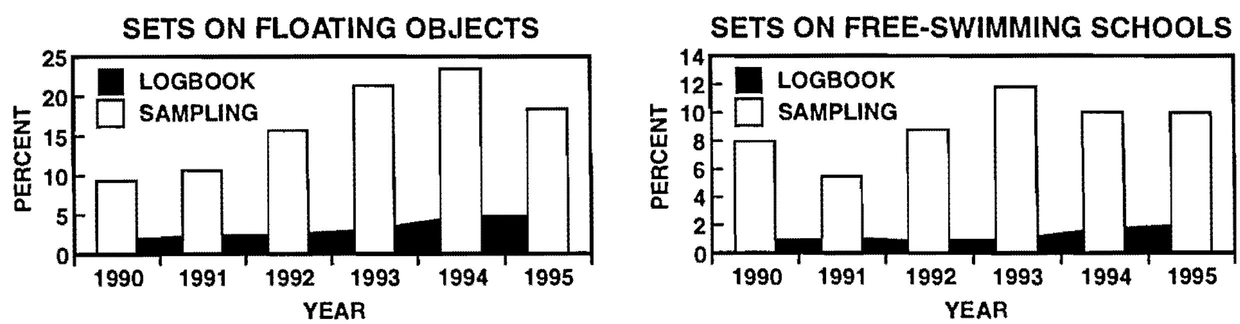

FIGURE 8 Percentages of bigeye recorded in the logbooks and obtained from multispecies sampling, by type of association, for fish of less than 10 kg (Category 1).

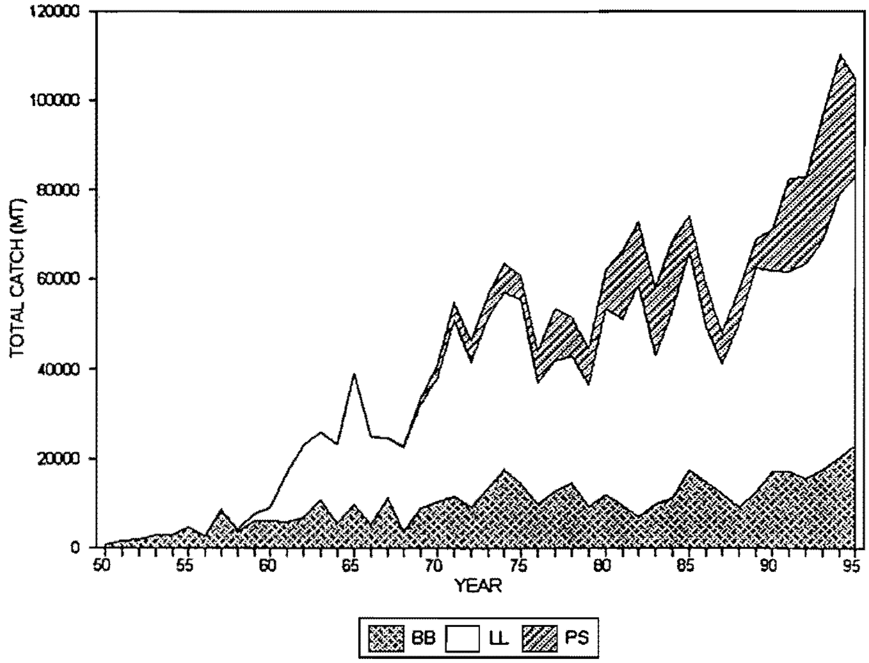

FIGURE 9. Catches of bigeye, by gear, 1950-1995.

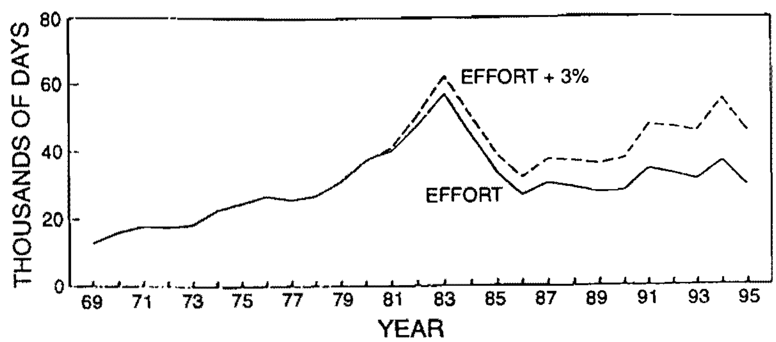

FIGURE 10a. Surface fishing effort, standardized to Category-5 French purse seiners, with and without assuming a 3-percent increase in efficiency during each year after 1980.

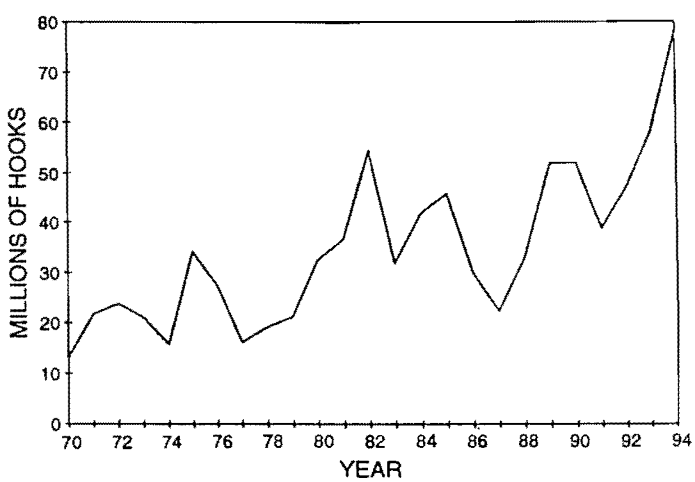

FIGURE 10b. Effective longline fishing effort estimated from CPUE data for Japanese vessels.

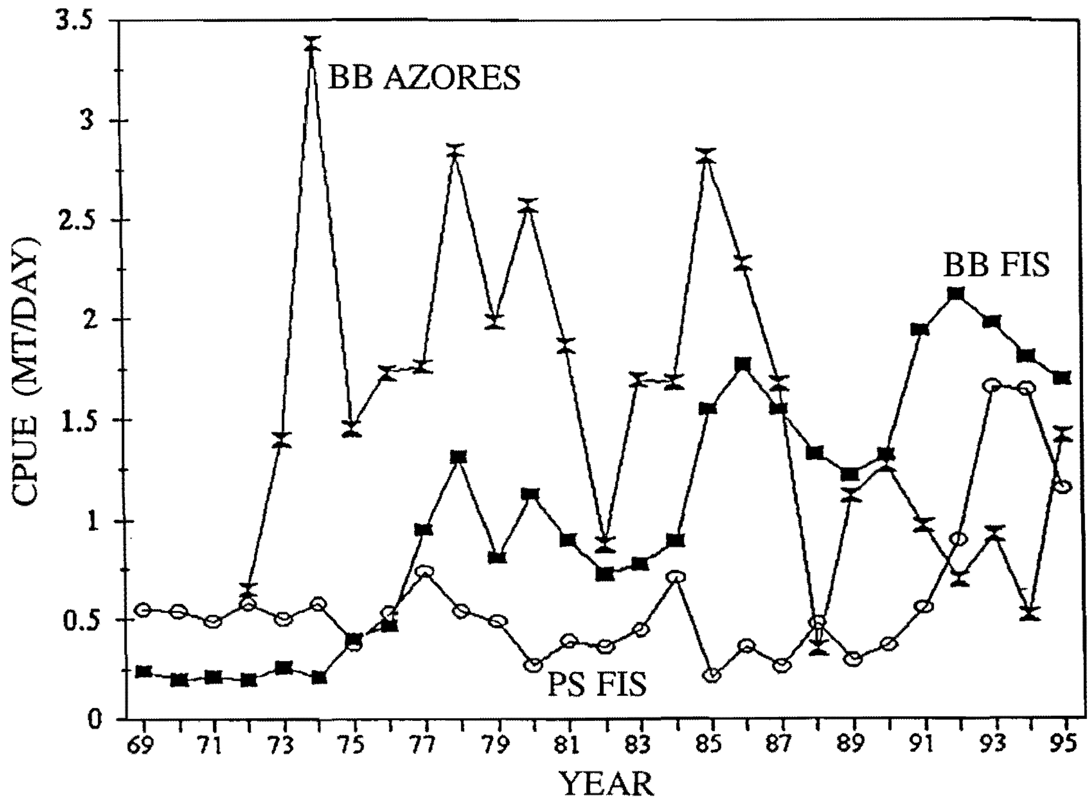

FIGURE 11. Unstandardized CPUEs of bigeye by the Azores baitboat fleet, the French, Ivory Coast, and Senegal (FIS) baitboat fleet, and the FIS purse-seine fleet.

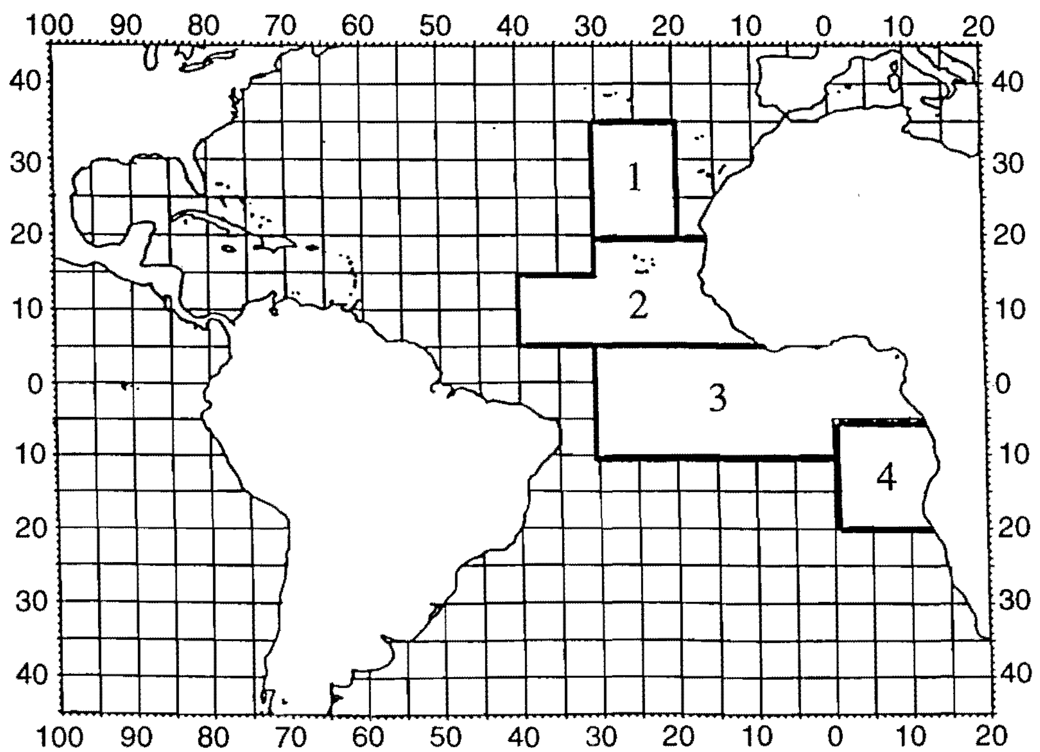

FIGURE 12. Areas used for standardizing the CPUEs of bigeye by longline vessels.

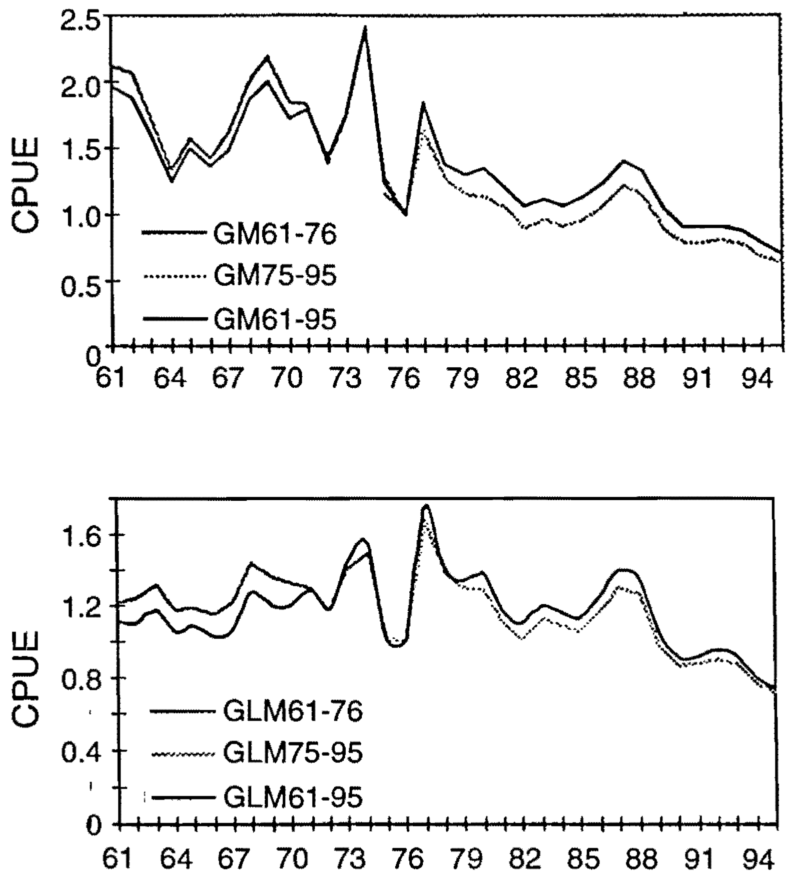

FIGURE 13. Standardized CPUEs of bigeye for the Japanese longline fishery in the central area. GM and GLM denote abundance indices estimated from Poisson and lognormal error distribution assumptions, respectively.

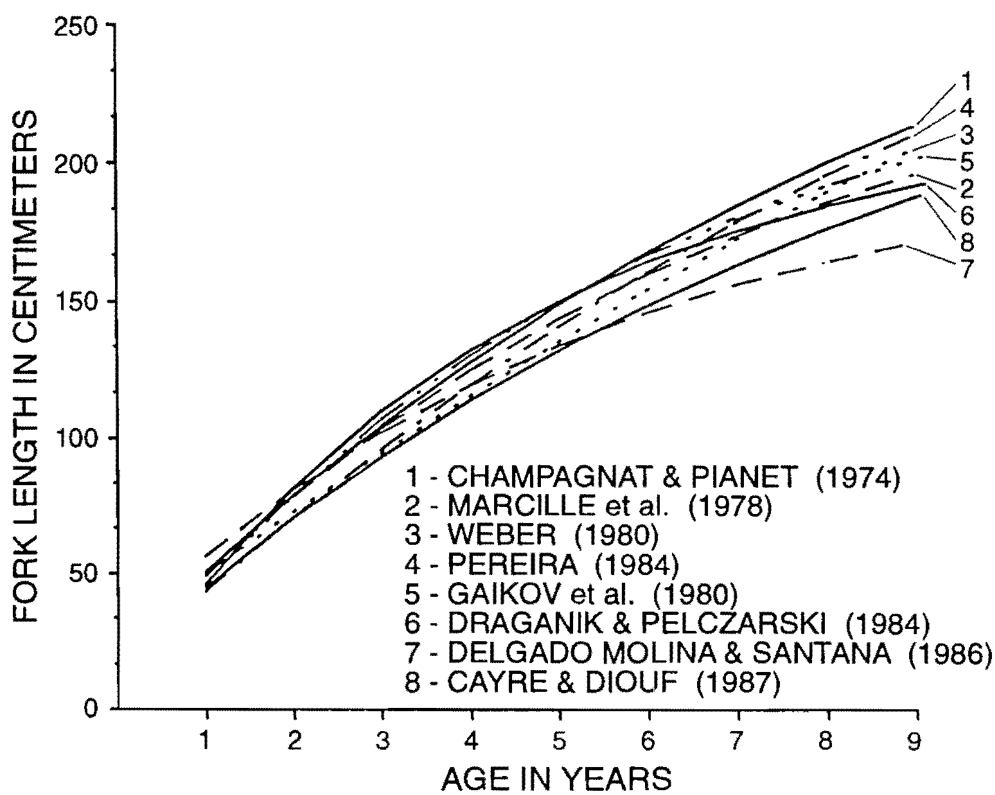

FIGURE 14. Growth curves for Atlantic bigeye tuna.

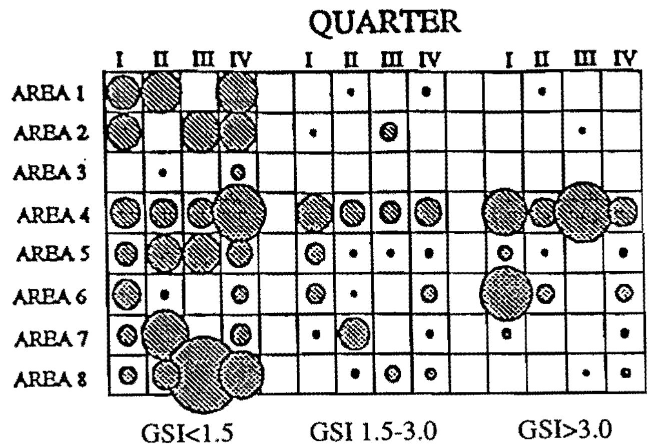

FIGURE 15a. Gonadosomatic indices of bigeye tuna caught by longline vessels in the Atlantic Ocean (from Sakamoto, 1969).

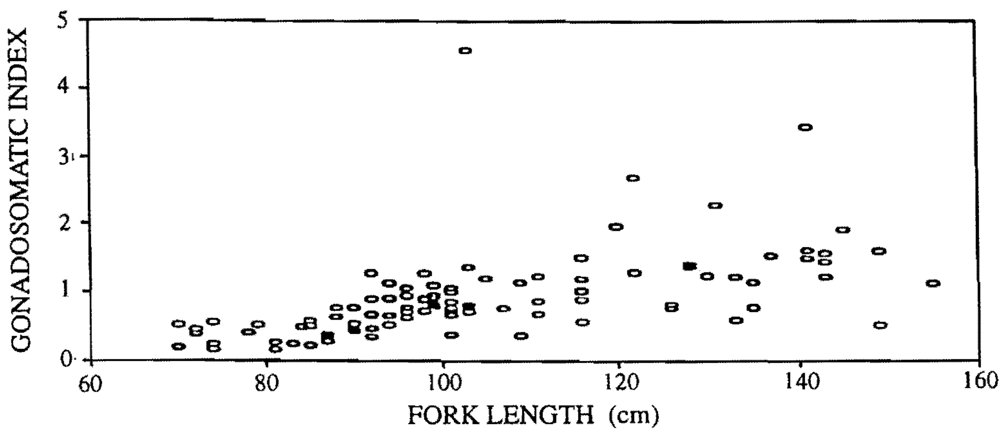

FIGURE 15b. Gonadosomatic indices of female bigeye caught in the tropical Atlantic Ocean by purse-seine vessels.

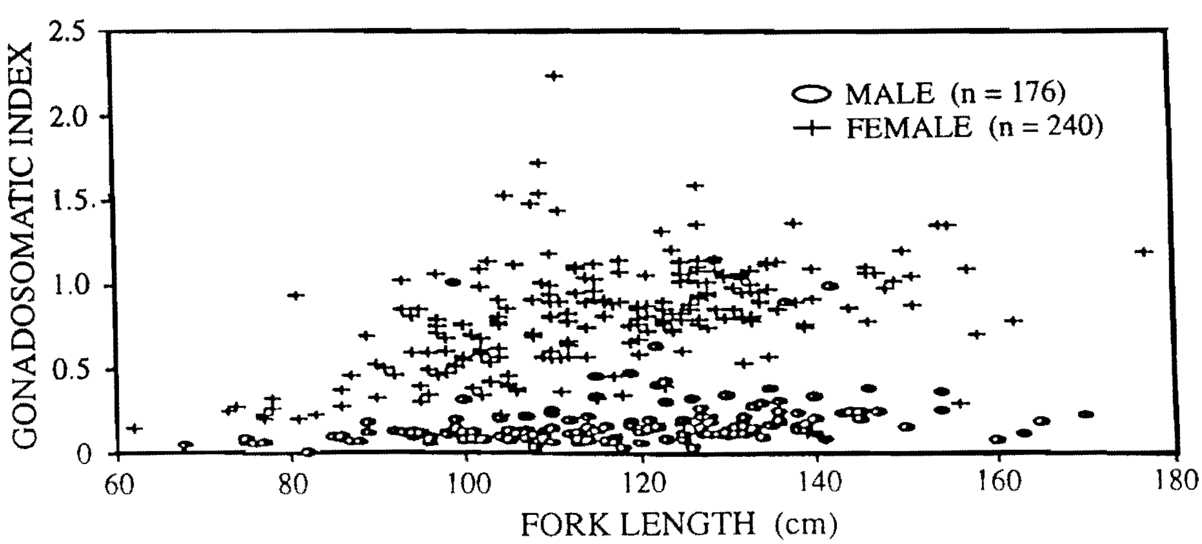

FIGURE 15c. Gonadosomatic indices of female bigeye caught near the Azores Islands by live-bait vessels.

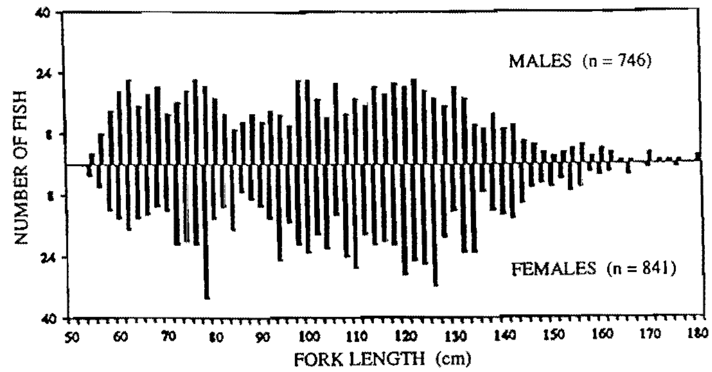

FIGURE 16a. Sex ratios of bigeye caught near the Azores Islands by live-bait vessels.

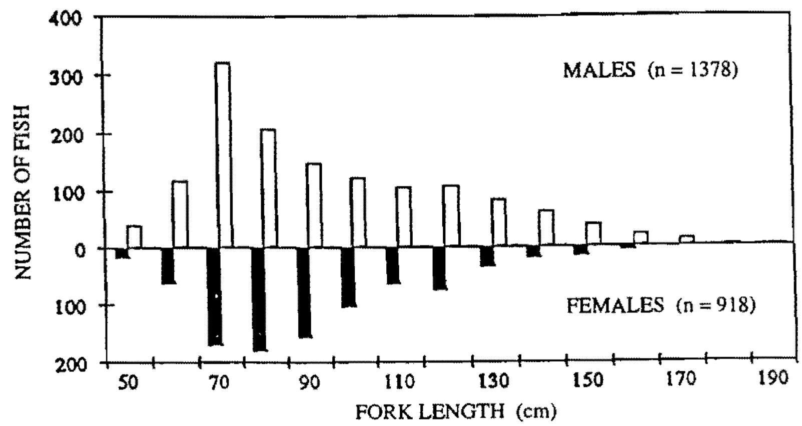

FIGURE 16b. Sex ratios of bigeye caught near Madeira by live-bait vessels.

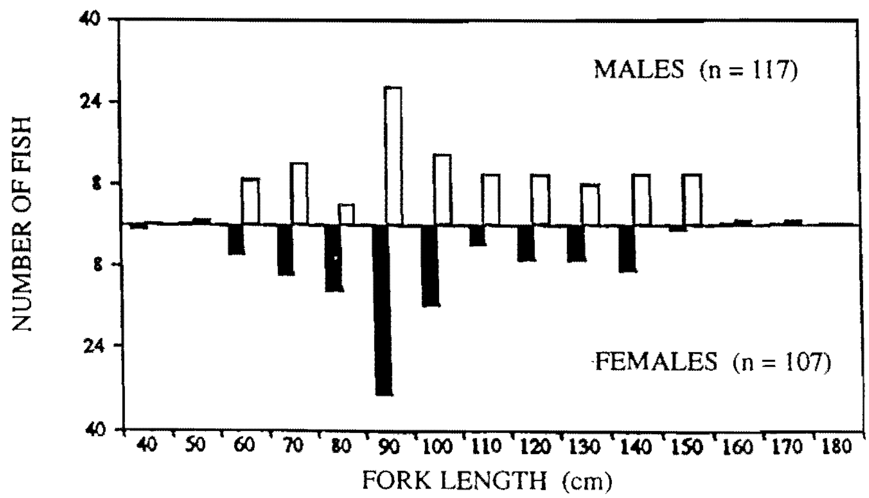

FIGURE 16c. Sex ratios of bigeye caught in the tropical Atlantic Ocean by purse-seine vessels.

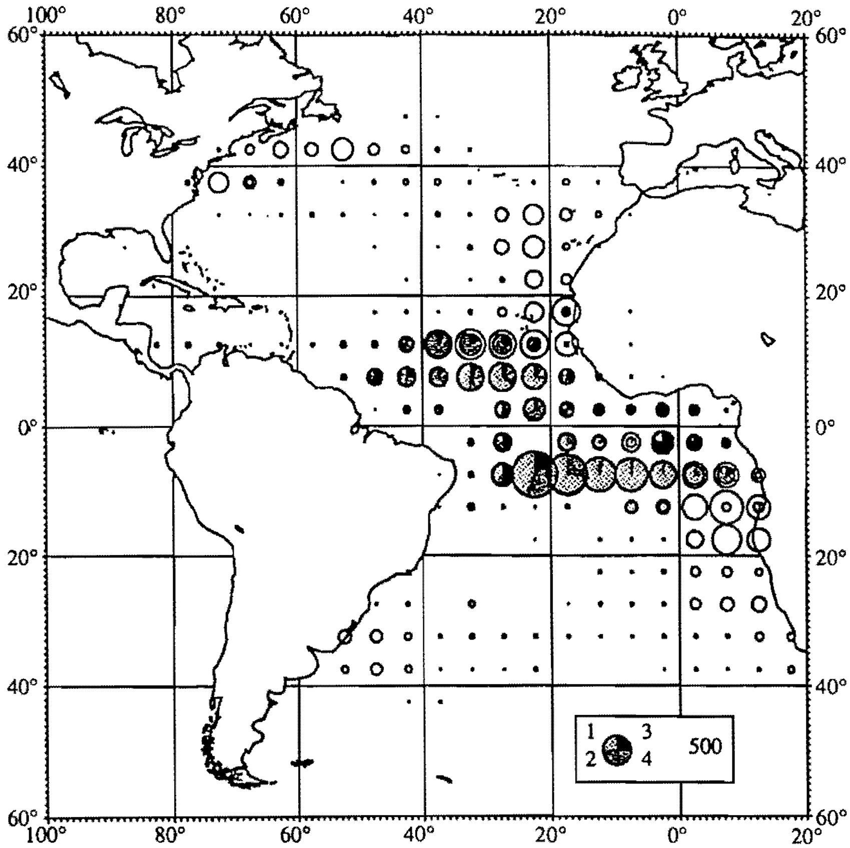

FIGURE 17. Sea-surface temperatures and catches of bigeye, by quarter.

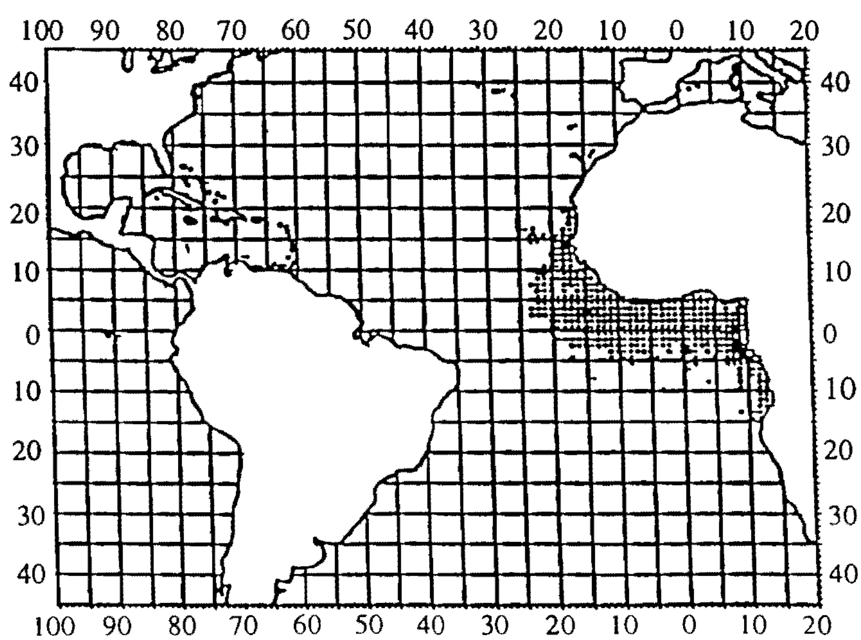

FIGURE 18. Distribution of surface catches of bigeye.

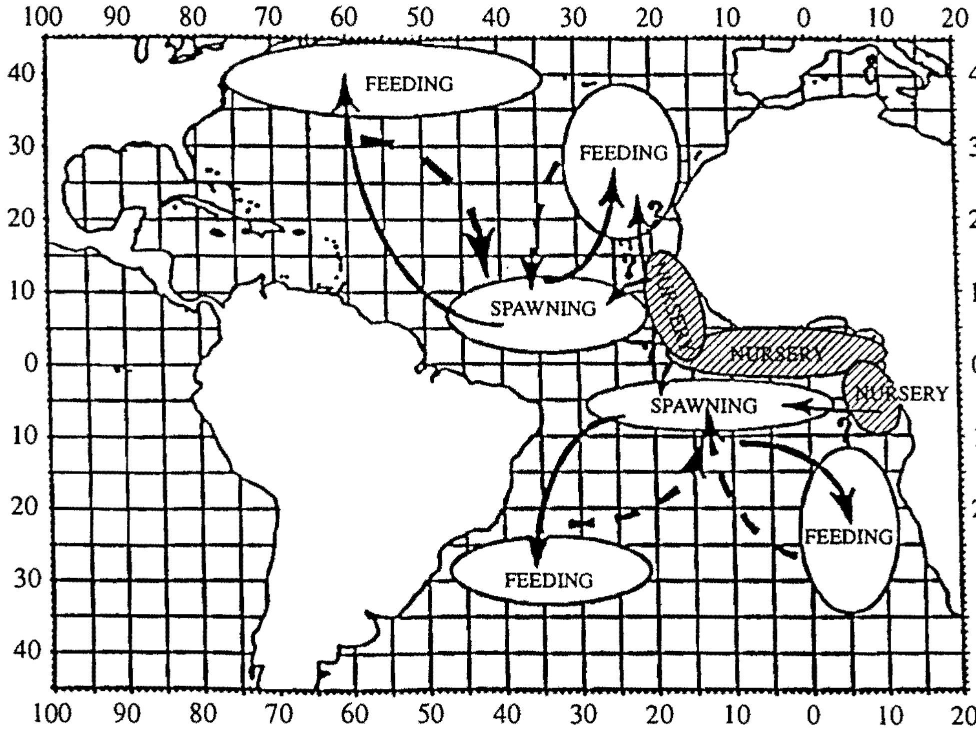

FIGURE 19. Hypothesis for the stock structure of bigeye in the Atlantic Ocean.

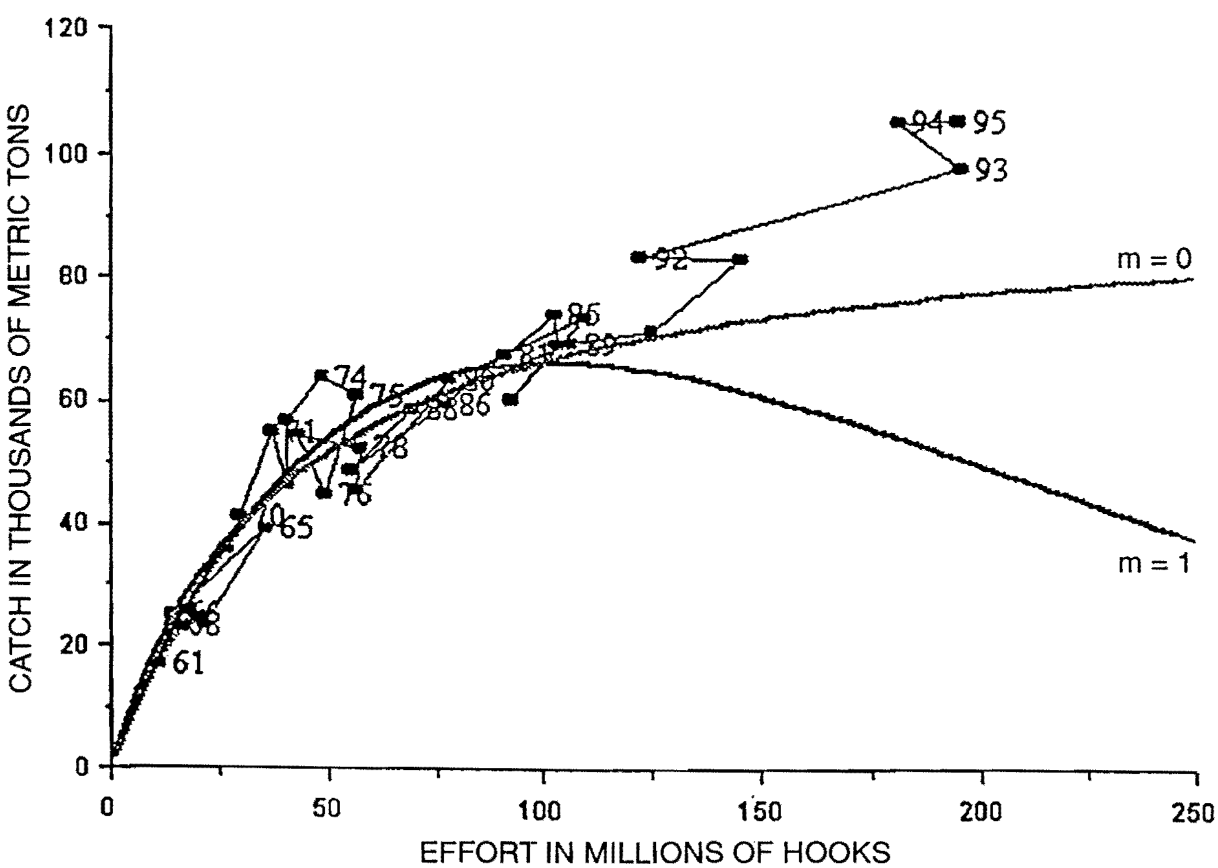

FIGURE 20. Production curves for bigeye in the Atlantic Ocean estimated with PRODFIT (Fox, 1975).

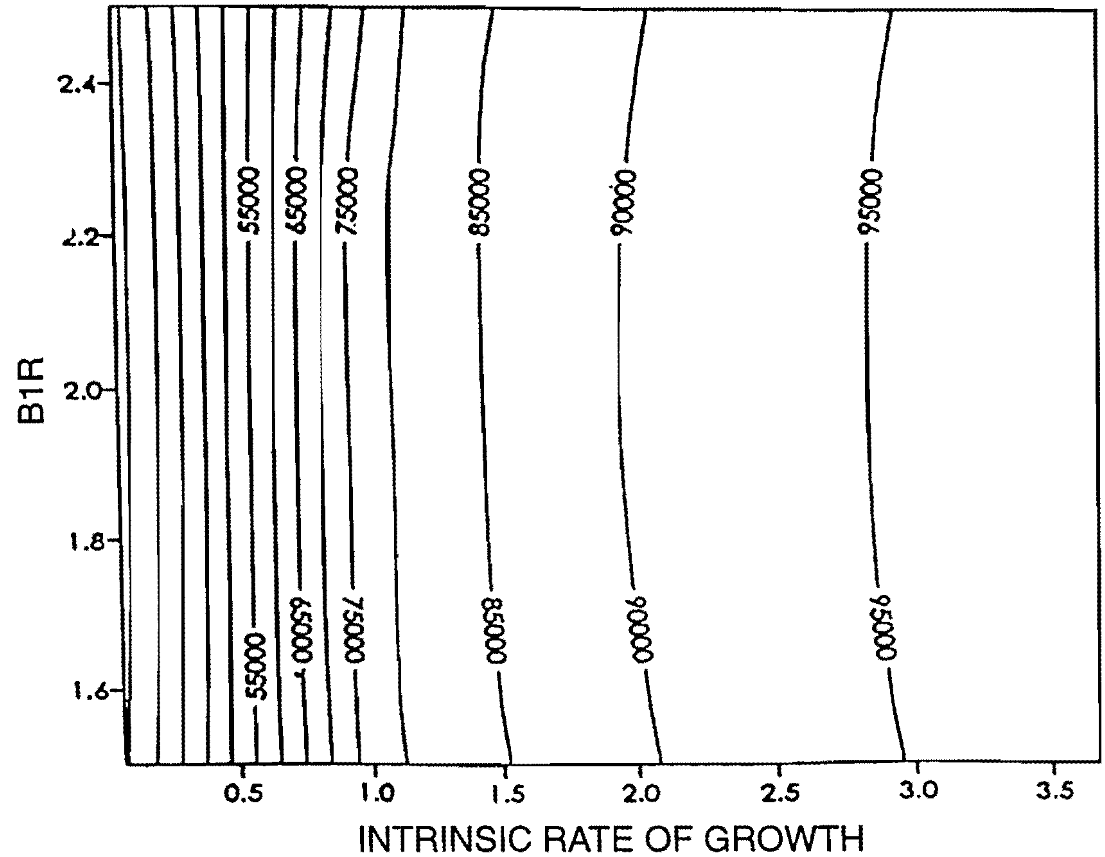

FIGURE 21. Contours of MSY of bigeye for the ASPIC production model (Prager, 1994) for various values of BIR (biomass in 1960/biomass$_{MSY}$) and r (intrinsic rate of growth).

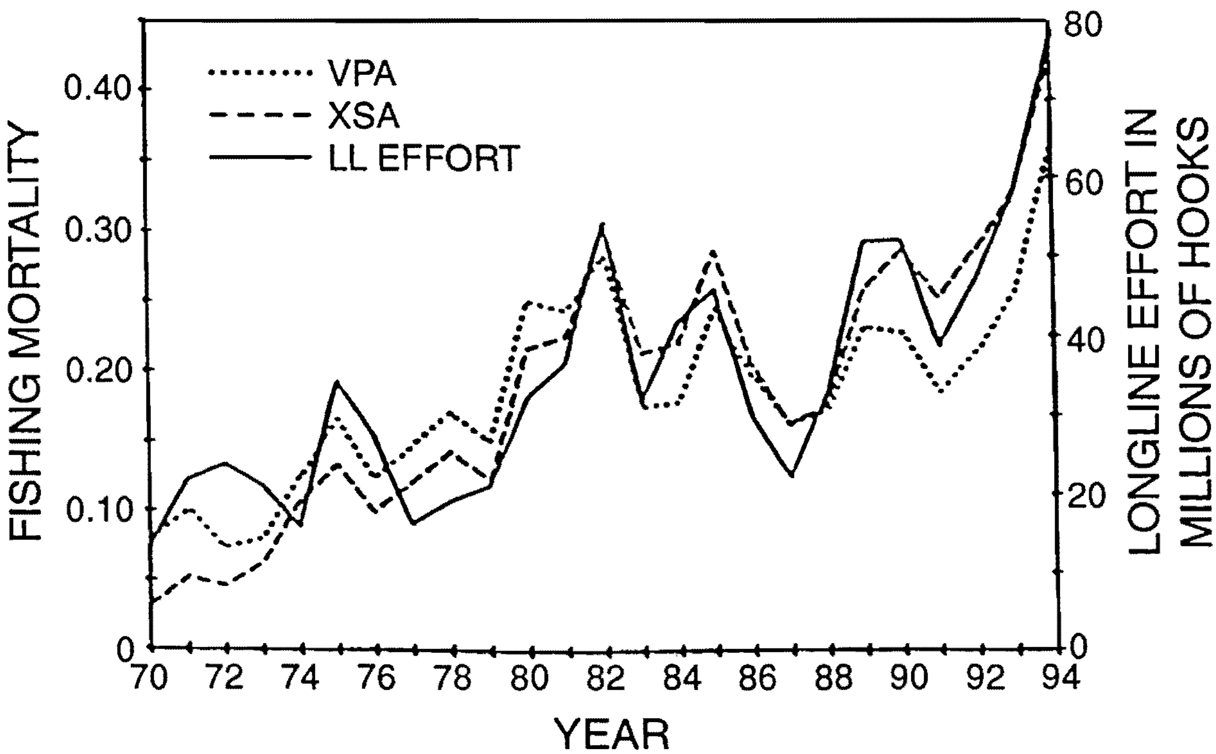

FIGURE 22. Estimates of fishing mortality for bigeye of ages 4-6 obtained from untuned VPA, XSA, and longline effort data.

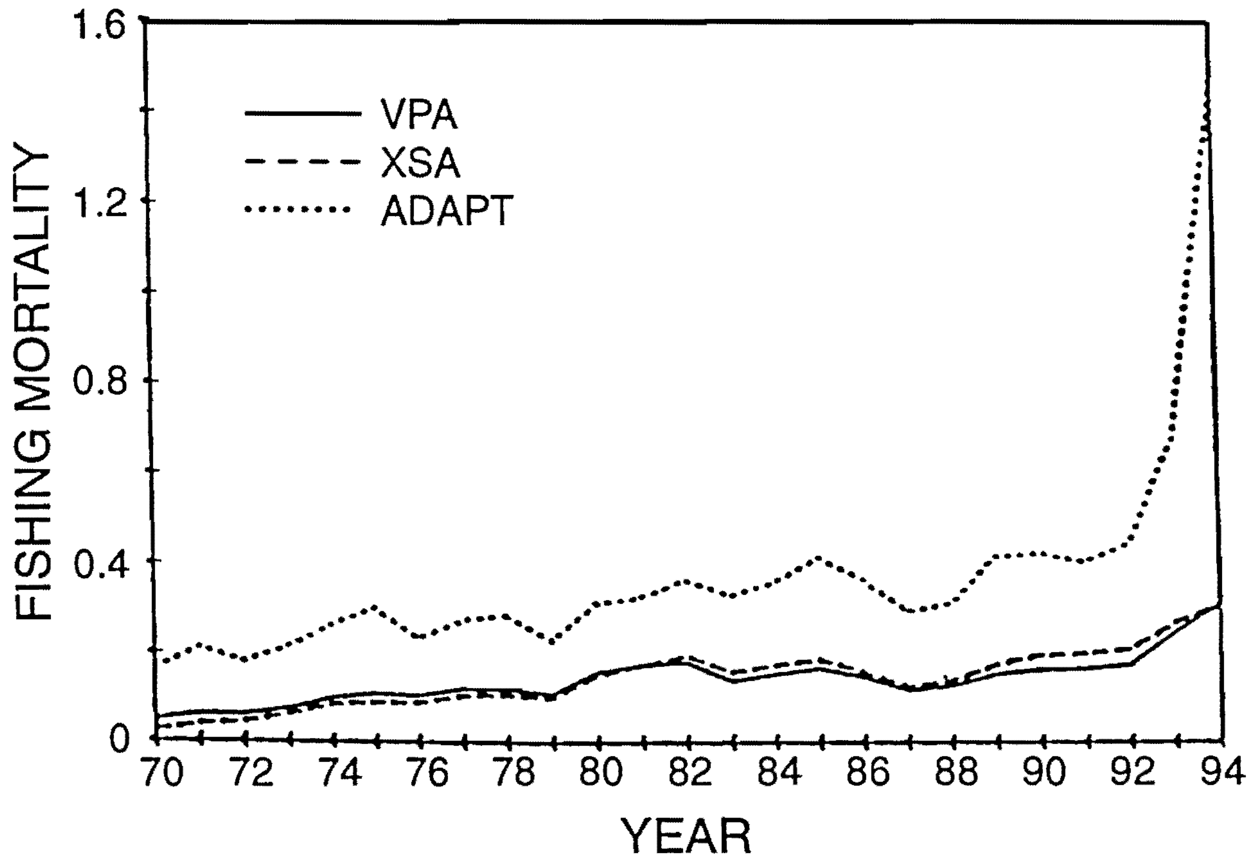

FIGURE 23. Estimates of fishing mortality for bigeye of all ages obtained from untuned VPA, XSA, and ADAPT.

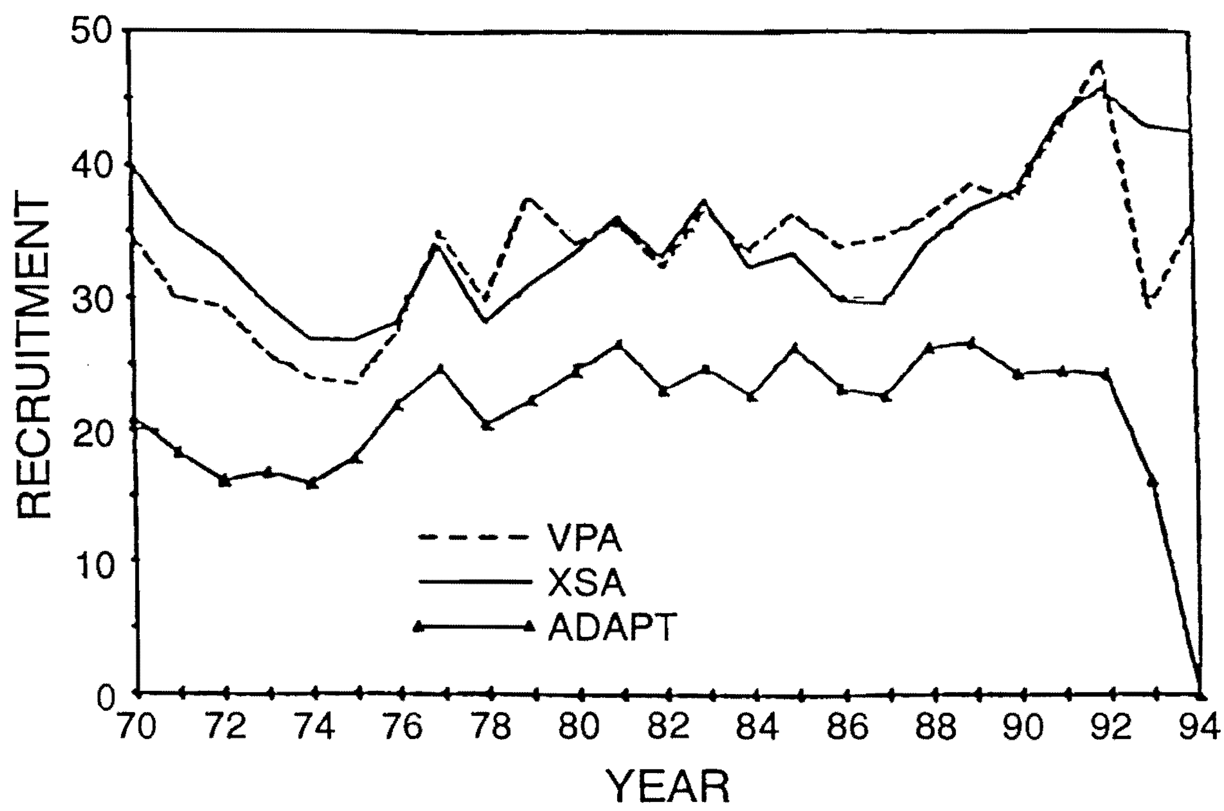

FIGURE 24. Estimates of recruitment of bigeye obtained from untuned VPA, XSA, and ADAPT.

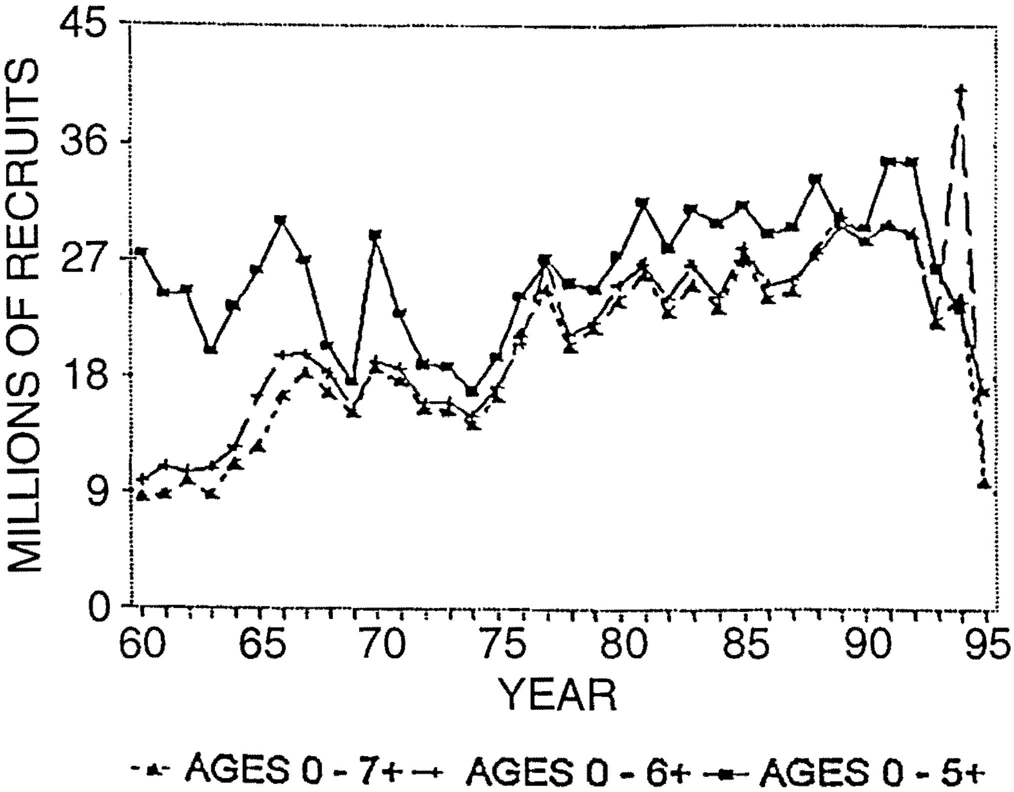

FIGURE 25. Estimates of recruitment of bigeye obtained from ADAPT for cases 1, 2, and 3.

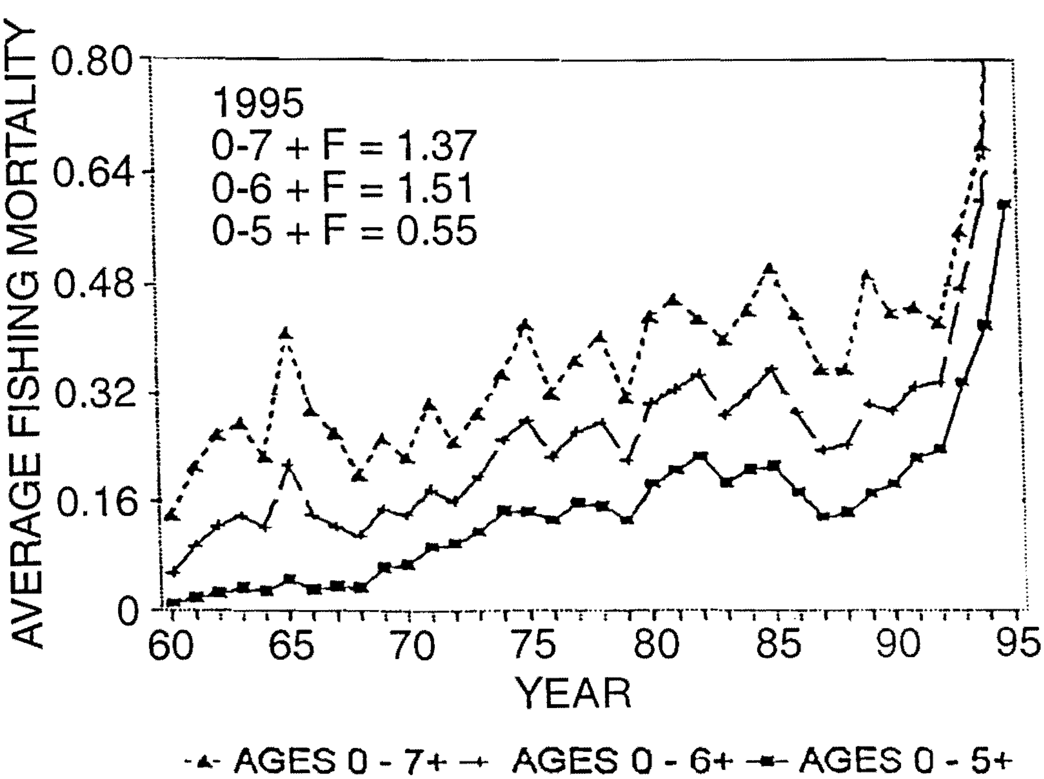

FIGURE 26. Estimates of fishing mortality of bigeye obtained from ADAPT for cases 1, 2, and 3.

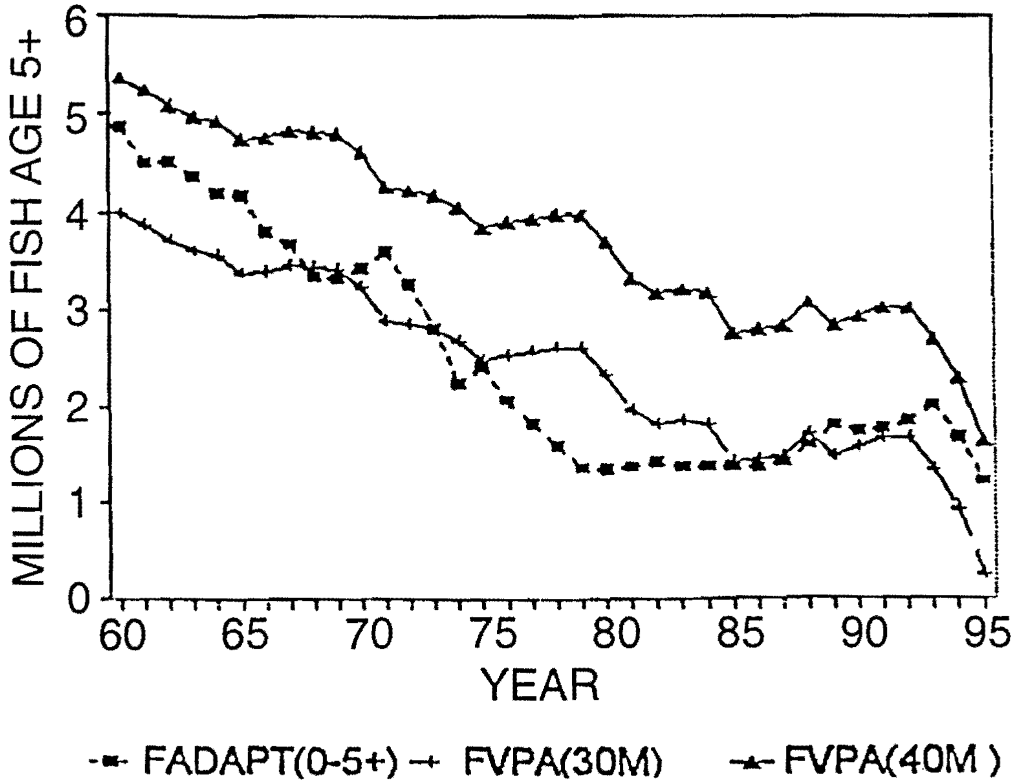

FIGURE 27. Estimates of bigeye population sizes obtained from ADAPT (Case 3) and VPAs.

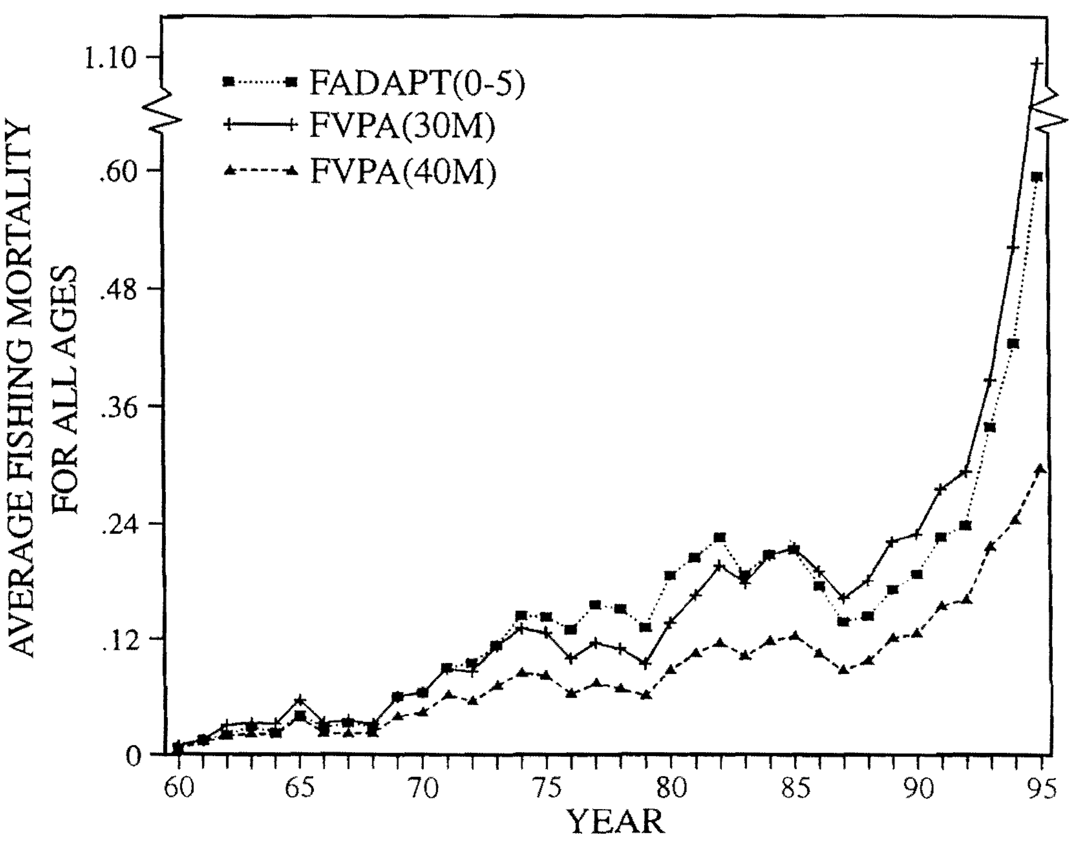

FIGURE 28. Estimates of fishing mortality of bigeye obtained from ADAPT (Case 3) and VPAs.

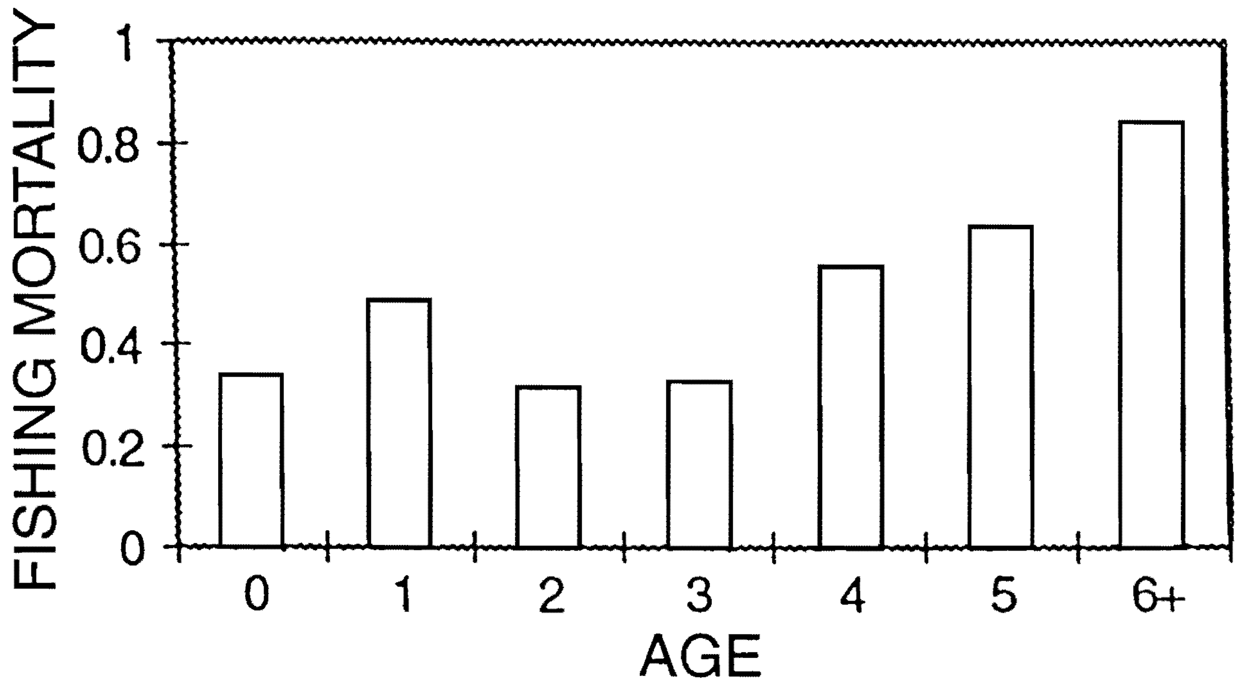

FIGURE 29. Estimates of age-specific fishing mortality of bigeye during 1991-1995.

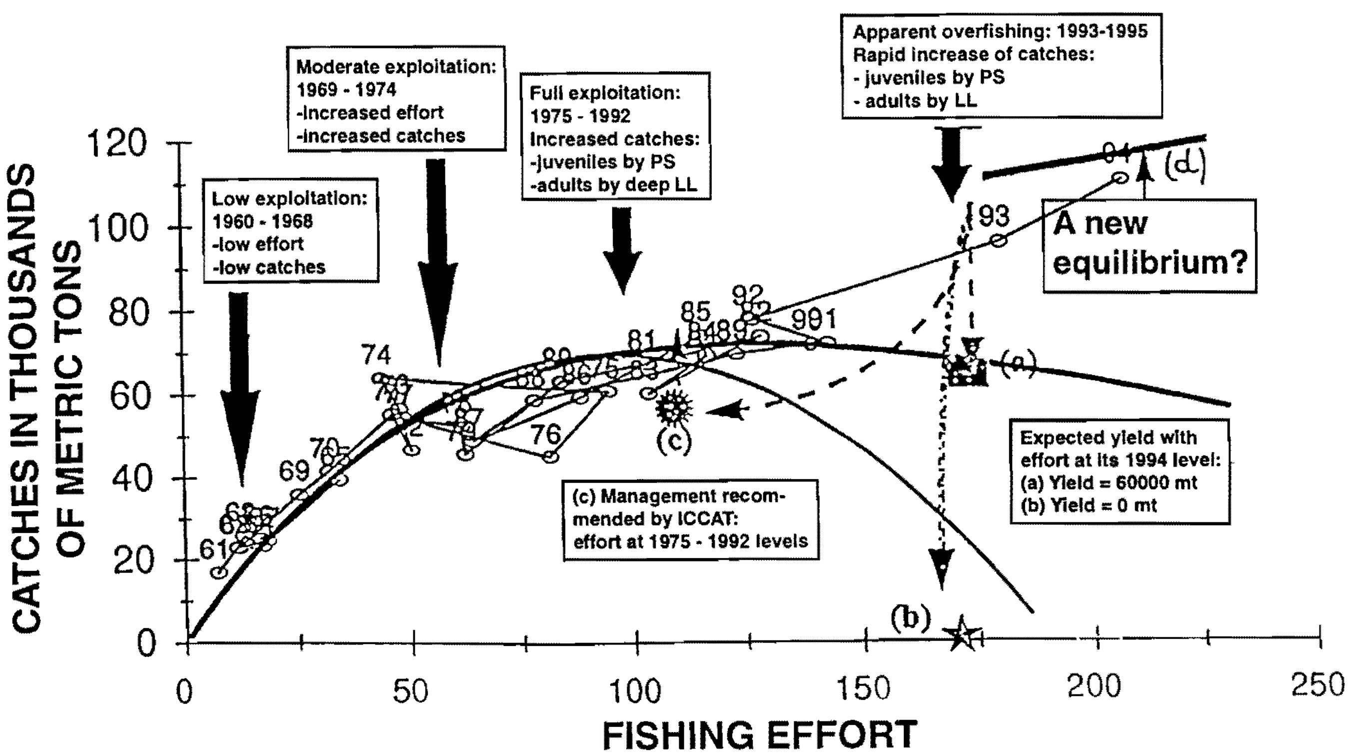

FIGURE 30. Overview of the status of bigeye in the Atlantic Ocean.

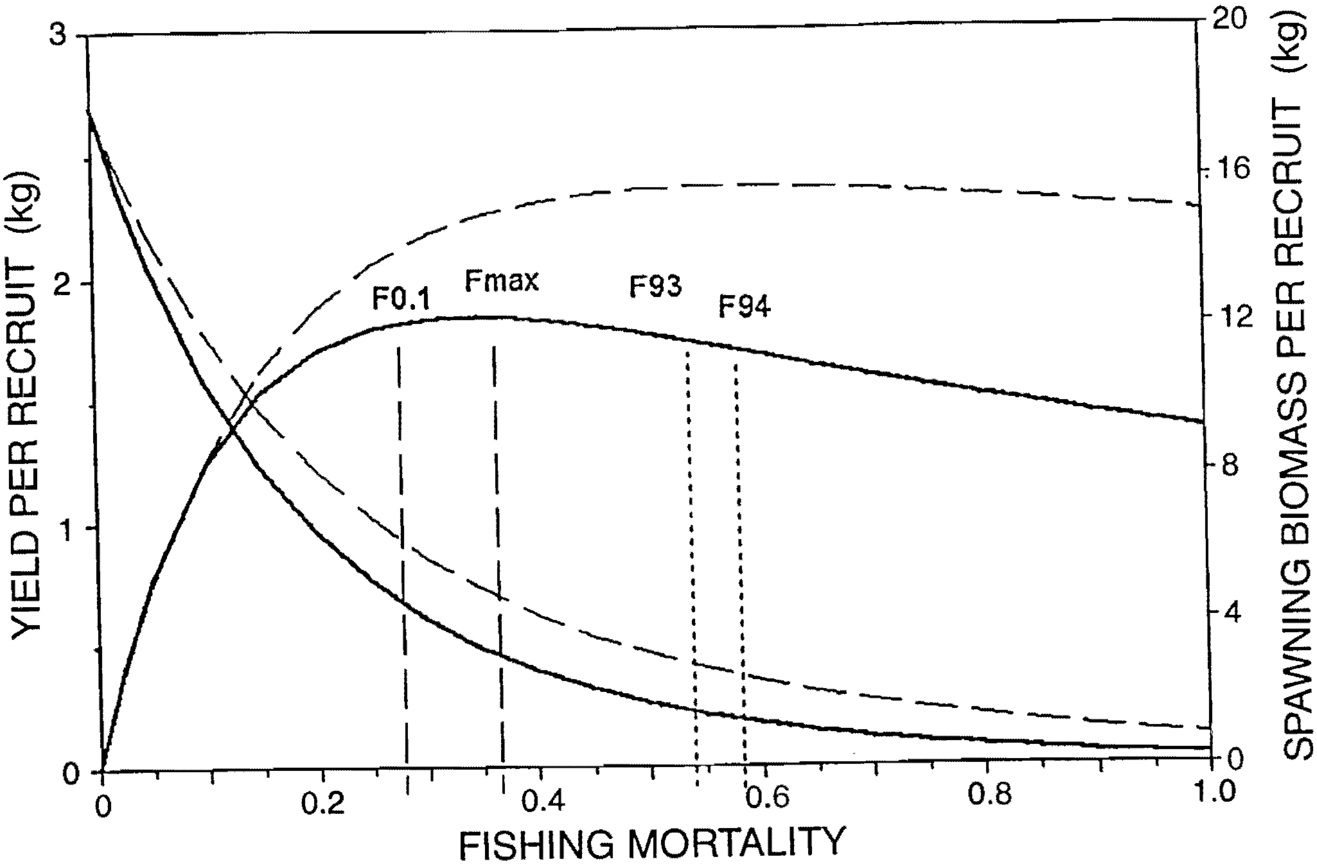

FIGURE 31. Yield-per-recruit curve for bigeye with no fishing mortality for fish of less than 3.2 kg.

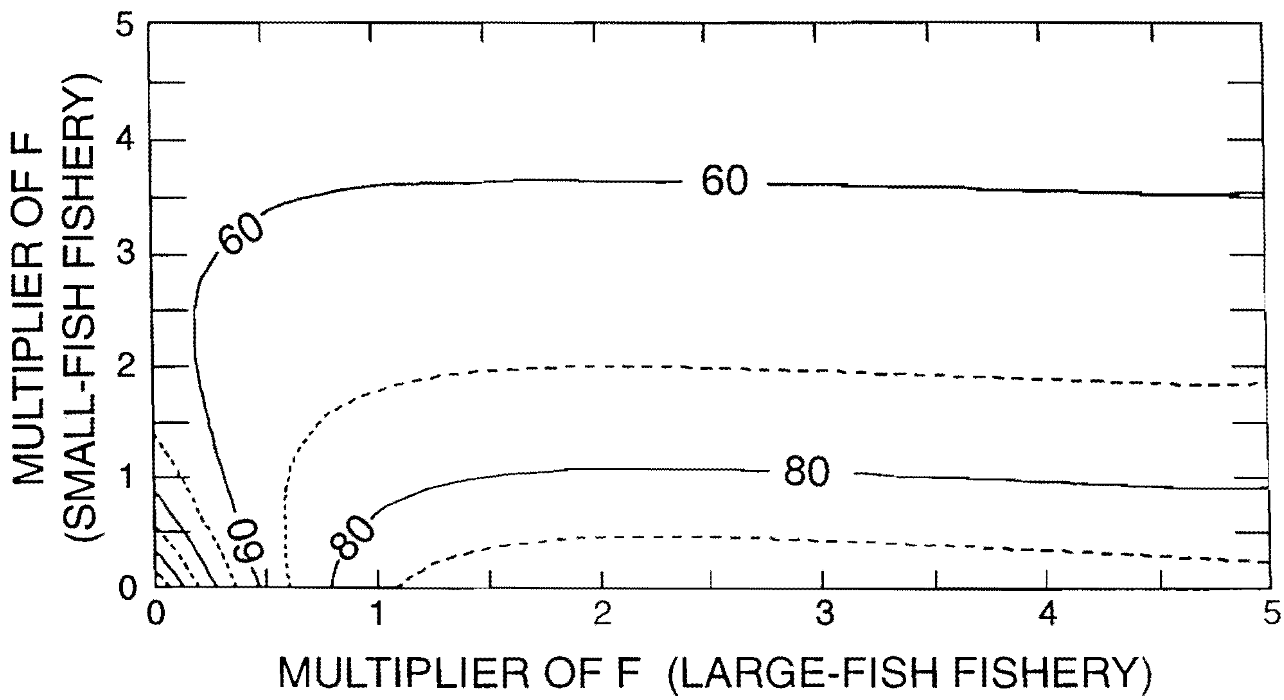

FIGURE 32. SSB-per-recruit curve for bigeye with no fishing mortality for fish of less than 3.2 kg.

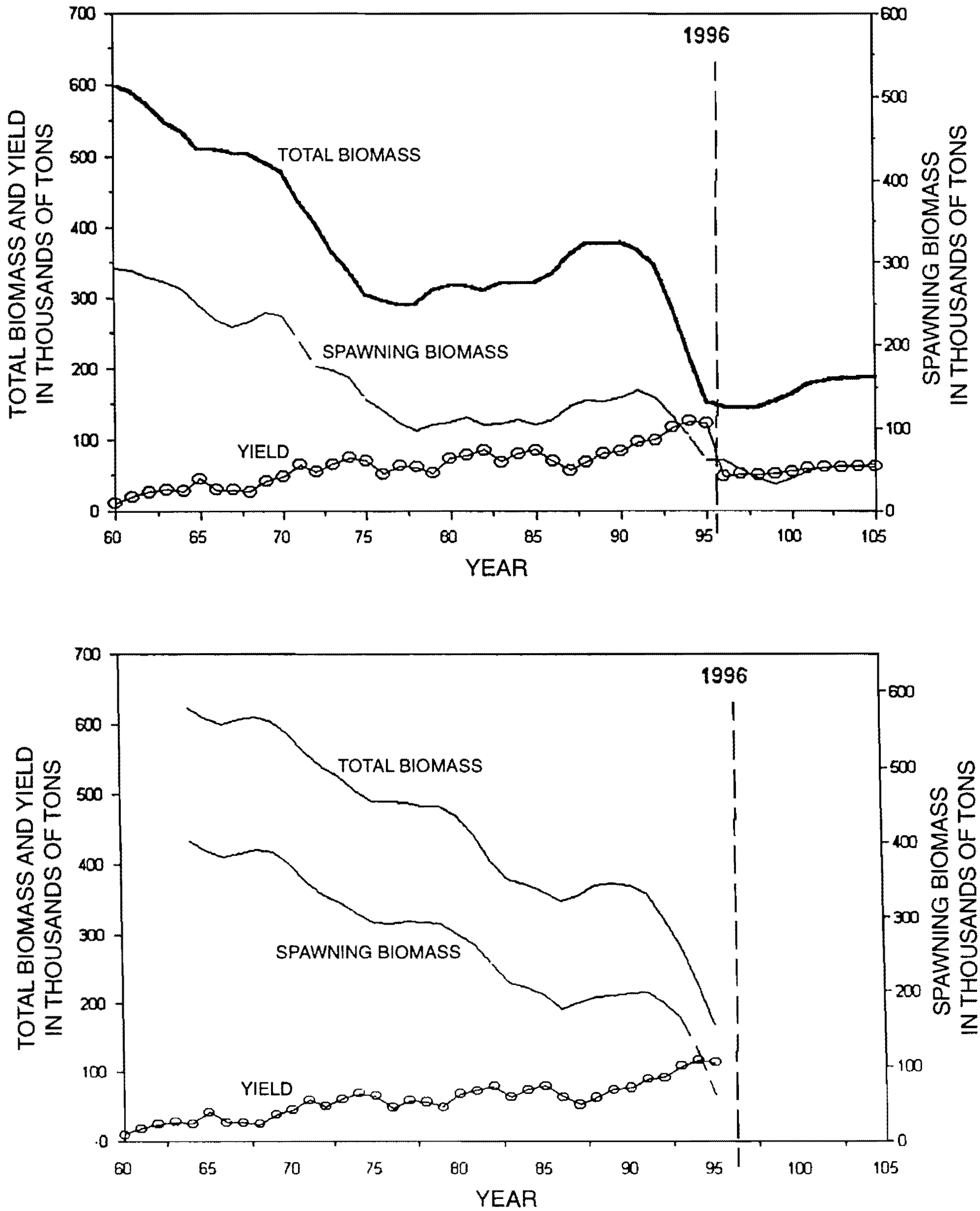

FIGURE 33. Total biomass and spawning biomass estimated from a tuned VPA (upper panel) and an untuned VPA (lower panel). The projections are based on an estimate of the population size in 1996 and estimates of recent fishing mortality rates obtained from a tuned VPA.

TABLE 1. Number of fish caught by the Atlantic tropical tuna surface fleets which were measured. Baitboat includes vessels registered in Dakar, the Canary Islands, Madeira, and the Azores. Purse seiners includes vessels registered in France and Spain and vessels registered under flags of convenience.

Year	Baitboat (excluding Tema)			Baitboat (Tema only)			Purse seine		
	YFT	SKJ	BET	YFT	SKJ	BET	YFT	SKJ	BET
1980	4599	5020	3485				32656	29903	3595
1981	1109	2125	919				33353	32111	3620
1982	1176	1541	696				37038	41880	6518
1983	1502	2409	1025				39720	45651	6933
1984	1881	2074	998	1959	5324	356	24176	48371	5543
1985	1910	2325	1631	8610	18696	1258	36586	28849	3609
1986	3753	2467	2363	4070	12421	427	35340	29129	2670
1987	4806	3563	2957	3331	10480	503	38321	37770	2947
1988	3635	3825	1799	5825	24416	456	45557	61593	5370
1989	2546	2986	1694	10715	37141	2709	54608	49610	4283
1990	3714	3324	2204	12754	33569	4111	62350	50511	4284
1991	3264	1984	2214	10304	28046	2989	44966	77422	8183
1992	2513	1799	1788	7458	15519	1966	53360	65703	10852
1993	2369	2031	1468				58529	73775	16892
1994	2297	2334	1939				53698	71589	19601
1995	1524	2713	2017				96352	125548	31656
1996							13139	20525	4419

TABLE 2. Total catches of bigeye tuna in the Atlantic Ocean, by gear.

Year	Longline	Purse seine	Baitboat	Other	Total
1950			808		808
1951			1651		1651
1952			2018		2018
1953			2951		2951
1954			2932		2932
1955			4808		4808
1956			2769		2769
1957	454		8266		8720
1958	453		3837		4290
1959	1478		6254		7732
1960	2960		6127		9087
1961	11207		5805		17012
1962	15951		7112		23063
1963	15052		10927		25979
1964	17785		5698		23483
1965	29412		9822		39234
1966	19640	20	5319		24979
1967	13212	92	11434		24738
1968	18803	436	3791		23030
1969	23033	2970	9769		35772
1970	27407	3389	10517		41313
1971	39100	4116	11841		55057
1972	32527	4690	9304		46521
1973	37942	4918	13620		56480
1974	39109	6636	17922		63667
1975	40833	5303	14651		60787
1976	27420	7067	9939	449	44875
1977	29145	11875	12758	716	54494
1978	28454	9094	14629	174	52351
1979	27274	8343	9493	481	45591
1980	41383	9204	12125	589	63301
1981	41391	15656	9685	798	67530
1982	51779	14476	6922	287	73464
1983	33461	15654	9796	179	59090
1984	41492	16063	11415	238	69208
1985	48669	7554	17667	203	74093
1986	34330	9286	15583	394	59593
1987	28726	7148	12672	586	49132
1988	40942	7859	9538	414	58753
1989	49713	6371	12683	593	69360
1990	44595	9407	17183	296	71481
1991	44519	20979	17146	417	83061
1992	47558	19481	15775	529	83343
1993	50912	28310	17911	611	97744
1994	58681	31208	20347	806	111042
1995	59513	21861	23497	404	105275

TABLE 3. Parameters of growth equations for the Atlantic bigeye tuna.

Author	Method	Gear	L_∞ (cm)	k (annual)	t_0 (year)	Size range (FL in cm)
Champagnat & Pianet (1974)	modal progression	PS ; BB	338.53	0.104097	-0.5425	60-140
Marcille *et al.*, (1978)	modal progression	PS ; BB	259.6	0.1488	-0.3983	45-150
Weber (1980)	modal progression	LL	491.6	0.054	-0.952	40-190
Pereira (1984)	modal progression	LL; PS; BB	381.47	0.08508503	-0.4	35-190
Gaikov *et al.*, (1980)	1st dorsal spine	LL	253.75	0.173	-0.15	30-200
Draganick & Pelczarski (1984)	1st dorsal spine	LL	218.8	0.23	-0.02	100-165
Delgado de Molina & Santana (1986).	1st dorsal spine	BB	206.14	0.1822	-0.74	58-187
Cayré & Diouf (1984)	tagging	PS; BB	285.37	0.1127	-0.5	40-150

TABLE 4. Results of the ASPIC non-equilibrium production model (all parameters estimated freely). MSY and K are given in 1000s of metric tons.

CPUE series	B1R	MSY	r	$q1$	$q2$	K	B-ratio	F-ratio
1 GM	2.14	26	0.045	5.28E-04		2326	0.87	4.50
1 GLM	0.72	51	0.072	9.04E-04		2802	0.52	3.88
2 GMs	2.51	107	5.987	1.61E-02	1.74E-02	72	1.16	0.85
2 GLMs	1.10	105	2.565	7.13E-03	7.65E-03	163	1.16	0.86

TABLE 5. Results of generalized production model analyses (GENPRO) based on general model and general linear model indices.

General model								
Shape parameter	SS(E+04)	MSY (1000 MT)	-H	B_{max}	B_{opt}	B_{95}	Ratio of B to B_{max}	Ratio of B to B_{opt}
0.4	0.3471	49.1	6.8620	2267	492	1041	0.46	2.12
0.5	0.3472	46.9	3.9631	2239	560	1024	0.46	1.83
0.6	0.3463	51.3	2.8890	1994	556	900	0.45	1.62
0.7	0.3476	44.2	1.5562	2187	666	998	0.46	1.50
0.8	0.3471	47.4	1.3233	1998	655	902	0.45	1.38
0.9	0.3478	44.3	1.1883	2065	720	937	0.45	1.30
1.0	0.3477	46.3	6.1746	1900	703	848	0.45	1.21
1.1	0.3477	49.7	0.3909	1721	664	763	0.44	1.15
1.2	0.3483	50.4	0.1050	1630	655	716	0.44	1.09
1.3	0.3488	46.6	0.0289	1776	741	792	0.45	1.07
1.4	0.3492	45.3	0.0100	1799	776	805	0.45	1.04
1.5	0.3498	46.8	0.0045	1695	753	753	0.44	1.00
1.6	0.3506	48.8	0.0020	1565	715	688	0.44	0.96
1.7	0.3507	44.8	0.0007	1733	812	774	0.45	0.95
1.8	0.3530	51.6	0.0005	1372	658	596	0.43	0.91
1.9	0.3531	49.7	0.0002	1444	708	632	0.44	0.89
2.0	0.3552	52.1	0.0001	1298	649	562	0.43	0.87

General linear model								
Shape parameter	SS(E+04)	MSY (1000 MT)	-H	B_{max}	B_{opt}	B_{95}	Ratio of B to B_{max}	Ratio of B to B_{opt}
0.4	0.2786	60	8.8516	1998	434	664	0.33	1.53
0.5	0.2787	62	5.8999	1765	441	641	0.36	1.45
0.6	0.2784	56	2.9029	2274	634	858	0.38	1.35
0.7	0.2840	41	0.9263	4066	1238	1423	0.35	1.15
0.8	0.2881	33	0.4402	5085	1664	1805	0.35	1.08
0.9	0.2868	35	0.4368	4815	1679	1708	0.35	1.02
1.0	0.2846	37	2.1332	4355	1610	1532	0.35	0.95
1.1	0.2790	50	0.3007	2197	847	737	0.34	0.87
1.2	0.2789	55	0.1127	1665	669	675	0.41	1.01
1.3	0.2793	58	0.0455	1478	617	631	0.43	1.02
1.4	0.2788	43	0.0044	3167	1366	1079	0.34	0.79
1.5	0.2781	45	0.0021	2798	1243	948	0.34	0.76
1.6	0.2781	46	0.0009	2724	1245	910	0.33	0.73
1.7	0.2783	46	0.0004	2566	1203	861	0.34	0.72
1.8	0.2786	47	0.0002	2466	1183	835	0.34	0.71
1.9	0.2795	49	0.0001	2037	998	755	0.37	0.76
2.0	0.2787	51	0.0001	1742	871	748	0.43	0.86

TABLE 6. Input data and options used in the FADAPT VPA.

Input	Options	Used
Age range		Case 1: 0-7+ Case 2: 0-6+ Case 3: 0-5+
Year range		1960-1995
Natural mortality at age	age-specific	Ages 0 and 1: 0.8 ages 2 and above : 0.4
Weights at age	by year	not needed (index refers to numbers of fish)
INDICES:		
Number of indices	1	Japanese longline (combined) standardized using GENMOD
Calculate max. likelihood variances by index?	replaces iterative reweighting	not needed (only one index)
objective function	normal or lognormal	log
for each index:	time of year to which index applies	mid
	biomass or number?	N
	age selectivity (equal across ages, selectivity varying each year for each age- known [input] or calculated by FADAPT [must input catch ratios of gear/total])	defined using yearly catch ratios, by gear
Catch-at-age matrix	yearly	FADAPT is designed for yearly catch values
Terminal-year *F*s to be estimated in search:	choose among ages for which there is relative abundance info in terminal year	all cases: age 4
	assign reference age to each age for which terminal year F will not be estimated	all cases: age 4
	relative selectivity at age for terminal year	AGE 0 1 2 3 4 5 6 7+ 1) .64 1.0 .57 .46 .62 .86 .8 .8 2) .64 1.0 .57 .46 .62 .86 .8 3) .64 1.0 .57 .46 .62 .83
F-ratios	yearly *F*-ratios of greatest age to that of next-greatest age	1.0 used for all cases, all years

TABLE 7. Partial selectivity for the Japanese longline fishery.

Year	Index	Partial selectivity for longline gear (longline catches by age and year/total catches by age and year)							
		0	1	2	3	4	5	6	7+
1960	NA	0.667	0.320	0.060	0.196	0.600	0.483	0.389	0.067
1961	1.43	0.900	0.667	0.274	0.493	0.836	0.778	0.725	0.400
1962	1.38	0.289	0.528	0.247	0.506	0.841	0.793	0.807	0.519
1963	1.18	0.056	0.277	0.150	0.349	0.739	0.719	0.750	0.452
1964	0.92	0.292	0.663	0.275	0.578	0.884	0.849	0.862	0.577
1965	1.10	0.895	0.747	0.370	0.603	0.899	0.857	0.850	0.592
1966	1.00	0.000	0.563	0.617	0.679	0.942	0.925	0.889	0.700
1967	1.08	0.000	0.025	0.144	0.448	0.787	0.824	0.692	0.192
1968	1.36	0.000	0.070	0.464	0.738	0.931	0.895	0.902	0.737
1969	1.47	0.000	0.026	0.545	0.539	0.736	0.667	0.607	0.385
1970	1.26	0.000	0.200	0.377	0.719	0.869	0.833	0.559	0.290
1971	1.31	0.004	0.233	0.452	0.571	0.788	0.860	0.790	0.644
1972	1.05	0.005	0.187	0.426	0.814	0.806	0.809	0.827	0.667
1973	1.28	0.000	0.175	0.493	0.611	0.829	0.900	0.863	0.556
1974	1.76	0.000	0.028	0.245	0.587	0.801	0.697	0.797	0.653
1975	0.91	0.000	0.030	0.286	0.592	0.831	0.817	0.795	0.679
1976	0.73	0.000	0.004	0.188	0.583	0.788	0.864	0.829	0.795
1977	1.35	0.000	0.018	0.279	0.522	0.723	0.776	0.773	0.563
1978	1.02	0.000	0.017	0.163	0.596	0.713	0.677	0.722	0.660
1979	0.95	0.000	0.023	0.414	0.686	0.759	0.776	0.768	0.677
1980	0.99	0.000	0.020	0.441	0.720	0.758	0.807	0.833	0.868
1981	0.88	0.000	0.015	0.272	0.683	0.819	0.861	0.835	0.939
1982	0.78	0.001	0.018	0.346	0.738	0.913	0.880	0.800	0.762
1983	0.81	0.000	0.007	0.205	0.667	0.776	0.805	0.800	0.902
1984	0.78	0.000	0.007	0.192	0.606	0.799	0.856	0.926	1.000
1985	0.82	0.000	0.016	0.380	0.751	0.766	0.804	0.788	0.892
1986	0.90	0.000	0.009	0.150	0.662	0.822	0.839	0.932	0.970
1987	1.03	0.000	0.012	0.239	0.632	0.798	0.794	0.813	0.846
1988	0.98	0.000	0.011	0.348	0.690	0.856	0.921	0.944	0.964
1989	0.76	0.000	0.003	0.293	0.693	0.824	0.926	0.981	1.000
1990	0.66	0.000	0.006	0.337	0.684	0.776	0.868	0.915	1.000
1991	0.66	0.000	0.001	0.126	0.597	0.780	0.868	0.913	0.967
1992	0.67	0.000	0.004	0.205	0.580	0.751	0.849	0.934	1.000
1993	0.64	0.009	0.018	0.128	0.557	0.903	0.916	0.923	1.000
1994	0.58	0.012	0.032	0.131	0.478	0.884	0.910	0.938	1.000
1995	0.52	0.013	0.028	0.193	0.450	0.823	0.911	0.903	0.881

A REVIEW OF THE BIOLOGY OF BIGEYE TUNA, *THUNNUS OBESUS*, AND THE FISHERIES FOR THIS SPECIES IN THE INDIAN OCEAN

by

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Introduction

The fishery for bigeye tuna in the Indian Ocean has become, in recent years, the third most important tuna fishery in the Indian Ocean. This species has traditionally been caught by the longline fleet operating in the area, but now it is also an important component in the catches of the various purse-seine fleets operating mostly in the western Indian Ocean. This has created the potential for interactions between these two fleets in the region.

During the 6th Expert Consultation on Indian Ocean Tunas, bigeye tuna was identified as one of the stocks that could be most vulnerable to excessive fishing pressure in this region (Anon. 1996). Because its life span is longer than those of most other tropical tunas, the population would probably take longer to recover from over-exploitation. Over-exploitation has become more likely as recent catches of juvenile bigeye tuna in the log-associated purse-seine fishery have exceeded those of all previous years. This increases the need for the gathering of information that would allow a closer monitoring of the status of the population in the Indian Ocean.

In this paper, we review the current status of the knowledge about the resource and identify research areas that will need to be addressed before effective management of this species is possible in the Indian Ocean.

Biogeography

Bigeye tuna is an epipelagic and mesopelagic species inhabiting oceanic waters, and is present throughout the inter-tropical zone. In the Indian Ocean, it is distributed throughout the ocean north of the West Wind Drift. It is also found in bordering areas, such as the Arabian Sea, with its low oxygen levels, and also in sub-tropical areas where water temperatures are lower (Stequert and Marsac 1989).

The quarterly distributions of longline catches by Japanese and Taiwanese vessels during 1989-1992 (Figure 1) provide a clear delimitation of the two main areas where bigeye congregate, namely the equatorial belt (10°N-10°S) and the subtropical waters between 30°S and 40°S. The available monthly data are plotted randomly in their 5° squares by circles whose areas are proportional to the catches. During the first half of the year, catches are concentrated in the Somali Basin, as far as the western boundary of the ocean. During the third quarter, the subtropical and temperate feeding grounds are exploited more intensively than the equatorial area, especially off South Africa. The eastern subtropical fishing grounds, extending from 70°E to Australia, are exploited mainly during the third and fourth quarters. Actually, albacore is targeted there, but bigeye represents a significant component of the catch as well.

The distribution of temperature and dissolved oxygen at 200 m, a depth within the range in which bigeye is targeted by deep longlines, explains fairly well the distribution of catch on a broad scale (Figure 2). The Indian Ocean is typically a southern ocean, and the two northern basins bordering the Asian continent, the Arabian Sea and the Bay of Bengal, are highly depleted in dissolved oxygen at intermediate

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depths (below 100 m). This is a consequence of combined effects of a low renewal rate of the waters and, seasonally (quarters 3 and 4), of the oxidation of high levels of organic biomass generated by coastal upwelling. At 100 m, oxygen is generally less than 2.0 ml/l, and the 0.5 ml/l isoline at 200 m is distributed zonally approximately along 10°N, which is the northern limit of the bigeye catches by longline throughout the year. The second interesting feature is the gap in catch distribution in the central part of the ocean, from 10°S to 25°S-30°S. The 19°C isotherm at 200 m gives a clear delimitation of the large anticyclonic gyre centered along 20°S, which is particularly developed west of 100°E. These relatively warm and highly-oxygenated waters (greater than 3.5 ml/l at 200 m) have a very low productivity, and are not conducive to the concentration of large schools. Finally, the southern boundary of the catch distribution, especially off South Africa, is clearly delineated by the Antarctic Convergence. The 13°C isotherm at 200 m is a good indicator of the lower habitat boundary for bigeye. The particularly high concentration of catches off South Africa during the third quarter is located in the continuation of the flow of the Agulhas Current, carrying the tropical waters of the Mozambique Channel southward. Bigeye, although able to penetrate the deeper layers, need to regain heat quickly (Holland *et al.* 1992), which can be achieved in areas where the surface temperature is greater than 17-18°C.

The information in the previous paragraph indicates that the general oceanography of the area provides a comprehensive view of the distribution patterns of bigeye according to its life stage. The adults congregate in the equatorial waters for spawning. Their tolerance for an oxygen-depleted habitat, enabling them to survive in the deeper layers, limits their competition with other predators. On the other hand, the southern latitudes off South Africa are characterized by well-marked fronts between subtropical and temperate ecosystems, where productivity is high. Therefore, these are areas where the sub-adults and young adults (less than 120 cm) congregate for feeding. Juveniles and small adults school at the surface in single-species groups or together with yellowfin tuna and/or skipjack. Schools are frequently found 50 to 100 m beneath floating objects, a behavior exploited by the purse-seine fishery through the use of fish-aggregating devices (FADs).

Movements

On the basis of catch and effort data, Kume *et.al.* (1971) identified two regions of greater bigeye abundance, one in the equatorial waters throughout the year and the other between 25° and 35°S during the second and third quarters. The seasonal occurrence of bigeye in the southern region, as well as the low gonad indices of bigeye sampled in this region, would indicate a seasonal migration, possibly related to feeding, as proposed by Kume *et.al.* (1971).

Most tagging studies in the Indian Ocean have concentrated on yellowfin and skipjack, although bigeye have also been tagged on an opportunistic basis (Yano 1991; Romanov and Silva 1994; Waheed and Anderson 1994; Anderson *et.al.* 1996; Cayré *et.al.* 1996). The most extensive study was undertaken by the R/V *Nippon Maru*, on which 1,344 bigeye were tagged during 1980 to 1990 (Yano 1991). A total of 3.04% of the bigeye tags were recovered, and movement was estimated to be 23 km/day, although no clear movement pattern emerged from the data.

Reproduction

The examination of the gonad index (ratio of weight of ovaries to weight of body) shows that bigeye found in equatorial waters are sexually active throughout the year, which would indicate that spawning takes place throughout the Indian Ocean in equatorial waters of relatively higher temperature (Kume *et.al.* 1971). In a study carried out in the Pacific Ocean (Hisada 1979), a temperature of 24°C and a depth of at least 50 m were observed as limiting factors in order for fish to mature.

The horizontal and vertical distributions of bigeye larvae in the Indian Ocean are not well known. Nishikawa *et al.* (1985) presented the average distribution of larvae of oceanic scombroid fishes based on data for 1956 to 1981 collected by members of a Japanese network of co-operating institutions and vessels. Figure 3, which depicts the average number of bigeye larvae observed, shows a concentration in the area between Indonesia and northwestern Australia and lesser quantities in the Bay of Bengal. These higher concentrations occurred during the fourth and first quarters of the year. The highly-localized concentrations of bigeye larvae, considering the wide distribution of this species in the Indian Ocean, may be the result of sampling strategy, as the coverage was considerably higher in the eastern Indian Ocean.

It is worth noting that, according to Nishikawa *et al.* (1985), bigeye larvae occur widely in the Indian Ocean to the north of 10° S, although the map they present indicates that the southern limit is, in fact, 20° S, but this may be specific for the area off northwestern Australia. On the other hand, the 10° S southern limit applies to the western Pacific Ocean. Also, Yabe *et al.* (1958) observed that young bigeye were found in the stomachs of large tunas and marlin caught between 10°N and 10°S.

Some inconsistencies regarding spawning period appear in the. Kume *et.al.* (1971), who were in possession of the most extensive data set on sexual maturity, found that spawning occurs throughout the year, although a peak in spawning activity may occur during the fourth and first quarters. This is consistent with observations off Madagascar, where the peak of spawning was estimated to be in November (Marcille and Stequert 1976). Bigeye reach maturity at 3 years of age, which would correspond to a size of 85 to 120 cm, with the males being slightly larger (Mimura and staff, 1963; Tankevich 1982; Stequert and Marsac 1989).

Feeding habits

Bashmakov *et.al.* (1991) studied the diet of yellowfin and bigeye in the vicinity of the Seychelles and Mauritius. Both species appear to have diverse diets, which is believed to be related to opportunistic feeding behavior. Twenty-three families were represented in the diet of bigeye, although the diet consisted primarily of Cephalopoda, the pelagic crab *Charibis smithi*, and fish of the family Paralepididae, in order of importance.

Kornilova (1980) studied bigeye feeding habits for the May to October period, and found that food assimilation rates were lowest off the east coast of Africa and on both sides of the equator between 2°N and 3°S. High assimilation rates were found in the area between 42°E and 75°E from 3°N to 10°N, where bigeye tuna prey mainly on fish and squid. Examination of stomach contents revealed that bigeye also prey on flying fish in the area between 5°S and 10°S. Kornilova suggested that, although bigeye and yellowfin prey on the same species, there is no direct competition between them, as they feed at different depths (Figure 4).

Growth

Although few studies on growth of bigeye have been undertaken, the results are generally consistent and in agreement with studies in other oceans. Figure 5 presents the estimated growth curves for bigeye obtained from studies in the Indian Ocean (Tankevich 1982), Atlantic Ocean (Cayré and Diouf 1984), and Pacific Ocean (Miyabe 1993).

In the Indian Ocean, Solovieff (1970) and Tankevich (1982) have estimated the growth rates of bigeye based on the reading of hard parts, such as scales, bones, and the first spine of the first dorsal fin (Stequert and Marsac 1989). Figure 6 presents data on size at age determined by these two studies. Only Tankevich (1982) segregates the results by sex, although sexual dimorphism in bigeye growth has been documented (Mimura and staff, 1963; Shomura and Keala 1963), the males attaining larger sizes. Tankevich (1982) listed the following equations:

females: $$L_{t(cm)} = 209.8\left(1 - e^{-0.171[t-(-0.86)]}\right)$$

males: $$L_{t(cm)} = 423.0\left(1 - e^{-0.058[t-(-1.773)]}\right)$$

The differences between sexes in the parameter estimates should perhaps be attributed to the range of sizes used in the analysis rather to physiological differences. The sequence of length at age for males, shown in Figure 7, does not suggest a decline of the growth rate with age, as is assumed to be the case in the von Bertalanffy model, but rather simple linear growth.

To better illustrate this problem, the parameters of the von Bertalanffy model were re-estimated from the pooled data (number of observations given) presented in Tankevich's paper for different age ranges. Considering that Tankevich mentions that age was difficult to determine for fish above 130 cm ($\approx$ > 5 years), ages above 5 years have been excluded in some cases. It should be borne in mind that these parameters are estimated from pooled data and, therefore, should not be compared directly to Tankevich's estimates. The results are shown in Table 1. As expected from the pattern in the Figure 7, in the case of males, both K and L_∞ converge to unlikely values when ages 7 and 8 are included. These results show how much the results are affected by inclusion of greater ages for the males. Figure 7 shows the estimated growth curves, estimated on the basis of ages 1 to 5, and the observed means for each age. Sample sizes were small for the older males; only two samples of 8-year-old males were obtained.

Marcille and Stequert (1976), using model progressions in samples obtained from the live-bait fishery off Madagascar, estimated the growth rate to be 16.5 to 18 cm/yr. for fish of 40 to 70 cm, which corresponds to ages of approximately 1 to 2 years. The length-frequency data (Figure 8) show clearly-defined modes. In a similar study, Tankevich (1982) observed a maximum growth rate of 59.0 cm/yr. during the first year of life and 24.2 cm/yr. during the second year. In subsequent years the rate of growth decreases, varying between 14.7 and 17.5 cm/yr. for ages 3 to 7. Talbot and Penrith (1963), who also used modal progressions, estimated the growth to be 30 to 35 cm/yr. off the south and east coasts of South Africa. Although there is considerable variation in the results published, the findings appear consistent when accounting for size and area variation.

Weight-length relationship

The following weight-length relationships have been determined for the Indian Ocean bigeye tuna.

Equation	Units	Reference
$w = (2.7 \times 10^{-5})l^{2.951}$	kilograms, centimeters	Cort 1986
$w = (2.74 \times 10^{-5})l^{2.908}$	kilograms, centimeters	Poreeyanond 1994

Natural mortality

No direct estimates of natural mortality have been obtained for the Indian Ocean. Marsac and Hallier (1987) applied the ICCAT convention, which is still in use (Pereira 1992), of assuming a natural mortality rate of 0.8 during the first two years of life and 0.4 thereafter. Miyabe (1988) used trial values of 0.2, 0.4, and 0.6 for fish of all ages.

Stock structure

For the purpose of stock assessment, the bigeye tuna resource in the Indian Ocean has been assumed to be comprised of one more-or-less homogenous unit (Kume *et al.* 1971; FAO 1980; Miyabe and Koido 1985; Marsac and Hallier 1986; Miyabe 1988; Miyabe and Suzuki 1991; Hsu and Chang 1994; Anon. 1995; Okamoto and Miyabe 1996).

Kume *et.al.* (1971) proposed the existence of a single stock, using data on distribution, size, and sexual maturity, noting that:

- Sexually active individuals are predominant in equatorial waters, indicating that fish of equatorial and southern waters intermingle.

- It is not possible to detect a change in pattern in an east-west direction, although this does not necessarily imply that the stock is homogenous.

- Morphometric comparisons between have shown some differences, but have not been conclusive.

- High hook rates observed off South Africa (see section on longline fisheries) indicate mixing of fish of the Indian and Atlantic Oceans.

- Mixing of Pacific and Indian Ocean populations appears to be slight.

According to these results, there is no indication that the Indian Ocean bigeye population consists of more than one stock, although more research, utilizing different approaches, for example genetic and tagging studies, should be undertaken. Also, the observation of high hook rates off South Africa could be related to oceanographic processes, rather than intermingling of populations, although the amount of mixing between the two oceans needs to be assessed.

Fisheries

The catches of bigeye tuna in the Indian Ocean have been traditionally from the industrial longline fishery since Japanese vessels began operations there during the early 1950s. However, the catches of bigeye by the industrial purse-seine fishery have increased considerably in recent years (Figure 9).

The FAO/UNDP Indo-Pacific Tuna Programme (IPTP) has statistics on catch and effort for a large proportion of the fleet for 1994 and 1995. Catches have been increasing steadily since the initial stages of the fishery, but, contrary to expectations, they have increased even more steeply in recent years. Spanish purse seiners accounted for much of the increase from 7,800 tons to nearly 30,000 tons from 1994 to 1995. Japanese longliners also experienced much greater catches. The catch of Taiwanese longliners, 24,000 tons, was substantial, but less than the all-time high of 34,000 tons in 1993 (see IPTP statistics in Appendix 1).

It is important in this context to take into account the proportion of bigeye to the total catch of tunas (yellowfin, bigeye, albacore, southern bluefin, and skipjack), as these fleets are usually not targeting bigeye. Figure 10 shows the evolution through time of this proportion. The question of targeting has to be considered, especially in the case of longliners. The proportion of bigeye to total tuna has been increasing steadily for purse seiners. This is related to the increasing importance of "log fishing" in the purse-seine fishery. For longliners, market forces, and as a result targeting, have affected the fishery, resulting in periods of increasing and decreasing catches.

The industrial longline fishery

The industrial longline fishery is dominated by Japan, South Korea, and Taiwan (Figure 11). Operations were initiated in the Indian Ocean by the Japanese in the early 1950s, and by the early 1960s the fishing grounds had expanded rapidly, covering almost the entire tropical area (Figure 12). Although the Japanese were primarily targeting yellowfin, albacore, and bigeye to export for canning, there was a gradual shift toward tuna of higher value, such as southern bluefin and bigeye (National Research Institute of Far Seas Fisheries, 1991). This also led to a shift toward fishing in higher latitudes. In recent times, greater effort has been placed in fishing for bigeye in tropical areas (Figure 13). The Korean longliners, which entered the fishery later and were dependent on the Japanese market, followed a strategy similar to that of the Japanese, with more emphasis on yellowfin and bigeye in tropical waters (Park *et al.* 1991). ,Yellowfin and bigeye were the initial targets of Taiwanese longliners, but this shifted to albacore during the 1972-1985 period. After that, the strategy shifted back to targeting yellowfin and bigeye in tropical waters, which is related to the increasing costs of operations and the higher value of these species, especially bigeye.

Around the mid-1970s the longline gear was gradually modified to increase the efficiency at catching bigeye. This was done by increasing the number of branch lines per basket, which increased the average depth of fishing. Most of the Japanese vessels were using deep longlines by 1982. Although the hook rate of bigeye is considered to be greater when deep longline gear is used, Koido (1985) observed that this applied only to equatorial waters of the eastern Indian Ocean. In higher latitudes and in the western Indian Ocean there was no clear difference between hook rates by regular longline and deep longlines. The hook rates of yellowfin were also not significantly different for the two gears.

Figure 14 depicts the nominal effort by country, which shows how their relative importance has shifted over time. Figure 15 shows that the vessels of these countries concentrate on different fishing grounds, rather than being evenly spread out over the Indian Ocean. The greatest effort was applied in the northern Arabian Sea and the area off Cape Horn.

The spatial distribution of CPUE by quarter in 1993 is illustrated in Figure 16, where the equatorial and southern groups of bigeye are clearly discernible, as observed by Kume *et al.* (1971). When averaging CPUE over the 1988-1992 period, the areal variability is reduced, as expected, although greater hook rates are usually observed in the eastern equatorial waters and in the northern Arabian Sea (Figure 17). Most of the catch for that period was taken off Cape Horn, as most effort was applied there (Figure 18).

The IPTP catch and effort database is not complete for 1994 and 1995, although Japan, one of the main longlining countries, has submitted data through 1995. Taiwan, another major country, has submitted catch and effort data for 1994. No major changes in the spatial distribution of catch and effort relative to 1993 are apparent.

The industrial purse-seine fishery

Following experimental fishing ventures undertaken by the Japanese beginning in 1978 and by the French during the early 1980s, the Indian Ocean purse-seine fishery became commercially viable in 1984. The fishing effort drastically increased in the western Indian Ocean, first in Seychelles waters, and then further north to 10°N, east to 80°E (Chagos Archipelago), and south to 23°S in the Mozambique Channel. Most of the catch comes from FAO area 51 (north of 45°S and west of 80°E (but including Sri Lanka)). The small part of the catch which comes from FAO area 57 (east of 80°E and north of 55°S) is taken primarily by Japanese purse-seine vessels. This fishery is well documented (especially for the French and the Spanish fleets, the two main ones), since logbook collection and size-sampling were undertaken from the beginning by ORSTOM and the Seychelles Fishing Authority (SFA).

The purse-seine fleet is comprised of vessels of five major nations (France, Japan, Mauritius, Russia, and Spain) and some vessels under flags of convenience such as Belize, the Cayman Islands, Liberia, Malta, and Panama. The number of vessels in operation has fluctuated over the years, and is now around 50 (Figure 19).

Two distinct fishing modes characterize the purse-seine operations. More than half of the total catch is made on fish associated with floating objects ("logs") (Figure 20). Initially, these floating objects were of "natural" origin (including debris resulting from man's activities), but later, given the profitable results of this technique, the fishermen started to deploy huge numbers of artificial rafts, which are tracked by radio or ARGOS buoys. The remainder of the catch is taken from free-swimming schools. The species compositions and the size distributions of fish caught in these two types of schools are very different (Table 2).

Since 1987, there has been an increase in the fishing efficiency of the vessels. Some of the factors which contributed to this increase were:

- Increased use of bird radar, which made it possible to detect schools at distances as great as 15 nautical miles (as compared to 4 to 6 nautical miles with binoculars);
- Increased use of sonar, which allows precise detection and evaluation of log-associated schools;
- Use of lighter nets and more powerful windlasses, which reduces setting time and, consequently, increases searching time;
- Use of supply vessels to assist the purse seiners, which increases searching time;
- Extensive use of artificial rafts, which reduces searching time and the occurrence of no-catch sets);

In the near future, the catches will be transferred at sea to factory vessels which will convert the whole fish to loins; this will enable the fishing vessels to spend more time searching for fish and less time travelling between port and the fishing grounds.

Specific analyses must be undertaken to quantify the relative impact of these factors on the fishing efficiency. However, an overall adjustment factor can be assessed through a CPUE stability hypothesis. If we postulate that the abundance has not changed significantly since the implementation of the purse-seine fishery (low hypothesis), the increasing nominal CPUEs of vessels fishing for free-swimming schools can be considered to be proportional to the increase in fishing power. Under this assumption, an overall increase of 56% in fishing efficiency is estimated for the purse-seine fleet from 1984-1986 to 1994. This estimate does not apply to log-associated fish, since other considerations, which will be reviewed further, apply to this type of operation. Another approach is based on the annual catch of the large purse seiners: the catch/boat was 3,400 tons in 1984-1985 and 5,565 tons in 1994-1995, a 64% increase. The increase between these two periods has been 51% for the eight large vessels that have been in operation since the beginning of the fishery. The three approaches yield estimates in the same magnitude, around 51 to 64%.

Contribution of the bigeye catch to the total catch

In the purse-seine fishery, in contrast to the longline fishery, bigeye tuna is not a target species. The deep habitat of the adults makes them rarely available to surface gear, and the occurrence of juveniles in the purse-seine catches is due to their mixing with yellowfin and skipjack, the target species.

However, the catch statistics displayed in Table 3 and in Figure 21 highlight the tremendous increase of the bigeye catches by purse seine, especially during 1994 and 1995. A record catch of 29,400 tons was recorded in 1995, due mainly to increased catches by the Spanish fleet. The catch data are obtained from various sources. The total and the bigeye tuna catches for Japan and Mauritius were extracted from the IPTP database (Anon. 1996). As for the Russian vessels (some of which are registered in Liberia), the bigeye catches were estimated from the total catches of all tunas and the results of size-composition sampling carried out by ORSTOM and the Seychelles Fishing Authority (SFA) at transshipment in the Seychelles. The statistics for the French and Spanish vessels (some of the latter registered in Belize, the Cayman Islands, Malta, and Panama) come entirely from adjusted data monitored by ORSTOM, IEO, and SFA. These adjustments were necessary because the amounts of bigeye recorded in the logbooks are considerably less than the amounts actually caught. As previously stated, most of the bigeye are juveniles and can easily be confused with yellowfin at this stage of life. Another reason is that the commercial value of the small bigeye is the same as that of small yellowfin or skipjack. Therefore, some vessel captains report their catches according to commercial categories, rather than species, unless they catch large bigeye. These considerations make necessary *ad hoc* sampling of the species composition of the catches. This is carried out apart from the normal size sampling, but for fish from the same well, provided that the selected well is clearly identified by date of capture, area of capture, and school type. Species identification of batches of 300 to 400 fish is made for two fractions of the wells, top (beginning of the unloading) and bottom. This sampling is directed toward yellowfin, skipjack, bigeye, and albacore, and is conducted separately for catches of log-associated and free-swimming fish (Thomas *et al.* 1995).

The procedure results in adjusted percentages, by weight, of each species for each sample. This information is used to adjust the catch figures pooled by 1°square/fortnight from the logbook reports. The adjustments result in considerable increases in the catches of bigeye, moderate increases in the catches of yellowfin, and corresponding decreases in the catches of skipjack. This is well illustrated in Figure 22, based on combined data sets for French and Spanish vessels that represent more than 80% of the purse-seine catches of bigeye. The proportion of the catch which was bigeye obtained from the logbooks was in the range of 2 to 3% during the period 1986-1994, while the adjusted values are three times the logbook values. Since the species sampling procedure was not fully implemented until 1990, the upward trend in bigeye catches observed from 1984 to 1987 is not significant. A provisional procedure was in force in 1988 and 1989. From 1988 to 1994, the adjusted bigeye figures leveled off at around 5% of the catch, and exhibited record values of 8% in 1991 and 9.5% in 1995.The adjustments result in increases in the catches of bigeye ranging from 6,000 to 15,000 tons per year.

The proportion of bigeye in the catch differs among nations (Figure 23). Two distinct groups can be identified: 1) Japan and Mauritius, with nearly 100% of their catches on logs, and consequently a relative high representation of bigeye tuna; and 2) France, Russia, and Spain, which operate on the both types of schools, and consequently catch smaller proportions of bigeye. However, Spain increased its effort on logs in 1995, which increased the proportion of bigeye in its catch for that year. The decreasing trend of the bigeye percentage from 1985 to 1993 for Japan and Mauritius is questionable, especially the high values for the first three years. An alternative explanation could be a change in fishing strategy. The sharp increase recorded by Japan in 1994 occurred when the fleet shifted entirely from the western to the eastern Indian Ocean, where there is no competition from vessels of other nations.

The fishing effort on logs is a key factor in understanding the positive trend of bigeye catches. As mentioned before, more and more boats are using FADs. The captains who use them report that they now deploy 10 to 40 rafts per trip. If the fleet consists of 50 vessels, all of which use FADs, there could be 500 to 2,000 FADs in the ocean at any given time. This is, of course, an overestimate, as the vessels are not always at sea, and as some of the FADS sink or are destroyed by storms. In addition, of course, floating objects other than FADs also attract tunas, and fishermen often make sets around such objects. Overall, FADs and other floating objects represent an important factor in purse-seining for tunas. These recent developments indicate that log fishing is shifting from an occasional activity (when no free-swimming schools are available) to an established fishing strategy.

Size distribution of the catch

The size distribution patterns differ according to the school type. Logs attract almost entirely small fish (mode at about 50 cm (3 kg)); only rarely are fish exceeding 80 cm (10 kg) found. According to the bigeye tuna growth curve estimated for the Atlantic (Cayré and Diouf 1984), those fish are less than 3 years old (Figure 24). In this report, therefore, fish less than 80 cm in length are considered to be juveniles, and larger ones are considered to be adults. In free-swimming schools, in addition to juveniles, there are also some adults (up to 150 cm), which are also targeted by longliners. The weight of adults exceeds that of juveniles in catches on free-swimming schools (Figure 25).

As shown in Figure 26, the increased purse-seine catches of bigeye during recent years is due to increased catches of juveniles. The catches of adults peaked at 6,600 tons in 1990, which represents 24% of the longline catches for that year in the western Indian Ocean.

The monthly catches, in numbers of fish, for each group (Figure 27) exhibit some peaks. In March 1990 this was the result of a large concentrations of free-swimming schools above a seamount 2478 m beneath the surface west of the Seychelles. In 1991, 1992, and 1995, the peaks were correlated with high occurrences of logs. The monthly series of the number of logs and free-swimming school sets (Figure 28) displays a strong seasonal signal, but an upward trend on log-associated fishing and a downward trend in fishing on free-swimming schools is apparent during the last two years.

Geographical distribution

There is a clear seasonal pattern in the location of the fishing grounds (Figure 29). The most productive fishing grounds are located west of the Seychelles, in the Mozambique Channel, and in the Somali Basin. The adults, still rare in the catch, are found east of the Seychelles (when the purse seiners target yellowfin in free-swimming schools) during the first and fourth quarters. In the other areas, the bulk of the catch is composed of juveniles. A monthly summary by subarea is presented in Figure 30. The highest level of catch is recorded in the Somali Basin, an area where considerable fishing effort is also deployed by longliners on adult bigeye.

The offshore drift gillnet fishery

Drift gillnet fishing was initiated by the Taiwanese for the primary purpose of catching albacore and sharks (Institute of Oceanography, National Taiwan University, 1991), although a substantial amount of bigeye was caught as by-catch (Appendix I). It can be seen in Figure 31 that this fishery was concentrated in higher latitudes, coinciding with the distribution of albacore, and that the greater catch rates were observed in two relatively limited areas. This fishery was terminated in 1992, following the UN moratorium on drift gillnetting on the high seas.

The IPTP category NEI

The category NEI, which stands for "not elsewhere included," includes Taiwanese longliners with gross registered tonnages of less than 100. It is estimated that there are about 335 of these (Anon. 1996). This highly-mobile fleet operates primarily in the Southeast Asian region, and its activities are not covered by the national fisheries statistics of Taiwan. When these vessels fish in Indonesian waters they operate under joint ventures, and the catch is supposed to be reported to the Indonesian authorities, but this system has not been effective in recent years. When these vessels are based in Penang, Malaysia, there is no requirement that the catches be included in any national statistics. The catch of this fleet in 1994 was estimated to be 36,600 tons (4,300 tons of bigeye) which is a substantial portion of the total catch (Appendix I). Also, these vessels are increasing their effort on bigeye, in view of the high value of this species for the Japanese sashimi market (Davis and Farley 1995; Mohd Ali 1996).

Artisanal fisheries

The catches of bigeye by the artisanal fisheries are negligible, but under-reporting is probably common, due to the fact that it is difficult to distinguish juvenile bigeye and yellowfin. The Maldives has a large traditional pole-and-line fishery which targets surface-swimming tuna. Most of the catch is skipjack and yellowfin, although lesser quantities of bigeye are also caught. Anderson (1996) looked into how much bigeye was being reported as yellowfin, and arrived at an estimate of approximately 5% (500 tons) of the total catch in weight of *Thunnus*. There was a considerable difference between the northern and the southern areas, as the estimates were 0.55% in the north and 15.8% in the south. This difference is due to the fact that the average size of bigeye caught in the south is larger (Figure 32). Similarly, Maldeniya *et al.* (1991) estimated that 0.5% of the so-called yellowfin caught by the gillnet and trolling gear and landed in Sri Lanka were actually bigeye.

More effort should be placed on studying possible under-reporting of catches of juvenile bigeye, especially as the use of FADs is becoming more widespread. Nevertheless, the artisanal catches of bigeye, even allowing for under-reporting, are negligible compared to the catches of the industrial fisheries.

Stock assessment

According to the type of information available, there are essentially two options to assess the status of a stock, production models of various types and age-structured models, such as virtual population analysis (VPA) and yield-per-recruit analysis. We will discuss the problems to be faced when applying each of these approaches to bigeye tuna in the Indian Ocean.

Stock structure

Before considering the application of any stock assessment method, we need to agree on how to define the population or populations under study. If more than one population is assumed, we need, in addition, to determine the rate of exchange of individuals among the populations. As reviewed in an earlier section, arguments have been put forward in favor of a single stock for the entire Indian Ocean.

However, the general question of the exchange among different regions of the fishery, in particular between the northern and southern Indian Ocean, is not resolved. Another problem deserving attention is the possibility of exchange between the Atlantic Ocean and the Indian Ocean.

How to best cope with this problem is not clear, as genetic methods might not be adequate to detect differences in rates of mixing at a level which could be useful for stock assessment. Tagging studies have been mentioned as a possibility, but the feasibility of tagging from purse seiners and longliners would have to be determined first.

Production models

The first study on the state of the Indian Ocean bigeye stock is described in FAO (1980). At the time, the fishery was still expanding and experiencing good catch rates, which led to the conclusion that the stock was only lightly exploited. The almost linear relationship between catch and effort meant that it was not possible to provide a reliable estimate of the maximum sustainable yield (MSY). Subsequent work with production models was carried out by Miyabe and Suzuki (1991) and Okamoto and Miyabe 1996). This work involved adjusting for differences in efficiency between regular and deep longlines and the standardization of effort using Honma's (1975) method or general linear models (Miyabe and Koido 1986; Miyabe 1988; Miyabe and Suzuki 1991; Hsu and Chang 1994; Anon. 1995; Okamoto and Miyabe 1996). Okamoto and Miyabe (1996) estimated the MSY to be between 32,000 and 77,000 tons, a range that includes all previous estimates. However, these applications present two problems: the traditional problem of lack of contrast in the trajectory of the population, and a varying vector of age-specific selectivity or partial recruitment.

Lack of contrast in the trajectory of the population

This refers to the fact that it is necessary to observe the effects of fishing on the population before we can properly estimate the some of the management parameters derived from the estimated parameters of a production model. Figure 33, taken from Anon. (1995), illustrates the problem. The parameters of the Schaefer (1957) and Fox (1975) models were fitted to the data available from the fishery. We see that, while both models produce similar estimates of MSY, they differ radically in the predictions of how the populations will react to increases in fishing mortality. The problem is that there are no data in the region of high fishing mortality which favor any of the alternative hypotheses postulated by the models. Even the estimation of MSY is remarkably dependent on the most recent data points. It is only recently that the catches have begun to show decreases with increases in effort, which would allow better assessment the optimum fishing mortality, but at this point we face a new problem in the application of production models, which will be discussed next.

Instability of the age-specific selectivity pattern

We use here the term selectivity pattern to define the relationship between the fishing mortality at any age and the fishing mortality at some age of reference. One of the basic tenets of production models is that the vector of age-specific selectivity remains constant over the study period. As production models combine yield-per-recruit and stock-recruitment effects implicitly, any change in age-specific selectivity (such as a change in age at entry to the fishery) would affect the long-term productivity of the population. A conventional production model will not capture this response.

In the case of bigeye tuna, the continuous increase in the catches of bigeye by the purse-seine fishery, in particular in association with floating objects, represents a serious violation of the stability in selectivity patterns because of the smaller average size of fish caught in association with floating objects. To illustrate this point, consider that the catch of bigeye by the purse-seine fleet was about 30% of the total catch, in weight, of bigeye in 1995, whereas during the late 1980s the corresponding percentage was only about 10%.

The consequences of this effect on the estimates of MSY depend on what observations are most influential in determining its value. In the case of the Indian Ocean bigeye, the observations which provide most of the information about the MSY level are from the late 1980s and early 1990s, when significant catches of small bigeye were already being made by the purse-seine fishery. However, it must be remembered that any effects of changes in selectivity will exhibit a delay associated with the transition to a new stable age composition.

These two effects combined suggest that the application of production modeling to bigeye tuna in the Indian Ocean must be done with the understanding that our view of the MSY might be biased. This problem could be addressed most effectively by complementing our assessment with age-structured models, in particular, multi-gear yield-per-recruit analyses.

Age-structured models

Age structured models have also been applied in the assessment of bigeye in the Indian Ocean, although not recently. A preliminary yield-per-recruit analysis of the bigeye stock for the 1962-1985 period indicated that higher yields could be obtained only by increasing F for fish of ages greater than 2 years (Marsac and Hallier 1987). It was noted that, while the purse-seine fishery targeted 0- to 3-year-old bigeye, the longline fishery targeted 4- to 8-year-olds. Marsac and Hallier concluded that, since the purse-seine catch was low, this would not have an important effect on the longline fishery. However, as has already been mentioned, the present purse-seine catches of bigeye are roughly 40%, by weight, of the longline catches, so the effect could now be important.

Another age-structured model, based on the ADAPT framework, was applied for practically the same period by Miyabe (1988). The catch at age was estimated with a length-age relationship for the Pacific Ocean (Suda and Kume 1967). After a decline in CPUE at the initial stages of the fishery, the standardized CPUE was considered stable, which was assumed to be the result of older fish being the primary targets of the longline fishery (Koido and Miyabe 1987). At that time, the catches of bigeye by purse seiners were estimated to be only 2,000 tons.

Although the results of the two studies which employed age-structured models were similar and complementary, they differed in explaining the CPUE trend. In both studies it was concluded that recruitment was relatively stable, and since most of fish taken were older ones, the standardized CPUE was also stable. Nevertheless, while Miyabe (1988) indicated that the rise in CPUE in 1977 was due to greater abundance of bigeye, Marsac and Hallier (1987) indicated that this was largely due to the deployment of deep longlining gear which increased the catchability of bigeye. A recent study by Okamoto and Miyabe (1996), using general linear models tostandardize effort, indicates that there was, in fact, an increase in CPUE in about 1977 which cannot be completely explained by an increase in the deployment of deep longline gear (Figure 34).

Considering the problems in the application of production models to bigeye, age-structured models should be the preferred tool for stock assessment of bigeye. However, a number of potential problems will have to be addressed, in particular the following.

Accuracy of the catch data

In particular, the misidentification of young bigeye caught in the surface fisheries is cause for concern. The recent discovery of some problems in the processing of this information has resulted in important revisions of the recent catches by some components of the purse-seine fleet. Another source of uncertainty is the lack of recent reporting of catches from the eastern Indian Ocean, especially by small Taiwanese longliners (<100 tons) operating from Indonesia and Malaysia.

Availability of an age-length key

This information is essential for converting the catches by size into catches at age. However, there have been no recent studies of growth in the Indian Ocean, and the only possible sources are Tankevich's (1982) research or the application of growth curves estimated for other oceans.

Indices of abundance

Indices of abundance are necessary in integrated VPA analyses in order to provide stability to the estimation of the parameters. Such indices have been calculated, especially for the longline fisheries. The most recent analyses (Okamoto and Miyabe 1996) involve application of general linear models incorporating components for area, season, and gear configuration (deep *versus* conventional longlines). This study indicated a significant year-area interaction, which could be important. This suggests that a different approach to the spatial integration of the standardization might be necessary, perhaps by integrating at a lower spatial resolution. For the purse-seine fishery, since most of the catches originate from log-associated sets, the problem of how to define effort adequately remains.

Purse-seine availability index for bigeye

Because bigeye is not a target species in the purse-seine fishery, it is difficult to obtain a meaningful abundance index from catch and effort statistics. However, some trends over time can be analyzed.

The first step is to define which effort should be considered to be effort for bigeye. As mentioned above, the bigeye catches by purse seiners have increased as the effort directed at log-associated fish has increased. Days of fishing or hours of searching are not appropriate measures of fishing effort on logs because the probability of catching fish is not necessarily related to the amount of time spent scouting for bird flocks or other signs of fish, as is the case for free-swimming schools. The practice of attaching a radio or ARGOS buoy has turned the fishermen into collectors, rather than hunters. Therefore, the number of sets on logs appears to be a more meaningful unit of effort, and the catch per successful set on logs an index potentially better related to abundance. This point has already been raised by Hallier (1995), but he addressed only data for catches of all species combined on logs. Some assumptions are involved in the use of catch per set as an index of abundance, mainly that the average number of logs remains relatively constant over time and that the "recruitment" to the floating objects is dependent on the abundance of fish (with a constant average rate of recruitment).

This index has been computed for the data for French and Spanish vessels for 1984-1995, because the sampling coverage for these is complete and because these data represent the bulk of the catch. The geographical distributions of the sets, by type, is given in Figure 35. The log sets (black area) are distributed everywhere in the fishery, but with a greater abundance in the Somali Basin. However, for a better coverage in time (because the Somali Basin area is exploited seasonally), the entire area of the fishery has been considered in this analysis.

First, CPUEs by fortnight are calculated, and then the annual CPUE is obtained by averaging the fortnightly CPUEs:

$$U'_{ij} = \Sigma C_{ijk} / \Sigma S_{ijk}$$

where

C = catch

S = number of successful sets on logs for year i, fortnight j, and area (1°sq) k, and

$$U_i = U'_{ij}/N_i$$

where

N_i = number of fortnights sampled in year *I*.

Two sets of CPUE data are calculated, one using all the information and the other using only the strata containing at least two successful sets. In order to provide a comparison with a target species which is abundant on logs, the same procedure was applied to skipjack. The plots are displayed in Figure 36.

The CPUE for skipjack decreased until 1992, and then leveled off at about 3 to 4 tons/set. During the same period, the trend for bigeye CPUEwas also downward. In 1995, however, there was a large increase in the CPUE of bigeye, due to the activities of Spanish vessels.

The relationship between catch and effort (as measured by the number of sets on logs) calls for another look on the situation (Figure 37). The recent catches of skipjack on logs have tended to level off, even though the effort increased. The situation for bigeye is somewhat different, as the catch has increased more rapidly than the effort. Most likely, this is a non-equilibrium situation, and the CPUE may decline sharply in the future.

These results should be interpreted with caution because of several uncertainties affecting the underlying assumptions. We do know whether a sequence of sets on the same log during consecutive days results in a change in relative importance of the various species or a decrease in the catch per set (Ianelli 1987; Hallier 1991). However, if the number of logs increases, there might be a "dilution" of the potential biomass and, consequently, a decline in the catch per set, if the biomass remains constant or declines, and if the number of logs decreases there might be the opposite effect. We still lack estimates on the exchange rate of schools or individuals among the logs concentrated in the same area that would enable the delimitation of homogeneous boxes to analyze the trend in catch per set for a limited period of time. Given these uncertainties, the purse-seine CPUE may be proportional to the vulnerable biomass, rather than to the real abundance.

Summary

As tuna fisheries management is implemented in the Indian Ocean, with the recent establishment of the Indian Ocean Tuna Commission, bigeye will become one of the main focuses of interest. The status of the stock is currently unknown, although concerns have been raised regarding the potential impact of recent catches of bigeye by the surface fisheries on the long-term productivity of the stock and on the catches of the traditional longline fisheries operating in the region.

Age-structured stock assessment should be undertaken to assess the recent trends in the age composition of the population and the possible trade-offs in productivity resulting from the changes in age-specific fishing mortality. Further research, especially tagging experiments, would contribute to better understanding of stock structure (including migration and rates of exchange among various areas) and natural mortality. These population parameters are crucial to assess the extent of interactions among fisheries and future effects of changes in exploitation patterns.

References

ANDERSON, R.C. 1996. Bigeye tuna (*Thunnus obesus*) in the Maldives, p. 219-224. *In* Anganuzzi, A.A., K.A. Stobberup, and N.J. Webb [eds.] Proceedings of the Expert Consultation on Indian Ocean Tunas, 6th Session, Colombo, Sri Lanka, 25-29 September 1995.

ANDERSON, R.C., M.S. ADAM, AND A. WAHEED 1996. Tuna tagging activities in the Maldives, 1993-1995, p.333-347. *In* Anganuzzi, A.A., K.A. Stobberup, and N.J. Webb [eds.] Proceedings of the Expert Consultation on Indian Ocean Tunas, 6th Session, Colombo, Sri Lanka, 25-29 September 1995.

ANON. 1995. Report of the Expert Consultation on Indian Ocean Tunas, 6th Session, Colombo, Sri Lanka, 25-29 September 1995. IPTP/95/GEN/23, 67 p.

ANON. 1996. Indian Ocean Tuna Fisheries Data Summary, 1984 - 1994. IPTP Data Summary No. 16, 146 p.

BASHMAKOV, V.F., V.V. ZAMOROV, AND E.V. ROMANOV 1991. Diet composition of tunas caught with longlines and purse seines in the Western Indian Ocean, p. 53-59. *In*: Workshop on Stock Assessment of Yellowfin Tuna in the Indian Ocean, Colombo, Sri Lanka, 7-12 October 1991. IPTP Coll. Vol. Work. Doc. 6.

CAYRE, P., AND T. DIOUF 1984. Croissance du thon obèse (*Thunnus obesus*) de l'Atlantique d'apres les résultats de marquage. ICCAT Col. Vol. Sci. Pap., Vol. 20 (1): 180-187.

CAYRE, P., D. NORUNGEE, AND C. LIM SHUNG 1996. Analysis of tag recoveries in Mauritius (1988-1993) and presentation of codification procedure in use, p. 348-356. *In* Anganuzzi, A.A., K.A. Stobberup, and N.J. Webb [eds.] Proceedings of the Expert Consultation on Indian Ocean Tunas, 6th Session, Colombo, Sri Lanka, 25-29 September 1995.

CORT, J.L. 1986. Data on tuna fishing by Spanish vessels in western Indian Ocean. *In* Expert Consultation on Stock Assessment of Tunas in the Indian Ocean, p. 165-167. *In* Expert Consultation on Stock Assessment of Tunas in the Indian Ocean, Colombo, Sri Lanka, 28 November -2 December 1985, 364 p. IPTP Coll. Vol. Work. Doc. 1.

DAVIS, T.L.O., AND J.H. FARLEY 1995. Catch monitoring of fresh tuna caught by the Bali-based Indonesian/Taiwanese longline fishery. Report for the 1995 CCSBT trilateral scientific assessment, Canberra, Australia. Commission for the Conservation of Southern Bluefin Tuna.

FAO 1980. State of selected stocks of tuna and billfish in the Pacific and Indian Oceans. Workshop on the assessment of selected tunas and billfish in the Pacific and Indian Oceans organized by the Honolulu Laboratory, Southwest Fisheries Center, National Fisheries Center and the Far Seas Fisheries Research Laboratory of the Fisheries Agency of Japan. FAO Fish. Tech. Pap., (200): 89 p.

FOX W.W., JR. 1975. Fitting the generalized production model by least squares and equilibrium approximation. Fish Bull., US. **73** (1): 23-36.

HALLIER, J.P. 1991. Tuna fishing on log associated schools in the western Indian Ocean: an aggregation behaviour, p. 325-342. *In* Expert Consultation on Stock Assessment of Tunas in the Indian Ocean, Bangkok, Thailand, 2-6 July 1990, 503 p. IPTP Coll. Vol. Work. Doc. 4.

HALLIER, J.-P. 1994. Purse seine fishery on floating objects: what kind of fishing effort? What kind of abundance indices? p. 192-198. *In* Ardill, J.D. [ed.] Proceedings of the Expert Consultation on Indian Ocean Tunas, 5th Session, Mahé, Seychelles, 4-8 October 1993, 275 p., IPTP Coll. Vol. 8.

HASTINGS, R.E., AND G. DOMINGUE 1996. Recent trends in the Seychelles Industrial Fishery, p. 97-109. *In* Anganuzzi, A.A., K.A. Stobberup, and N.J. Webb [eds.] Proceedings of the Expert Consultation on Indian Ocean Tunas, 6th Session, Colombo, Sri Lanka, 25-29 September 1995.

HISADA, K. 1979. Relationship between water temperature and maturity status of bigeye tuna caught by longline in the central and eastern Pacific Ocean. Bull. Far Seas Fish. Res. Lab., (17): 159-175.

HOLLAND, K.N., R.W. BRILL, R.K.. CHANG, J.R. SIBERT, AND D.A. FOURNIER 1992. Physiological and behavioural thermoregulation in bigeye tuna (*Thunnus obesus*). Nature, 358(6385): 410-412.

HSU, C.C., AND H.C. CHANG 1994. An ASPIC analysis of the Indian Ocean bigeye tuna stock, p. 124-127. *In* Ardill, J.D. [ed.] Proceedings of the Expert Consultation on Indian Ocean Tunas, 5th Session, Mahé, Seychelles, 4-8 October 1993, 275 p., IPTP Col. Vol. 8.

IANELLI, J. 1987. A method for estimating recruitment patterns of tunas to floating objects using removal data. S.P.C. Internal Report, 11: 5 p.

INSTITUTE OF OCEANOGRAPHY, NATIONAL TAIWAN UNIVERSITY 1991. National report of Taiwan, p. 149-153. *In* Workshop on Stock Assessment of Yellowfin Tuna in the Indian Ocean, Colombo, Sri Lanka, 7-12 October 1991. IPTP Coll. Vol. Work. Doc. 6.

KOIDO, T. 1986. Comparison of fishing efficiency between regular and deep longline gears on bigeye and yellowfin tunas in the Indian Ocean, p. 62-70. *In* Expert Consultation on Stock Assessment of Tunas in the Indian Ocean, Colombo, Sri Lanka, 28 November-2 December 1985, 364 p. IPTP Coll. Vol. Work. Doc. 1.

KOIDO, T., AND N. MIYABE 1987. Trend of Japanese longline CPUE for yellowfin and bigeye tunas in the Indian Ocean, p. 40-43. *In* Expert Consultation on Stock Assessment of Tunas in the Indian Ocean, Colombo, Sri Lanka, 4-8 December 1986, 374 p. IPTP Coll. Vol. Work. Doc. 2.

KORNILOVA, G.N. 1980. Feeding of yellowfin tuna, *Thunnus albacares*, and bigeye tuna, *Thunnus obesus*, in the equatorial zone of the Indian Ocean. J. Ichthyology, 20(6): 111-119.

KUME, S., Y. MORITA, AND T. OGI 1971. Stock structure of the Indian bigeye tuna, *Thunnus obesus* (Lowe), on the basis of distribution, size composition and sexual maturity. Bull. Far Seas Fish. Res. Lab., (4): 141-164.

MALDENIYA, R., P. DAYARATNE, AND B. BONIFACE 1991. Incidence of juvenile bigeye tuna (*Thunnus obesus*) among the tuna catches in the south-west coast of Sri Lanka. p 108-110. *In* Expert Consultation on Stock Assessment of Tunas in the Indian Ocean, Bangkok, Thailand, 2-6 July 1990, 503 p. IPTP Coll. Vol. Work. Doc. 4.

MARCILLE, J., AND B. STEQUERT 1976. Croissance des jeunes albacores, *Thunnus albacares*, et patudos, *Thunnus obesus*, de la cote nord-ouest de Madagascar. Cah. O.R.S.T.O.M., sér. Océanogr., 14(2): 153-162.

MARSAC, F., AND J.P. HALLIER 1987. Preliminary yield per recruit analysis of the Indian Ocean yellowfin and bigeye fisheries, p. 58-72. *In* Expert Consultation on Stock Assessment of Tunas in the Indian Ocean, Colombo, Sri Lanka, 4-8 December 1986, 374 p. IPTP Coll. Vol. Work. Doc. 2.

MIMURA, K., AND STAFF 1963. Synopsis on the biology of bigeye tuna, *Parathunnus mebachi* Kishinouye 1923 (Indian Ocean), p. 350-379. *In* Rosa, H., Jr. [ed.] Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, FAO Fish. Rep., 6(2), 2272 p.

MIYABE, N. 1988. Production model analysis and preliminary application of virtual population analysis on the Indian bigeye tuna, p. 74-81. *In* Expert Consultation on Stock Assessment of Tunas in the Indian Ocean, Mauritius, 22-27 June 1988, 418 p. IPTP Coll. Vol. Work. Doc. 3.

MIYABE, N. 1994. A review of the biology and fisheries of bigeye tuna, *Thunnus obesus*, in the Pacific Ocean, p. 207-243. *In* Shomura, R.S., J. Majkowski, and S. Langi [eds.] Proceedings of the 1st FAO Expert Consultation on Interactions of Pacific Tuna Fisheries, 3-11 December 1991. FAO Fish. Tech. Pap., No 336, Vol. 2, Rome, FAO.

MIYABE, N., AND T. KOIDO 1986. Production model analysis of bigeye and yellowfin tunas based on Japanese longline fishery data. *In* Expert Consultation on Stock Assessment of Tunas in the Indian Ocean, Colombo, Sri Lanka, 28 November-2 December 1985, 364 p. IPTP Coll. Vol. Work. Doc. 1.

MIYABE, N., AND Z. SUZUKI 1991. Stock analysis of bigeye and yellowfin tunas based on longline fishery data, p. 84-90. *In* Expert Consultation on Stock Assessment of Tunas in the Indian Ocean, Bangkok, Thailand, 2-6 July 1990, 503 p. IPTP Coll. Vol. Work. Doc. 4.

MOHD ALI, B.B. 1996. Landings of Indian Ocean tuna by foreign vessels in Malaysia, p. 26-29. *In* Anganuzzi, A.A., K.A. Stobberup, and N.J. Webb [eds.] Proceedings of the Expert Consultation on Indian Ocean Tunas, 6th Session, Colombo, Sri Lanka, 25-29 September 1995.

NATIONAL RESEARCH INSTITUTE OF FAR SEAS FISHERIES 1991. Status report of Japanese longline fishery with respect to yellowfin tuna in the Indian Ocean, p. 178-182. *In* Workshop on Stock Assessment of Yellowfin Tuna in the Indian Ocean, Colombo, Sri Lanka, 7-12 October 1991. IPTP Coll. Vol. Work. Doc. 6.

NISHIKAWA, Y., M. HONMA, S. UEYANAGI, AND S. KIKAWA 1985. Average distribution of larvae of oceanic species of scombrid fishes, 1956 - 1981. Contribution (Atlas) No. 236. Far Seas Fisheries Research Laboratory, 99 p.

OKAMOTO, H., AND N. MIYABE 1996. Updated standardised CPUE of bigeye caught by the Japanese longline fishery in the Indian Ocean, and stock assessment by production model, p. 225-231. *In* Anganuzzi, A.A., K.A. Stobberup, and N.J. Webb [eds.] Proceedings of the Expert Consultation on Indian Ocean Tunas, 6th Session, Colombo, Sri Lanka, 25-29 September 1995.

PARK, Y.C., W.S. YANG, AND T.I. KIM 1991. Status report of the Korean tuna longline fishery for yellowfin tuna in the Indian Ocean, p. 138-142. *In* Workshop on Stock Assessment of Yellowfin Tuna in the Indian Ocean, Colombo, Sri Lanka, 7-12 October 1991. IPTP Coll. Vol. Work. Doc. 6.

PEREIRA, J. 1992. Etat du stock de patudo de l'Atlantique au 30 Septembre 1992. SCRS/92/160. ICCAT, Col. Vol. Sci. Pap., 40 (2): 174-184.

POREEYANOND, D. 1994. Catch and size groups distribution of tunas caught by purse seining survey in the Arabian Sea, Western Indian Ocean, 1993, p. 53-54. *In* Ardill, J.D. [ed.] Proceedings of the Expert Consultation on Indian Ocean Tunas, 5th Session, Mahé, Seychelles, 4-8 October 1993, 275 p., IPTP Col. Vol. 8.

ROMANOV, E.V., AND R. DE P. E SILVA 1994. Preliminary results of tuna tagging during Soviet-Mozambican tagging programme in the Indian Ocean, p. 239-241. *In* Ardill, J.D. [ed.] Proceedings of the Expert Consultation on Indian Ocean Tunas, 5th Session, Mahé, Seychelles, 4-8 October 1993, 275 p., IPTP Coll. Vol. 8.

SCHAEFER, M.B. 1957. A study of the dynamics of the fishery for yellowfin tuna in the eastern tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 2 (6): 245-285.

SHOMURA, R.S., AND B.A. KEALA 1963. Growth and sexual dimorphism of bigeye tuna (*Thunnus obesus*). A preliminary report. p. 1409-1417. *In* Rosa, H., Jr. [ed.], Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species. FAO Fish. Rep., 6 (3), 2272 p.

SUDA, A., AND S. KUME. 1967. Survival and recruit of bigeye tuna in the Pacific Ocean, estimated by the data of tuna longline catch. Rep. Nankai Reg. Fish. Res. Lab. (25): 91-103.

SUDA, A., S. KUME, AND T. SHIOHAMA 1969. An indicative note on a role of permanent thermocline as a factor controlling the longline fishing ground for bigeye tuna. Bull. Far Seas Fish. Res. Lab., (1): 99-114.

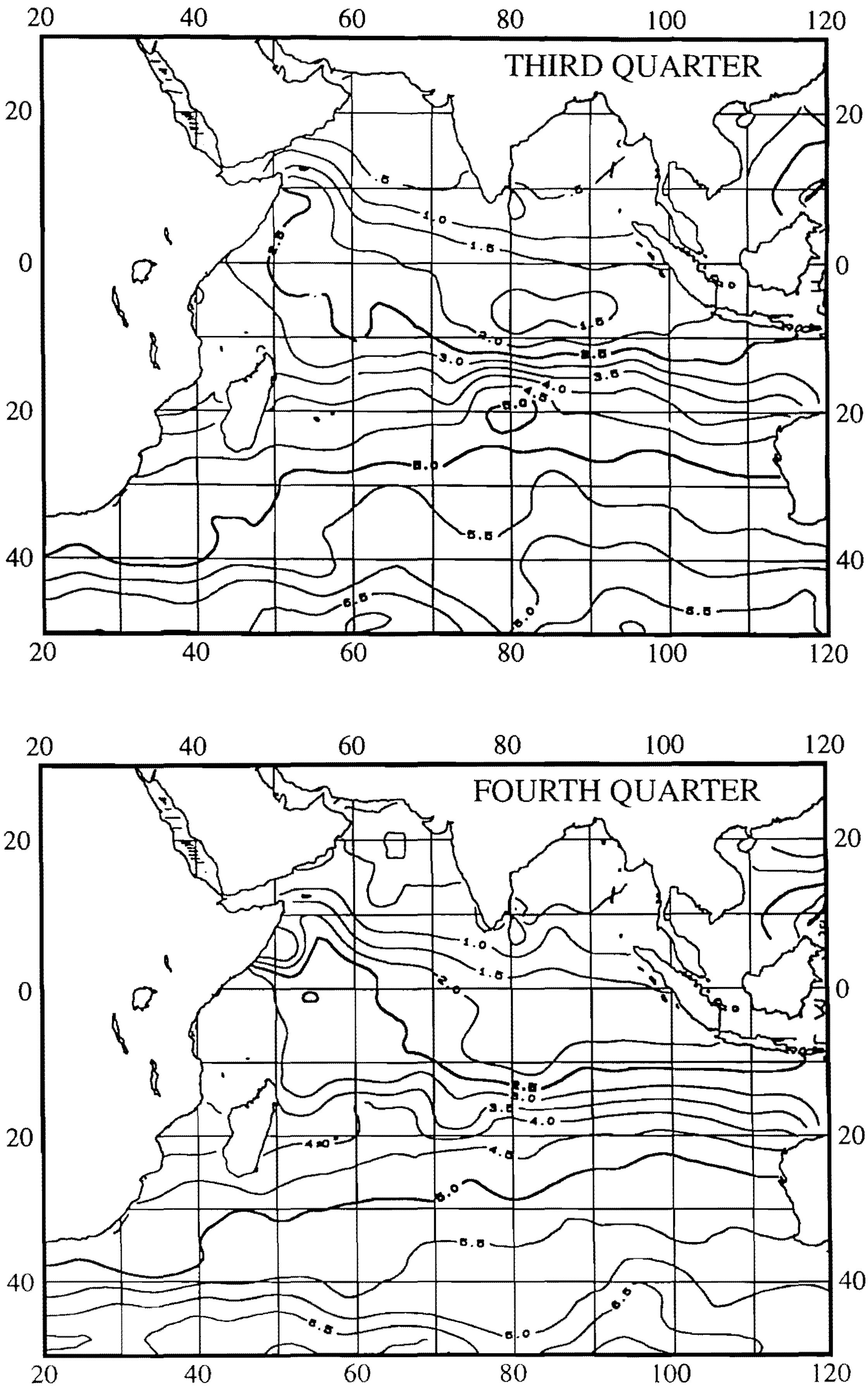


FIGURE 2a. (continued)

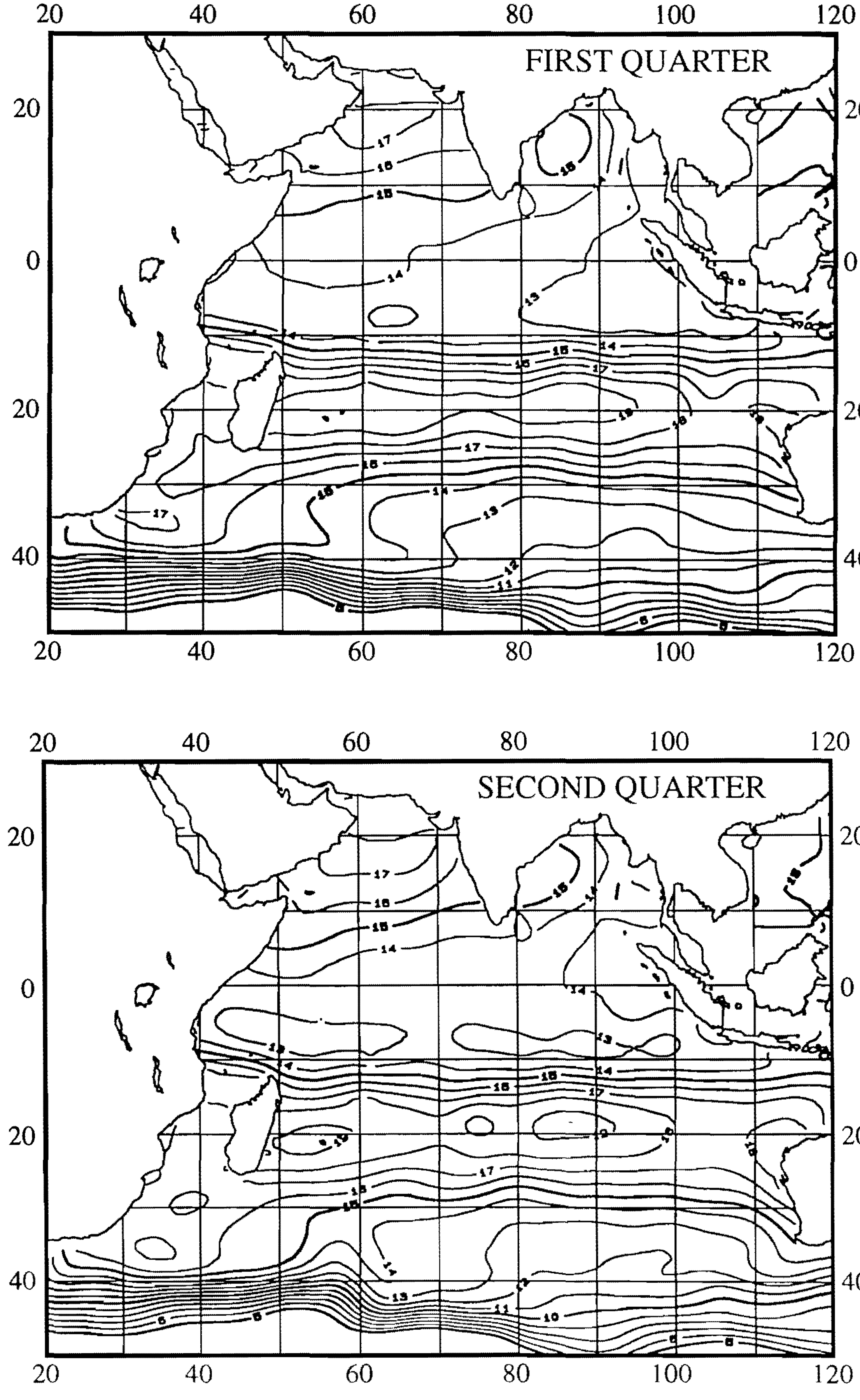


FIGURE 2b. Temperature at 200 m.

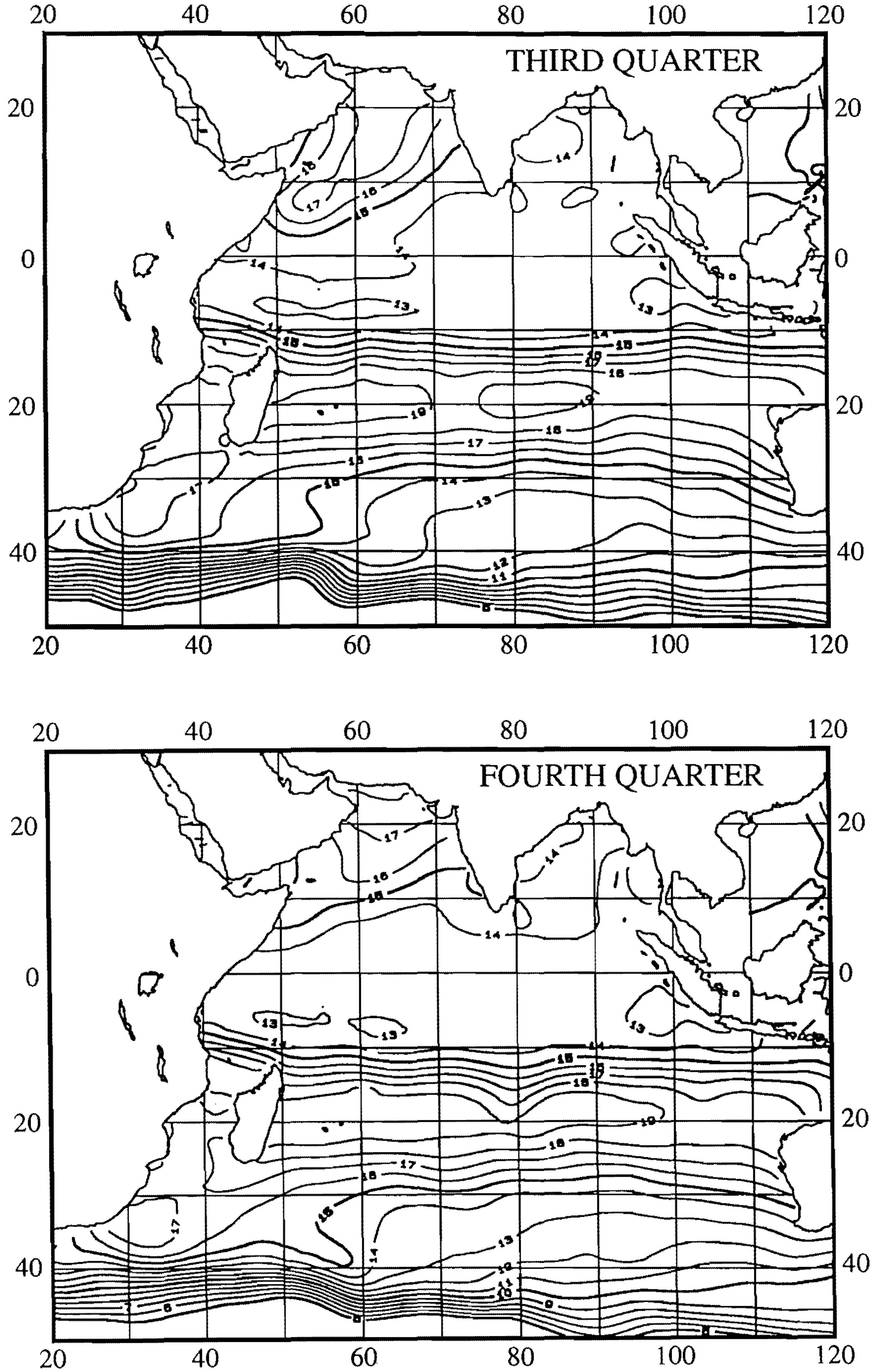


FIGURE 2b. (continued)

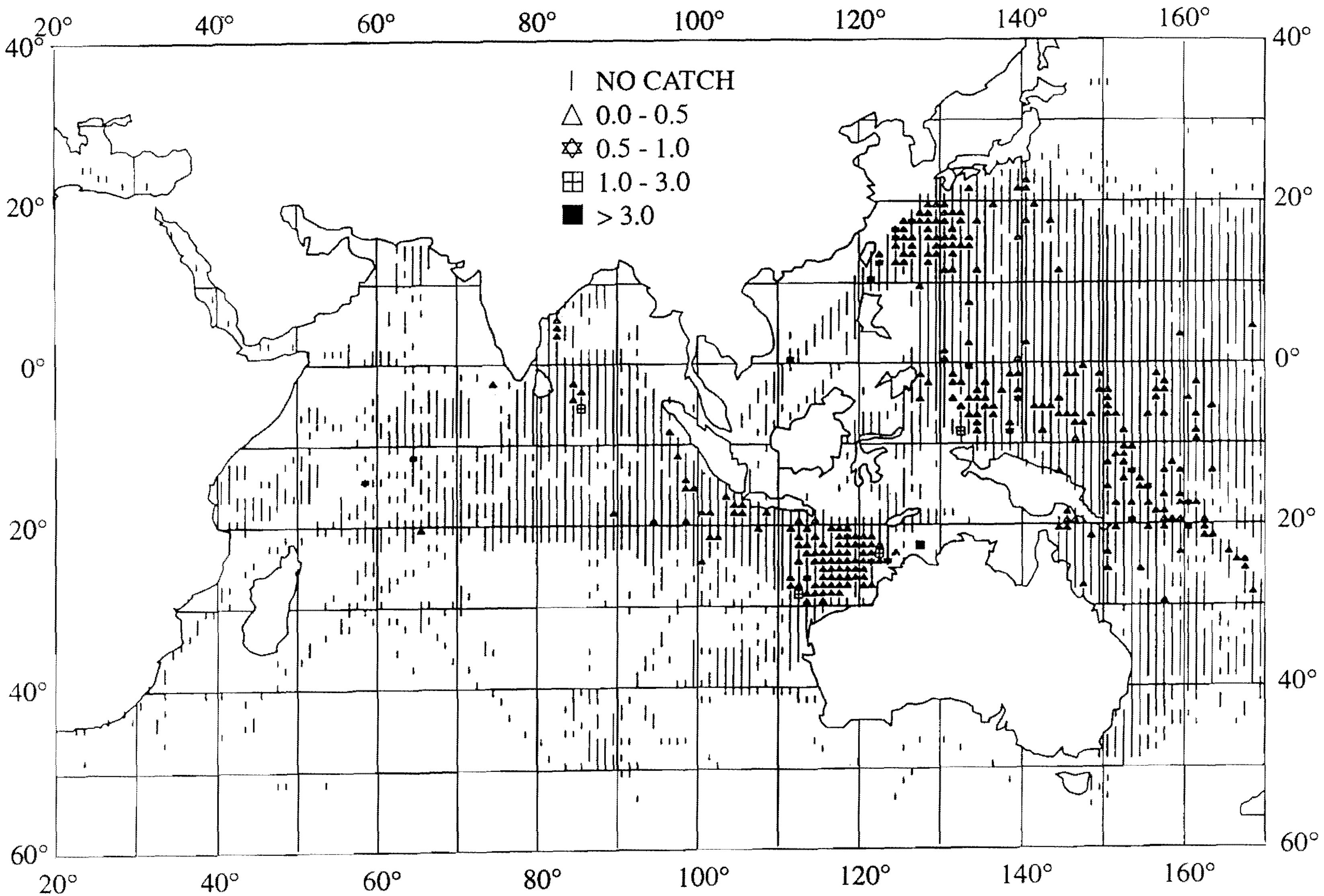


FIGURE 3. Number of bigeye larvae per 1000 m^3 of water strained (after Nishikawa *et al.* 1985).

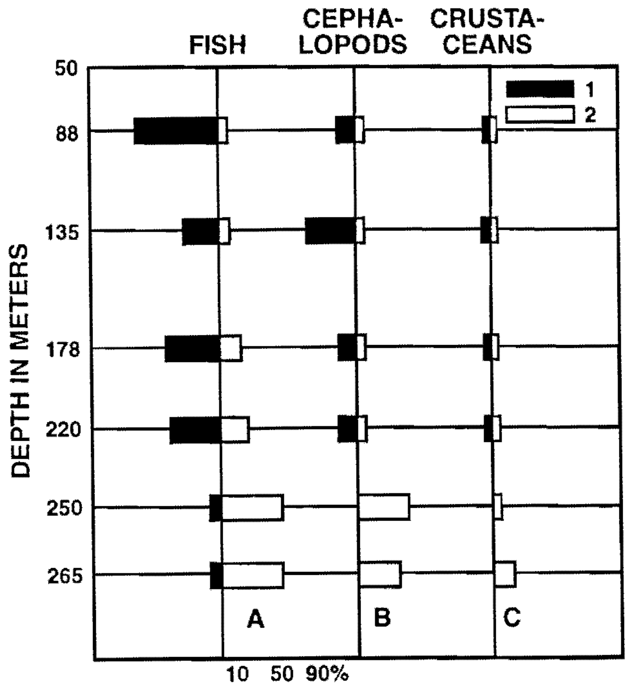


FIGURE 4. Food in stomachs of yellowfin (1) and bigeye (2) caught at various depths (after Kornilova 1980). The percentages at each depth for both species combined add up to 100 percent.

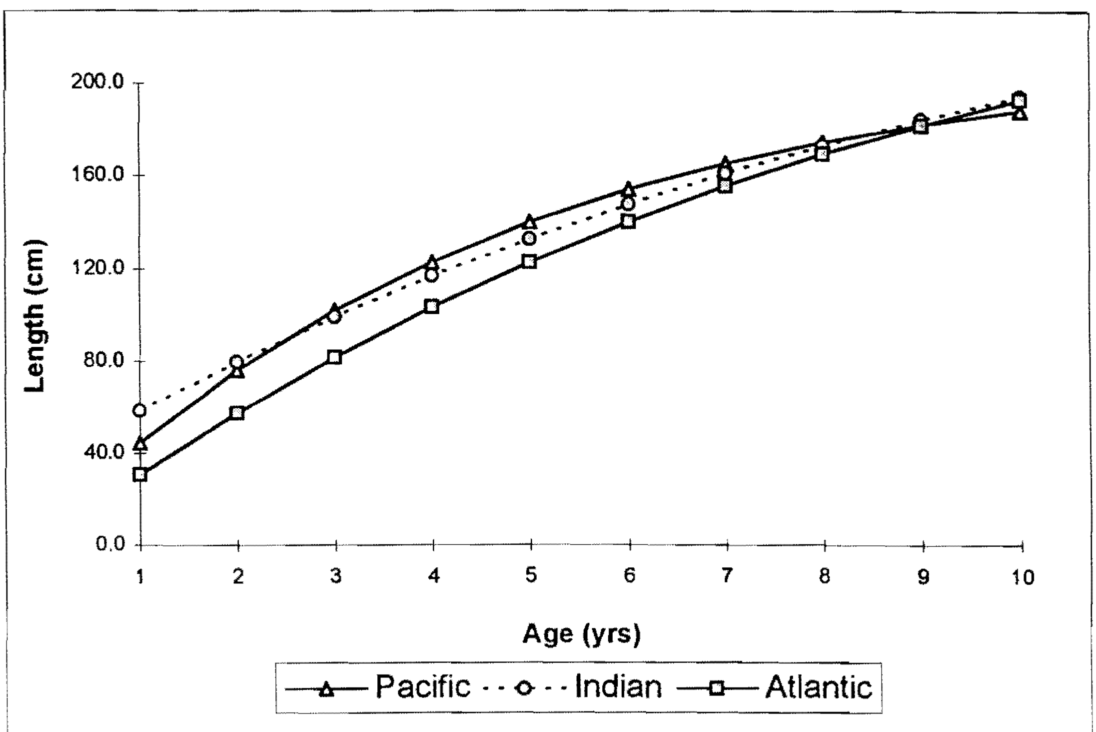


FIGURE 5. Growth curves for bigeye in different oceans.

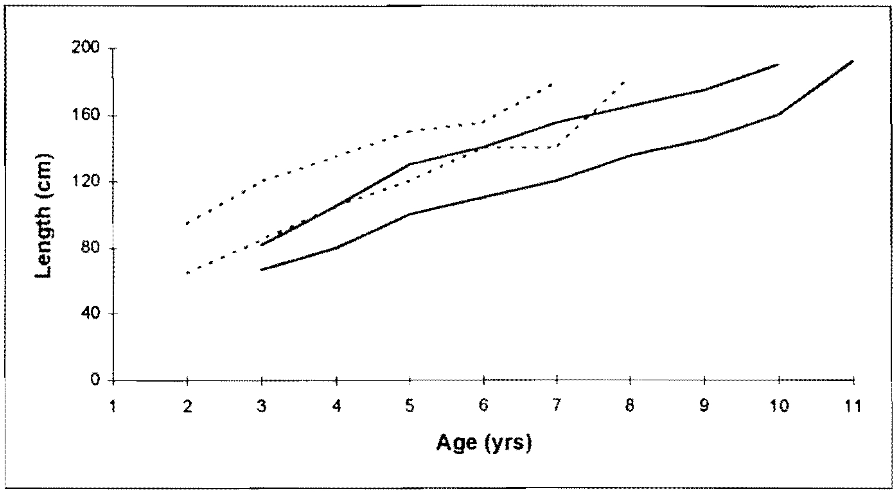
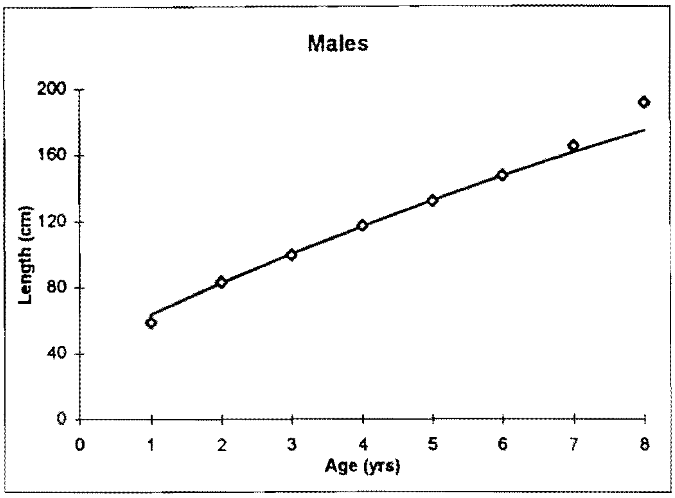


FIGURE 6. Lower and upper lengths at age for bigeye estimated by Tankevich (1982) (broken lines) and Solovieff (1970) (solid lines).



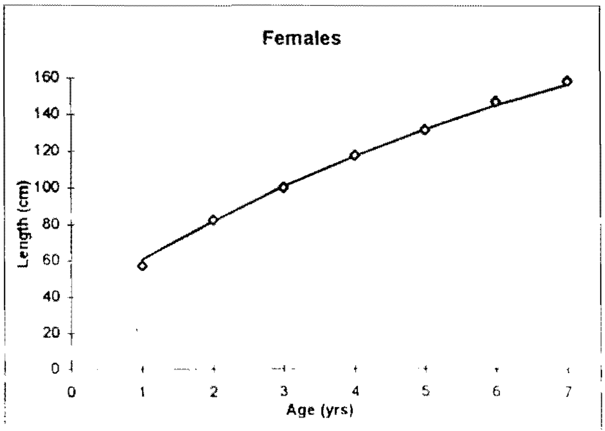


FIGURE 7. Estimated growth curves and observed mean lengths at age for bigeye. Only data for fish of ages 1 through 5 were used for estimating the growth curve for males.

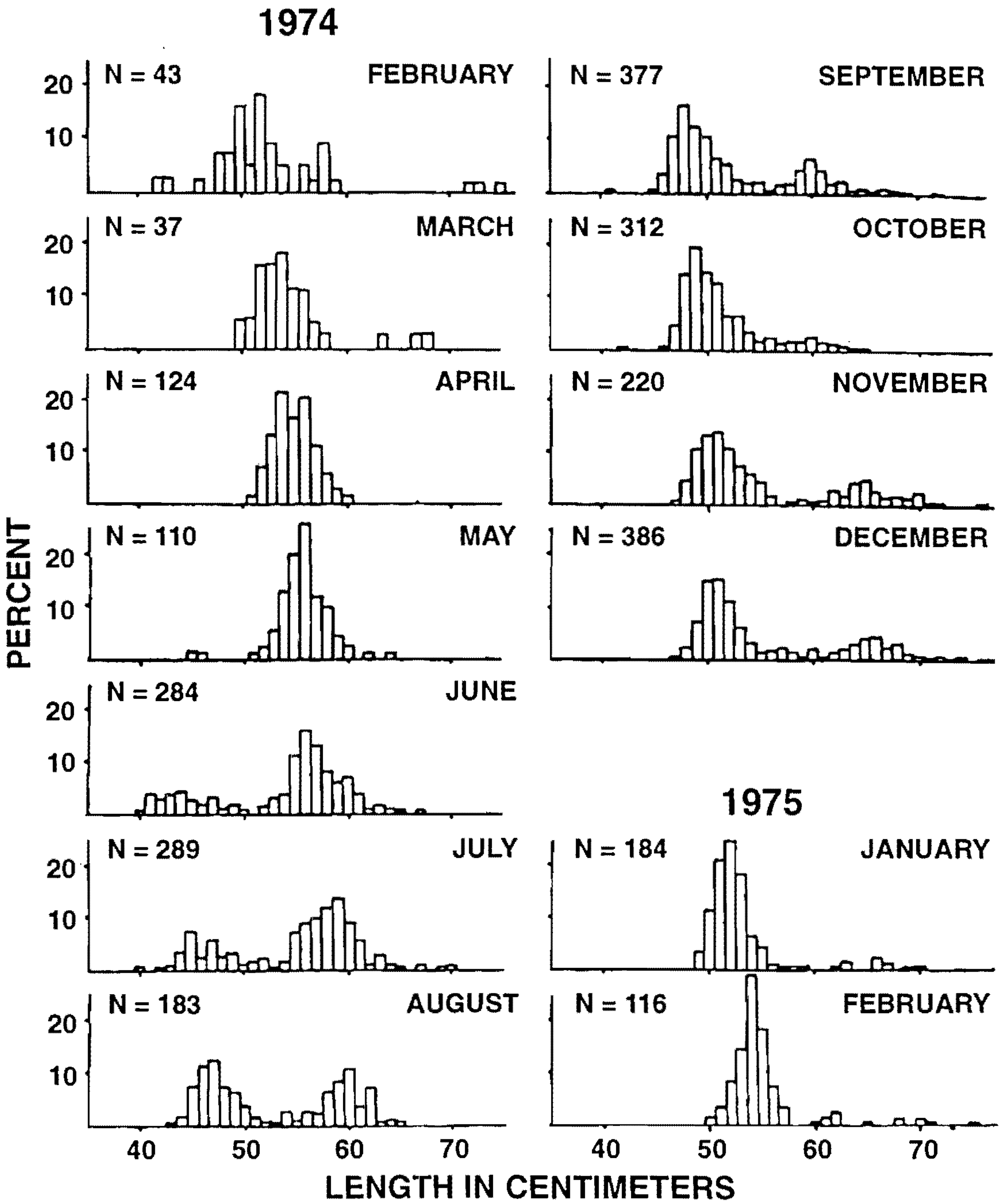


FIGURE 8. Length-frequency histograms of bigeye caught by the live-bait fishery off Madagascar (after Marcille and Stequert 1976).

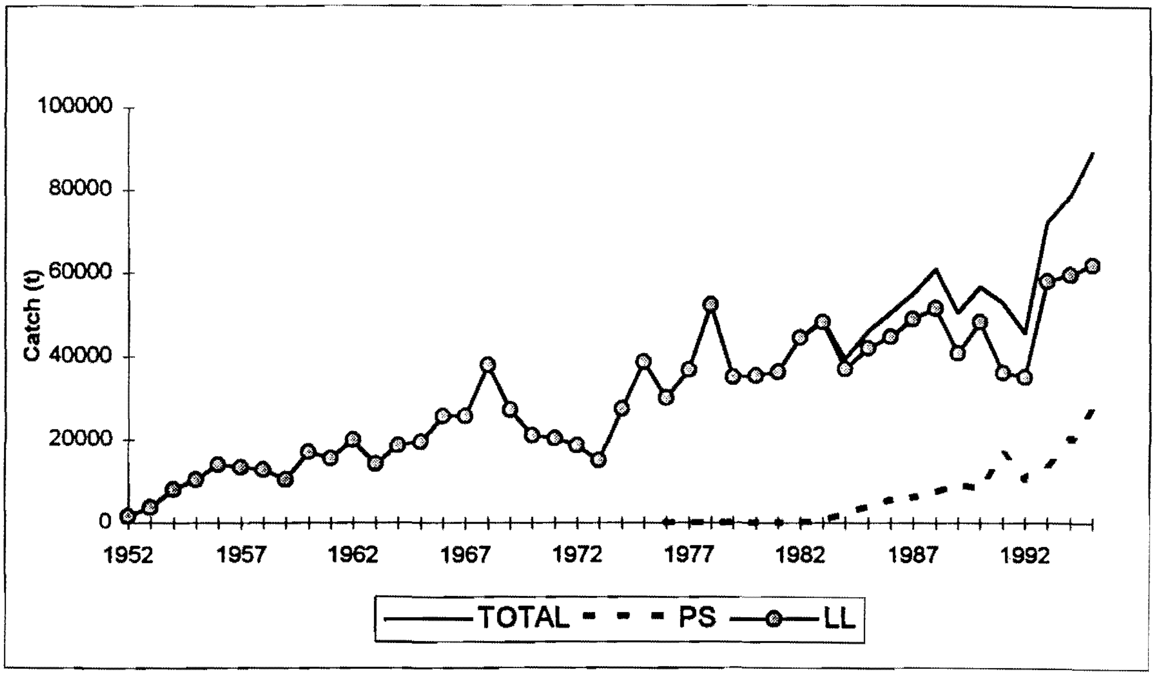


FIGURE 9. Catches of bigeye in the Indian Ocean. "Total" includes catches by all countries and gears, while the catches by gear include only major countries. The 1995 data are preliminary.

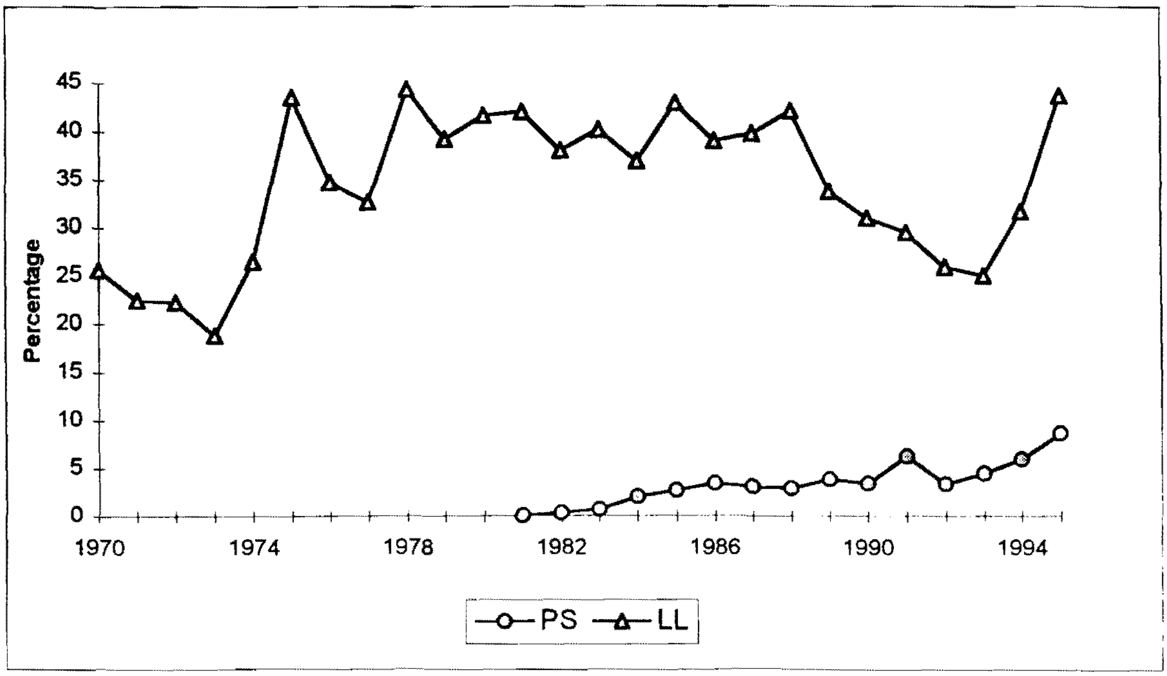


FIGURE 10. Percentages of bigeye catches relative to total tuna (yellowfin, bigeye, albacore, southern bluefin, and skipjack) catches in the Indian Ocean. The 1995 estimates are based on preliminary data.

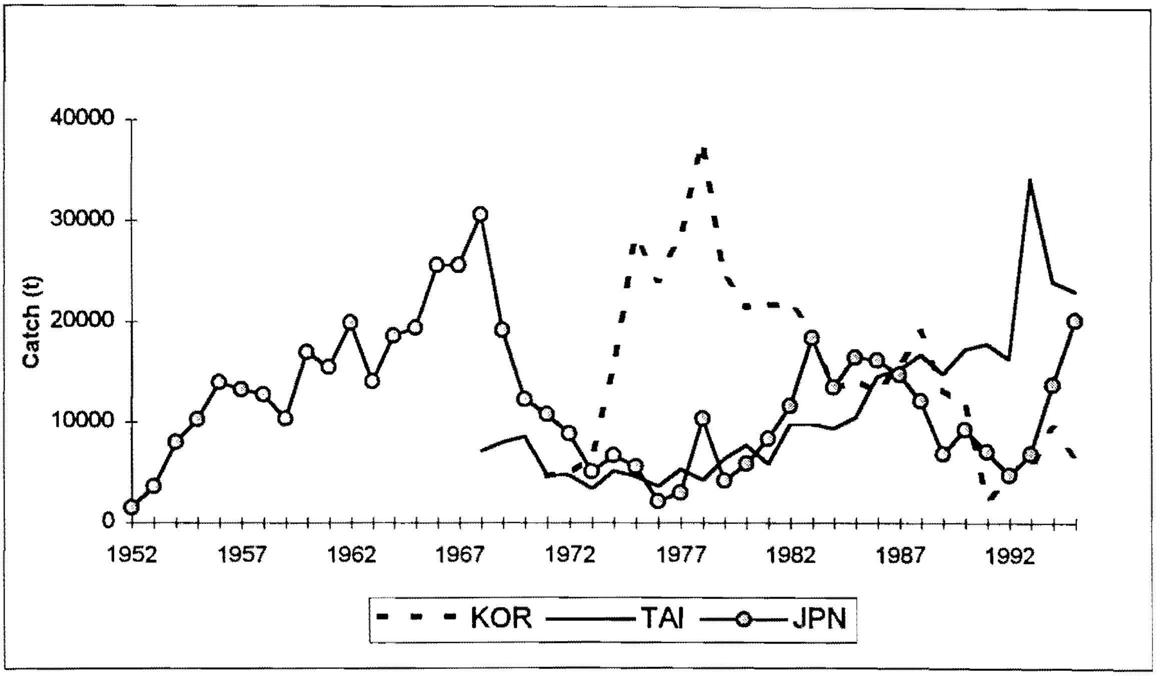


FIGURE 11. Longline catches of bigeye in the Indian Ocean. The 1995 estimates are preliminary.

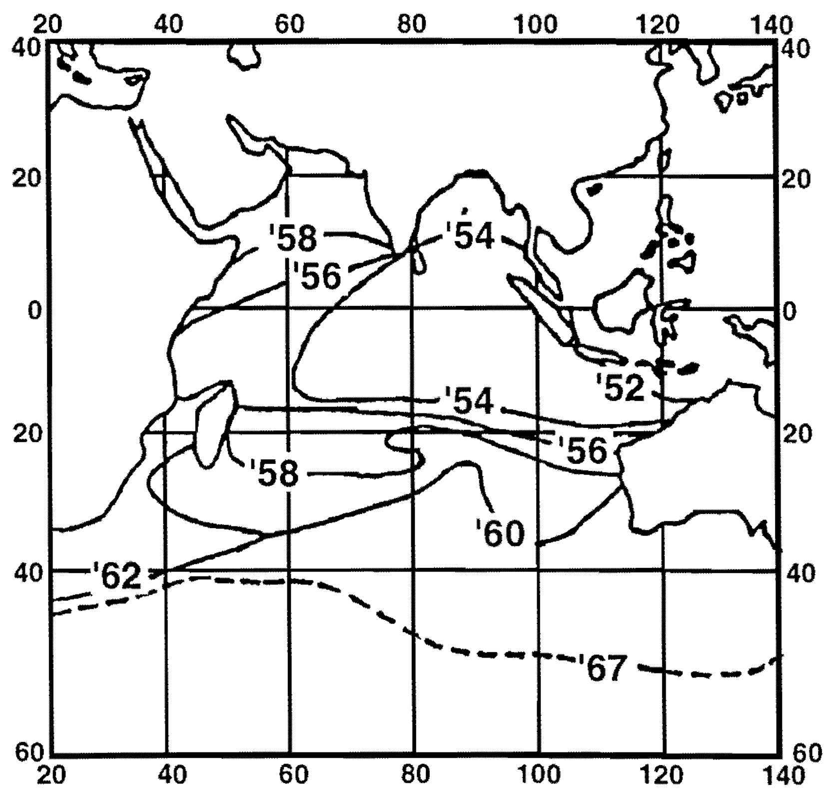


FIGURE 12. Expansion of the fishing operations by the Japanese longline fleet in the Indian Ocean from 1952 to 1967 (after National Research Institute of Far Seas Fisheries, 1991).

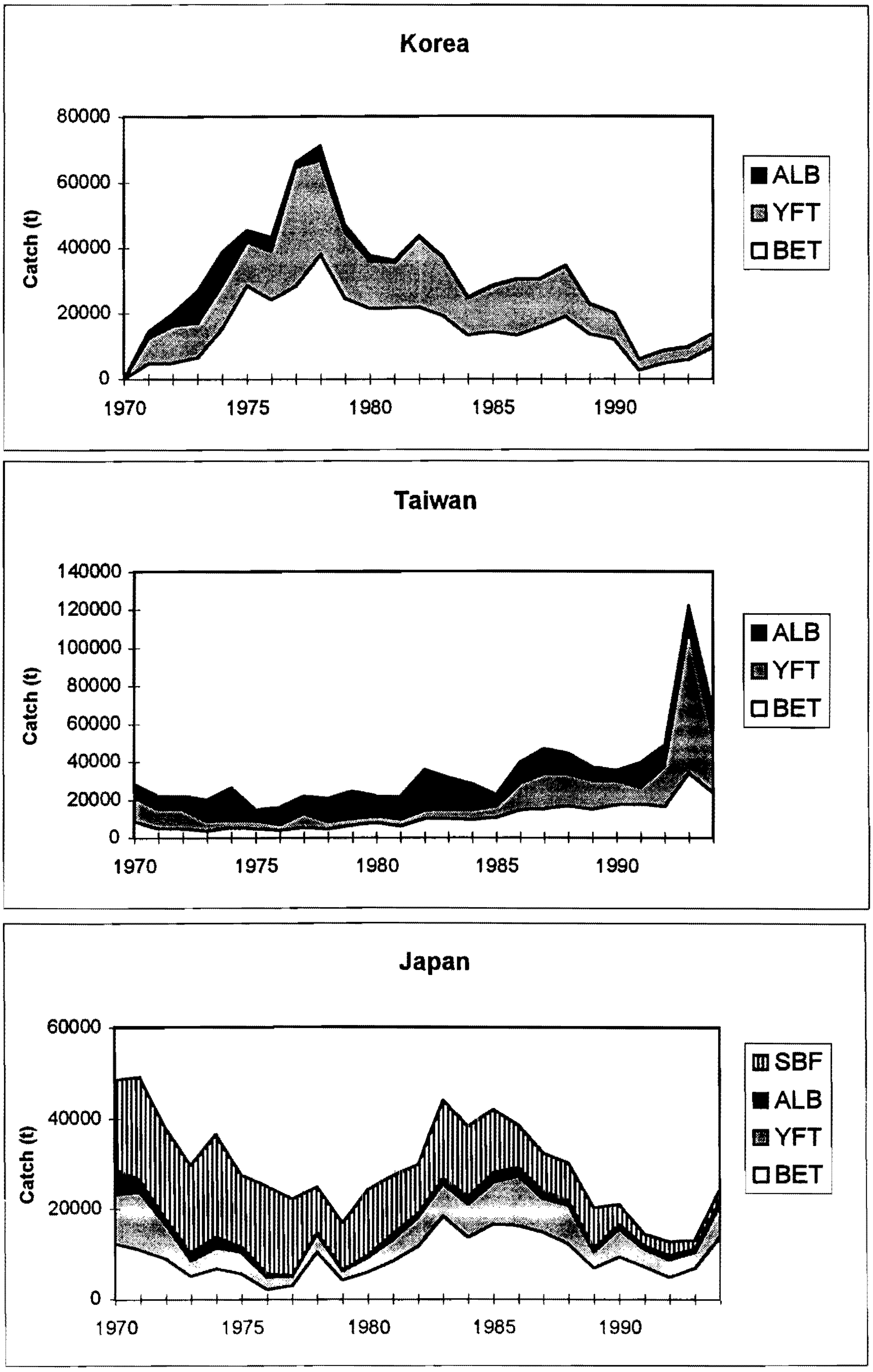


FIGURE 13. Species composition of the longline catches in the Indian Ocean.

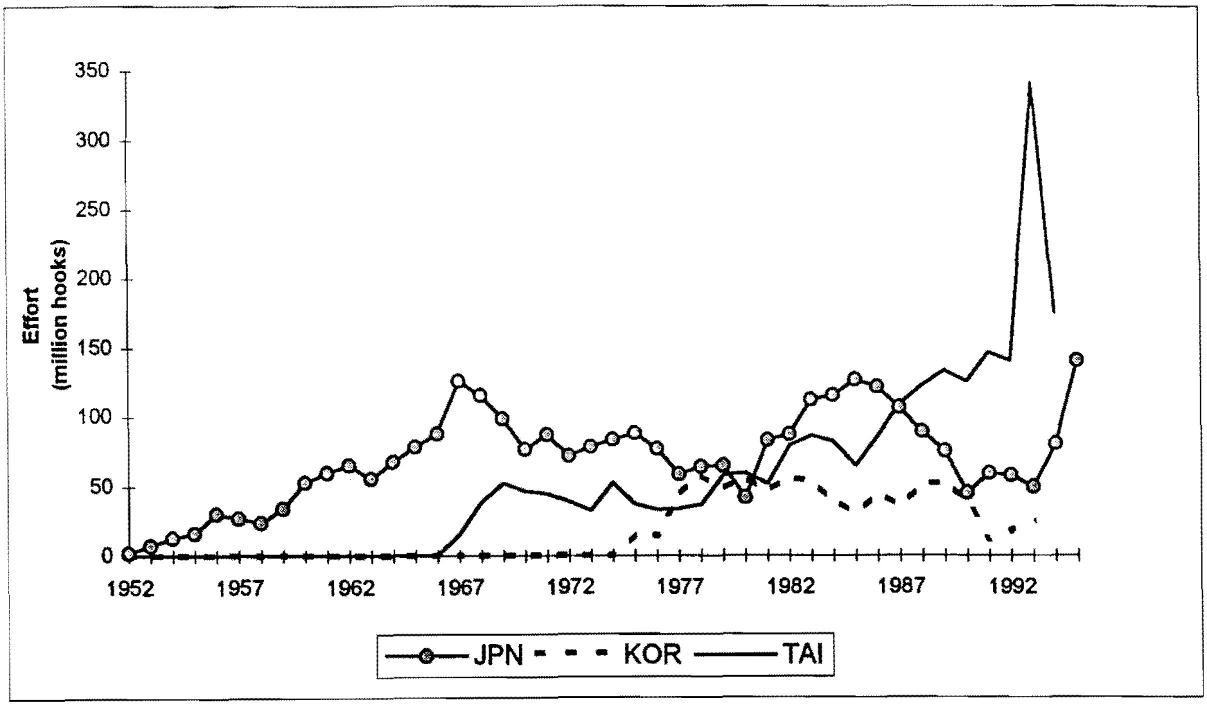


FIGURE 14. Nominal longline fishing effort in the Indian Ocean.

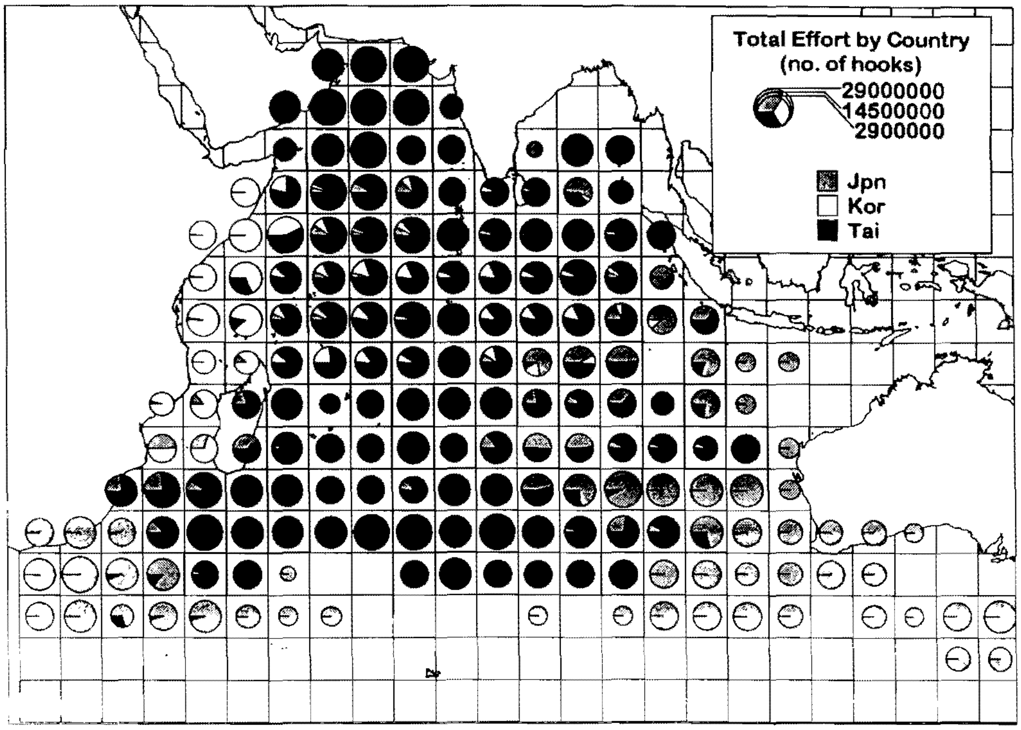


FIGURE 15. Distribution of longlining effort in the Indian Ocean in 1993.

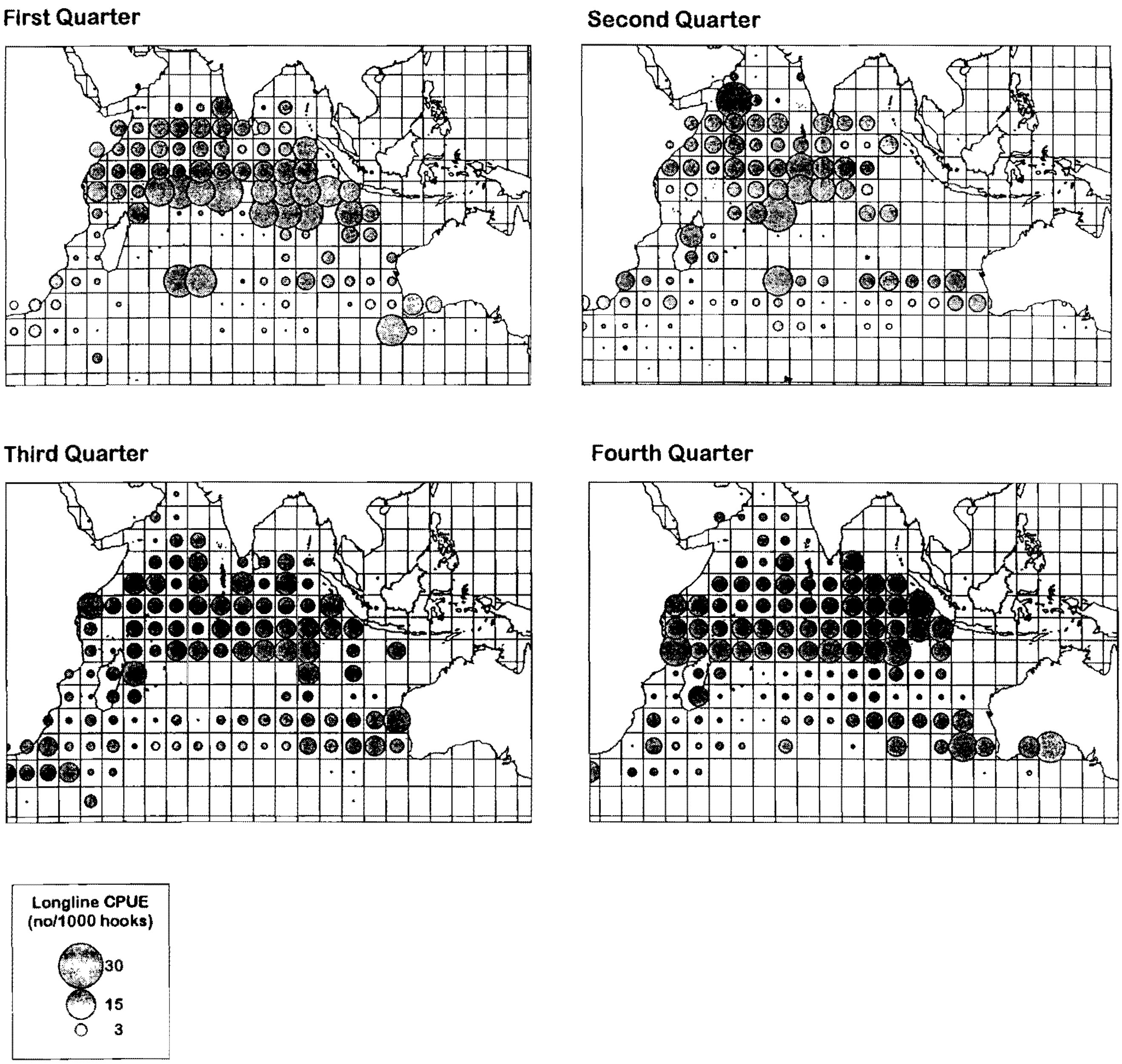


FIGURE 16. Longline CPUE of bigeye (fish per thousand hooks) in 1993.

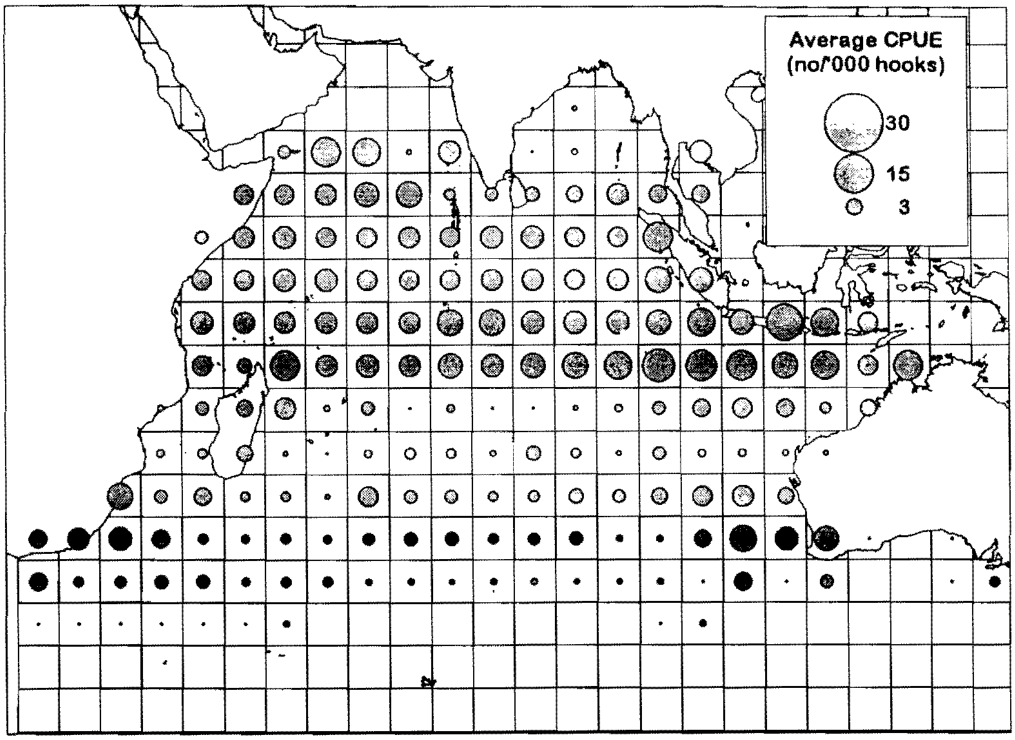


FIGURE 17. Average longline CPUE of bigeye (fish per thousand hooks) for 1988-1992.

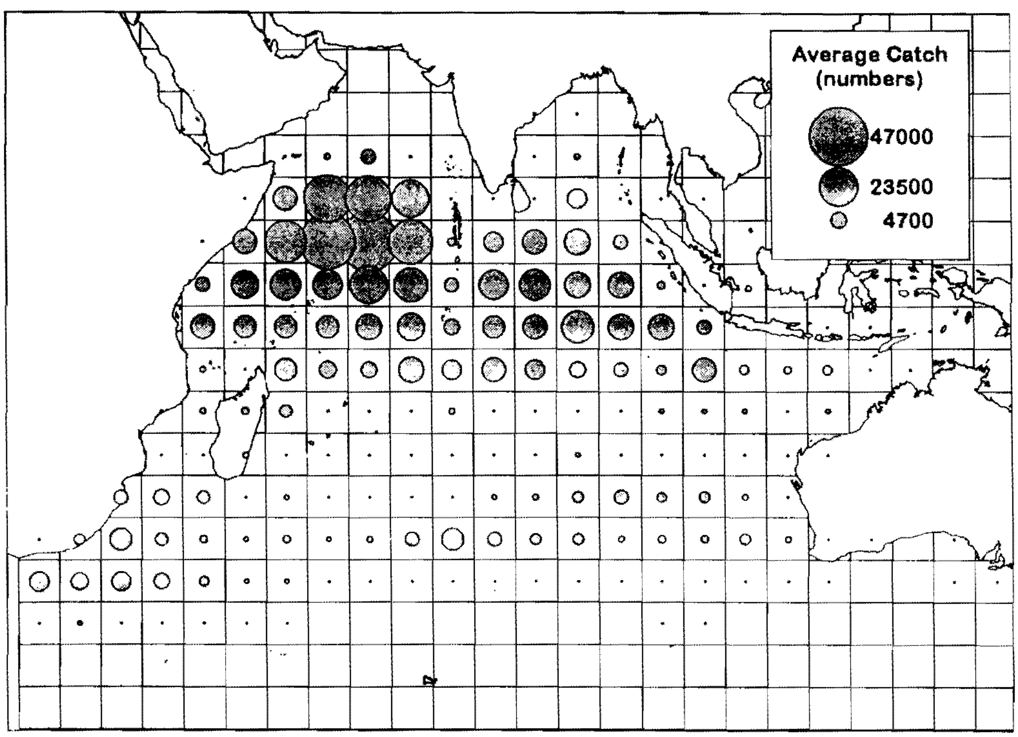


FIGURE 18. Average annual longline catch of bigeye (number of fish) for 1988-1992.

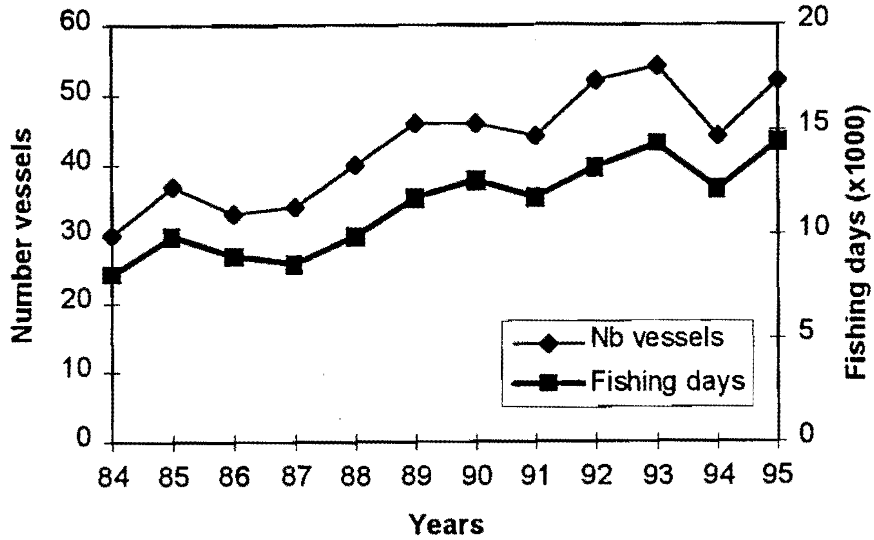


FIGURE 19. Numbers of purse seiners in operation and fishing effort (days of fishing) in the Indian Ocean.

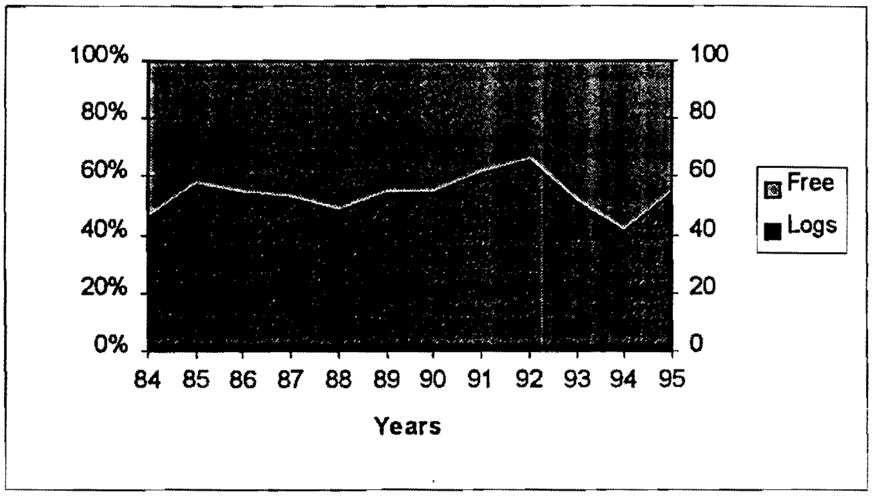


FIGURE 20. Percentages of the purse-seine catches of tunas in the Indian Ocean taken in sets on free-swimming schools and in schools associated with logs.

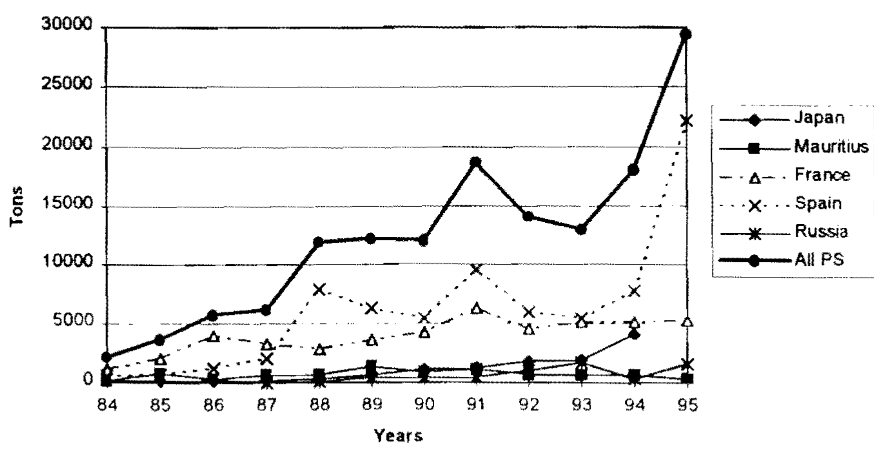


FIGURE 21. Catches of bigeye, by nation, in the Indian Ocean.

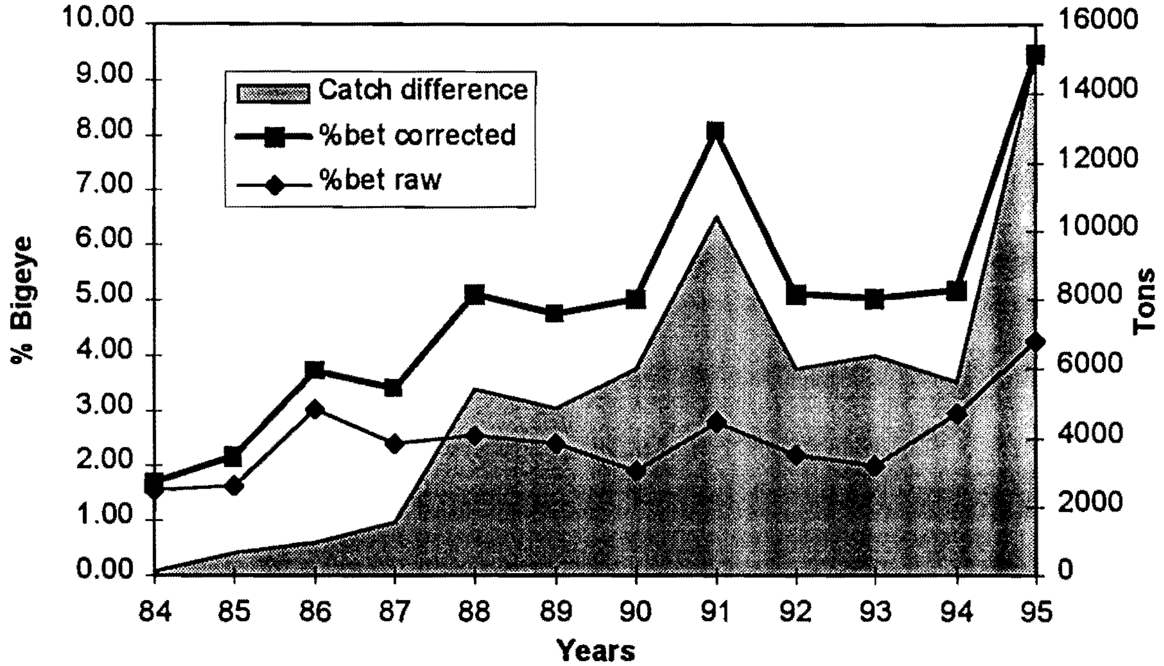


FIGURE 22. Unadjusted and adjusted percentages of bigeye in the catches of French and Spanish purse seiners, and differences, in tons of fish, between the two.

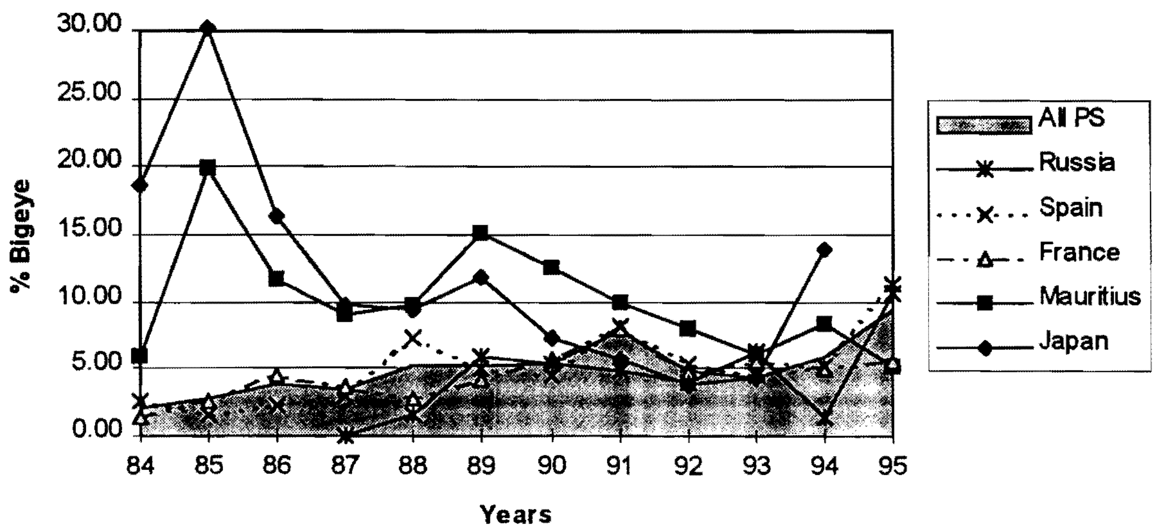


FIGURE 23. Percentages of bigeye in the catches of the various nations.

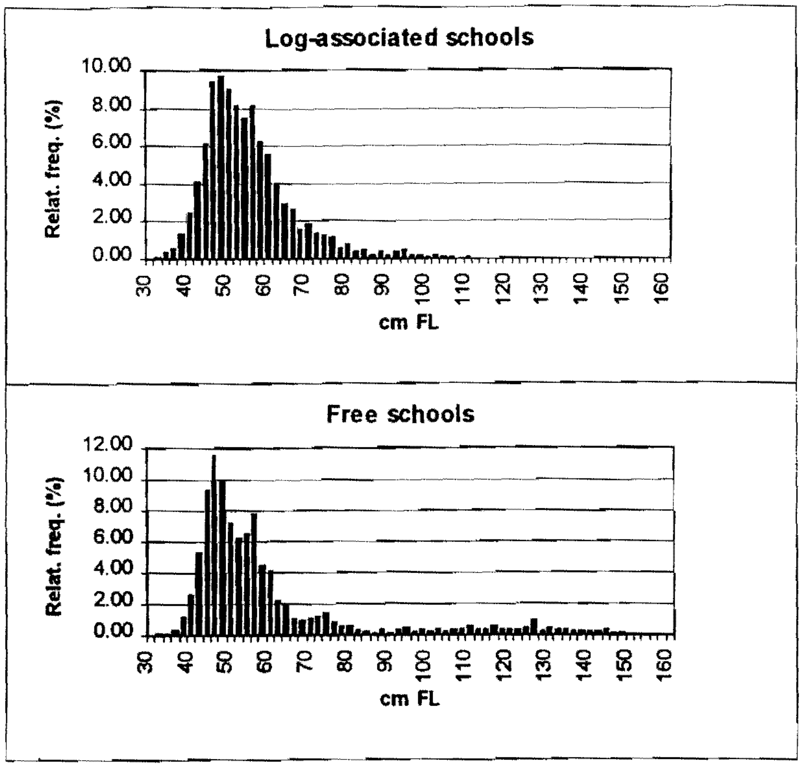


FIGURE 24. Size distributions (in numbers) of bigeye in log-associated and free-swimming schools.

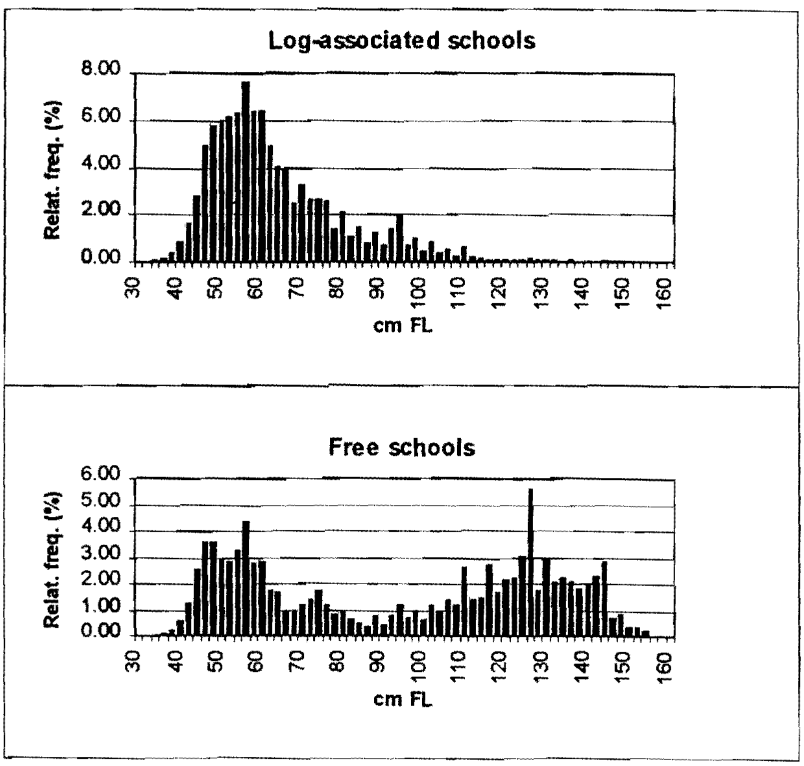


FIGURE 25. Size distributions (by weight) of bigeye in log-associated and free-swimming schools.

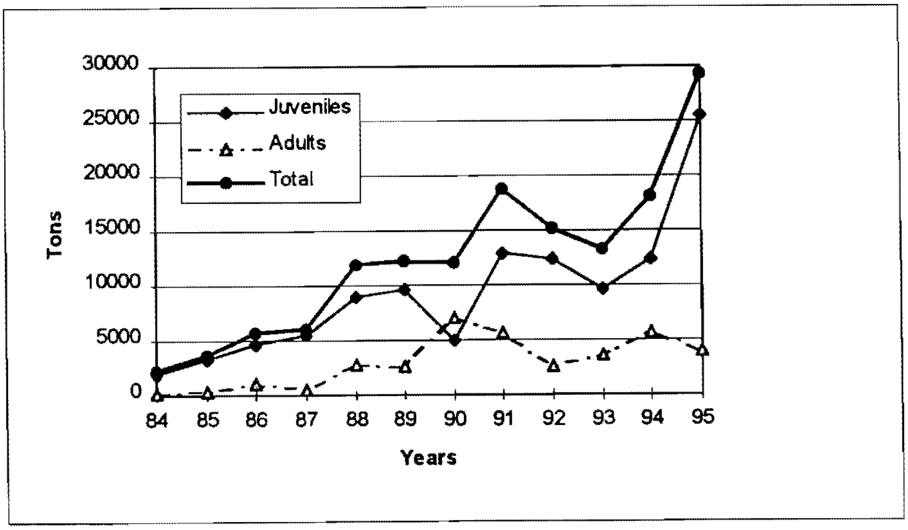


FIGURE 26. Purse-seine catches of bigeye by size group.

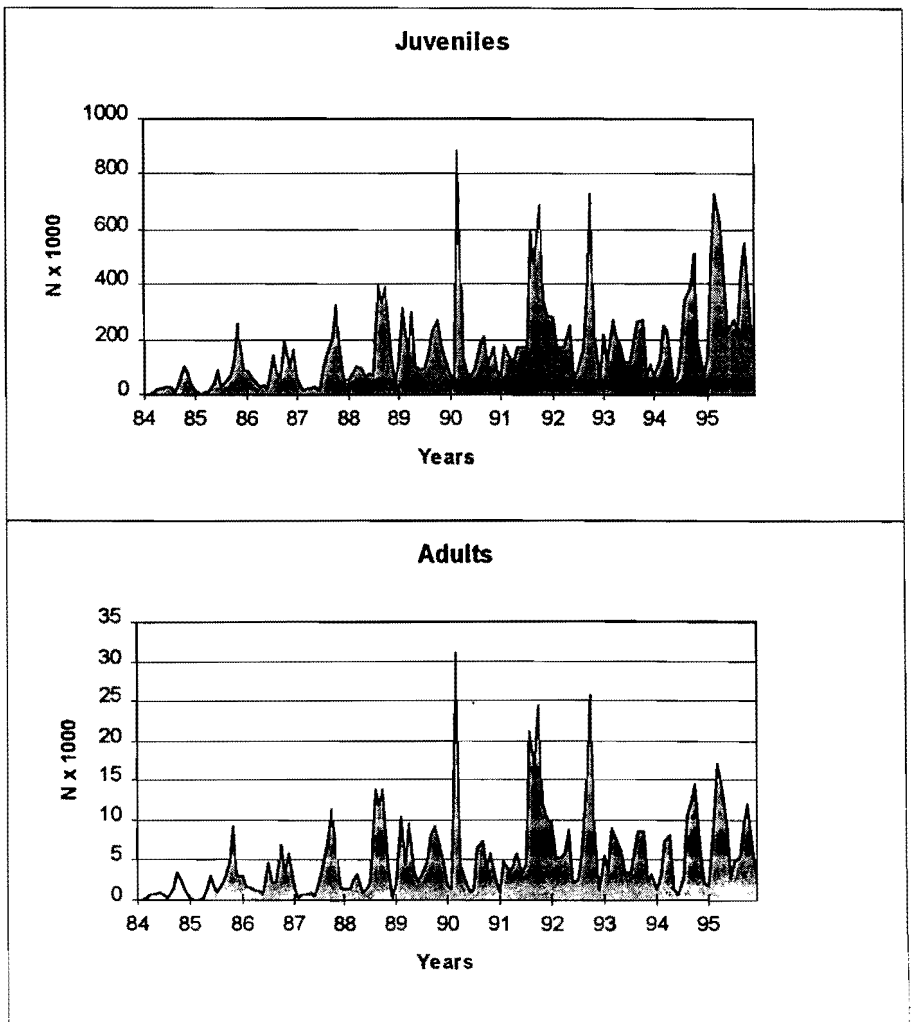


FIGURE 27. Monthly catches of juvenile and adult bigeye, in numbers of fish, by the industrial purse-seine fishery.

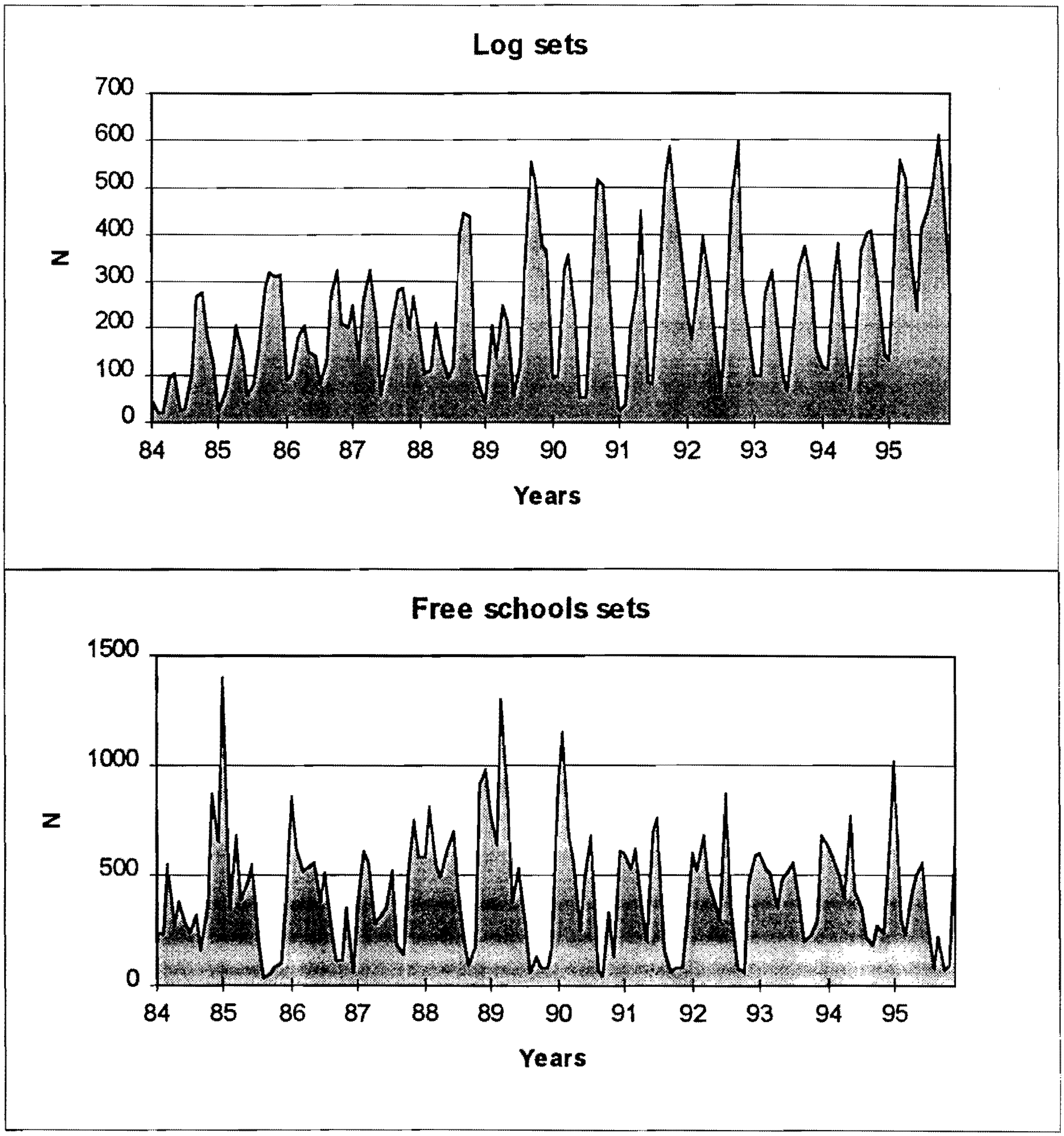


FIGURE 28. Monthly numbers of sets on log-associated and free-swimming schools of tuna by French and Spanish purse seiners.

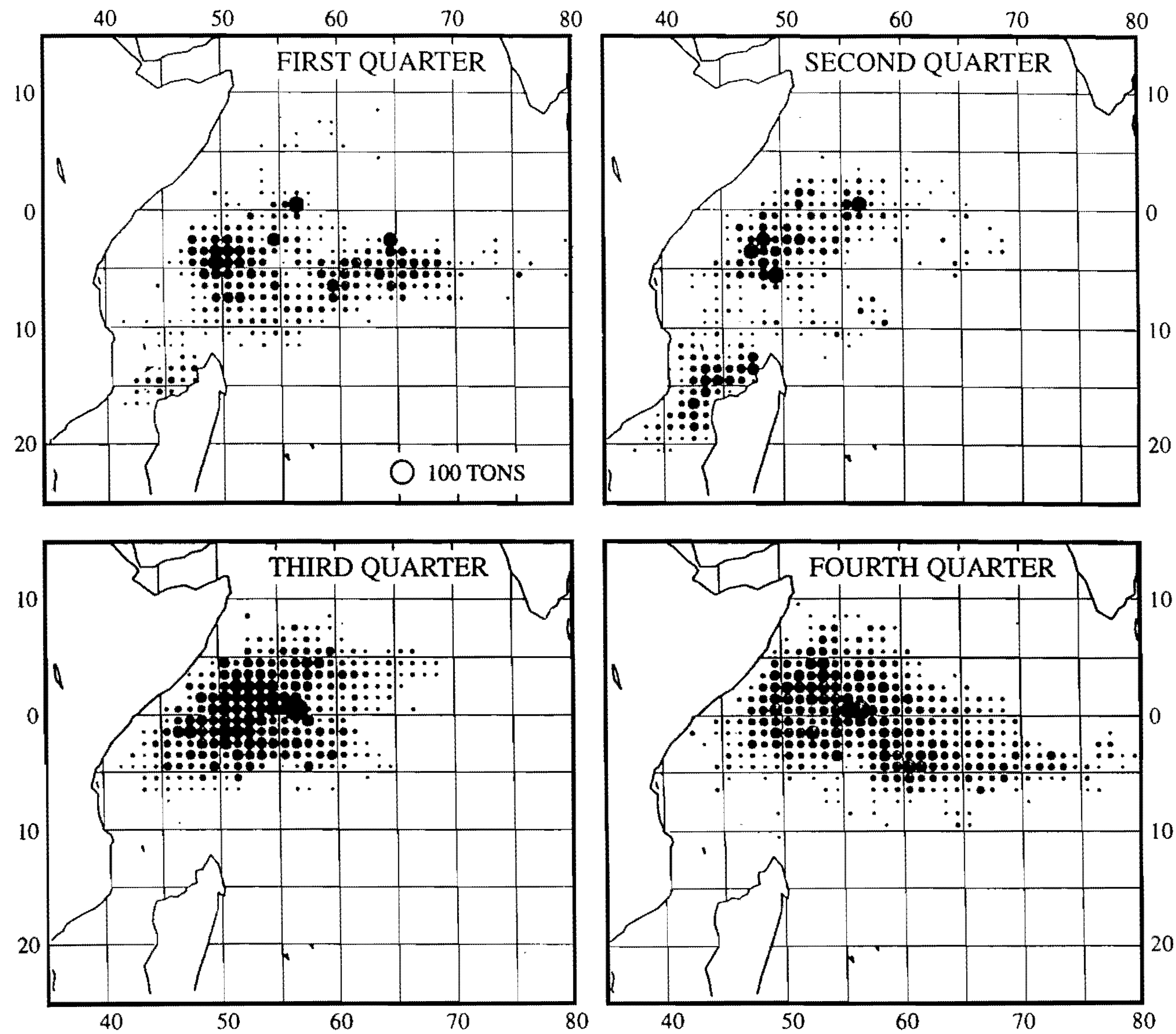


FIGURE 29. Geographic distribution of purse-seine catches of juvenile (solid) and adult (concentric circles) bigeye during 1984-1995.

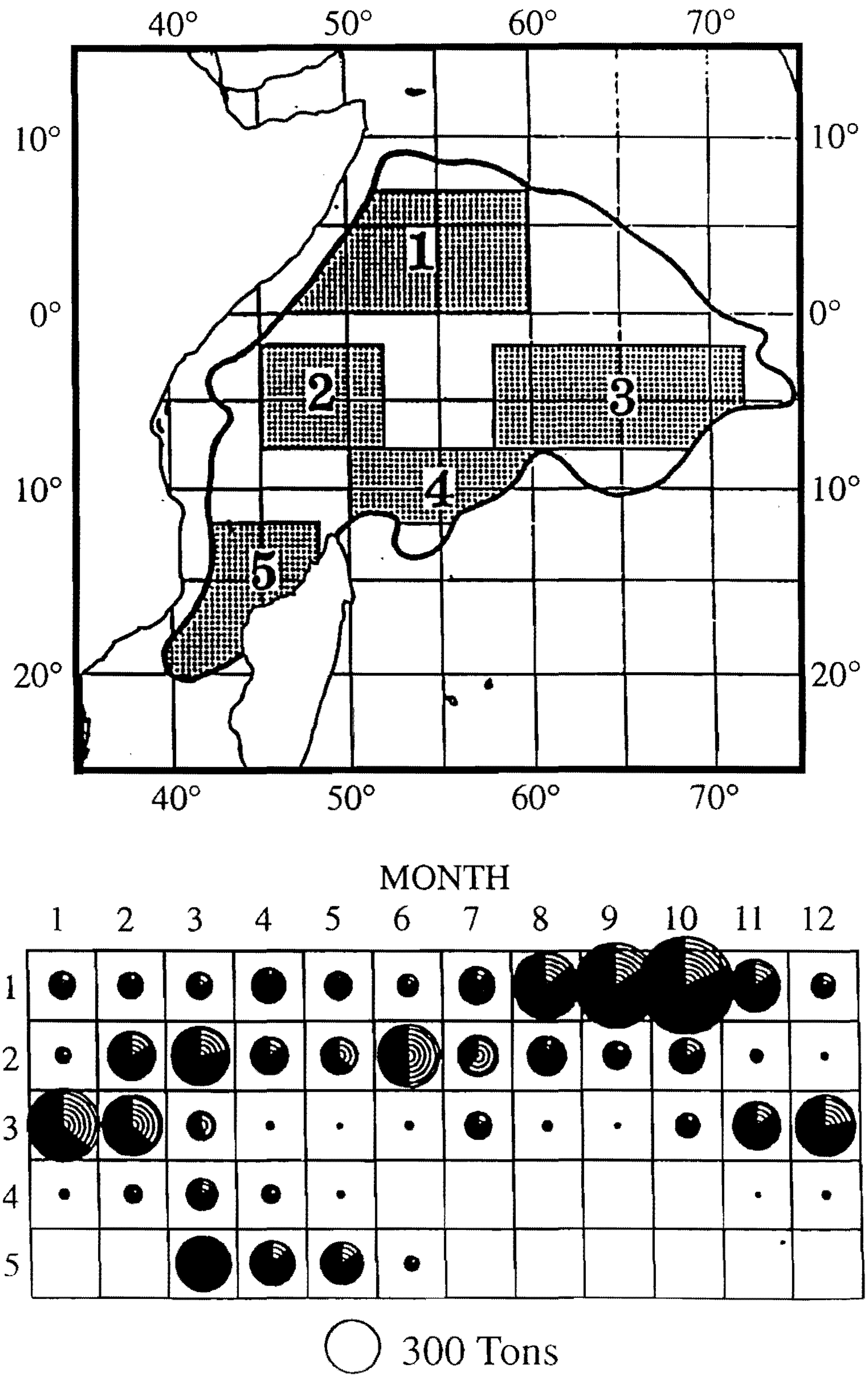


FIGURE 30. Monthly catches of juvenile (solid) and adult (concentric circles) bigeye in five sub-areas during 1984-1995.

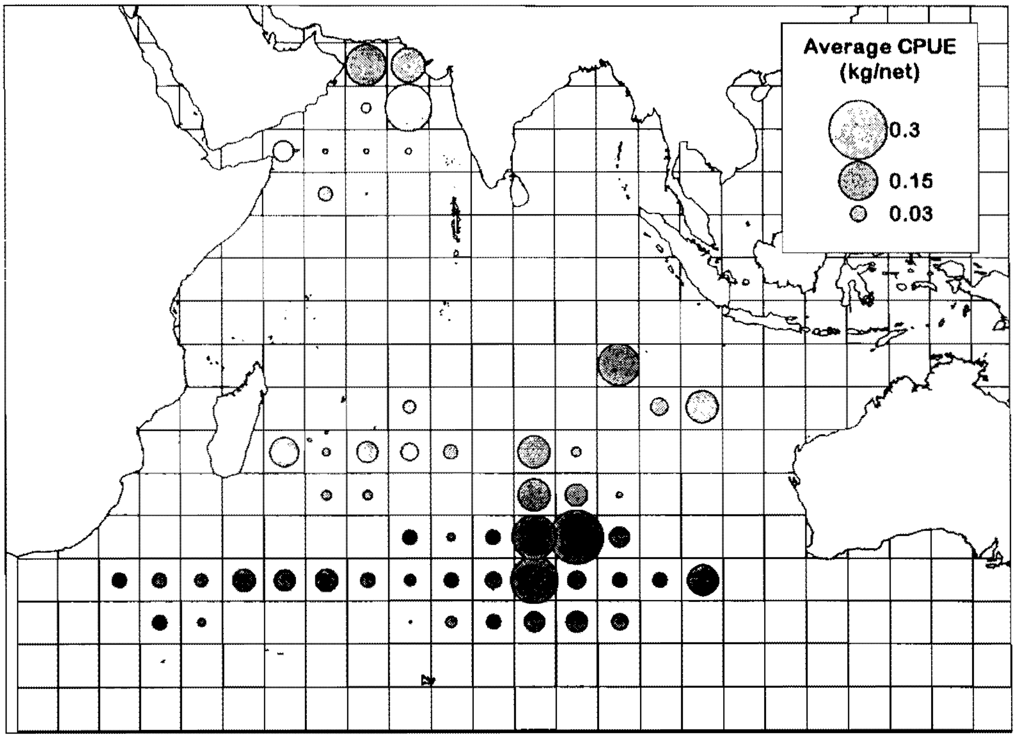


FIGURE 31. Average CPUEs (kg/net) for the Taiwanese drift gillnet fishery for the 1987-1991 period.

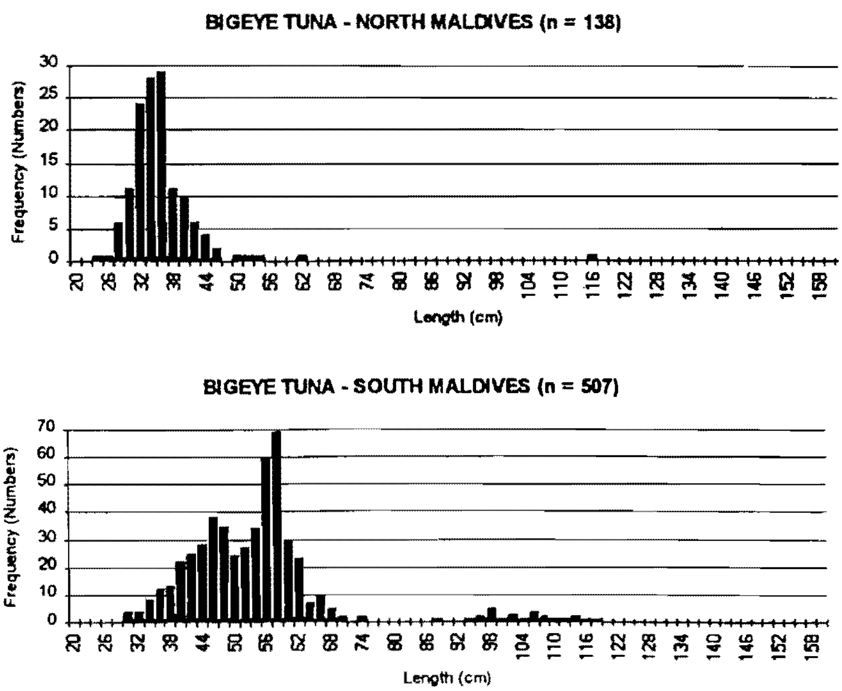


FIGURE 32. Length frequency distributions of bigeye sampled from the catches of artisanal fisheries operating north and south of the Maldives.

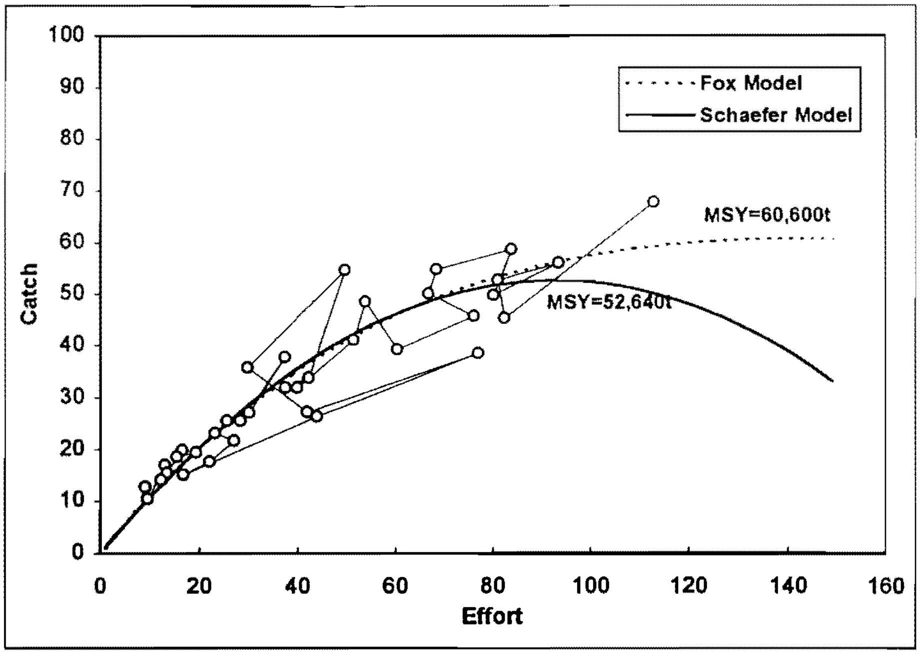


FIGURE 33. Results from two production models fitted to catch and effort data for bigeye tuna (from Anon. 1995).

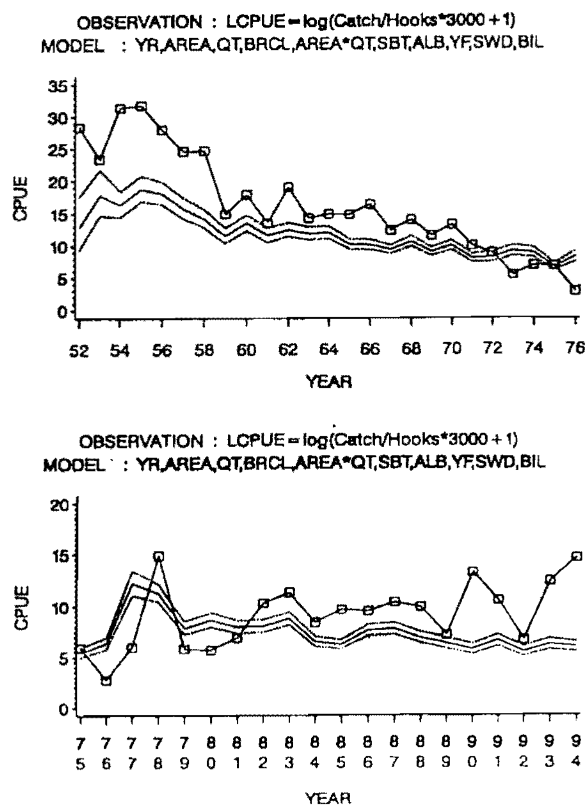


FIGURE 34. Standardized and nominal (square symbols) CPUEs of bigeye for the Japanese longline fishery in the Indian Ocean (from Okamoto and Miyabe 1996). The broken lines indicate the 95% confidence intervals. The data in the upper panel were standardized by area and season, while those in the lower panel were standardized by area, season, and hook depth.

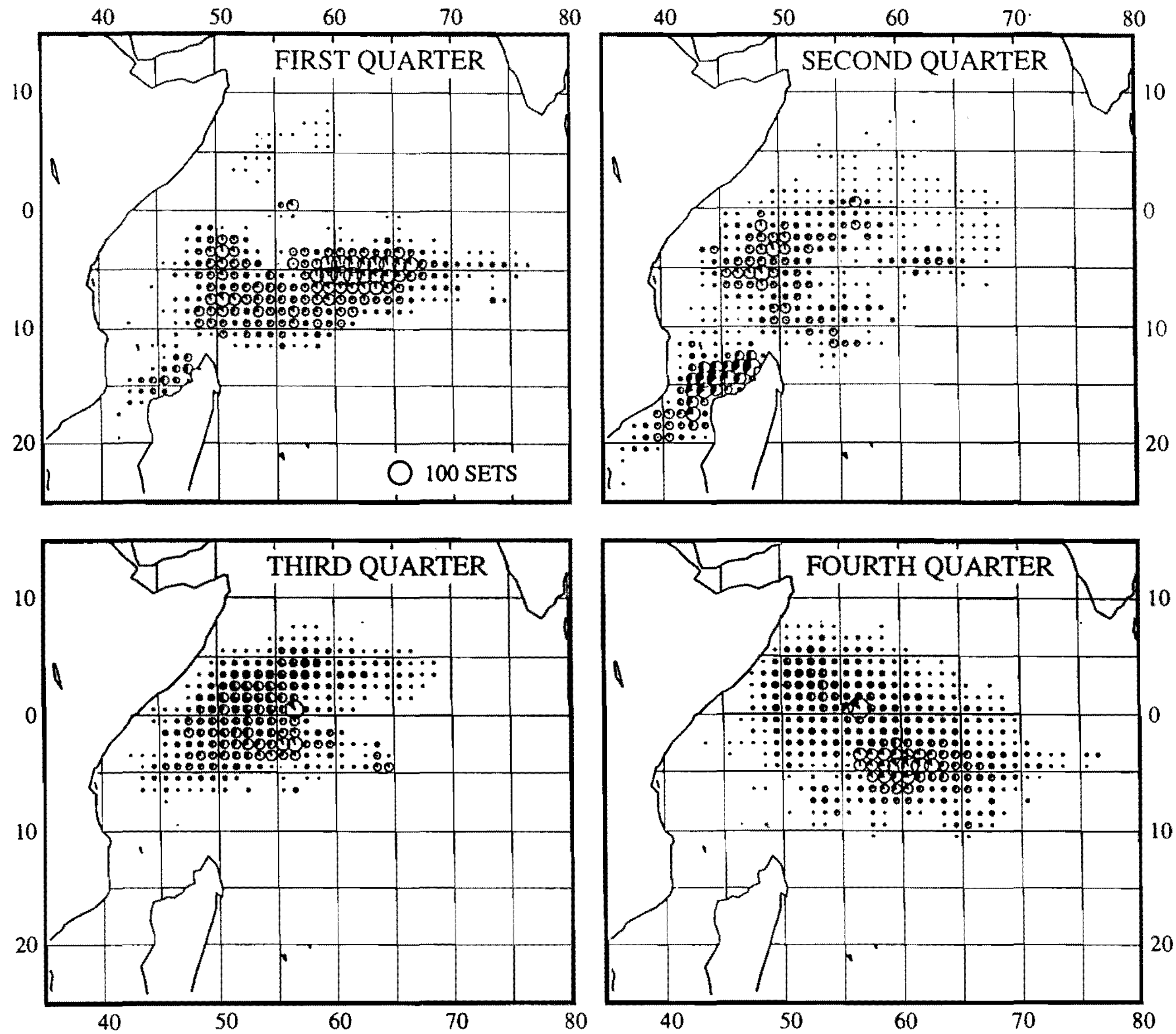


FIGURE 35. Quarterly distribution of sets by type (black: sets on log-associated schools; white: sets on free-swimming schools) during 1984-1995.

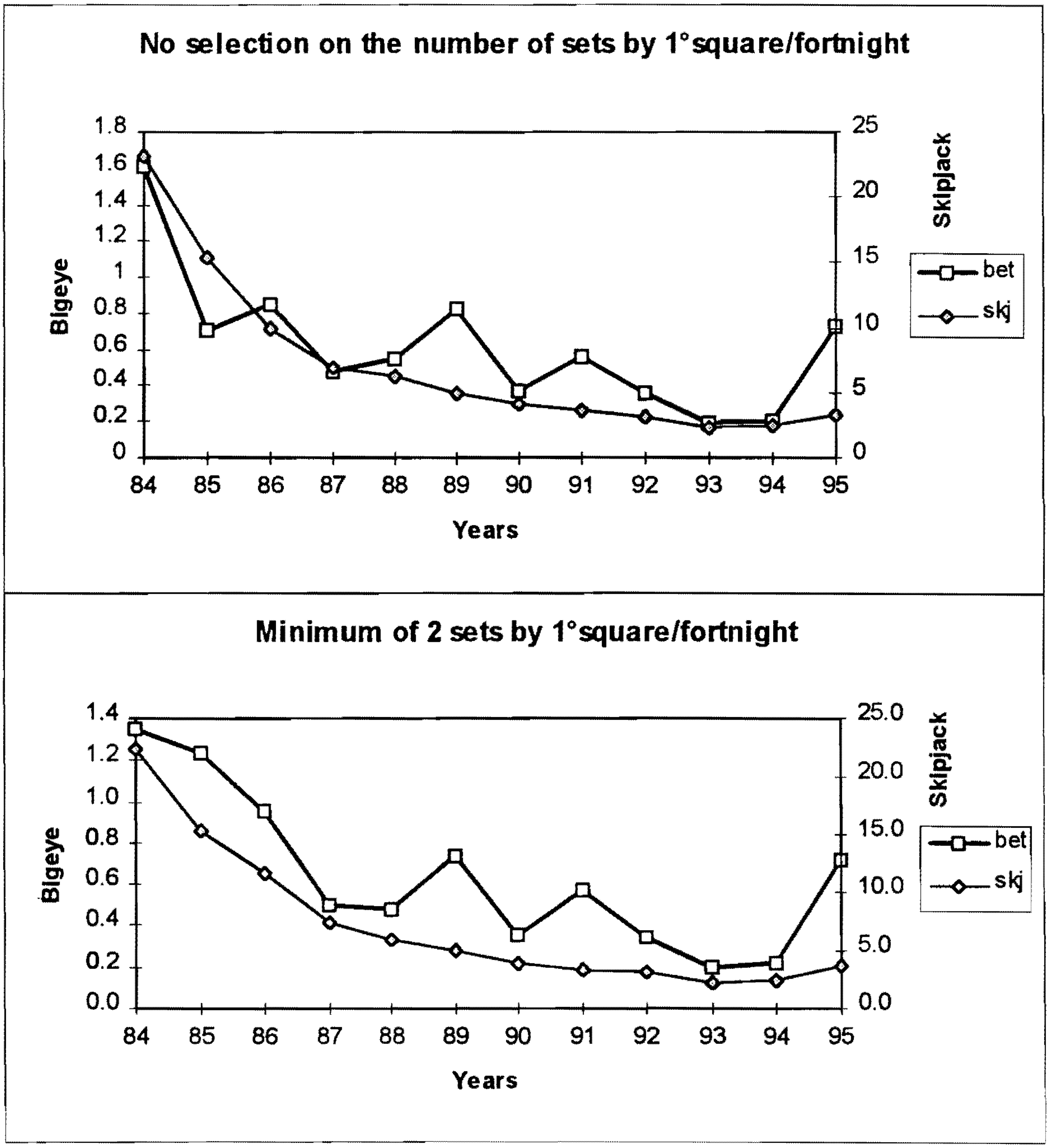
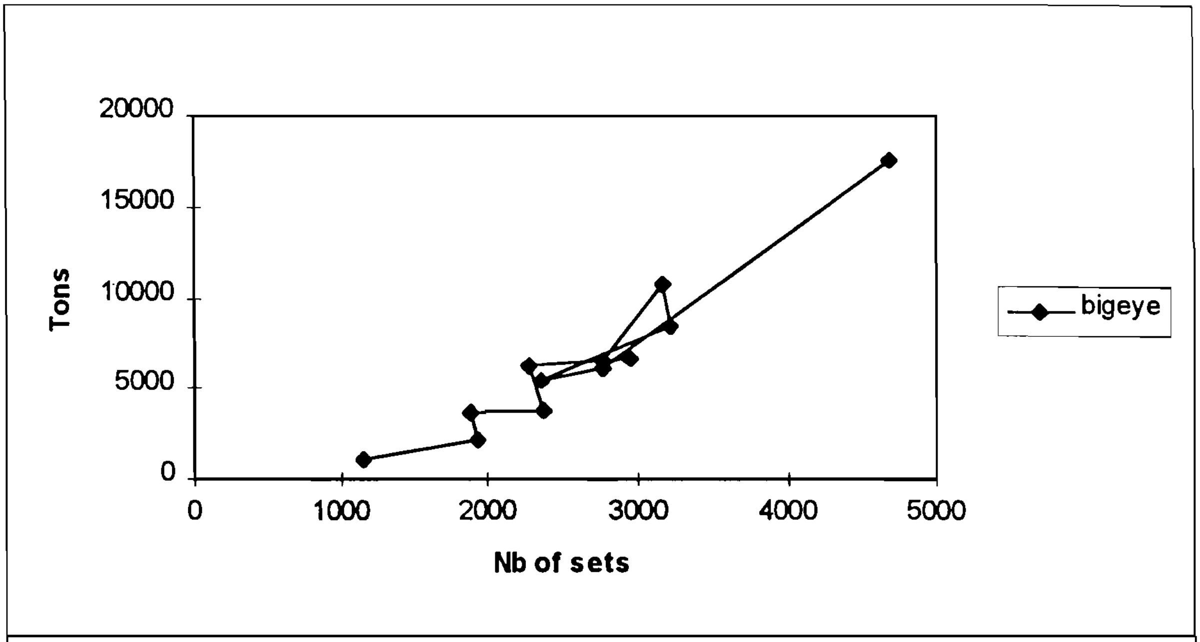


FIGURE 36. CPUE indices (tons/successful set on logs) in the purse-seine fishery of the western Indian Ocean.



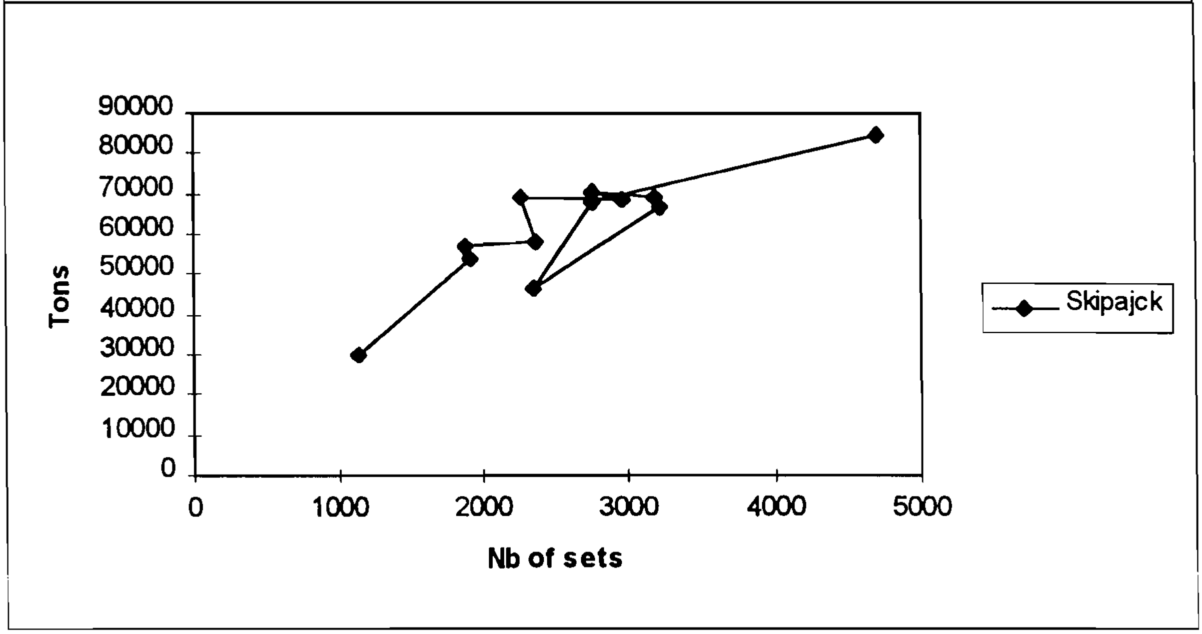


FIGURE 37. Relationship between catch and number of sets for the purse-seine fisheries of France and Spain combined.

TABLE 1. Parameter estimates obtained from the von Bertalanffy growth equation for bigeye. Ages indicate which age observations were included in the iteration procedure. The sum of squared residuals (SS) is weighted by the number of observations.

	Males				Females		
Age (years)	1 to 5	1 to 6	1 to 7	1 to 8	1 to 5	1 to 6	1 to 7
K	0.06	0.06	0.03	0.00	0.12	0.09	0.10
t_0	-2.03	-2.07	-2.48	-2.93	-1.33	-1.58	-1.53
L_∞	392	410	747	6097	247	290	282
SS (weighted)	100.04	100.44	138.19	355.61	59.74	79.64	81.00

TABLE 2. Percentages, in numbers of fish, of yellowfin, bigeye, and skipjack of various sizes caught in log-associated and free-swimming schools.

Size range	Log-associated	Free-swimming
	Yellowfin	
<80 cm	87	17
>80 cm	13	83
	Bigeye	
<80 cm	96	89
>80 cm	4	11
	Skipjack	
30-50 cm	59	48
52-60 cm	28	47
>60 cm	13	5

TABLE 3. Summary of purse-seine catches of tunas in the FAO areas 51 and 57 of the Indian Ocean, with emphasis on bigeye and its contribution to the total catch.

	Catches of bigeye in tons						Percentages of bigeye in catches						Catches of tunas in tons					
Year	Japan	Maurit.	France	Spain[1]	Russia[2]	Total	Japan	Maurit.	France	Spain[1]	Russia[2]	Total	Japan	Maurit.	France	Spain[1]	Russia[2]	Total
1977													166					166
1978	5					5	0.44						1138					1138
1979	1					1	0.15						670					670
1980	8	12				20	1.45	1.18					551	1020				1571
1981	1					1	1.27						79	1755	470			2304
1982	21	86				107	3.54	3.41					594	2522	1995			5111
1983	54	284				338	6.40	10.32					844	2753	20848		250	24695
1984	215	241	1151	585		2192	18.65	6.00	1.45	2.56		2.02	1153	4016	79638	22862	741	108410
1985	168	747	2064	719		3698	30.11	19.88	2.55	1.52		2.75	558	3757	80841	47362	1769	134287
1986	142	340	4023	1241		5746	16.44	11.69	4.58	2.29		3.81	864	2908	87776	54298	5165	151011
1987	123	601	3322	2108		6154	9.71	9.11	3.71	2.99		3.49	1267	6594	89439	70401	8393	176094
1988	277	681	2858	7944	107	11867	9.49	9.80	2.79	7.25	1.48	5.18	2918	6947	102371	109538	7206	228980
1989	581	1305	3593	6331	354	12164	11.83	15.19	4.22	5.10	5.90	5.32	4913	8593	85137	124191	5995	228829
1990	1105	816	4271	5483	369	12044	7.37	12.65	5.71	4.54	5.45	5.38	14996	6453	74770	120815	6769	223803
1991	1269	1059	6344	9562	430	18664	5.71	9.96	7.97	8.12	4.81	7.80	22236	10636	79647	117805	8927	239251
1992	1757	727	4523	5997	1101	14005	3.86	8.07	4.72	5.46	4.06	4.92	45460	9006	95731	109877	24639	284713
1993	1959	619	5175	5492	1690	12976	4.42	6.02	5.65	4.55	6.33	4.42	44278	10279	91607	120632	26714	293510
1994	4178	646	5137	7819	286	18066	14.01	8.40	5.14	5.19	1.36	5.84	29812	7692	99998	150556	21072	309130
1995		323	5334	22114	1625	29396		5.15	5.56	11.39	10.70	9.44		6266	95973	194069	15184	311492

[1] includes Belize, Cayman Islands, Malta, and Panama
[2] includes Liberia

A REVIEW OF INFORMATION ON THE BIOLOGY, FISHERIES, AND STOCK ASSESSMENT OF BIGEYE TUNA, *THUNNUS OBESUS*, IN THE PACIFIC OCEAN

by

Naozumi Miyabe[1] and William H. Bayliff[2]

1. Introduction

This paper is a modified and updated version of a previous synopsis (Miyabe, 1994b) prepared by the senior author.

2. Taxonomy

Whitelaw and Unnithan (1997) list the synonyms for the bigeye tuna, *Thunnus obesus*.

The bigeye tuna is similar in appearance to the yellowfin tuna, *T. albacares*, but juveniles and adults of the two species are distinguishable by characteristics given by Honma *et al.* (1973), Collette and Nauen (1983), and Itano (1992). The liver of the bigeye is striated, and its middle lobe is slightly longer than the other two, whereas that of the yellowfin is not striated, and the right lobe is much longer and narrower than the other two. Also, the swim bladder of the bigeye is highly visible, and extends nearly the entire length of the body cavity, whereas that of the yellowfin is less conspicuous, and extends only about half the length of the body cavity. The pectoral fins of bigeye are normally longer than those of yellowfin of the same size, often extending beyond the middle of the base of the second dorsal fin. Fish greater than about 70 cm in length can also be distinguished by the longer second dorsal and anal fins of yellowfin. The lateral keels on the caudal peduncle are less well developed in bigeye than in yellowfin. The notch at the center of the trailing edge of the caudal fin of the bigeye is semicircular, whereas in the yellowfin it is v-shaped. In addition, the eyes of larger bigeye are larger than those of yellowfin of the same size. Early juvenile bigeye and yellowfin can be distinguished by electrophoretic methods (Graves *et al*., 1988).

3. Life history

3.1 Distribution and habitat

Juvenile and adult bigeye tuna are distributed throughout the Pacific Ocean from about 40ºN to 40ºS (Figure 1). The distribution of this species is similar to that of yellowfin. The larvae are widely dispersed from about 30ºN to 20ºS in the western Pacific and about 20ºN to 0º in the eastern Pacific (Figure 2).

Many investigators have reported that bigeye inhabit deeper waters, on average, than yellowfin. Suda *et al*. (1969) reported that bigeye prefer waters in or just below the thermocline. Suzuki and Kume (1982) formulated a hypothesis which explains why longlines are more effective in some areas than in others. They stated that bigeye prefer temperatures of about 20°C, but tolerate temperatures as low as 11° or 12°C. Temperatures within the range of bigeye occur between the surface and 100 meters in temperate regions, but occur in much deeper waters in the equatorial zone. Therefore bigeye are more likely to be caught by deep longlines, for which some of the hooks fish at greater depths than do any of those for conventional longlines, in the tropics. Hanamoto (1987) later showed that the greatest catch rates for bigeye were obtained at temperatures of about 10° to 17°C. Holland *et al*. (1992) found that bigeye tagged with ultrasonic transmitters descended to depths of about 375 m. Brill (1994) stated that bigeye "spend most daylight hours well below the thermocline (in 15°C water) but make regular, brief upward excursions into the mixed layer."

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The areas where the 20°C isotherm occurs at depths of 100 to 200 meters beneath the surface, which is believed to be favorable habitat for bigeye, and the CPUEs of bigeye by longline gear are shown in Figures 3 and 4. In general, these correspond well with one another, although the CPUEs were low in nearshore waters off Mexico and Central America and high off Ecuador south of the equator. It is noteworthy that the correspondence for 1960-1975 appears to be much better than that for 1980-1994. This was probably because deep longlining was introduced during the latter period, and high CPUEs were recorded in waters where the thermocline is deeper than 200 m.

Data obtained from commercial longline operations are of limited value because they do not yield complete information on the depth at which each fish was caught, nor do they shed light on why the fish are caught more in some circumstances than in others. The development of new technology, however, has recently made it possible to collect catch and oceanographic data simultaneously. Boggs (1992) attached electronic microchip hook timers to the branch lines to record when bites occurred and time-depth recorders to selected positions on the mainline to record its depth. Sonic tracking studies (Koido and Miyabe, 1990; Holland *et al.*, 1990 and 1992; Holland and Sibert, 1994) indicate that bigeye tend to inhabit deeper waters (around 250 m) during the day than at night (around 80 m).

3.2 Anatomy, physiology, and behavior

Bigeye, like other tunas, have countercurrent heat exchangers, networks of arteries and veins in their bodies in which the relatively cool arterial blood coming from the gills is warmed by the relatively warm venous blood coming from the muscles (Carey *et al*., 1971; Carey and Lawson, 1973; Brill *et al*., 1994). Holland *et al*. (1992) and Holland and Sibert (1994), who used sonic tags which measured both the ambient temperature and the body temperature of the fish, showed that when a bigeye descends to deeper water it activates this system to maintain its temperature at a higher level than that of the environment, and when it ascends to warmer water it deactivates the system so as to increase its body temperature as quickly as possible.

Magnuson (1973) discussed the physical adaptations for continuous swimming and hydrostatic equilibrium of scombrid fishes. He pointed out that all of the larger scombrids have swim bladders, which overcome the negative buoyancy of the fish and reduce the minimum required swimming speeds. He also stated that the larger species tend to have larger pectoral fins, which provide greater lift. (As pointed out in Section 2, bigeye have larger swim bladders and pectoral fins than do yellowfin of the same size.) He also pointed out that when bigeye are close to the surface rapid upward or downward excursions for food would greatly affect the volume of gas in the swim bladder, whereas at greater depths the effects would be much less. Accordingly, fish inhabiting greater depths have access to a greater volume of water for foraging than do those which live close to the surface.

Bushnell *et al*. (1990) measured several cardiorespiratory variables of bigeye which were able to control their own ventilation volume (by adjusting their swimming speed, gape, and/or opercular openings) during conditions of sufficient and insufficient oxygen. Brill (1994), who reviewed studies on temperature and oxygen tolerance of tunas, stated that "widely-cited estimates of limiting oxygen levels, based on estimated metabolic rates at minimum hydrostatic equilibrium swimming speeds are not accurate because tunas have exceptionally high oxygen demands even at slow speeds," and suggested that "the capacity of tunas' cardioorespiratory systems to deliver oxygen at extraordinarily high rates was evolved to allow rapid recovery from strenuous exercise, rapid digestion, and high rates of gonadal and somatic growth, not high cruising speeds." He said that "the ambient oxygen levels which prolong the time required for fish to recover from strenuous exercise appears to be a good index of habitat suitability, with respect to oxygen." He did not present any data on bigeye.

Kawamura *et al*. (1981) and Pereira (1998) reported on the presence of the *tapetum lucidum* in the pigment epithelium layer of the eye of bigeye. This acts as a mirror, reflecting the light back to the retina, which increases the effectiveness of the photoreceptors and enables the fish to detect the presence of prey in the low-light conditions found in deeper waters.

3.3 Age and growth

Estimates of the parameters of the von Bertalanffy growth equation calculated by various investigators are listed in Table 1. Because Yukinawa and Yabuta (1963) and Kume and Joseph (1966) used half-year and quarterly intervals, respectively, the values of *K* and t_0 were adjusted accordingly. Shomura and Keala (1963) used weight data, rather than length data, to calculate their estimates of the parameters. The weights at ages 2.0, 3.0, …, and 7.0 in their Table II were converted to lengths with the weight-length equation of Nakamura and Uchiyama (1966), and then von Bertalanffy equations were fitted to these data to obtain the estimates of the parameters in lines 3 and 5 of the table. To minimize the measurement errors, Hampton *et al*. (1998), who used data for releases and recaptures of tagged fish, considered only data for fish at liberty more than 50 days. They found that the growth of the tagged fish at liberty 500 days or less was nearly linear, so they estimated the parameters of the equation for fish at liberty more than 500 days, as well as for all fish at liberty more than 50 days. They calculated the linear growth rate for fish at liberty 51 to 500 days, and found it to be 26.63 cm per year. Mr. Patrick K. Tomlinson of the IATTC staff used length- or weight-frequency data from Shomura and Keala (1963) and Kume and Joseph (1966), plus data from the IATTC length-frequency data base, to estimate the parameters of the Richards growth curve. Estimates of the lengths at various ages calculated from the parameter estimates in Table 1 and the weights in Shomura and Keala (1963: Table II) and obtained from Tomlinson's (1998) Table 7 are listed in Table 2 and shown in Figure 5. A value of 0.528 was assigned to t_0 for Hampton *et al*.'s (1998) second estimate, as this produced an estimate of the length at age 2 equal to that obtained with their first estimate and close to those obtained by other investigators.

Unfortunately, the ranges of the estimates of *K* and L_∞, particularly the former, are wide. The best way to get better estimates would probably be to tag enough small and medium fish to ensure that appreciable numbers of returns of medium and large fish are obtained.

3.4 Weight-length relationship

Information on the weight-length relationship of bigeye in the Pacific Ocean is given in Table 3. The fish of Kume and Shiohama (1964) were gilled and gutted before they were weighed, so the round weights were estimated by multiplying the gilled-and-gutted weights by 1.16 (Morita, 1973).

3.5 Natural mortality

Suda and Kume (1967) estimated the annual instantaneous rate of natural mortality (*M*) of bigeye to be 0.361. Anonymous (1995a: 77) used the method of Pauly (1980) and estimates of the parameters of the von Bertalanffy growth equation (Kume and Joseph, 1966) to obtain an estimate of 0.477 for *M*. Values of 0.4, 0.6, and 0.8 were used by Tomlinson (1998) in his cohort and yield-per-recruit analyses.

Hampton *et al.* (1998) estimated *M* from data for tagging conducted in the western Pacific. There was little mixing among areas, so they analyzed the experiments initiated in the Philippines, the Coral Sea, and the western equatorial Pacific, between 10°N and 10°S and between 130°E and 180°, separately. They considered only recaptures within the release areas. Such being the case their estimates of *M* are inflated because fish which emigrated from these areas are implicitly considered to have died from natural causes. In each of the analyses *M* was estimated with assumed reporting rates 0.5 to 1.0, and greater estimates of *M* were obtained for the higher reporting rates. Nearly all of the tagged fish released in the Philippines were less than 40 cm long, with most being between 25 and 30 cm in length, According to Table 2, these would be less than 1 year old. Most of the fish were at liberty less than 6 months. They estimated *M*, on a monthly basis, to be 0.3435 to 0.5645, equivalent to 4.12 to 6.77 on an annual basis. Nearly all of the tagged fish released in the Coral Sea were between 60 and 100 cm long. In contrast to the fish released in the Philippines, returns from those released in the Coral Sea were continuing to be received after 5 years. Two models were used to analyze the data. Model 1, for which it is assumed that the fishing mortality in a given season is proportional to the nominal effort, produced estimates of *M*, on an annual basis, of 0.05 to 0.06, whereas Model 2, for which it is assumed that the fishing mortality in a given season is proportional to the catch per unit of effort, produced estimates of *M*, on an annual basis, of 0.46 to 0.51. They pointed out that the estimates from Model 2 are much closer to those obtained by other investigators, and suggested that further analyses are needed to develop a realistic index of effort directed at bigeye. Most of the tagged fish released in the western equatorial Pacific were between 45 and 60 cm long. Most of the recaptures took place within about two years after release, which corresponds to the period which fish of that size would remain vulnerable to the purse-seine fishery of the area. The estimates of *M*, on a monthly basis, ranged from 0.0875 to 0.1157, equivalent to 1.05 to 1.39 on an annual basis. These data appear to indicate that the rate of natural mortality decreases with increasing size, within the range of sizes of fish tagged.

3.6 Movements

The number of tagged bigeye tuna released in the Pacific Ocean is considerably less than those of skipjack, *Katsuwonus pelamis*, and yellowfin, so much less is known of movements of this species. Some long-distance movements of bigeye are listed in Table 4. Two of the 13 fish exhibited net movements of more than 2,000 nautical miles (nm). Wild (1994: Table 3) lists nine "unusual" returns of tagged yellowfin, three of which had traveled net distances of more than 2,000 nm, so the distances traveled by bigeye may be similar to those traveled by yellowfin.

Hampton *et al*. (1998) released more than 8,000 tagged bigeye in the western Pacific Ocean during 1990-1992, and nearly 1,000 of the tags from these had been returned by the end of 1996. Information on the net movements of these is shown in their Figure 11. Two fish released in the Coral Sea were recaptured by longliners in the vicinity of 130°W, and two fish released near Kiribati were recaptured by longliners near Hawaii. Approximately 25 percent of the fish for which the tags were returned had moved more than 200 nm, and more than 5 percent had moved more than 1000 nm.

3.7 Feeding and food

According to Alverson and Peterson (1963), bigeye tuna "feed from the surface layers to water approximately 425 ft [130 m] deep. Fish feeding on the surface usually occur in compact schools, many times in company with other tunas such as skipjack and yellowfin, while those feeding at greater depths are apparently solitary or in loose aggregations composed of a few fish. The fish feeding at the surface are usually less than 100 cm in length and are generally encountered in the vicinity of continental land masses, islands, seamounts, banks or around floating objects. Bigeye feed primarily during the hours of daylight. However, Watanabe (1958) deduced that some of the subsurface bigeye ascend to the shallower layers and feed at night. … The relatively large size of their eyes may enable them to feed at lower light intensity and this accounts for their occurrence at greater depths than the other tunas." This, of course, gives them access to food not accessible to other tunas. Kume and Morita (1966) reported that bigeye were caught with longlines baited with squid and set at night, and agreed that bigeye probably feed at night, as well as during the daytime.

Information on the food consumed by bigeye tuna in the Pacific Ocean is shown in Table 5.

3.8 Sex ratio

Iversen (1955) found that the portion of males in bigeye caught by longlines in the central and western Pacific increased nearly steadily from 25 percent at 50 cm to 100 percent at 160 cm. Kikawa (1966) and Kume (1969b) observed that males make up more than half the longline catch of bigeye tuna in the Pacific Ocean, and that the advantage for males increases with increasing size. Hampton *et al*. (1998) found the same to be the case for the western Pacific Ocean. The sex ratio was found to be approximately equal in (1) the eastern equatorial Pacific where the sea-surface temperatures were less than 24°C, for immature fish (Kume 1969b), and (2) north of 28°N between 180° and 140°E, for fish of all sizes (Kume 1969a).

3.9 Reproduction

Spawning of bigeye tuna occurs in tropical waters throughout the year and in higher latitudes during periods when the temperatures are highest (Figure 2). It takes place only in areas where the sea-surface temperatures are greater than about 23° or 24°C (Kume 1967).

The reproductive status of male and female fish can best be determined by histological criteria. Maturity of females is indicated by the presence of hydrated oocytes and that of males by various criteria (Nikaido *et al.* 1991). Most of the fish greater than 100 cm in length which were sampled off Java during January-March and southwest of Hawaii during May-June were mature. Individual fish spawn nearly every day.

The relationship between batch fecundity and fish length estimated by them is shown in Figure 6 and Table 6.

3.10 Egg and larval development

Information on the development of the eggs and larvae of bigeye is given by Kume (1962) and Yasutake, Nishi, and Mori (1973).

3.11 Stock structure

There is not enough information available to determine whether the bigeye tuna of the Pacific Ocean constitute a single stock or several stocks. Some stock assessments have been carried out assuming that there is a single, Pacific-wide stock, and others have been based on the assumption that there are two stocks, one in the eastern Pacific and the other in the central and western Pacific. Mitochondrial DNA and DNA microsatellite analyses are currently being used to investigate the stock structure of bigeye in the Pacific Ocean (SPC 1996). These are based on samples collected at nine widely-scattered locations.

3.12 Interaction with other species

Small bigeye are frequently found in association with yellowfin, skipjack, kawakawa (*Euthynnus affinis*), and frigate tuna (*Auxis thazard*) (Miyabe, 1994b). Hisada (1973) reported that small to medium (50 to 120 cm) bigeye and yellowfin are caught together in the Coral Sea during October-December. These fish are often associated with sharks. Calkins *et al*. (1993) reported that bigeye are caught in association with yellowfin and skipjack in the eastern Pacific. Miyabe (1994b) stated that bigeye are caught by baitboat and purse-seine fisheries in pure or mixed schools with yellowfin and/or skipjack, but seldom with albacore (*Thunnus alalunga*), in the vicinity of Japan. According to Coan (1994), about 6 to 9 percent of the fish landed as yellowfin by U.S. purse seiners in the central and western Pacific are actually bigeye. The same would presumably be the case for fish caught in the central and western Pacific and landed as yellowfin by purse seiners registered in other countries.

4. Fisheries

In this section the area to the west of 150°W will be referred to as the western Pacific Ocean (Anonymous, 1996b: Figure 1), and the area to the east of that longitude will be referred to as the eastern Pacific Ocean (Anonymous, 1997a: Figure 1).

Longlines have accounted for the greatest share of the catch of bigeye since the early 1950s. The baitboat fishery, which has a long history, has also accounted for a significant share of the catch of bigeye. The purse-seine fishery, which developed more recently (during the early 1960s in the eastern Pacific and during the mid-1970s in the western Pacific) and has largely replaced the baitboat fishery, has also produced substantial catches of bigeye. In addition, small amounts of bigeye are taken by local troll, handline, and small-scale purse-seine fisheries.

4.1. Longline fishery

Data on the longline fleets of the western Pacific Ocean are shown in Table 7. Vessels registered in Japan, Korea, Taiwan, the United States, and several Latin American nations fish with longlines in the eastern Pacific Ocean.

Japan

In terms of weight, bigeye is the second-most important species of tuna caught by Japanese vessels, being exceeded only by skipjack, and in terms of value it is the most important species (MAFFJ, 1990). Japanese longliners operate in almost the entire Pacific; the principal exception being the central Pacific south of 10°S (Figure 7). Fishing grounds are located in both tropical (between about 10°N and 15°S) and temperate (between about 25°N and 40°N and about 25°S and 40°S, particularly in the western Pacific) waters. In tropical waters fishing takes place throughout the year, while in temperate waters it is conducted mainly during the winter. The fishery is directed mainly at bigeye, but there are substantial bycatches of yellowfin, albacore, and billfishes. The catches by distant-water longliners are frozen at temperatures below -60°C for consumption as *sashimi* in the domestic market. A limited-entry system has been adopted for this fishery, and vessels larger than 20 gross tons (GT) are required to obtain permits to operate from the Japanese government. Longliners which have permits are not allowed to unload their catches in foreign countries except for transshipment to Japan, and the total amount of transshipments of longline-caught fish is limited by the government During the 1977-1989 period the numbers of the smallest (20- to100-GT) Japanese vessels decreased, while those of the 100- to 200-GT vessels doubled (Table 8). The number of longliners in the largest size class was stable. Further information about the Japanese longline fishery in the eastern Pacific Ocean is available in Nakano and Bayliff (1992).

Korea

The geographical distribution of fishing effort by Korean vessels is shown in Figure 8. Fishing takes place mainly between 10°N and 15°S and between 95°W and 160°E, and the fishery is directed mainly at bigeye. Less extensive operations are conducted in the North Pacific around Hawaii during the northern winter (Miyabe, 1994b: Figure 7). The number of Korean longliners operating in the Pacific decreased from 270 in 1974 to 94 in 1985, and then increased to 160 in 1994 (Table 7).

Taiwan

The geographical distribution of fishing effort by Taiwanese vessels is shown in Figure 9. Fishing takes place mainly between 5S°and 40°S and between 115°W and 160°E, and the fishery is directed mainly at albacore. The number of Taiwanese longliners based in the Pacific Ocean decreased from 194 in 1976 to 44 in 1985, and then increased to 119 in 1993 (Table 7).

4.2. Baitboat fishery

Western Pacific Ocean

Data on the baitboat fleets of the western Pacific Ocean are shown in Table 9. The Japanese distant-water baitboat fishery operates in the western Pacific between and 40°N and 10°S and about 120°E and 170°W (Figure 10). Bigeye is a bycatch of this fishery, which is directed primarily at skipjack and albacore. Fishing takes place all year round in the tropics and during the spring, summer, and fall in higher latitudes. The numbers of baitboats decreased precipitously during the 1980s (Table 9).

Eastern Pacific Ocean

During the late 1950s and early 1960s most of the medium to large baitboats which fished for tropical tunas in the eastern Pacific Ocean were converted to purse seiners. The few remaining baitboats operate off northern Mexico and off Ecuador. Their catches of bigeye since the early 1960s are insignificant.

4.3. Purse-seine fishery

There are two major purse-seine fisheries for tropical tunas in the Pacific Ocean, one in the western Pacific and the other in the eastern Pacific.

Western Pacific Ocean

Data on the purse-seine fleets of the western Pacific Ocean are shown in Table 10. The offshore purse-seine fishery for tropical tunas commenced operations in the western and central Pacific during the late 1970s. The thermocline is normally deeper in this area than in the eastern Pacific, so the vessels must employ deeper nets to prevent the fish from swimming beneath the leadline. The areas in which Japanese, Korean, and U.S. purse seiners fished during 1995 are shown in Figure 11. (According to Lehodey *et al*. (1997), the distribution of fishing effort by

U.S. purse seiners is further to the east in El Niño years than in non-El Niño years; 1995 was a non El Niño year.)

Eastern Pacific Ocean

Data on the purse seine fleets of the western Pacific Ocean are shown in Table 11, and data on the numbers of vessels of six size classes are shown in Table 12. This fishery was a minor one prior to the late 1950s and early 1960s, when most of the medium to large baitboats which fished for yellowfin and skipjack in the eastern Pacific Ocean were converted to purse seiners. During the early and mid-1960s the fishery was confined to waters within about 250 miles of the mainland and to the vicinities of a few offshore islands and banks, but after that, as the smaller vessels were replaced by larger ones, the fishery expanded further offshore. The approximate extent of the fishery during the mid-1990s is shown in Figure 12.

4.4. Fishing effort

It is obvious from Tables 7, 9, 10, 11, and 12 that the numbers of longline and purse-seine vessels have increased since 1970, while the number of baitboats has decreased. Of these, only the longline fishery (but not that of Taiwan) is directed primarily toward bigeye.

4.5. Catches

Data on the catches of bigeye in the Pacific Ocean are shown in Table 13. Catch data obtained from different sources often disagree with one another, as is apparent in the last two columns of this table. The surface catches were almost insignificant relative to the longline catches until the mid-1990s, at which time the surface catches in the eastern Pacific began to increase greatly.

The distributions of the catches of bigeye by Japanese and Korean longliners are shown in Figures 13 and 14, respectively. Except in the area south of 20°S and west of 180°, the distribution of catches by Japanese longliners is remarkably close to the distribution of effort by Japanese longliners (Figure 7). Tomlinson (1998: Figure 2) shows data on the geographic distribution of catches of bigeye by surface gear in the eastern Pacific Ocean during 1996. He also gives information on the length frequencies of bigeye caught by the surface and longline fisheries of the eastern Pacific Ocean (his Figures 3 and 7, respectively) and the average weights of fish caught by these fisheries (his Tables 3 and 2, respectively). The bigeye caught by surface gear are much smaller than those caught by longlining.

As noted in Section 2, it is difficult to distinguish yellowfin and bigeye tuna, which results in surface-caught bigeye often being reported as yellowfin. Accordingly, for some fisheries the catch statistics for bigeye are almost certainly less than the actual catches, and the catch statistics of yellowfin are almost certainly greater than the actual catches. (Since the actual surface catches of yellowfin are much greater than those of bigeye, the bigeye statistics would be proportionately more in error than the yellowfin statistics.) Attempts are being made to evaluate the extent of this problem and to eliminate or minimize it. According to Anonymous (1992a: 34-35), misidentification of yellowfin and bigeye appears not to be a significant problem in the eastern Pacific Ocean. Nevertheless, the situation is being monitored closely by the IATTC staff. Fortunately, all trips of larger vessels are accompanied by observers who are able to distinguish yellowfin and bigeye. Also, IATTC staff members who measure fish at canneries report instances in which tunas are misidentified by cannery employees so that the statistics can be adjusted to compensate for this. Coan (1994) estimated that about 6 to 9 percent of the fish caught in the western Pacific by U.S. purse seiners and reported as yellowfin are actually bigeye. The purse-seine catches of yellowfin in the western Pacific ranged from 176 to 251 thousand tons per year during the 1990-1994 period (Anonymous, 1996b: Table E3). If 6 to 9 percent of this was actually bigeye, this would amount to about 11 to 23 thousand tons of bigeye per year.

5. Stock assessment

Knowledge of stock structure is a prerequisite for stock assessment. Unfortunately, as pointed out in Section 3.11, little is known about the stock structure of bigeye in the Pacific Ocean. Such being the case, the stock assessments described below must be regarded as provisional.

5.1 Catch per unit of effort

Data on the geographical distribution of catch per unit of effort (CPUE) of bigeye by Japanese longliners in the Pacific Ocean are shown in Figure 15.

A series of studies (Suda and Schaefer, 1965; Kume and Schaefer, 1966; Kume and Joseph, 1969; Shingu *et al.*, 1974; Miyabe and Bayliff, 1987; Nakano and Bayliff, 1992; Uosaki and Bayliff, 1998) on the Japanese longline fishery in the eastern Pacific Ocean includes analyses of the relationship between nominal fishing effort and CPUE of bigeye in the equatorial area east of 150°W (Figure 16). This area was selected because it includes the major bigeye fishing grounds, and it is believed that inclusion of data for higher latitudes with large amounts of effort and low catches of bigeye would tend to mask whatever relationship may exist between effort and bigeye catch. Five periods, 1957-1961, 1962-1964, 1965-1984, 1985-1986, and 1987-1992, are evident. During 1957-1961 the CPUE was high, at about 3 fish per hundred hooks, but during 1962-1964 the CPUE declined to less than half of that. After 1964 the CPUE fluctuated between about 0.7 and 1.0 fish per hundred hooks, except during 1985-1986, when it was greater than 1 fish per hundred hooks.

Miyabe (1994c) estimated the standardized CPUE of bigeye for the entire Pacific Ocean, using a general linear model with year, month, area, gear configuration (number of hooks between floats), and bycatches of other species as variables. The results indicated that the relative CPUE decreased from about 2.6 times the 1975 CPUE during the late1950s to about 0.7 times the l975 CPUE during the early 1980s. After that, until 1993, it fluctuated between about 0.7 and 1.0 times the 1975 CPUE (Figure 17).

Kume (1979a) presented data on the CPUEs of bigeye of different ages in four areas of the Pacific Ocean during five 2-year periods between 1955 and 1976 (Figure 18). The nominal CPUEs by area and time interval were used with length-frequency data to estimate the age-specific CPUEs. The CPUEs for fish more than 3 years of age decreased greatly between 1960-1961 and 1965-1966 in all areas. After that the CPUEs for the older fish may have decreased further, although it is not certain that this was the case.

5.2 Production model analysis

The following assumptions are implicit in production model analyses: (1) the rate of natural increase of the stock responds immediately to changes in population density: (2) the rate of natural increase of the stock at any given level of biomass is independent of the age (or size) composition of the stock. Neither of these assumptions is satisfied. Nevertheless, the longline fishing effort in the Pacific Ocean has not differed greatly in adjacent years, and the age and size composition of the longline catches have been fairly stable, so production model analysis may provide useful information on the status of the stock. The catches of bigeye in the eastern Pacific by surface gear have increased greatly during the mid-1990s (Table 13), however, and this may create further problems in obtaining meaningful results with production model analyses.

Production model analysis requires complete catch and effort data for a series of years during which there has been a wide range of fishing effort. If complete effort data are not available for some or all years, these can be estimated by dividing the catches of all vessels by the CPUEs of a group of similar vessels for which such data are available. Since most longline effort is directed at bigeye, it is logical to estimate the total effort by dividing the total catch by the CPUE of all or a portion of the longline vessels. Unfortunately, however, as mentioned in Section 5.1, not all longline effort is necessarily directed at bigeye, and this creates problems if the portion of longline effort directed at bigeye varies with time. Also, if the efficiency of the vessels varies with time adjustments must be made to compensate for this.

Production model analyses for the entire Pacific Ocean have been carried out by Suda (1970b), Kume (1979b), and Miyabe (1989, 1991, 1994c, and 1995), each of whom divided the total catches of all vessels by the CPUEs of Japanese longline vessels, standardized by various methods, to obtain estimates of the total effort. Kume (1979b) and Miyabe (1989 and 1991) used the program PRODFIT of Fox (1975) to fit the data, whereas Miyabe 1994c and 1995) used the methods of Hilborn and Walters (1992) and Prager (1994) for that purpose. Miyabe (1995) also carried out separate analyses for the western and eastern Pacific Ocean (west and east of 160°W), fitting the data with the method of Prager (1994). Tomlinson (1998) conducted analyses for the eastern Pacific Ocean east of 150°W, using only longline data. He standardized the effort with a logarithmic model, and fitted the data with a least-squares procedure. All of these results are summarized in Table 14. The estimates of the maximum sustainable yield are quite variable, which is not surprising in view of the many problems mentioned above.

5.3 Virtual population analyses

Virtual population analyses (VPAs), also called cohort analyses, make use of age-specific catch data to estimate the condition of a stock, including recruitment and the numbers and weights of fish of each age group which is exploited.

Kume (1979b) used length-frequency data and the growth equation of Suda and Kume (1967) to estimate the catches of fish at various ages caught by the Japanese longline fishery during 1957-1975. Then, assuming that the age compositions of the fish caught by Korean and Taiwanese longliners were the same as those caught by Japanese longliners in the same areas, he estimated the catches of fish of various ages by Korean and Taiwanese longliners and combined the catch data for vessels of the three nations. He then used "minimum stock size analysis" (Honma 1978), a type of VPA analysis, with an annual natural mortality rate (M) of 0.361 (Suda and Kume, 1967), to estimate the recruitment of age-1 fish. This was estimated to be about 9 million fish for the 1956 and 1957 cohorts and 6 to 6.5 million fish for the 1964, 1965, and 1966 cohorts. Miyabe (1994b) plotted the relationship between the reciprocal of the CPUE and the fishing effort (Suda, 1970a) to obtain an estimate of the recruitment at age 1 (constant from year to year) of 7.4 million fish, which is close to those of Suda and Kume (1979b).

Miyabe (1989) estimated the catches of fish at various ages caught by the Japanese longline fishery during 1965-1987, but did not perform calculations analogous to those of Kume (1979b) to incorporate the data for the Korean and Taiwanese longline fisheries. He assumed the annual natural morality rate to be 0.4, and used the method of Parrack (1986) to carry out the analyses. The objective function to be minimized is

$$SSQ = \Sigma(CPUE_{cal} - CPUE_{obs})^2$$

where

SSQ = sum of squares,

$CPUE_{cal}$ = CPUE calculated by VPA, and

$CPUE_{obs}$ = observed CPUE.

The values of $CPUE_{cal}$ and N (population size) obtained from the VPA are then fitted to the equation

$$CPUE_{cal} = qN$$

to estimate q, the coefficient of catchability. The estimates of population size at age 1 range from 11 to 13 million, with fluctuations of about 10 to 20 percent among years. This is similar to the findings of Kume (1979b) although the level of recruitment is different.

Tomlinson (1998) performed cohort analyses for the eastern Pacific Ocean (east of 150°W) with trial values of 0.4, 0.6, and 0.8 for M. His analyses produced estimates of recruitment, at 30 cm, of about 7 to 12 million fish for M = 0.4, 23 to 37 million fish for M = 0.6, and 76 to 120 million fish for M = 0.8 (his Figure 14). His estimates of recruitment at 30 cm for M = 0.4 for the eastern Pacific Ocean (7 to 12 million fish) are not much different from Miyabe's (1989) estimates of recruitment at age 1 for M = 0.4 for the entire Pacific Ocean (11 to 13 million fish). Fish 30-cm in length are probably a little less than 1 year old (Table 2).

The above analyses are based on length-frequency samples which were inadequate for some strata. More importantly, not all the assumptions are satisfied, so the results should be interpreted with caution.

5.4 Yield-per-recruit analyses

Miyabe (1991) used the method of Thompson-and-Bell-(1934) to perform yield-per-recruit (Y/R) analyses on Pacific Ocean bigeye. The inputs were an estimate of annual *M* (0.4) and estimates of weights and gear selectivities at ages 1 through 7. The selectivity at age for the most recent year was estimated by the Pope and Shepherd's (1982) separable VPA method with recent catch-at-age data for the Japanese longline fishery. The estimated Y/R (Figure 19) increases to about 8 kg as the fishing mortality increases, but essentially levels off after reaching an annual fishing mortality rate (*F*) of approximately 0.8. Judging from current information on the average size of bigeye (40 to 45 kg) caught by longline gear, it appears that *F* is about 0.2 to 0.4 for the fully-recruited ages.

Tomlinson (1998) used estimates of growth from his Table 7, estimates of age-specific rates of annual fishing mortality (*F*) from his cohort analyses, and values of *M* of 0.4, 0.6, and 0.8 to perform Y/R analyses. Estimates of the Y/Rs obtainable with various multiples of the fishing effort during 1982 (when the catches of bigeye by the surface fishery were low) and 1994 (when the catches of bigeye by the surface fishery were much greater) and the three values of *M* are shown in his Figure 15. If $M = 0.4$ greater yields per recruit can be obtained by limiting fishing effort, but if it is 0.8 greater yields can be obtained with greater amounts of fishing effort.

6. Interactions among fisheries

Since the surface fisheries exploit small to medium fish, and the longline fishery exploits medium to large fish, the surface fishery has a direct negative effect on the longline fishery, but the reverse is not the case. (The longline fishery could have an indirect negative effect on the surface fisheries if it reduces that spawning stock sufficiently to reduce recruitment, but there is no evidence indicating that this is the case (Tomlinson, 1998: Figure 16).) According to Miyabe (1994a), “in general, any increase in catch by the surface fishery will lead to a decrease [in the overall] yield per recruit except when fishing intensity of the longline fishery is very small.” Historically, nearly all the catches of bigeye have been taken by longlines, but during the 1990s the catches of bigeye by surface gear began to increase, and the effects of these catches on the longline fishery became a matter of considerable concern. Tomlinson (1998) used data obtained from his cohort analyses, trial values of 0.4, 0.6, and 0.8 for *M*, and three hypothetical patterns of fishing effort to predict the catches of bigeye by the surface and longline fisheries during 1996 through 2006. Regardless of the value of *M*, the predicted catches by the surface fishery were less than those by the longline fishery when *F* for the surface fishery for 1996-2006 was set at 0.1 times the value of *F* for the surface fishery for 1996 (Pattern A), but the reverse was the nearly always case when the multiplier was 1.0 (Pattern B) or 1.5 (Pattern C) (Tomlinson, 1998: Figure 23). The predicted total catches were greatest with Pattern A (after 2000) when $M = 0.4$ and greatest with Pattern C when $M = 0.6$ or 0.8 (Tomlinson, 1998: Figure 22). Research on the interactions between the surface and longline fisheries is continuing. The greatest need, from the standpoint of evaluation of the effect of the surface fishery on the longline fishery, is obtaining more precise estimates of age-specific *M*. If a decision is made to curtail the catch of bigeye by the surface fisheries, ways to accomplish this without undue adverse effects on the catches of yellowfin and skipjack by surface gear should be sought.

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8. References

Alverson, F. G., and C. L. Peterson. 1963. Synopsis of biological data on bigeye tuna *Parathunnus sibi* (Temminck and Schlegel) 1844. FAO Fish. Rept., 6(2):482-514.

Anonymous. 1970a-1998a. Annual reports of the Inter-American Tropical Tuna Commission.

Anonymous. 1996b. Report of the fifth meeting of the Western Pacific Yellowfin Tuna Research Group. Southwest Fisheries Science Center, U.S. National Marine Fisheries Service, La Jolla, California, USA, and Oceanic Fisheries Programme, South Pacific Commission, Noumea, New Caledonia:vi, 91pp.

Blunt, C. E., Jr. 1960. Observations on the food habits of longline caught bigeye and yellowfin tuna from the tropical eastern Pacific 1955-1956. Calif. Fish Game, 46(1):69-80.

Boggs, C. H. 1992. Depth, capture time, and hooked longevity of longline-caught pelagic fish: timing bites of fish with chips. Fish. Bull., 90(4):642-658.

Brill, R. W. 1994. A review of temperature and oxygen tolerance studies of tunas pertinent to fisheries oceanography, movement models and stock assessments. Fish. Ocean., 3(3):204-216.

Brill, R. W., H. Dewar, and J. B. Graham. 1994. Basic concepts relevant to heat transfer in fishes, and their use in measuring the physiological thermoregulatory abilities of tunas. Envir. Biol. Fish., 40(2):109-124.

Bushnell, P. G., R. W. Brill, and R. E. Bourke. 1990. Cardiorespiratory responses of skipjack tuna (*Katsuwonus pelamis*), yellowfin tuna (*Thunnus albacares*), and bigeye tuna (*Thunnus obesus*) to acute reductions of ambient oxygen. Canad. Jour. Zool., 68(9):1857-1865.

Calkins, T. 1980. Synopsis of biological data on the bigeye tuna, *Thunnus obesus* (Lowe, 1839), in the Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Spec. Rept., 2:213-259.

Calkins, T. P., M. Yamaguchi, and N. Miyabe. 1993. Some observations on bigeye tuna (*Thunnus obesus*) caught by the surface and longline fisheries for tunas in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 20 (8):441-499.

Carey, F. G., and K. D. Lawson. 1973. Temperature regulation in free-swimming bluefin tuna. Comp. Biochem. Physiol., 44(2A):375-392.

Carey, F. G., J. M. Teal, J. W. Kanwisher, K. D. Lawson, and J. S. Beckett. 1971. Warm-bodied fish. Amer. Zool., 11 (1):135-143.

Coan, A. L., Jr. 1994. USA distant-water and artisanal fisheries for yellowfin tuna in the central and western Pacific. FAO Fish. Tech. Pap., 336(2):138-152.

Collette, B. B., and C. E. Nauen. 1983. FAO species catalogue. Vol. 2. Scombrids of the world. FAO, Fish. Synop., 125(2):vii, 137pp.

FAO. 1966-1997. Catches and Landings. FAO Yearbook of Fishery Statistics. Vols.20-80.

FJTFCA. 1959. Average year's fishing condition of tuna longline fisheries, 1958 edition. Edited by Nankai Regional Fisheries Research Laboratory. Federation of Japan Tuna Fisheries Co-operative Associations, 414pp.

Fox, W. W., Jr. 1975. Fitting the generalized stock production model by least squares and equilibrium approximation. Fish. Bull., 73(1):23-37.

FSFRL. 1988. Report of tagging activity on tuna and skipjack for the fiscal year 1984-1986, released by Japan Marine Resources Research Center. Far Seas Fisheries Research Laboratory, Division of Pelagic Fish Resources. In Japanese.

Fujino, K., and T. Kang. 1968. Serum esterase groups of Pacific and Atlantic tunas. Copeia, (1):56-63.

Gibbs, R. H., Jr., and B. B. Collette. 1967. Comparative anatomy and systematics of the tunas, genus *Thunnus*. Fish. Bull., 66(1):65-130.

Gong, Y., J. U. Lee, Y. C. Park, D. Y. Moon, W. S. Yang, T. I. Kim, J. N. Kwon, J. B. Kim, H. S. Jo, and Y. J. Lee. 1993. Fishery statistics and fishing grounds for the Korean longline fishery, 1988-1992. Korea, Nat. Fish. Res. Develop. Agency, Tech. Rept., 106:465pp.

Graves, J. E., M. A. Simovich, and K. M. Schaefer. 1988. Electrophoretic identification of early juvenile yellowfin tuna, *Thunnus albacares*. Fish. Bull., 86(4):835-838.

Hampton, J., A. Lewis, and P. Williams. 1998. Estimates of western and central Pacific Ocean bigeye tuna catch and population parameters. Inter-Amer. Trop. Tuna Comm., Spec. Rept., 9: 212-234.

Hanamoto, E. 1974. Fishery biology of bigeye tuna—I. Depth of capture by bigeye tuna longline gear in the eastern tropical Pacific Ocean. La Mer, 12(3):128-136.

Hanamoto, E. 1975. Fishery biology of bigeye tuna—II. Thermocline and dissolved oxygen content in relation to tuna longline fishing grounds in the eastern tropical Pacific Ocean. La Mer, 13(2):58-71.

Hanamoto, E. 1976. The swimming layer of bigeye tuna. Bull. Japan. Soc. Fish. Oceanogr., 29:41-44.

Hanamoto, E. 1987. Effect of oceanographic environment on bigeye tuna distribution. Bull. Japan. Soc. Fish. Oceanogr., 51(3):203-216.

Hilborn, R., and C. J. Walters. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. Chapman and Hall, New York:xv, 570pp.

Hinton, M. G., and G. Ver Steeg. 1994. Statistics of the eastern Pacific Ocean tuna fishery, 1979 to 1992. Inter-Amer. Trop. Tuna Comm., Data Rept., 8:ii, 96pp.

Hisada, K. 1973. Investigation on tuna hand-line fishing ground and some biological observations on yellowfin and bigeye tunas in the northwestern Coral Sea. Bull. Far Seas Fish. Res. Lab., 8:35-69.

Holland, K. N., R. W. Brill, and R. K. C. Chang. 1990. Horizontal and vertical movements of yellowfin and bigeye tuna associated with fish aggregating devices. Fish. Bull., 88(3):493-507.

Holland, K. N., R. W. Brill, R. K. C. Chang, J. R. Sibert, and D. A. Fournier. 1992. Physiological and behavioural thermoregulation in bigeye tuna (*Thunnus obesus*). Nature, 358(6385):410-412.

Holland, K. N., and J. R. Sibert. 1994. Physiological thermoregulation in bigeye tuna, *Thunnus obesus*. Envir. Biol. Fish., 40(3):319-327.

Honma, M. 1974. Estimation of overall effective fishing intensity of tuna longline fishery--yellowfin tuna in the Atlantic Ocean as an example of seasonally fluctuating stocks. Bull. Far Seas Fish. Res. Lab., 10:63-85.

Honma, M. 1978. Calculation of minimum stock size. Collective volume of computer programs for fisheries stock analysis. Fishery Agency of Japan, 19:193-197.

Honma, M., and T. Kamimura. 1955. Biology of the big-eyed tuna, *Parathunnus mebachi* (Kishinouye) - II. A consideration on the size composition of the big-eyed tuna caught by pole and line. Bull. Japan. Soc. Sci. Fish., 20(10):863-869.

Honma, M., Y. Warashina, and Z. Suzuki. 1973. Identification of young yellowfin and bigeye tunas in the western Pacific Ocean. Examination of practical standards based on external characteristics and the reliability in field survey. Bull. Far Seas Fish Res. Lab., 8:1-23.

Itano, D. 1992. Are you sure that fish was a yellowfin? South Pacif. Comm., Fish. News., 62:29-32.

Iversen, E. S. 1955. Size frequencies and growth of central and western Pacific bigeye tuna. U.S. Fish Wildl. Serv., Spec. Sci. Rept. Fish., 162:40pp.

Iwai, T., I. Nakamura, and K. Matsubara. 1965. Taxonomic study of the tunas. Kyoto Univ., Misaki Mar. Biol. Inst., Spec. Rept., 2:51pp.

Juhl, R. 1955. Notes on the feeding habits of subsurface yellowfin and bigeye tunas of the eastern tropical Pacific Ocean. Calif. Fish Game, 41(1):99-101.

Kamimura, T., and M. Honma. 1953. Biology of the big-eyed tuna, *Parathunnus mebachi* (Kishinouye) - I. Length frequency of the big-eyed tuna caught in the North Pacific with special reference to biennial frequency. Contr. Nankai Reg. Fish. Res. Lab., 46:18pp.

Kawamura, G., W. Nishimura, S. Ueda, and T. Nishi. 1981. Vision in tunas and marlins. Mem. Kagoshima Univ. Res. Center, S. Pacif., 2(1):3-47.

Kawasaki, T. 1958. Biological comparison between the Pacific tunas. Part I. Bull. Tohoku Reg. Fish. Res. Lab., 12:46-79.

Kawasaki, T. 1960. Biological comparison between the Pacific tunas. Part II. Bull. Tohoku Reg. Fish. Res. Lab., 16:1-40.

Kikawa, S. 1953. Observations on the spawning of the big-eyed tuna (*Parathunnus mebachi* Kishinouye) near the southern Marshall Islands. Contr. Nankai Reg. Fish. Res. Lab., 1(42):10pp.

Kikawa, S. 1957. The concentrated spawning area of bigeye tuna in the western Pacific. Rept. Nankai Reg. Fish. Res. Lab., 5:145-157.

Kikawa, S. 1961. The group maturity of bigeye tuna *Parathunnus mebachi* (Kishinouye) in the spawning areas of the Pacific. Rept. Nankai Reg. Fish. Res. Lab., 13:35-46.

Kikawa, S. 1962. Studies on the spawning activity of Pacific tunas, *Parathunnus mebachi* and *Neothunnus macropterus*, by the gonad index examination. Occas. Rept. Nankai Reg. Fish. Res. Lab., 1:43-56.

Kikawa, S. 1966. The distribution of maturing bigeye and yellowfin and an evaluation of their spawning potential in different areas in the tuna longline grounds in the Pacific. Rept. Nankai Reg. Fish. Res. Lab., 23:131-208.

King, J. E,. and I. I. Ikehara. 1956. Comparative study of food of bigeye and yellowfin tuna in the central Pacific. Fish. Bull., 57(108):60-85.

Kiyota, M., T. Koido, N. Miyabe, K. Mizuno, Y. Nishikawa, Z. Suzuki, Y. Warashina, and M. Yukinawa (in alphabetical order). 1988. Report of Juten-Kiso-Kenkyuu. Science and Technology Agency, 59:13pp.

Koido, T., and N. Miyabe. 1990. II. Field observation, 5. Tunas. Application of Telemetry to Aquatic Animal Behavior, edited by H. Soeda. Suisangaku series 80. Kouseisha-kouseikaku, Tokyo, 55-66.

Kume, S. 1962. A note on the artificial fertilization of bigeye tuna, *Parathunnus mebachi* (Kishinouye). Rept. Nankai Reg. Fish. Res. Lab., 15:79-84.

Kume, S. 1967. Distribution and migration of bigeye tuna in the Pacific Ocean. Rept. Nankai Reg. Fish. Res. Lab., 25:75-80.

Kume, S. 1969a. Ecological studies on bigeye tuna - V. A critical review on distribution, size composition and stock structure of bigeye tuna in the North Pacific Ocean (north of 16°N). Bull. Far Seas Fish. Res. Lab., 1:57-75.

Kume, S. 1969b. Ecological studies on bigeye tuna - VI. A review on distribution and size composition of bigeye tuna in the equatorial and south Pacific Ocean. Bull. Far Seas Fish. Res. Lab., 1:77-98.

Kume, S. 1979a. Fishery biology of the bigeye tuna resources in the Pacific Ocean. Japan Fisheries Resource Conservation Association, Suisan Kenkyuu Sousho, 32, 54pp.

Kume, S. 1979b. Bigeye tuna resource in the Pacific Ocean, its fishery biology and a status of the stock. Working Pap. Tuna and Billfish Stock Assessment Workshop, Shimizu, Japan, June 1979, 28pp.

Kume, S., and J. Joseph. 1966. Size composition, growth and sexual maturity of bigeye tuna, *Thunnus obesus* (Lowe), from the Japanese longline fishery in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 11(2):45-99.

Kume, S., and J. Joseph. 1969. The Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean east of 130°W, 1964-1966. Inter-Amer. Trop. Tuna Comm., Bull., 13(2):275-418.

Kume, S., and N. Miyabe. 1987. On the relation of El Niño with the formation of bigeye tuna fishing grounds in the eastern equatorial Pacific. Bull. Japan. Soc. Fish. Oceanogr., 51(1):62-68.

Kume, S., and Y. Morita. 1966. Ecological studies on bigeye tuna -- III. On bigeye tuna, *Thunnus obesus*, caught by "nighttime longline" in the North Pacific Ocean. Rept. Nankai Reg. Fish. Res. Lab., 24:21-30.

Kume, S., and Y. Morita. 1967. Ecological studies on bigeye tuna -- IV. Size composition of bigeye tuna *Thunnus obesus* (Lowe), caught by pole-and-line fishery in the north-western Pacific Ocean. Rept. Nankai Reg. Fish. Res. Lab., 25:81-90.

Kume, S., and M. B. Schaefer. 1966. Studies on the Japanese long-line fishery for tuna and marlin in the eastern tropical Pacific Ocean during 1963. Inter-Amer. Trop. Tuna Comm., Bull., 11(3):101-170.

Kume, S., and T. Shiohama. 1964. On the conversion between length and weight of bigeye tuna landings in the Pacific Ocean (preliminary report). Rept. Nankai Reg. Fish. Res. Lab., 20:59-67.

Lawson, T. (editor). 1996. South Pacific Commission Tuna Fishery Yearbook 1995:vi, 92pp.

Lehodey, P., M. Bertignac, J. Hampton, A. Lewis, and J. Picaut. 1997. El Niño Southern Oscillation and tuna in the western Pacific. Nature, 389(6652):715-718.

Lowe, R. T. 1839. A supplement to a synopsis of the fishes of Madeira. Proc. Zool. Soc. Lond., 7:76-92.

MAFFJ. 1955-1990. Annual report of statistics on fishery and aquaculture. Statistics and Information Division. Ministry of Agriculture, Forestry and Fishery of Japan.

Magnuson, J. J. 1973. Comparative study of adaptations for continuous swimming and hydrostatic equilibrium of scombroid and xiphoid fishes. Fish. Bull., 71(2):337-356.

Martínez F., C., and G. Bohm S. 1983. Sinopsis biológica del atún ojo grande *Thunnus obesus* (Lowe) con especial referencia al Océano Pacífico oriental. Rev. Com. Perm. Pacíf Sur, 13:103-123.

Meehan, J. M. 1965. First occurrence of bigeye tuna on the Oregon coast. Oregon Fish Comm., Res. Briefs, 11(1):53-54.

Miyabe, N. 1989. Preliminary stock assessment of Pacific bigeye tuna. Rept. The 3rd Southeast Asian tuna conference. Indo-Pacific Tuna Development and Management Programme, FAO, 122-130.

Miyabe, N. 1991. Stock status of Pacific bigeye tuna. Bull. Japan. Soc. Fish. Oceanogr., 55(2):141-144.

Miyabe, N. 1994a. A brief analysis of fishery interaction for bigeye tuna in the Pacific Ocean. FAO Fish. Tech. Pap., 336(1):239-248.

Miyabe, N. 1994b. A review of the biology and fisheries for bigeye tuna, *Thunnus obesus*, in the Pacific Ocean. FAO Fish. Tech. Pap., 336(2):207-243.

Miyabe, N. 1994c. Assessment of bigeye tuna in the Pacific Ocean by production model analysis. Seventh meeting of the South Pacific Commission Standing Committee on Tuna and Billfish, Koror, Palau, August 5-8, 1994:17pp.

Miyabe, N. 1995. Follow-up study on the stock status of bigeye tuna in the Pacific Ocean. unpublished manuscript:10pp.

Miyabe, N., and W. H. Bayliff. 1987. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1971-1980. Inter-Amer. Trop. Tuna Comm., Bull., 19(1):1-163.

Morita, Y. 1973. Conversion factors for estimating live weight from gilled-and-gutted weight of bigeye and yellowfin tunas. Bull. Far Seas Fish. Res. Lab., 9:109-121.

Nakamura, E. L., and J. H. Uchiyama. 1966. Length-weight relations of Pacific tunas. *In* Proc, Governor's Conf. Cent. Pacif. Fish. Resources, edited by T. A. Manar, Hawaii, 197-201.

Nakamura, H., and H. Yamanaka. 1959. Relation between the distribution of tunas and the ocean structure. J. Oceanogr. Soc. Jap., 15(3):1-7.

Nakano, H., and W. H. Bayliff. 1992. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1981-1987. Inter-Amer. Trop. Tuna Comm., Bull., 20(5):183-355.

Nelson, J. S. 1984. Fishes of The World, Second Edition. John Wiley and Sons, New York, xv, 618pp.

NFRDA. 1986. Annual report of catch and effort statistics and fishing grounds for the Korean tuna longline fishery, 1981-1982. National Fisheries Research and Development Agency, 523pp.

Nikaido, H., N. Miyabe, and S. Ueyanagi. 1991. Spawning time and frequency of bigeye tuna, *Thunnus obesus*. Bull. Nat. Res. Inst. Far Seas Fish., 28:47-73.

Nishikawa, Y., and D. W. Rimmer. 1987. Identification of larval tunas, billfishes and other scombroid fishes (Suborder Scombroidei): an illustrated guide. CSIRO Mar. Labs., Rept., 186:20pp.

Nishikawa, Y., M. Honma, S. Ueyanagi, and S. Kikawa. 1985. Average distribution of larvae of oceanic species of scombroid fishes, 1956-1981. Far Seas Fish. Res. Lab., S series, 12:99pp.

Otsu, T., and R. N. Uchida. 1956. Tagged bigeye tuna recovered. Pacific Sci., 10(2):236.

Paloheimo, J. E. 1961. Studies on estimation of mortalities. I. Comparison of a method described by Beverton and Holt and a new linear formula. J. Fish. Res. Bd. Canada, 18(5):645-662.

Parrack, M. L. 1986. A method of analyzing catches and abundance indices from a fishery. Inter. Comm. Conserv. Atl. Tunas, Coll. Vol. Sci. Pap., 24:209-221.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J Cons. Int. Explor. Mer, 39(2):175-192.

Pereira, J. G. 1998. Bigeye tuna: access to deep waters. Inter-Amer. Trop. Tuna Comm., Spec. Rept., 9: 243-249.

Pope, J. G., and J. G. Shepherd. 1982. A simple method for the consistent interpretation of catch-at-age data. J. Cons. Int. Explor. Mer, 40(2):176-184.

Prager, M. H. 1994. A suite of extensions to a nonequilibrium surplus-production model. Fish. Bull., 92(2):374-389.

Punsly, R., and H. Nakano. 1992. Analysis of variance and standardization of longline hook rates of bigeye (*Thunnus obesus*) and yellowfin (*Thunnus albacares*) in the eastern Pacific Ocean during 1975-1987. Inter-Amer. Trop. Tuna Comm., Bull., 20(4):165-184.

Radovich, J. 1961. Relationships of some marine organisms of the northeast Pacific to water temperatures particularly during 1957 through 1959. Calif. Dept. Fish Game, Fish Bull., 112:62pp.

Saito, S. 1975. On the depth of capture of bigeye tuna by further improved vertical long-line in the tropical Pacific. Bull. Japan. Soc. Sci. Fish., 41(8):831-841.

Saito, S., and S. Sasaki. 1974. Swimming depth of large sized albacore in the south Pacific Ocean -- II. Vertical distribution of albacore catch by an improved vertical long-line. Bull. Japan. Soc. Sci. Fish., 40(7):643-649.

Sharp, G. D. 1978. Behavioral and physiological properties of tuna and their effects on vulnerability to fishing gear. *In* The Physiological Ecology of Tunas, edited by Sharp, G. D. and A. E. Dizon. Academic Press, New York, 397-449.

Sharp, G. D., and S. Pirages, 1978. The distribution of red and white swimming muscles, their biochemistry, and the biochemical phylogeny of selected scombrid fishes. *In* The Physiological Ecology of Tunas, edited by Sharp, G. D. and A. E. Dizon. Academic Press, New York, 41-78.

Shingu, C., P. K. Tomlinson, and C. L. Peterson. 1974. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1967-1970. Inter-Amer. Trop. Tuna Comm., Bull., 16(2):65-230.

Shomura, R. S,. and B. A. Keala 1963. Growth and sexual dimorphism in growth of bigeye tuna (*Thunnus obesus*) a preliminary report. FAO Fish. Rept., 6(3):1409-1417.

SPC. 1990a. Catches of tuna in the western tropical Pacific, 1965-1988. South Pacific Commission, Third standing committee on tuna and billfish, Working paper 7, 29pp.

SPC. 1990b. Regional Tuna Bulletin, First quarter 1990. Tuna and Billfish Assessment Programme, South Pacific Commission, 49pp.

SPC. 1996. Oceanic Fisheries Programme work programme review 1995-96 and work plans for 1996-97. Ninth Standing Committee on Tuna and Billfish, Working Paper 2, 40pp.

Suda, A. 1970a. Approximate estimation of parameters in dynamics of fish population utilizing effort and catch statistics with little informations on biological features. Bull. Far Seas Fish. Res. Lab., 3:1-14.

Suda, A. 1970b. Methods of dealing with sustainable yields for fish species with marked differentiations of living pattern on a course of life history--I. Basic considerations on the conditions to realize a sustainable yield and applications of techniques to calculate amounts of sustainable yield from fish populations which are exploited in simple ways. Bull. Far Seas Fish. Res. Lab., 3:115-146.

Suda, A. an,d S. Kume 1967. Survival and recruit of bigeye tuna in the Pacific Ocean, estimated by the data of tuna longline catch. Rept. Nankai Reg. Fish. Res. Lab., 25:91-103.

Suda, A., S. Kume, and T. Shiohama. 1969. An indicative note on a role of permanent thermocline as a factor controlling the longline fishery for bigeye tuna. Bull. Far Seas Fish. Res. Lab., 1:99-114.

Suda, A,. and M. B. Schaefer. 1965. General review of the Japanese tuna long-line fishery in the eastern tropical Pacific Ocean 1956-1962. Inter-Amer. Trop. Tuna Comm., Bull., 9(6):305-462.

Sund, P. N., M. Blackburn, and F. Williams. 1981. Tunas and their environment in the Pacific Ocean: a review. Oceanogr. Mar. Biol. Ann. Rev., 19:443-512.

Suzuki, Z., and S. Kume. 1982. Fishing efficiency of deep longline for bigeye tuna in the Atlantic as inferred from the operations in the Pacific and Indian Oceans. Inter. Comm. Conserv. Atl. Tunas, Coll. Vol. Sci. Pap. 17(2):471-486.

Suzuki, Z., Y. Warashina, and M. Kishida. 1977. The comparison of catches by regular and deep tuna longline gears in the western and central equatorial Pacific. Bull. Far Seas Fish. Res. Lab., 15:51-73.

Tanaka, T. 1989. Shift of the fishing ground and features of shoals caught by purse seine fishery in the tropical seas of the western Pacific Ocean. Bull. Tohoku Reg. Fish. Res. Lab., 51:75-88.

Thompson, W. F., and F. H. Bell. 1934. Biological statistics of the Pacific halibut fishery (2) Effect of changes in intensity upon total yield and yield per unit of gear. Inter. Fish. Comm., Rept., 8:49pp.

Tomlinson, P. K. 1998. Assessment studies of bigeye tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Spec. Rept., 9: 250-290.

TRC 1983. Annual catch statistics of Taiwan's tuna longline fishery, 1982. Tuna Research Center.

Uda, M.. 1957. A consideration on the long years trend of the fisheries fluctuation in relation to sea conditions. Bull. Japan. Soc. Sci. Fish., 23(7-8):368-372.

Uosaki, K., and W. H. Bayliff. 1998. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1988-1992. Inter-Amer. Trop. Tuna Comm., Bull., 21(6):in preparation.

Watanabe, H. 1958. On the difference of the stomach contents of the yellowfin and bigeye tunas from the western equatorial Pacific. Rept.Nankai Reg. Fish. Res. Lab., 7:72-81.

Whitelaw, A. W., and V. K. Unnithan. 1997. Synopsis of the distribution, biology and fisheries of the bigeye tuna (*Thunnus obesus*, Lowe) with a bibliography. Australia, CSIRO Mar. Lab., Rept., 228:62pp.

Wild, A. 1994. A review of the biology and fisheries for yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean. FAO Fish. Tech. Pap., 336(2):52-107

Yamanaka, H., and N. Anraku. 1962. Relation between the distribution of tunas and water types of the North and South Pacific Oceans west of 160°W. Occas. Rept. Nankai Reg. Fish. Res. Lab., 1:23-34.

Yasutake, H., G. Nishi, and K. Mori. 1973. Artificial fertilization and rearing of bigeye tuna (*Thunnus obesus*) on board, with morphological observations on embryonic through to early post-larval stage. Bull. Far Seas Fish. Res. Lab., 8:71-78.

Yuen, H. S. H. 1955. Maturity and fecundity of bigeye tuna in the Pacific. U. S. Fish Wildl. Serv., Spec. Sci. Rept. Fish., 150:30pp.

Yukinawa, M., and Y. Yabuta. 1963. Age and growth of bigeye tuna, *Parathunus mebachi* (Kishinouye). Rept. Nankai Reg. Fish. Res. Lab., 19:103-118.

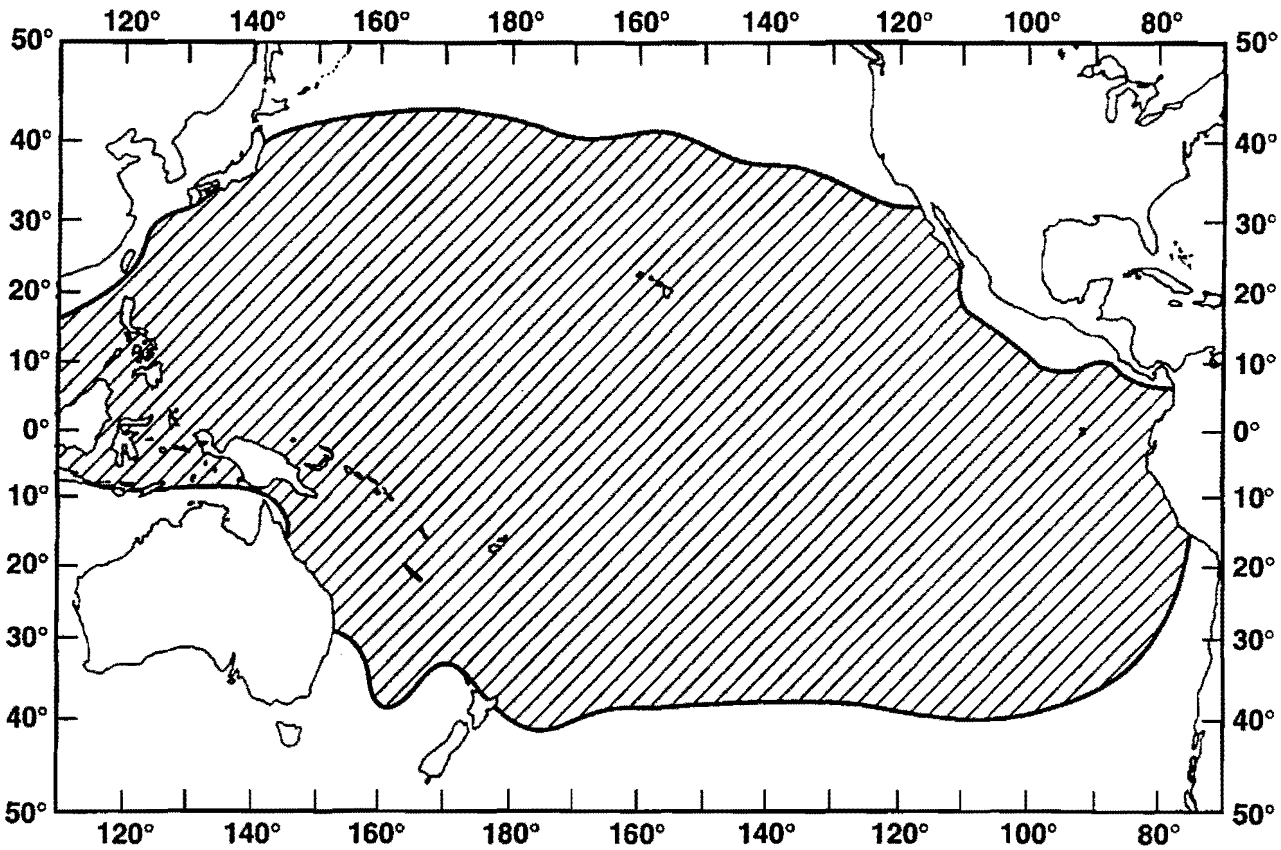

FIGURE 1. Geographical distribution of juvenile and adult bigeye tuna in the Pacific Ocean (after Calkins, 1980).

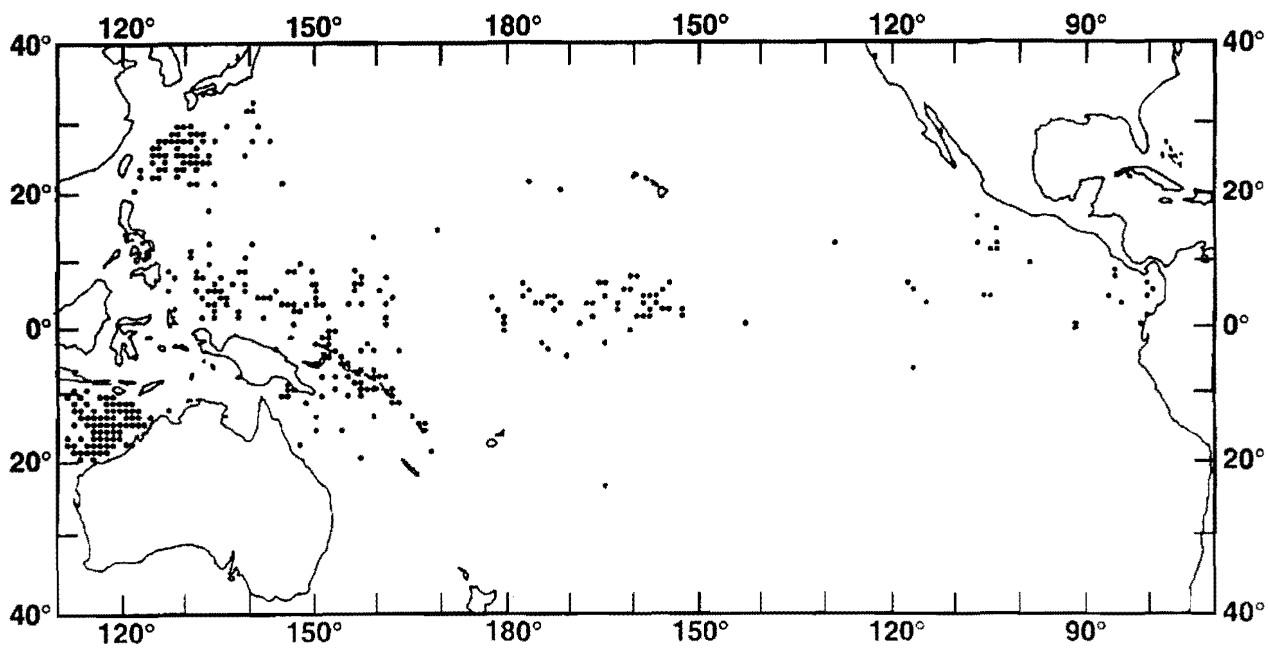

FIGURE 2. Average geographical distribution of larvae of bigeye tuna in the Pacific Ocean during 1956-1981 (after Nishikawa *et al.* (1985: Figure 6).

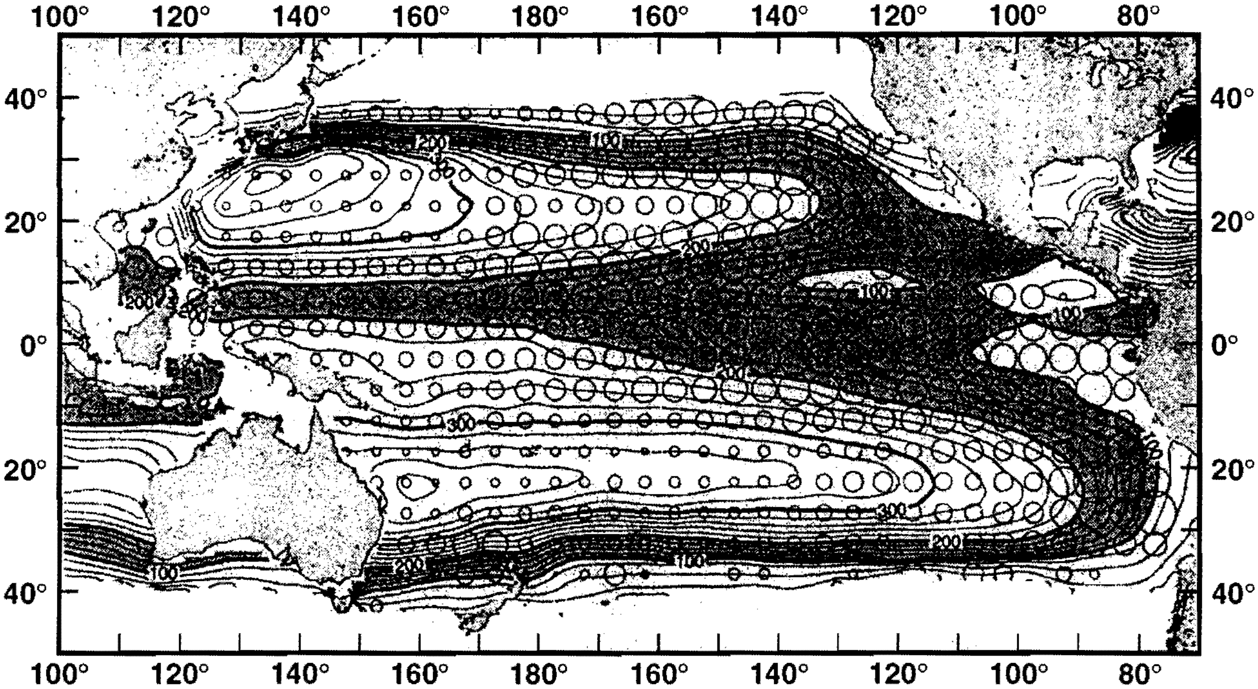

FIGURE 3. Areas (shaded) where the 20°C isotherm occurs at depths between 100 and 200 meters and CPUEs of bigeye by longline gear during 1960-1975.

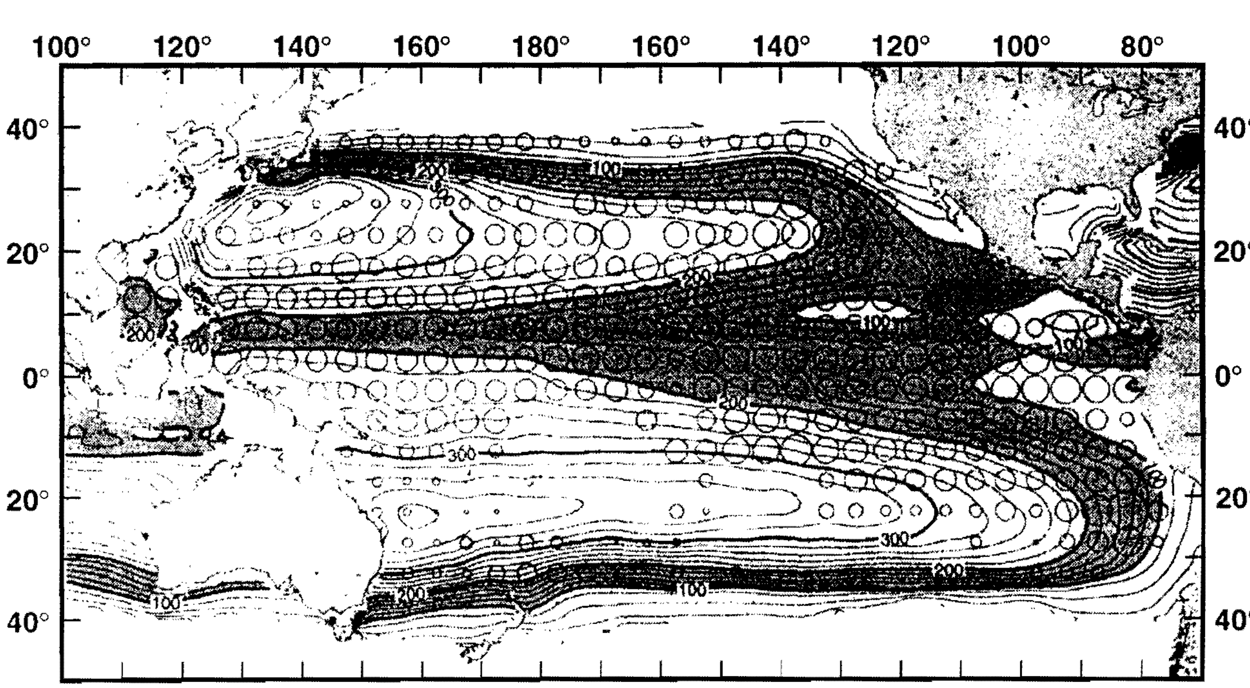

FIGURE 4. Areas (shaded) where the 20°C isotherm occurs at depths between 100 and 200 meters and CPUEs of bigeye by longline gear during 1980-1994.

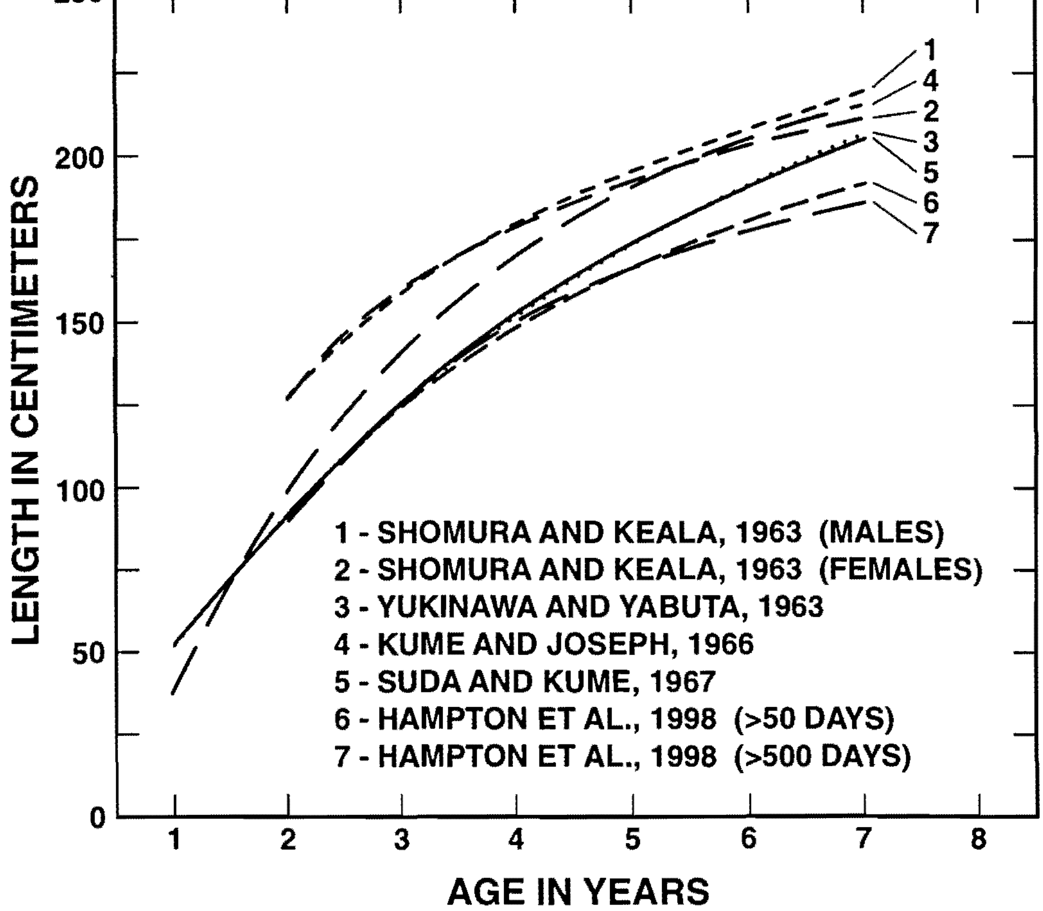

FIGURE 5. Growth curves of bigeye tuna in the Pacific Ocean.

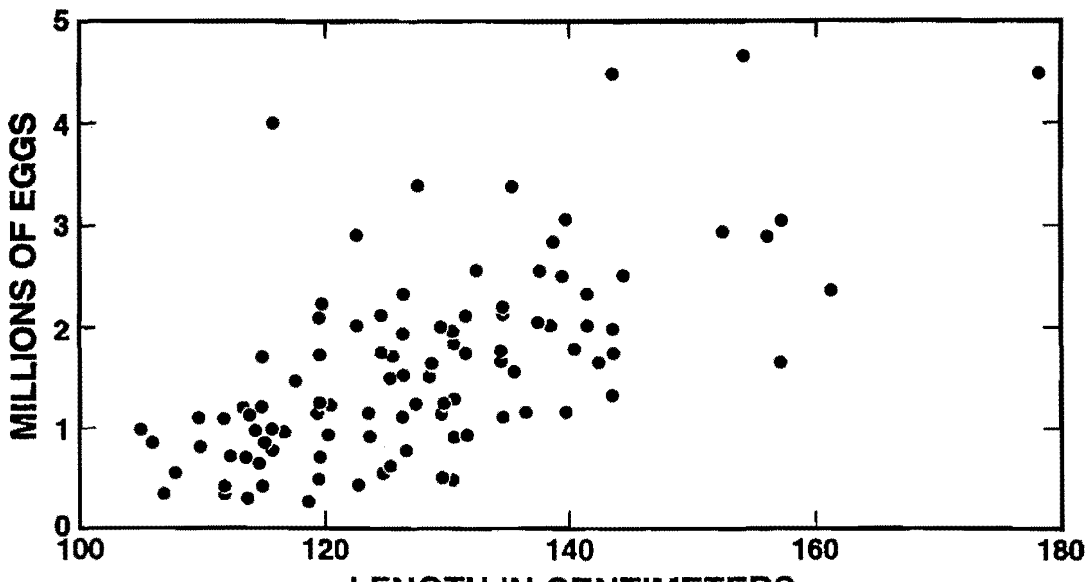

FIGURE 6. Relationship between batch fecundity and fish length for bigeye tuna caught in two areas of the Pacific Ocean (after Nikaido *et al.*, 1991).

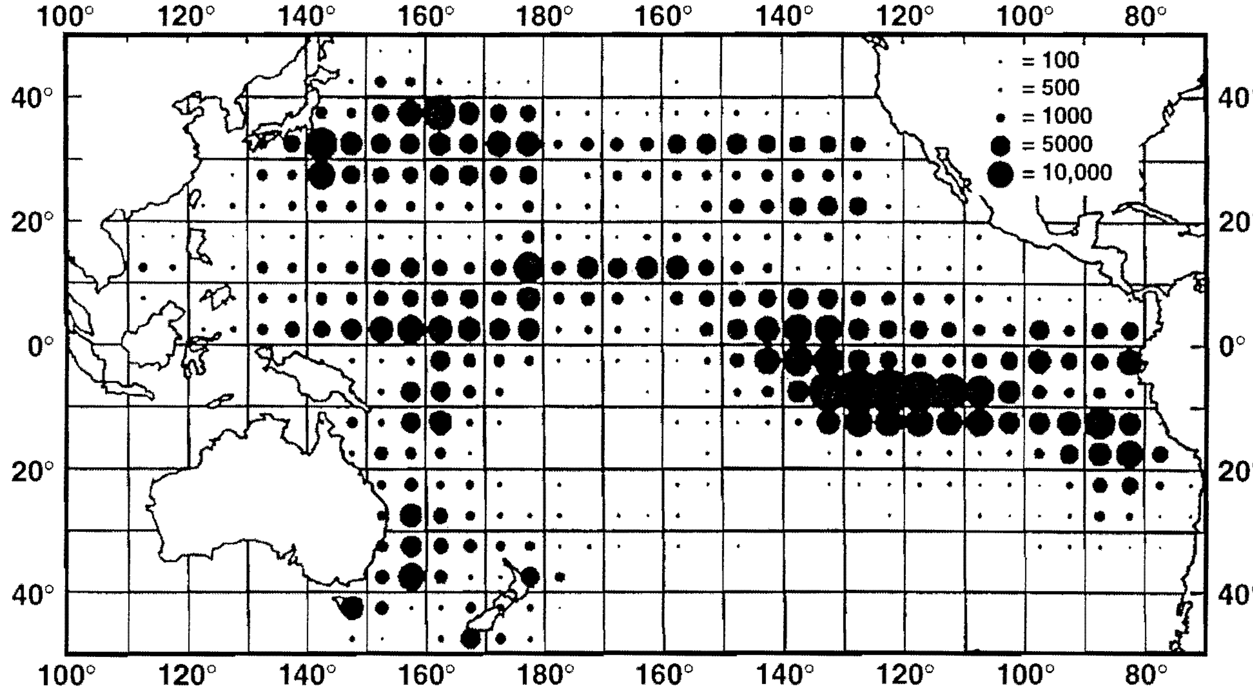

FIGURE 7. Fishing effort by Japanese longliners, in thousands of hooks, in the Pacific Ocean during 1990-1994.

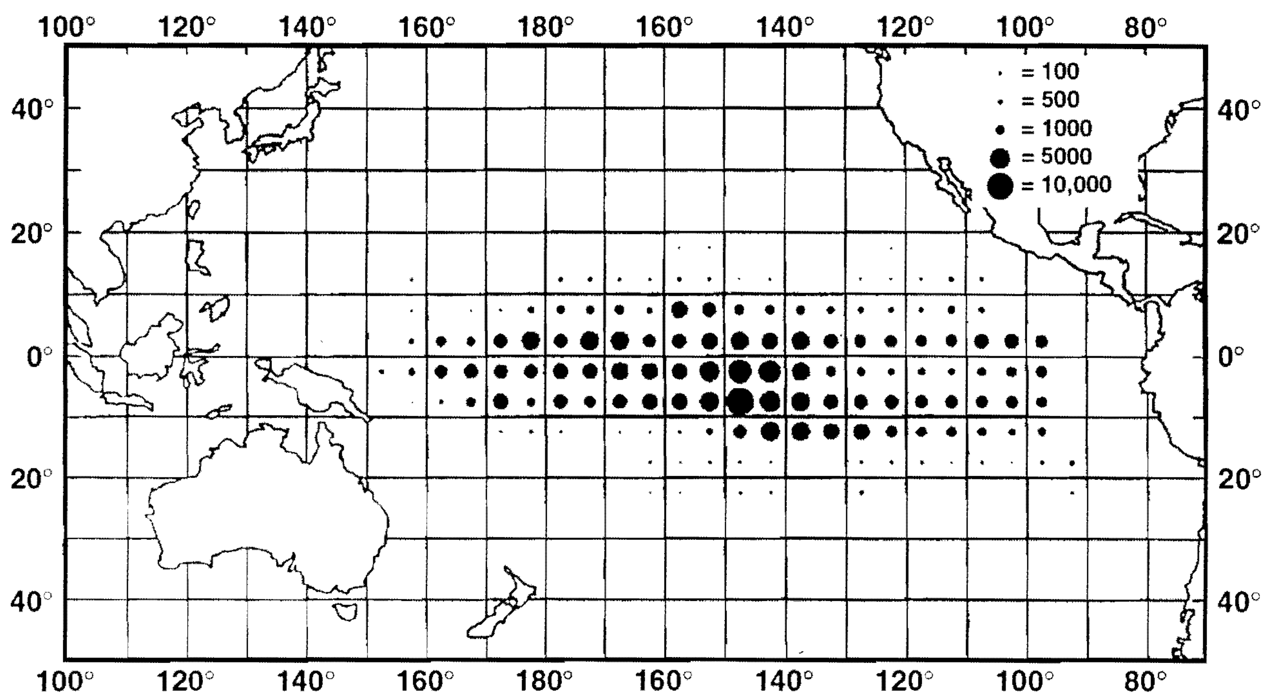

FIGURE 8. Fishing effort by Korean longliners, in thousands of hooks, in the Pacific Ocean during 1990-1992.

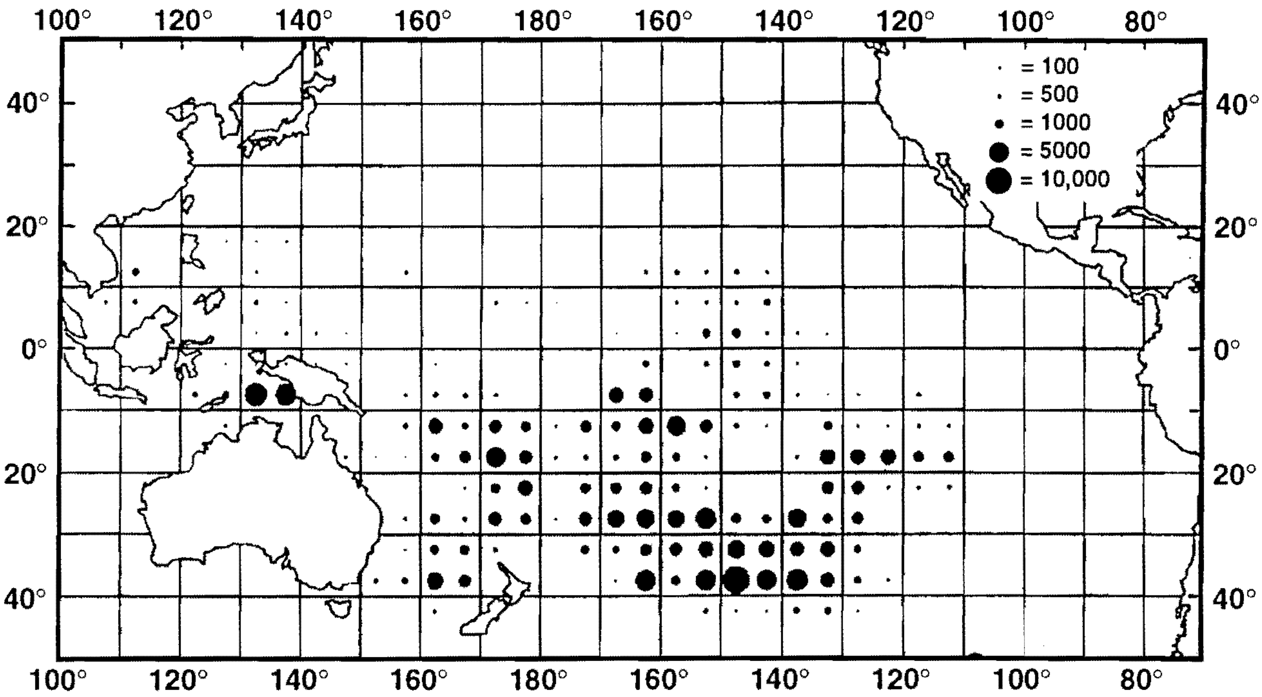

FIGURE 9. Fishing effort by Taiwanese longliners, in thousands of hooks, in the Pacific Ocean during 1990-1993.

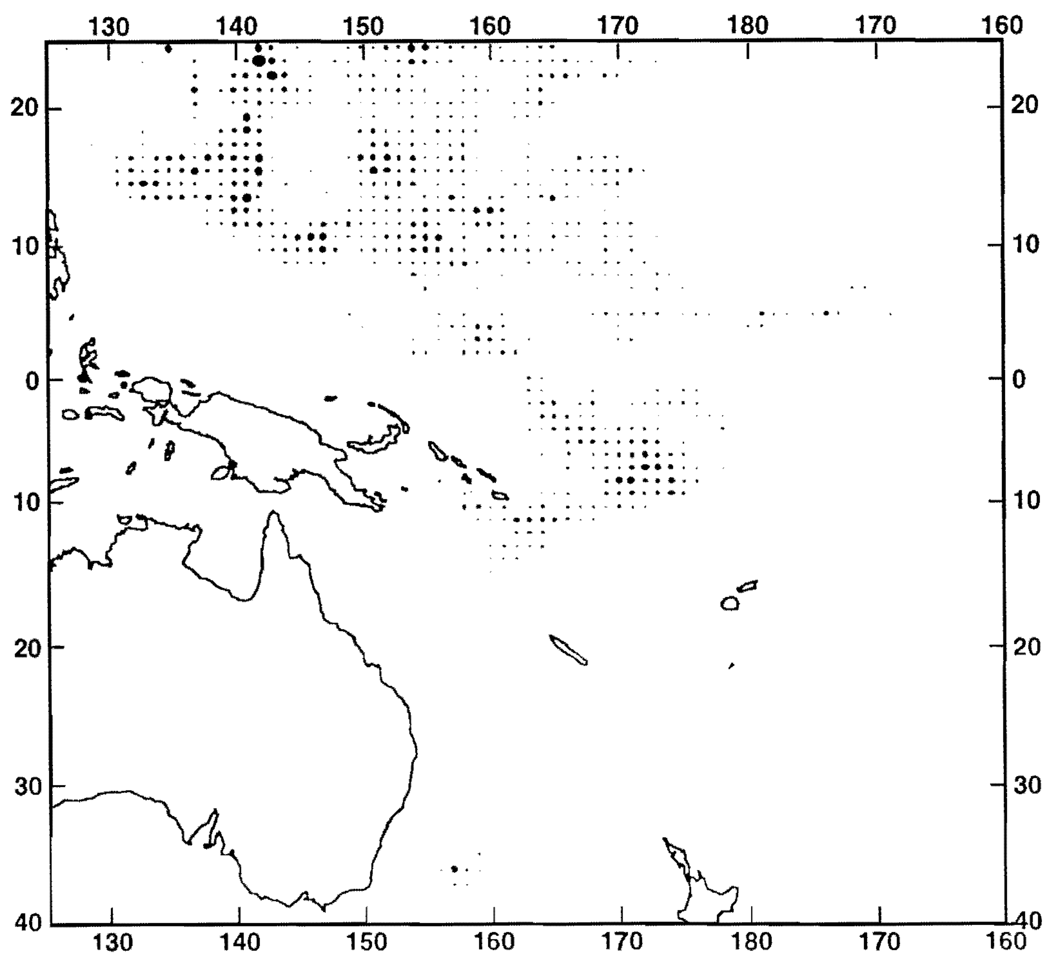

FIGURE 10. Fishing effort by Japanese baitboats in the Pacific Ocean during 1994 (after Lawson, 1996: Figure 37).

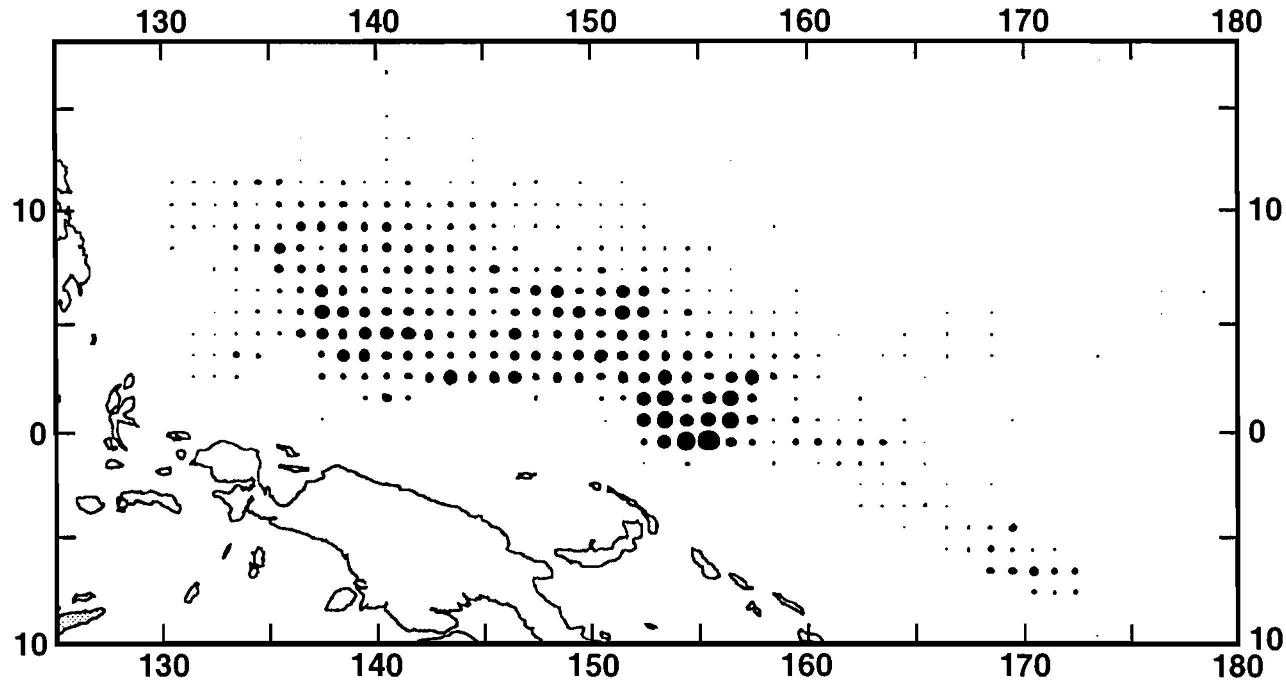

FIGURE 11a. Fishing effort by Japanese purse seiners in the Pacific Ocean during 1995 (after Lawson, 1996: Figure 50).

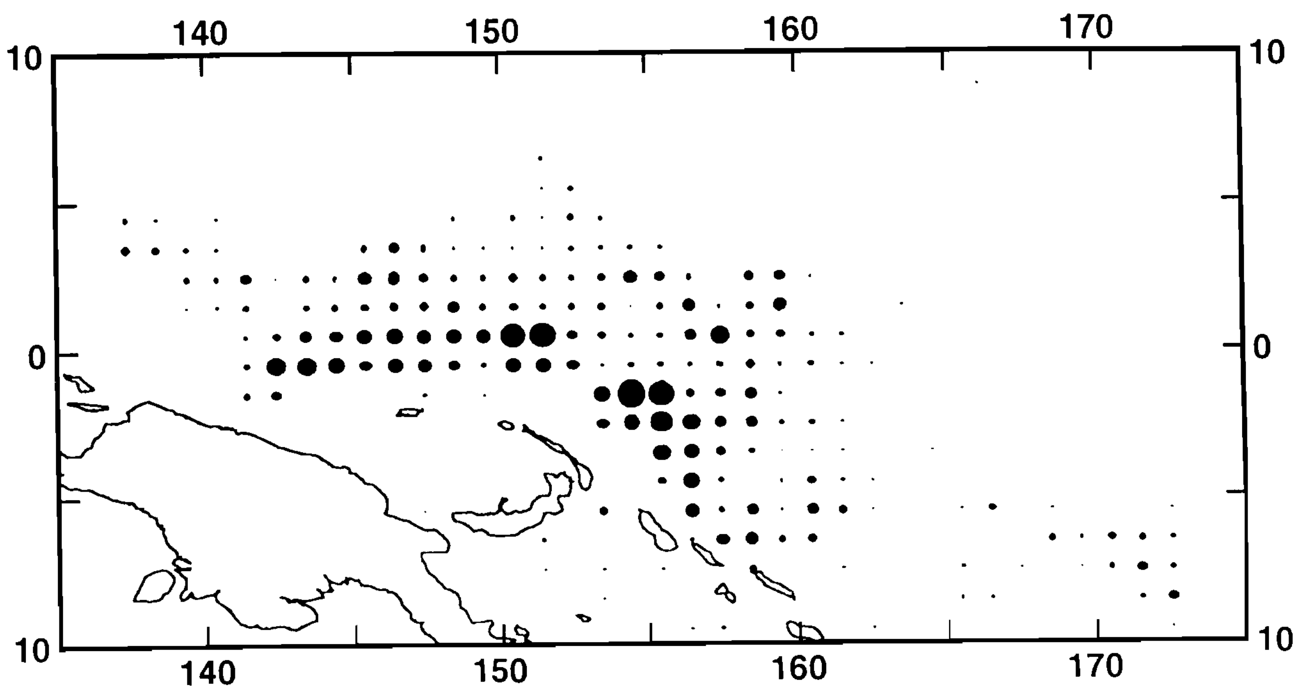

FIGURE 11b. Fishing effort by Korean purse seiners in the Pacific Ocean during 1995 (after Lawson, 1996: Figure 53).

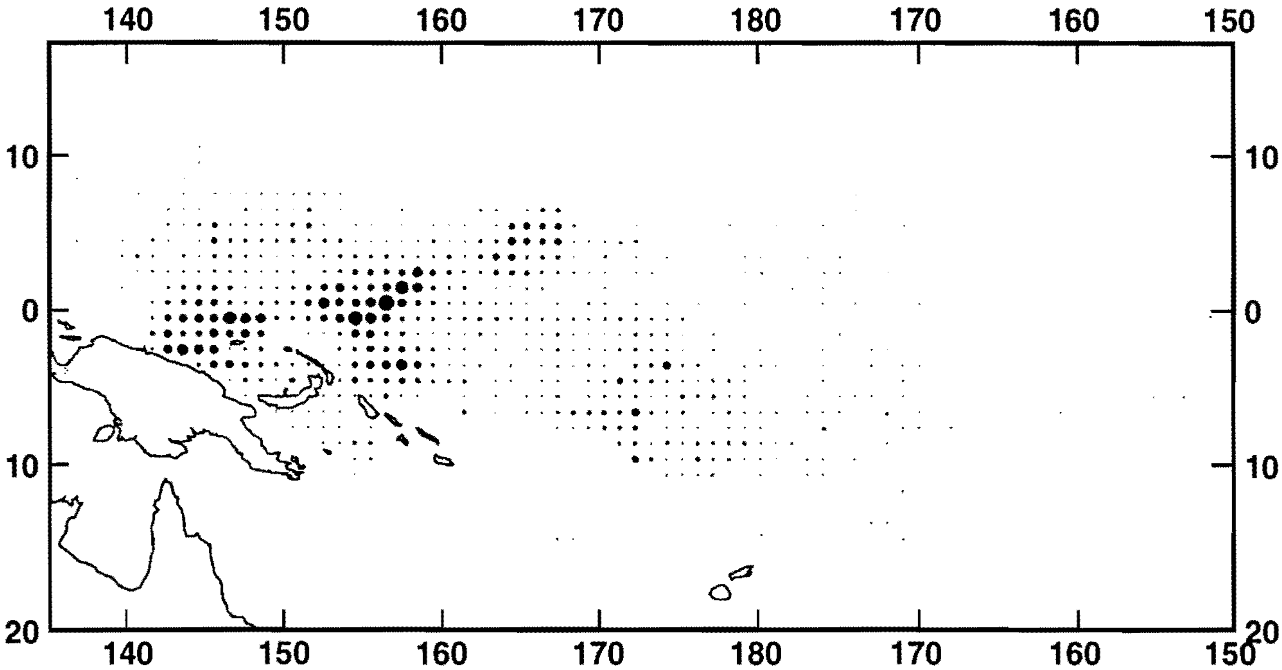

FIGURE 11c. Fishing effort by U.S. purse seiners in the Pacific Ocean during 1995 (after Lawson, 1996: Figure 63).

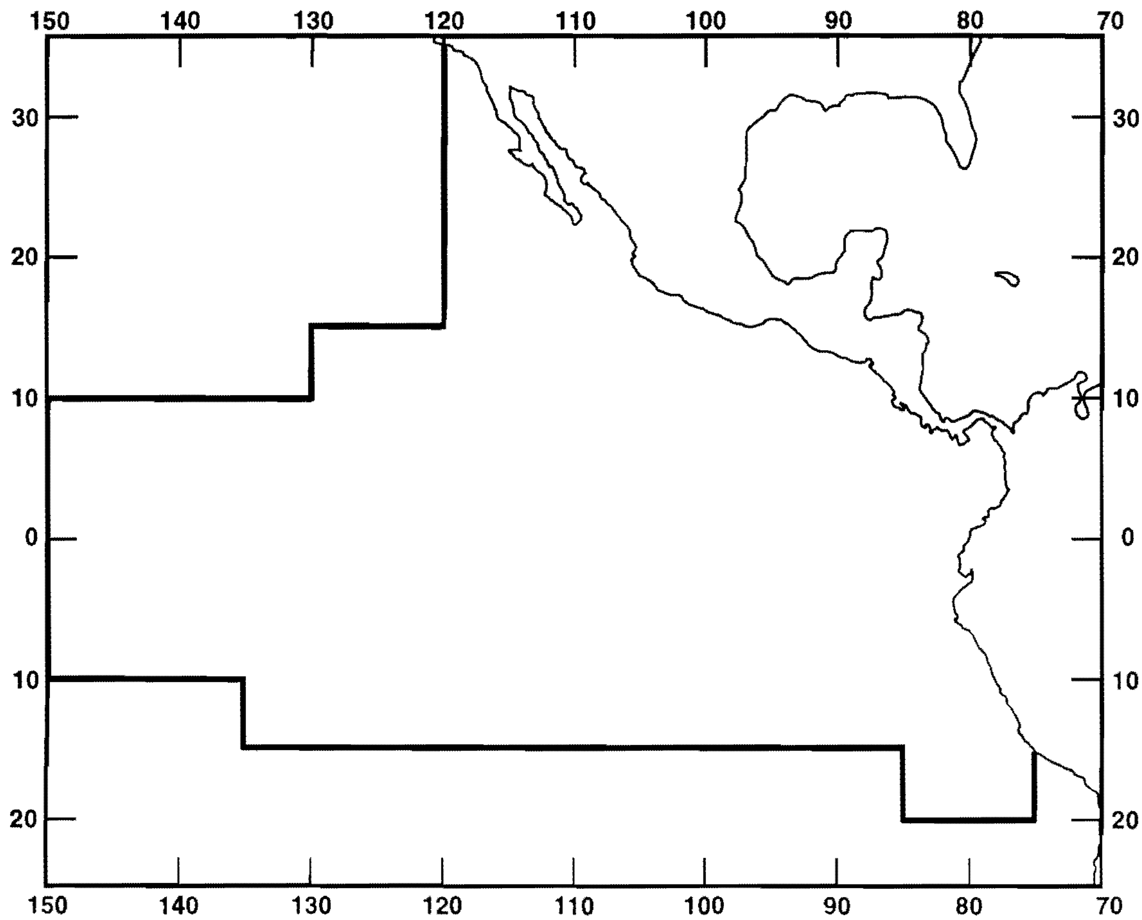

FIGURE 12. Area in which most of the purse-seine effort in the eastern Pacific Ocean takes place.

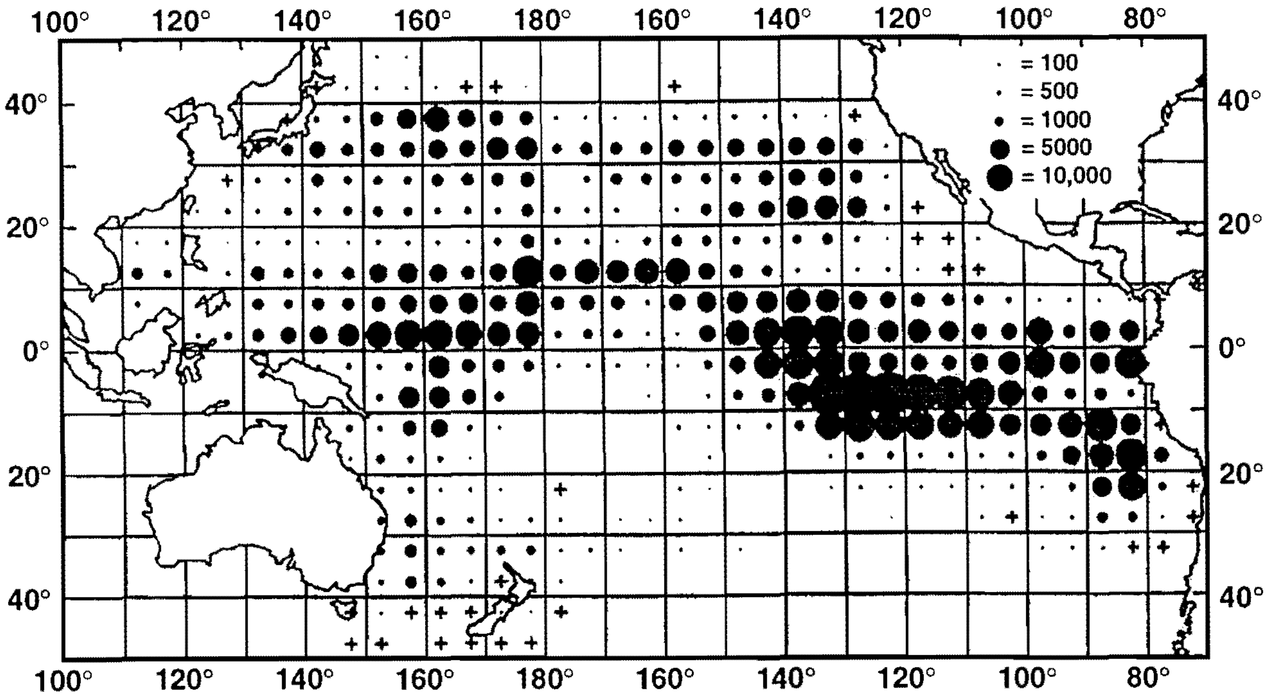

FIGURE 13. Catches of bigeye tuna by Japanese longliners in the Pacific Ocean during 1990-1994.

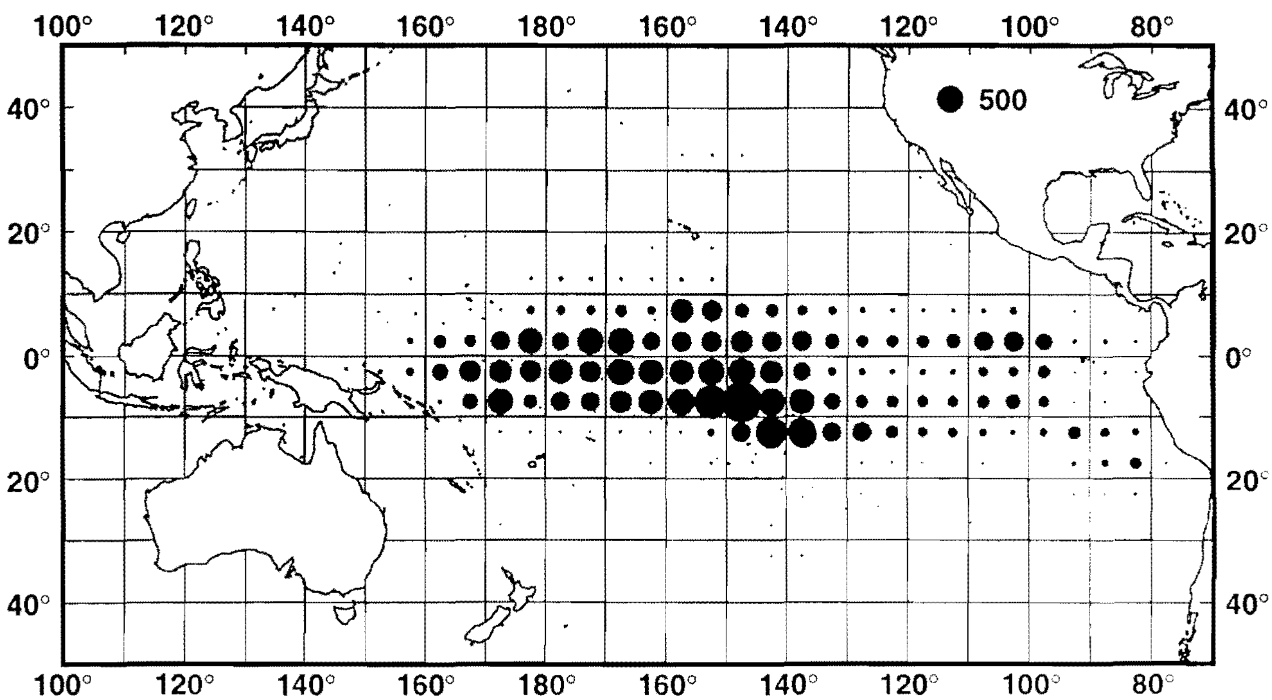

FIGURE 14. Catches of bigeye tuna by Korean longliners in the Pacific Ocean during 1989-1992.

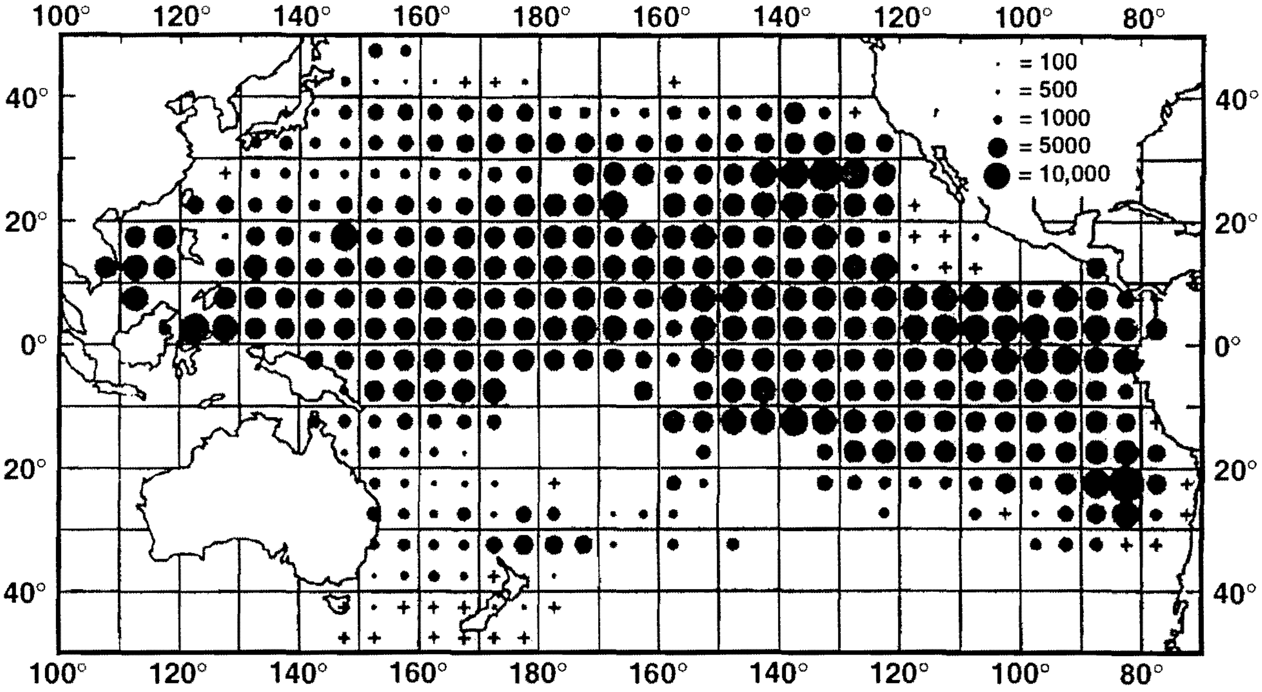

FIGURE 15. CPUEs of bigeye tuna by Japanese longliners in the Pacific Ocean during 1990-1994.

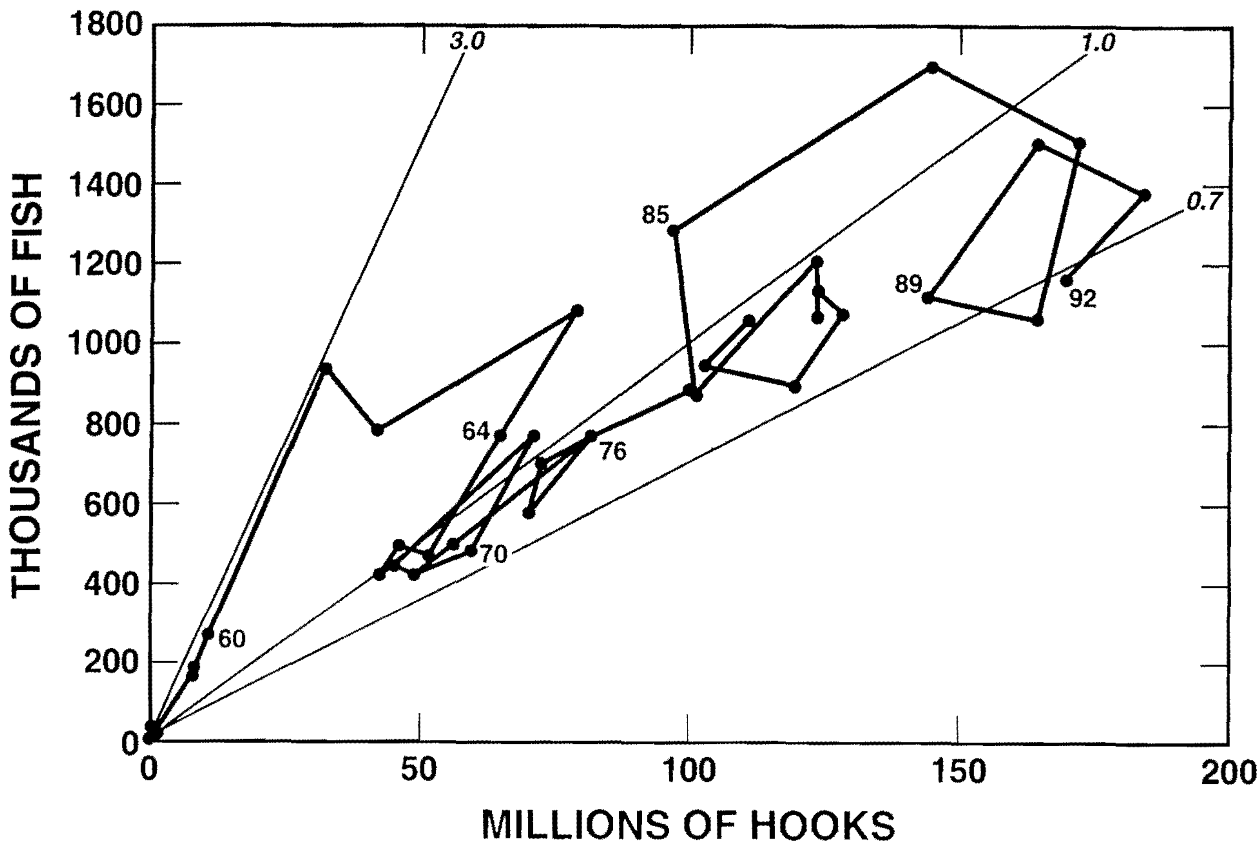

FIGURE 16. Relationship between estimated catch of bigeye tuna by longliners and fishing effort in the equatorial eastern Pacific Ocean between 1955 and 1992 (after Uosaki and Bayliff. 1998).

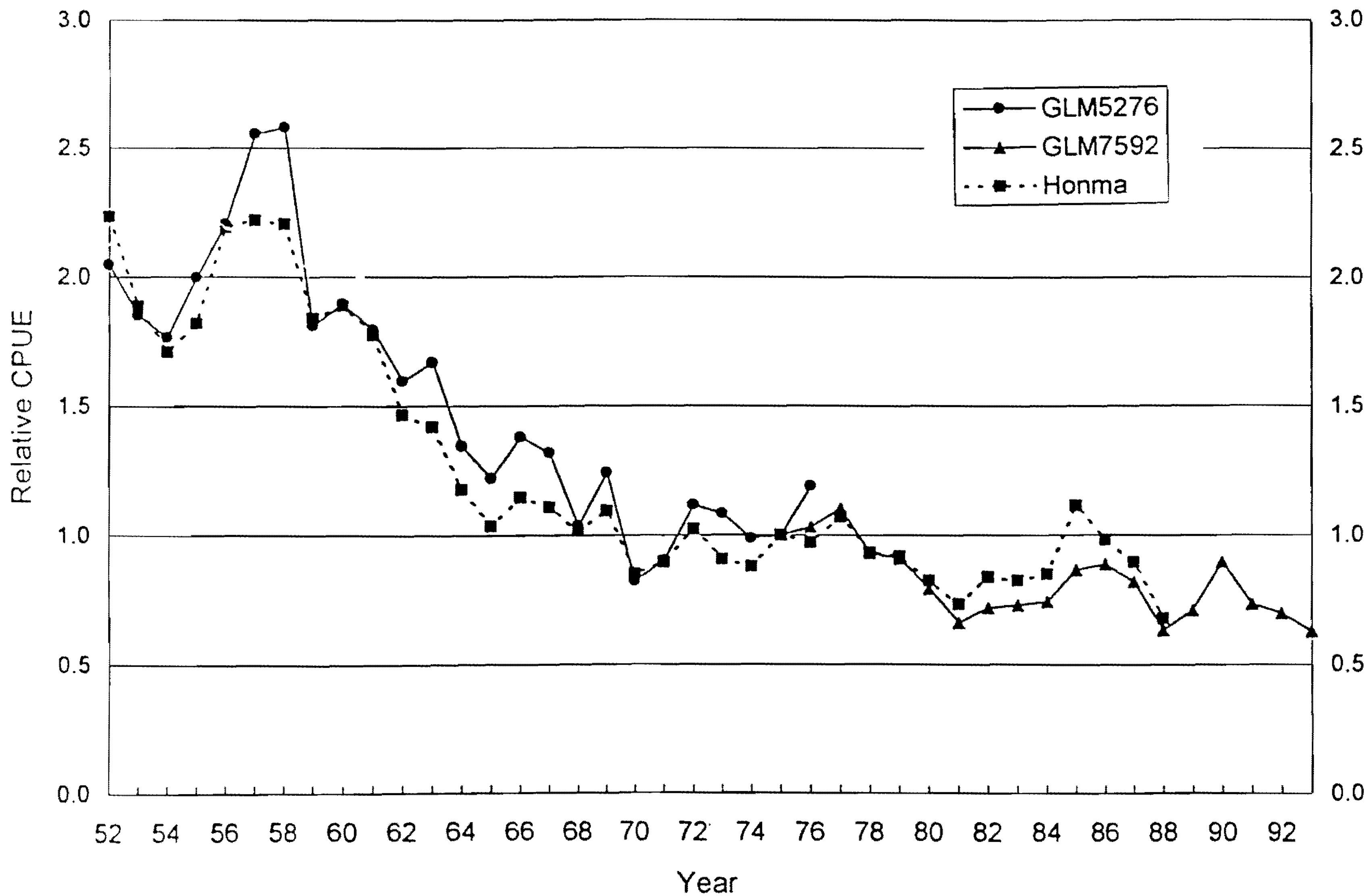

FIGURE 17. Relative CPUEs of bigeye tuna by Japanese longliners in the Pacific Ocean (after Miyabe, 1994c).

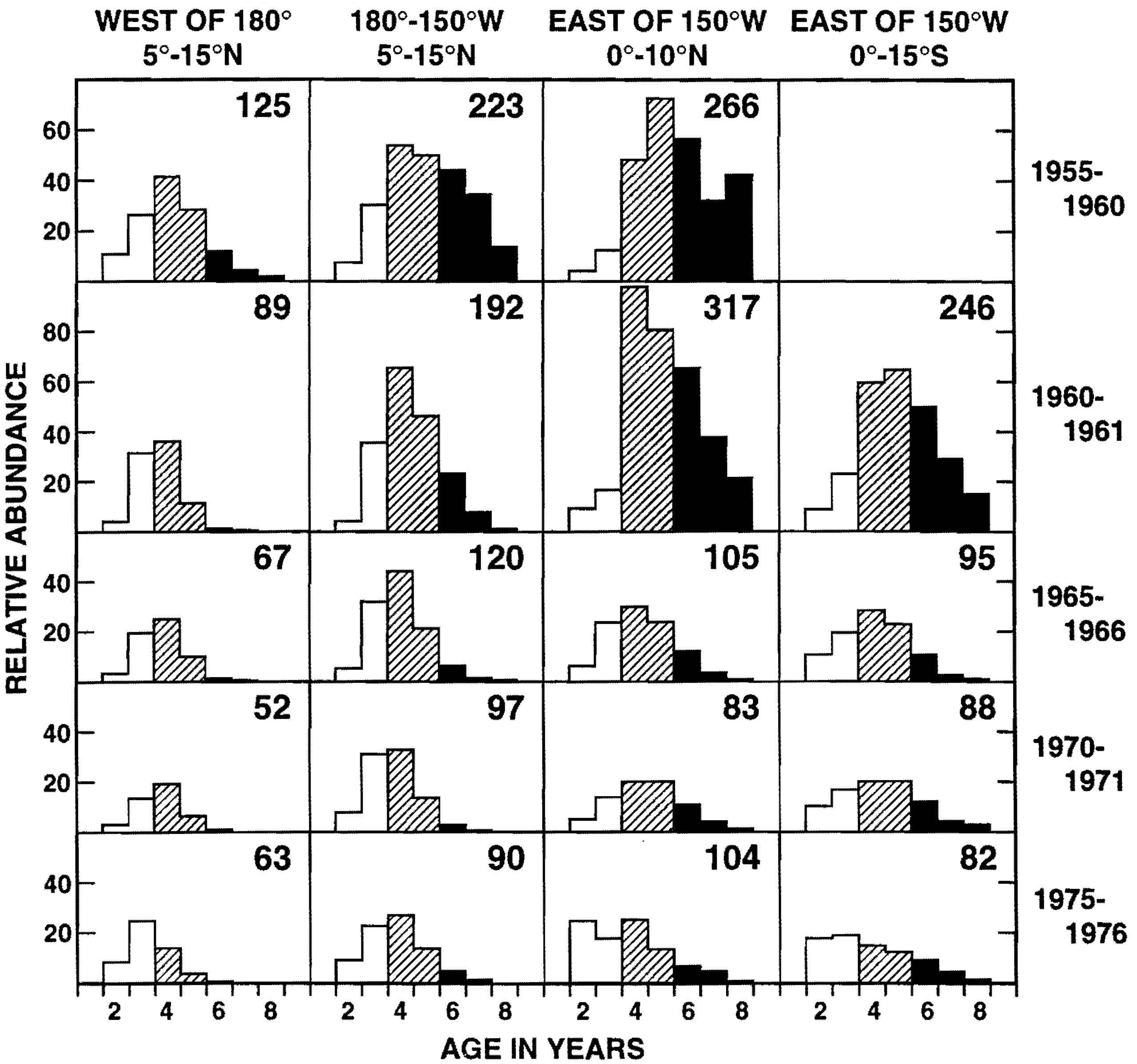

FIGURE 18. CPUEs of bigeye tuna, by age, in four areas of the Pacific Ocean during five 2-year periods (after Kume, 1979a).

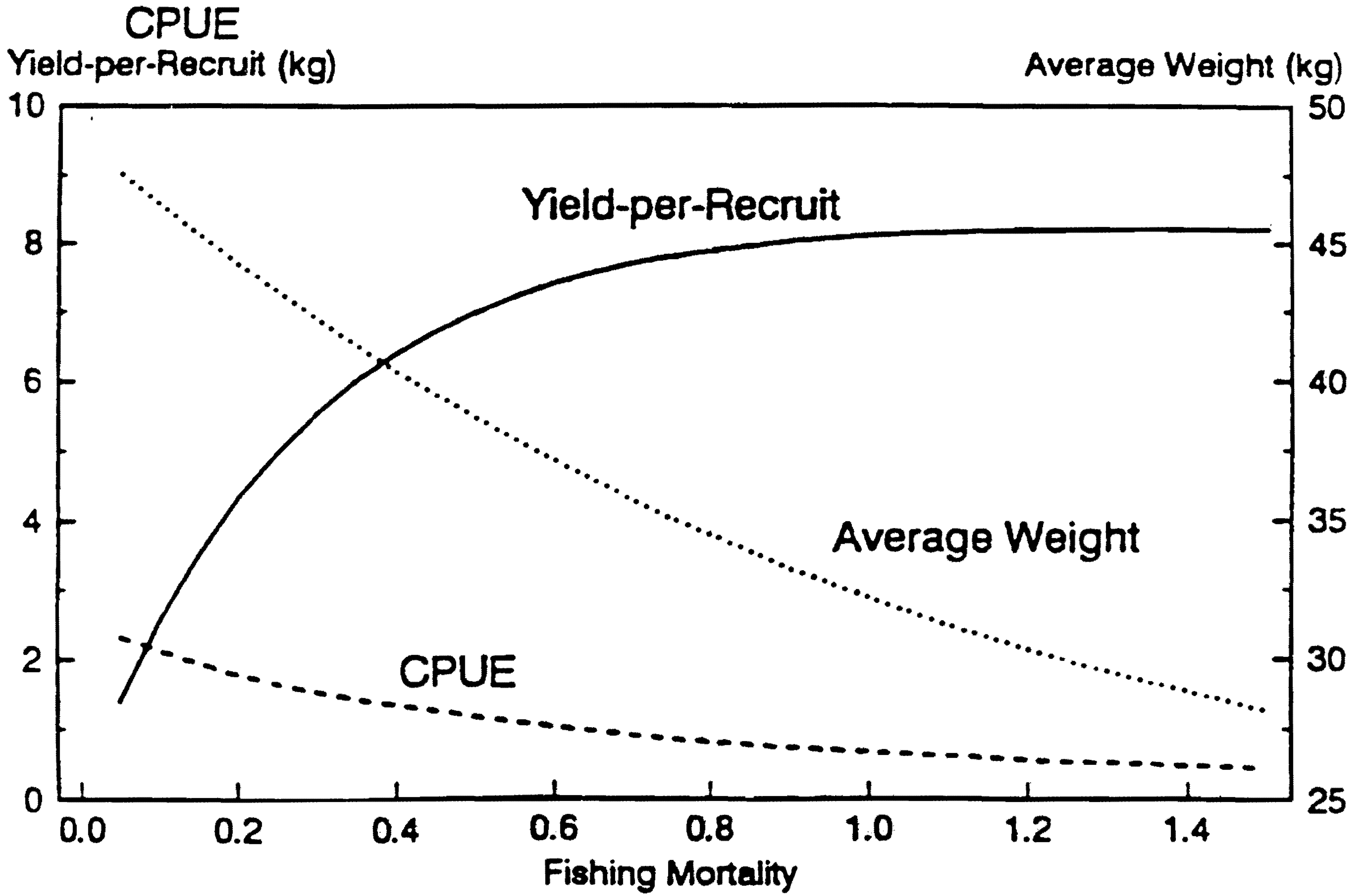

FIGURE 19. Estimated yield-per-recruit relationship for bigeye tuna in the Pacific Ocean (after Miyabe, 1991).

TABLE 1. Estimates of the parameters of the von Bertalanffy growth equation for Pacific bigeye tuna. The lengths were measured from the tip of the snout to the fork of the tail, and the weights are round weights.

Unit	L_∞ or W_∞	K	t_0	Method	Source
Length	215 cm	0.20824	-0.0055	hard parts	Yukinawa and Yabuta, 1963
Weight	234.9 kg (≈221.8 cm)	0.114	1.07	modal progres-sions	Shomura and Keala, 1963 (males)
Length	190.7 cm	0.3239	-0.3274	modal progres-sions	Shomura and Kreala, 1963 (males)
Weight	165.1 kg (≈196.4 cm)	0.167	1.06	modal progres-sions	Shomura and Keala, 1963 (females)
Length	179.3 cm	0.3665	-0.2730	modal progres-sions	Shomura and Keala, 1963 (females)
Length	186.95 cm	0.38	0.5275	modal progres-sions	Kume and Joseph, 1966
Length	214.8 cm	0.2066	-0.0249	modal progres-sions	Suda and Kume, 1967
Length	184.0 cm	0.2536		tagging	Hampton *et al*., 1998 (fish at liberty more than 50 days)
Length	156.82 cm	0.4272	0.528	tagging	Hampton *et al*., 1998 (fish at liberty more than 500 days)

TABLE 2. Estimated lengths of bigeye of various ages estimated from the equations in Table 1 and taken from Tomlinson's (1998) Table 7.

Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Reference
40.6	73.4	100.0	121.6	139.2	153.4	165.0	Yukinawa and Yabuta, 1963
	100.6	126.7	143.7	156.1	165.8	173.5	Shomura and Keala, 1963 (males)
	101.0	126.2	141.7	152.7	161.0	167.4	Shomura and Keala, 1963 (females)
30.7	80.1	113.9	137.0	152.8	163.6	171.0	Kume and Joseph, 1966
40.3	72.9	99.4	120.9	138.4	152.7	164.3	Suda and Kume, 1967
41.2	73.2	98.0	117.3	132.2	143.8	152.8	Hampton *et al*., 1998
	73.2	102.3	121.2	133.6	141.7	146.9	Hampton *et al*., 1998
	73.1	103.6	128.5	145.6	158.0	168.9	Tomlinson, 1998

TABLE 3. Weight-length relationships ($W = aL^b$) estimated for Pacific bigeye tuna. L is the length from the tip of the snout to the fork of the tail in centimeters and W is the round weight in kilograms.

Area	*a*	*b*	Sample size	Length range(cm)	Source
Central Pacific	2.9537×10^{-5}	2.9304			Iversen, 1955
Central Pacific	3.3263×10^{-5}	2.9180	1,832		Kume and Shiohama, 1964
Central Pacific	3.661×10^{-5}	2.90182	9,144	80-190	Nakamura and Uchiyama, 1966
Western North Pacific	1.3504×10^{-5}	3.1056	4,121		Kume and Shiohama, 1964
Western equatorial Pacific	1.7265×10^{-5}	3.0475	2,538		Kume and Shiohama, 1964
Western Pacific	1.9731×10^{-5}	3.0247	481	46-164	Morita, 1973
Eastern and central Pacific	1.9793×10^{-5}	3.0216	15	66-173	Morita, 1973
Philippines	4.786×10^{-5}	2.94430	27	112-186	Ronquillo, 1963 (males)
Philippines	1.721×10^{-5}	2.74669	28	105-170	Ronquillo, 1963 (females)

TABLE 4. Recapture records of tagged bigeye tuna at liberty for long periods. The lengths were measured in centimeters from the tip of the snout to the fork of the tail, and the distances are given in nautical miles. LL: longline, HL: handline.

Release			Recapture				Distance	Days free	Direction	Reference
Area	Date	Length	Area	Date	Length	Gear				
30°59'N 171°14'W	Jan. 31, 1955	122.3	32°41'N 155°57'W	Nov. 24, 1955	126.8	LL	785	298	82	1
30°59'N 171°14'W	Jan. 31, 1955	109.0	29°50'N 177°50'W	Feb. 2, 1956	127.5	LL	348	368	259	2
32°59'N 143°19'E	May 31, 1955	82	29°15'N 133°45'E	Nov. 11, 1959	110-115	LL	182	597	324	2
32°59'N 143°19'W	May 31, 1955	81	35°27'N 141°10'W	Jan. 17, 1960	119	LL	182	597	324	2
3°18'N 90°50'W	May 6, 1967	80	2°12'S 81°01'W	Jan 13, 1968	?	?	664	253	117	3
3°18'N 90°50'W	May 12, 1967	50	4°32'N 107°50'W	Jun. 18, 1969	128.0	?	1,020	769	274	4
1°01'S 157°18'E	Dec. 30, 1981	42	2°-4°N 152°-157°E	Feb. 15-Mar. 18, 1986	126	LL	200-700	1,508-1,539	330-360	5
15°06'S 146°13'E	Nov. 16, 1986	96	16°35'S 146°56'E	Oct. 29, 1987	112	HL	129	345	148	6
15°06'S 146°13'E	Nov. 19, 1986	109	7°10'S 155°40'W	Feb. 6, 1990	160	LL	3,408	1,292	89	6
15°06'S 146°13'E	Nov. 19, 1986	108	16°26'S 146°49'E	Feb. 11, 1987	127	HL	110	349	148	6
15°16'S 146°08'E	Nov. 21, 1986	78	3°25'S 171°19'W	Jun. 17, 1989	131	LL	2,591	940	79	6
15°16'S 146°08'E	Nov. 21, 1986	98	16°25'S 146°43'E	Jan. 11, 1987	124	HL	94	346	143	6
15°06'S 146°13'E	Nov. 19, 1986	?	2°S 160°E	Dec. 27, 1991	160.0	LL	1,133	1,865	46	

1. Otsu and Uchida, 1956
2. Kume, 1967
3. Calkins, 1980: Table 1
4. Anonymous, 1970: 28
5. FSFRL, 1988
6. Ward, Peter, Fisheries Resources Branch, Bureau of Rural Resources, Australia, personal communication.

TABLE 5. Food consumed by bigeye tuna in the Pacific Ocean. The values in parentheses are percentages of the volumes of food in the stomachs.

Area	Gear	Length range	Food consumed	Source
western Pacific	longline		fish - mostly Chiasmodontidae, Alepisauridae, Paralepididae, and Acinaceidae crustaceans - mostly decapods and amphipods molluscs - all squid and octopi tunicates - all salps	Watanabe, 1958
central Pacific	longline	<140 cm	fish (70.1) - mostly Bramidae and Gempylidae molluscs (27.5) - mostly squid crustaceans (2.3)	King and Ikehara, 1956
central Pacific	longline	=>140 cm	fish (58.2) - mostly Bramidae, Gempylidae, and Thunnidae molluscs (40.3) - mostly squid crustaceans (1.4)	King and Ikehara, 1956
eastern Pacific	longline	991-1814 mm	fish (37.6) squid (45.6) - including *Dosidicus gigas* decapods (16.8) - including *Euphylax dovii*	Juhl, 1955
eastern Pacific	longline	83-184 cm	fish (21.6) - mostly Trachipter-dae, Gempylidae, and Thunnidae molluscs (63.2) - mostly squid, especially *Dosidicus gigas* crustaceans (15.1) - mostly decapods, especially *Euphylax dovii*	Blunt, 1960
eastern Pacific	baitboat	839-1375 mm	fish (85) - mostly Thunnidae, Exoceotidae, Sciaenidae, and Trichiuridae squid (5) crustaceans (9) - mostly decapods unidentified material - (1)	Alverson and Peterson, 1963

TABLE 6. Batch fecundity of bigeye tuna (number of eggs spawned per day) (after Nikaido *et al*., 1991).

Length in centimeters	Off Java	Offshore southwest of Hawaii	Length in centimeters	Off Java	Offshore southwest of Hawaii
100	0.56×10^6	0.40×10^6	150	2.85×10^6	2.19×10^6
110	0.83×10^6	0.60×10^6	160	3.69×10^6	2.87×10^6
120	1.17×10^6	0.86×10^6	170	4.70×10^6	3.69×10^6
130	1.61×10^6	1.20×10^6	180	5.90×10^6	4.69×10^6
140	2.16×10^6	1.64×10^6			

TABLE 7. Numbers of longliners of various nations fishing for tunas in the western Pacific Ocean (after Anonymous, 1996b: Table D1). FSM stands for Federated States of Micronesia, and DW stands for distant-water. Hyphens indicate unavailable data, and the data in parentheses are estimates.

Year	Australia	China	Cook Islands	FSM	Fiji	French Polynesia	Indonesia	Japan		Korea	Marshal Islands	New Caledonia	Philippines	Solomon Islands	Taiwan		Tonga	USA	Western Samoa	Total
								Coastal	DW						Coastal	DW				
1970	-	-	-	-	-	-	-	890	1,553	105	-	-	-	-	829	-	-	45	-	3,422
1971	-	-	-	-	-	-	-	908	1,562	122	-	-	-	-	863	-	-	46	-	3,501
1972	-	-	-	-	-	-	-	940	1,431	178	-	-	-	-	899	-	-	42	-	3,490
1973	-	-	-	-	-	-	-	959	1,428	222	-	-	-	2	1,255	-	-	32	-	3,898
1974	-	-	-	-	-	-	-	518	1,516	270	-	-	-	-	1,451	-	-	33	-	3,788
1975	-	-	-	-	-	-	-	720	1,418	253	-	-	-	-	1,411	92	-	31	-	3,925
1976	-	-	-	-	-	-	-	827	1,396	257	-	-	-	2	1,331	194	-	33	-	4,040
1977	-	-	-	-	-	-	-	726	1,428	217	-	-	-	2	1,382	176	-	35	-	3,966
1978	-	-	-	-	-	-	-	669	1,480	223	-	-	-	2	1,670	168	-	29	-	4,241
1979	-	-	-	-	-	-	-	648	1,495	216	-	-	-	2	1,840	157	-	21	-	4,379
1980	-	-	-	-	-	-	-	821	1,520	211	-	-	-	2	1,900	182	-	11	-	4,647
1981	-	-	-	-	-	-	-	774	1,522	209	-	-	-	2	1,846	140	-	13	-	4,506
1982	-	-	-	-	-	-	-	722	1,356	121	-	-	61	2	1,831	115	1	10	-	4,219
1983	-	-	-	-	-	-	-	561	1,270	102	-	1	62	2	1,872	65	1	18	-	3,954
1984	-	-	-	-	-	-	-	523	1,288	96	-	2	62	2	1,944	61	1	23	-	4,002
1985	-	-	-	-	-	-	28	620	1,299	94	-	3	55	2	2,129	44	1	23	-	4,298
1986	-	-	-	-	-	-	63	536	1,260	134	-	2	41	0	2,084	51	1	21	-	4,193
1987	64	-	-	-	-	-	79	661	1,217	138	-	3	62	0	2,207	60	1	37	-	4,529
1988	62	-	-	-	-	-	70	586	1,192	124	-	4	27	0	1,977	70	1	50	-	4,163
1989	93	-	-	-	4	-	138	650	1,159	152	-	4	3	0	1,671	85	1	80	-	4,040
1990	98	-	-	-	6	-	151	685	1,153	182	-	7	26	0	1,139	96	1	138	-	3,682
1991	82	34	-	2	9	-	145	768	1,122	220	-	6	(12)	0	800	82	1	143	-	(3,426)
1992	98	72	-	6	18	19	141	793	1,070	166	4	4	10	0	1,898	92	1	129	-	4,521
1993	79	319		7	21	49	309	790	1,039	148	5	4	10	0	1,791	119	7	124	2	4,823
1994	80	461	2	10	37	66	293	(790)	(1,039)	160	4	6	(10)	0	(1,753)	(70)	9	(127)	2	(4,919)

TABLE 8. Numbers of tuna longliners of various sizes registered in Japan. The data were obtained from MAFFJ (1978-1990).

Year	20-50 GT	50-100 GT	100-200 GT	>200 GT	Total
1977	86	658	72	612	1,428
1978	87	707	69	617	1,480
1979	69	720	82	624	1,495
1980	57	715	103	645	1,520
1981	55	706	100	661	1,522
1982	43	634	90	589	1,356
1983	38	593	89	550	1,270
1084	32	546	100	610	1,288
1985	28	534	109	628	1,299
1986	25	471	132	632	1,260
1987	23	398	147	649	1,217
1988	21	368	154	649	1,192
1989	20	334	152	653	1,159

TABLE 9. Numbers of baitboats of various nations fishing for tropical tunas in the western Pacific Ocean (after Anonymous, 1996: Table D3). DW stands for distant-water. Hyphens indicate unavailable data, and the data in parentheses are estimates.

Year	Australia	Fiji	French Polynesia	Indonesia	Japan		Kiribata	New Caledonia	New Zealand	Palau	Papua New Guinea	Solomon Islands	Tuvalu	Total
					Coastal	DW								
1970	-	-	-	-	3,148	512	-	-	-	10	5	-	-	3,675
1971	-	-	-	-	3,168	510	-	-	-	20	29	-	-	3,727
1972	-	-	-	-	3,596	554	-	-	-	11	45	-	-	4,206
1973	-	-	-	-	3,020	650	-	-	-	12	43	11	-	3,736
1974	-	-	-	-	3,225	716	-	-	-	24	47	11	-	4,023
1975	-	-	-	-	2,648	696	-	-	-	21	48	12	-	3,425
1976	9	2	-	-	3,101	653	-	-	-	33	40	14	-	3,852
1977	-	6	-	-	3,348	662	-	-	-	23	51	20	-	4,110
1978	14	6	-	-	3,035	645	-	-	-	26	48	20	-	3,794
1979	-	8	-	-	3,480	625	1	-	-	21	45	21	-	4,201
1980	-	11	46	-	3,232	572	-	-	-	31	50	22	-	3,964
1981	-	12	51	-	3,064	548	2	1	-	36	44	23	-	3,781
1982	20	14	46	-	3,011	475	2	3	-	20	-	25	1	3,617
1983	-	13	46	-	3,021	434	4	3	-	0	-	27	1	3,549
1984	8	11	51	-	3,904	396	4	0	-	0	-	30	1	4,405
1985	-	7	49	1,115	2,754	356	4	0	-	1	-	33	1	4,320
1986	5	6	51	1,287	2,455	330	4	0	-	1	0	35	1	4,175
1987	5	8	64	1,170	2,404	314	4	0	-	1	0	34	1	4,005
1988	18	8	53	1,577	2,613	277	5	0	-	1	0	34	1	4,587
1989	15	8	56	921	2,254	269	6	0	-	1	0	33	1	3,564
1990	17	10	55	900	2,228	255	5	0	-	1	0	33	1	3,505
1991	16	10	31	872	2,277	242	3	0	4	-	0	32	1	3,488
1992	10	11	36	849	2,093	216	3	0	-	1	0	32	1	3,252
1993	10	9	24	823	1,927	203	3	0	-	1	0	27	-	3,027
1994	11	8	70	820	(1,927)	(203)	4	0	-	1	0	27	-	(3,071)

TABLE 10. Numbers of purse seiners of various nations fishing for tropical tunas in the western Pacific Ocean (after Anonymous, 1996: Table D2). FSM stands for Federated States of Micronesia, and DW stands for distant-water. Hyphens indicate unavailable data, and the values in parentheses are estimates.

Year	Australia	FSM	Indonesia	Japan		Korea	Mexico	New Zealand	Philip-pines		Russia	Solomon Islands	Taiwan	USA	Total
				Coastal	DW				Coastal	DW					
1970	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1971	-	-	-	23	6	-	-	-	-	-	-	-	-	-	29
1972	-	-	-	31	7	-	-	-	-	-	-	-	-	-	38
1973	-	-	-	37	6	-	-	-	-	-	-	-	-	-	43
1974	-	-	-	42	10	-	-	-	-	-	-	-	-	-	52
1975	-	-	-	42	12	-	-	-	-	-	-	-	-	-	54
1976	-	-	-	43	15	-	-	-	-	-	-	-	-	3	61
1977	-	-	-	50	14	-	-	-	-	-	-	-	-	1	65
1978	-	-	-	47	14	-	-	-	-	-	-	-	-	2	63
1979	-	-	-	46	17	-	-	-	-	-	-	-	-	8	71
1980	-	-	-	50	16	2	-	-	570	-	-	1	-	14	653
1981	-	-	-	50	23	3	-	-	697	-	-	1	-	14	788
1982	-	-	-	52	33	10	-	-	785	(1)	-	1	-	24	(906)
1983	-	-	-	59	36	11	-	7	686	0	-	1	-	62	862
1984	-	-	3	54	33	12	2	5	712	(3)	-	1	5	61	(891)
1985	-	-	3	47	35	11	-	5	724	(5)	5	1	5	40	(881)
1986	-	-	3	53	38	13	-	-	685	(5)	8	1	11	36	(853)
1987	-	-	3	47	34	20	-	-	813	(5)	5	2	15	35	(979)
1988	3	-	3	48	39	23	-	-	779	(9)	5	4	24	32	(969)
1989	1	-	3	43	37	30	-	-	198	(14)	5	4	22	35	(392)
1990	9	-	3	43	35	39	-	-	549	(13)	5	4	31	43	(774)
1991	4	6	3	38	35	36	-	-	546	(15)	4	3	40	43	(773)
1991	3	7	3	31	38	36	-	-	407	(14)	3	3	43	44	(632)
1993	3	7	3	27	36	34	-	-	(399)	(14)	8	3	43	42	(619)
1994	4	6	3	(27)	(36)	32	-	-	(399)	(14)	4	3	43	49	(620)

TABLE 11. Numbers of purse seiners of various nations fishing for tropical tunas in the eastern Pacific Ocean (from Anonymous, 1971a-1997a and Hinton and ver Steeg, 1994: Table 7). "Others" includes vessels registered in Belize, Bermuda, the Cayman Islands, the Congo, Cyprus, France, Japan, the Federated States of Micronesia, Korea, Liberia, the Netherlands Antilles, New Zealand, Portugal, Russia, Senegal, Spain, St. Vincent and the Grenadines, and the USSR. The numbers are slightly inflated because vessels which change their countries of registry are counted under each country during the years in which the changes were made. The data for 1996 are preliminary.

Year	Canada	Colombia	Costa Rica	Ecuador	El Salvador	Honduras	Mexico	Nicaragua	Panama	Peru	United States	Vanuatu	Venezuela	Others	Total
1970	7	0	0	13	0	0	12	0	3	1	121	0	0	2	159
1971	6	0	3	14	0	0	18	0	4	3	124	0	0	6	178
1972	8	0	4	15	0	0	14	0	5	5	127	0	0	11	189
1973	8	0	4	16	0	0	18	0	6	24	133	0	1	13	223
1974	8	0	2	19	0	0	21	0	11	8	135	0	0	12	216
1975	6	0	2	22	0	0	20	0	9	7	142	0	1	19	228
1976	5	0	2	27	0	0	25	2	9	9	155	0	1	18	253
1977	5	0	6	28	0	0	24	2	8	11	142	0	3	20	249
1978	6	0	7	48	0	0	23	2	6	10	140	0	3	24	269
1979	6	0	11	41	0	0	28	2	5	10	144	0	4	23	274
1980	1	0	9	41	0	0	47	0	6	10	132	0	5	23	274
1981	1	0	3	36	2	0	52	0	10	2	131	0	7	16	260
1982	1	0	4	29	2	0	43	0	5	0	124	0	5	12	225
1983	1	0	1	29	0	0	50	0	4	5	104	0	7	3	204
1984	1	0	1	26	0	0	48	0	1	0	75	0	11	3	166
1985	0	0	1	30	0	0	54	0	3	0	75	2	13	3	181
1986	0	0	1	30	1	0	45	0	4	0	65	3	15	3	167
1987	0	0	1	28	2	0	54	0	6	3	54	6	25	1	180
1988	0	0	1	33	2	0	55	0	6	0	60	6	25	2	190
1989	0	0	1	34	1	0	52	0	8	0	51	8	21	2	178
1990	0	1	1	34	0	1	52	0	7	1	46	11	24	1	179
1991	0	3	0	33	0	1	49	0	6	1	24	11	21	3	152
1992	0	3	0	35	0	0	58	0	7	0	20	11	17	4	155
1993	0	6	0	33	0	0	50	0	5	0	25	12	18	3	152
1994	0	10	0	37	0	0	53	0	5	0	27	12	18	4	166
1995	0	10	1	46	0	0	56	0	6	0	20	14	19	3	175
1996	0	10	1	47	0	1	58	0	6	0	22	12	20	5	182

TABLE 12. Numbers and capacities of purse seiners and baitboats of all nations fishing for tunas in the eastern Pacific Ocean. The vessel size classes, based on fish-carrying capacity, are as follows: 1, <51 short tons (st) (46 metric tons (mt)); 2, 51-100 st (46-91 mt); 3, 101-200 st (92-181 mt); 4, 201-300 st (182-272 mt); 5, 301-400 st (273-363 mt); 6, >400 st (363 mt).

Gear	Size class	1955	1960	1965	1970	1975	1980	1985	1990	1995
Purse seine	1	15	16	18	0	8	11	4	2	0
	2	12	5	12	13	24	18	22	18	19
	3	51	56	39	24	33	32	18	17	25
	4	2	32	43	33	25	25	10	6	19
	5	0	16	29	27	17	20	6	6	11
	6	0	2	22	65	146	164	117	123	101
	Total	80	127	163	162	253	270	177	172	175
Baitboat	1	13	45	81	22	44	16	6	8	5
	2	11	9	9	12	30	17	8	6	10
	3	46	29	14	10	27	9	10	8	5
	4	71	16	4	4	1	4	1	0	0
	5	31	15	1	1	0	0	0	0	0
	6	11	3	0	0	0	0	0	0	0
	Total	183	117	109	49	102	46	25	22	20

TABLE 13. Catches of bigeye, in thousands of tons, in the Pacific Ocean (after Anonymous, 1996b (Tables F1-F5) , Tomlinson, 1998 (Table 1), and Anonymous, 1998a (Table 6)). Hyphens indicate unavailable data, and the data in parentheses are estimates. The values in Column 7 represent mostly surface (baitboat and purse-seine) catches, but also some catches of fish taken with handlines well below the surface. The values in the next-to-last column are the sums of those in Columns 8 and 15, and those in the last column are from Anonymous (1998a: Table 6).

Year	Western Pacific							Eastern Pacific							Total	Total (FAO)
	Longline					Other gear	Total	Longline					Surface	Total		
	Japan	Korea	Taiwan	Other	Total			Japan	Korea	Taiwan	Other	Total				
1970	0.6	(2.2)	2.8	-	(5.5)	0.2	(5.8)	31.8	-	-	-	31.8	1.3	33.1	(38.9)	84
1971	30.2	(8.8)	3.5	-	(42.5)	0.4	(42.9)	29.2	-	-	-	29.2	2.6	31.8	(74.7)	66
1972	40.2	(14.7)	4.9	-	(59.8)	2.7	(62.5)	34.7	-	-	-	34.7	2.2	36.9	(99.4)	88
1973	28.7	(16.7)	5.7	>0	(51.2)	1.8	(52.9)	51.0	-	-	-	51.0	2.0	53.0	(105.9)	90
1974	32.5	(27.2)	4.2	-	(63.9)	1.8	(65.7)	35.3	-	-	-	35.3	0.9	36.2	(101.9)	88
1975	31.4	(13.5)	5.2	-	(50.2)	2.3	(52.5)	41.2	0.6	-	-	41.8	3.7	45.5	(98.0)	103
1976	40.8	(20.2)	3.0	>0	(63.9)	4.7	(68.7)	49.5	1.1	0.4	-	51.0	10.2	61.2	(129.9)	129
1977	42.2	(16.0)	2.6	>0	(60.9)	4.6	(65.5)	67.4	3.3	0.3	-	71.0	7.1	78.1	(143.6)	145
1978	34.2	(7.9)	2.8	>0	(45.0)	5.9	(50.8)	67.3	3.0	0.2	-	70.5	11.7	82.2	(133.0)	122
1979	38.9	(12.4)	3.3	>0	(50.7)	4.2	(58.9)	55.0	0.8	0.2	-	56.0	7.5	63.5	(122.4)	129
1980	36.9	11.5	4.1	>0	52.6	3.6	56.3	55.6	2.0	0.7	-	58.3	15.4	73.7	130.0	132
1981	30.9	4.9	2.4	>0	38.2	5.1	43.3	45.2	2.7	0.5	-	48.4	10.1	58.5	101.8	104
1982	35.6	6.1	1.3	>0	43.0	7.6	50.6	41.3	2.4	0.1	-	43.8	4.1	47.9	98.5	109
1983	33.2	4.5	1.1	>0	38.9	6.0	44.9	74.1	4.2	0.1	-	78.4	3.3	81.7	126.6	111
1984	36.7	6.0	1.4	>0	44.1	4.7	48.8	64.1	2.6	0.1	-	66.8	5.9	72.7	121.5	103
1985	38.0	6.9	2.0	>0	46.9	7.0	53.9	65.8	4.9	0.1	-	70.8	4.5	75.3	129.2	124
1986	34.3	3.8	0.9	>0	39.0	5.6	44.6	96.6	10.7	0.1	-	107.4	1.9	109.3	153.9	150
1987	42.4	9.6	1.2	0.9	54.1	6.0	60.1	91.6	10.1	0.4	-	102.1	0.8	102.9	163.0	149
1988	34.3	8.3	1.9	1.2	45.8	3.5	49.4	58.7	5.0	0.4	-	64.1	1.1	65.2	114.6	120
1989	38.3	8.6	1.2	1.5	49.5	9.6	59.2	62.8	2.6	0.6	-	66.0	1.5	67.5	126.5	126
1990	44.2	10.6	1.3	1.5	57.5	8.7	66.2	78.2	10.9	0.4	-	89.5	4.7	94.2	160.4	163
1991	32.5	4.7	1.9	2.2	41.3	7.5	48.7	74.8	20.0	0.4	-	95.2	3.7	98.9	147.6	144
1992	38.2	10.9	4.1	3.2	56.5	11.2	67.6	62.3	7.2	0.6	-	70.1	5.5	75.6	143.2	153
1993	30.1	9.2	3.4	5.7	48.4	11.7	60.1	54.8	-	-	-	-	8.1	-	-	129
1994	(30.1)	12.3	4.8	9.5	(56.8)	9.2	65.9	52.9	-	-	-	-	29.4	-	-	141
1995	-	-	-	-	-	-	-	40.0	-	-	-	-	36.9	-	-	127

TABLE 14. Estimates of the parameters of the production models for bigeye tuna in the Pacific Ocean.

Area	Maximum sustainable yield in tons	Coefficient of catchability	Shape parameter	Optimum effort in millions of hooks	Source
entire Pacific Ocean	85,000	3.61×10^{-9}		152,450,000	Suda, 1970b
entire Pacific Ocean	100,000-106,000		0.0		Kume, 1979b
entire Pacific Ocean	167,000		0.0	∞	Miyabe, 1991
entire Pacific Ocean	130,000		2.0		Miyabe, 1991
entire Pacific Ocean	108,147	5.1×10^{-4}			Miyabe, 1994c (method of Hilborn and Walters, 1992)
entire Pacific Ocean	65,850-120,400	1.2×10^{-7}-8.9×10^{-7}			Miyabe, 1994c (method of Prager, 1994)
entire Pacific Ocean	119,000-120,000	8.0×10^{-4}-94×10^{-4}			Miyabe, 1995
Pacific Ocean west of 160°W	39,000-40,000	6.6×10^{-3}-9.7×10^{-3}			Miyabe, 1995
Pacific Ocean east of 160°W	65,000-87,000	0.6×10^{-3}-1.9×10^{-3}			Miyabe, 1995
Pacific Ocean east of 150°W	66,400		0.8	230,900,000	Tomlinson, 1998 (“best” estimate of optimum effort)
Pacific Ocean east of 150°W	92,200		0.8	400,000,000	Tomlinson, 1998 (effort set at 400,000,000 hooks)

BIGEYE TUNA (*THUNNUS OBESUS*) AND THE TUNA FISHERIES OF FRENCH POLYNESIA

by

François Xavier Bard[1], Erwan Josse[1], and Arsène Stein[2]

1. INTRODUCTION

French Polynesia has a wide Exclusive Economic Zone (EEZ), established in October 1979, stretching over 4.8 million km² in the South Pacific, in which most species of tropical tunas and tuna-like species are fished, at the surface or in subsurface waters. The main commercial species are:

- Yellowfin tuna (*Thunnus albacares*), caught at the surface and in subsurface waters;
- Bigeye tuna (*Thunnus obesus*), caught only in subsurface waters;
- Albacore tuna (*Thunnus alalunga*), caught only in subsurface waters;
- Blue marlin (*Makaira mazara*), caught at the surface and in subsurface waters;
- Skipjack tuna (*Katsuwonus pelamis*), caught only at the surface;
- Wahoo (*Acanthocybium solandri*), caught only at the surface.

Other istiophorids (*Tetrapturus audax*, *T. angustirostris*, and *Istiophorus platypterus*) are also caught at the surface and in subsurface waters. Swordfish (*Xiphias gladius*) is present, but uncommon. Minor tunas such as black skipjack (*Euthynnus affinis*) and dogtooth tuna (*Gymnosarda unicolor*) are present, but not actively sought.

There is a long tradition of coastal tuna fishing in French Polynesia. Historically, fishermen in canoes have fished for deep-swimming tunas, using handlines made of vegetable fibers, hooks made of wood and mother-of-pearl, and chunks of fish or live fish for bait. Sinking the line was achieved with a stone, around which the line was initially coiled. The fish, caught in precise fishing spots known as "tuna holes," were mainly yellowfin and *mana* (*Prometichthys prometheus*). This "stone fishery," which uses small boats with outboard engines, locally called *poti marara,* and modern lines and hooks, which generally operate close to fish-aggregating devices (FADs) moored in the vicinity of the larger islands (Moarii and Leproux, 1996), but tuna holes are sometimes fished as well. The catch still consists of yellowfin, but albacore is now important because the handlines are operating deeper than in the past (Abbes *et al.*, 1994). Very few bigeye are caught by this fishery.

Alongside this modernized traditional fishery, a fishery targeting skipjack, using locally-built Chriscraft called *bonitiers*, has developed since World War II, with much success (Brun and Klawe, 1968). The catches of the bonitiers catches consist mainly of skipjack, but include lesser quantities of small yellowfin and dolphinfish (*Coryphaena hippurus*). The fishing method used is a jigline rigged with a barbless hook tied on a traditional lure made of mother-of-pearl. This fishery was the most important supplier of tuna for the local market for several decades, but since 1990 the development of monofilament longlining has caused it to decline. Recently the number of active *bonitiers* has stabilized because prices of fresh skipjack have increased, and the fishery now seems economically viable.

The use of monofilament longlines stems from a fishery which originated in Hawaii. The gear consists of a main line made of synthetic fiber, 3 to 4 mm in diameter and up to more than 40 nautical miles long, on which

[1] ORSTOM, B.P. 529, Papeete, Tahiti, French Polynesia
[2] EVAAM, B.P. 20, Papeete, Tahiti, French Polynesia

branch lines and hooks are attached with a "snap." Setting the line begins just before dawn, and retrieving is done in the evening. French Polynesian longliners are of various sizes, with the largest over 25 m. Such large vessels can set 1,500 to 2,000 hooks per day, and can stay at sea for several weeks. This fishery started in 1990 and developed rapidly, favored by strong demand in local fresh-fish market. The fleet is now quite large, and stabilized at 60 longliners in 1996. The species caught vary according to fishing grounds, seasons, and the depth at which the hooks are set. The main targets are yellowfin, albacore, bigeye and billfishes. Very recently, experimental fishing for swordfish at night, setting the longline close to the surface, was successful.

Since the Japanese began expanding their traditional longline fishery in the 1950s, Asian-flag longliners have operated in the South Pacific, targeting yellowfin, albacore and bigeye. Recently, bigeye tuna has been actively sought by "super freezer" longliners which supply the high-priced *sashimi* market in Japan. In the French Polynesian EEZ these long-range longliners, mainly Japanese and Korean, operate under license. Taiwanese vessels have not been allowed to fish since 1980, and since 1992 the Japanese fleet has not applied for licenses, so now only Korean longliners operate.

The purpose of this paper is to summarize the data, statistics, and biological information collected on these various fisheries inside and around the French Polynesian EEZ, with emphasis on bigeye tuna. The prospects of developing a French Polynesian longline fishery targeting bigeye in the northern part of the EEZ are discussed.

2. CATCHES

Table 1 presents the best estimates of the French Polynesian tuna catches for 1954-1995, obtained from various sources. It is not complete, particularly for the earlier years, as fishermen operating in coastal waters are not required to report their catches. The quantities of skipjack and small yellowfin sold at the Papeete Market are a good estimator of the total catches by *bonitiers* in French Polynesia, as shown by the data provided by a surey made in 1976-1978 and 1980-1992. Catches by *poti marara* are recorded only by some fishermen's unions. Extrapolation to the whole of French Polynesia yields estimates ranging from 200 to 500 MT per year of tunas and other large pelagic fish, mainly albacore, yellowfin and dolphinfish.

The catches of French Polynesian longliners include several species of tunas, billfish and some other species of minor importance. Sharks are generally discarded at sea, with some exceptions for mako shark (*Isurus oxyrinchus*). Catches increased steadily with of the entry of new vessels. The greatest annual catch was 2,650 MT in 1994, and preliminary estimates for 1996 are over 3,000 MT. The goal is to reach a steady production of 11,000 MT per year in the future. The bulk of the catch is sold fresh or frozen on the French Polynesian market, with some exports to Japan, Hawaii, and France. It is hoped that such exports can be increased in the future.

Reporting catches has been a condition for licensing for foreign longliners since 1980; figures for earlier years are estimates. Currently the quota is negotiated with Korea, as Japan has not sought access to the EEZ since 1992. Catches by foreign longliners are estimated to have reached 7,000-8,000 MT per year in the past; current catches are moderate.

3. DISTRIBUTION OF EFFORT, CPUE AND ABUNDANCE INDICES

3.1. French Polynesian vessels under French flag

There are no reliable statistics of effort by coastal craft, because of the multiplicity of landing points and the absence of legal obligations. A partial survey of some landing points has provided some sparse data, which will be improved. Surveys were conducted in some years, but these are difficult to maintain for financial reasons.

Fishery statistics for the French Polynesian longline fleet are not yet complete. These should be stratified by size of vessel and areas fished to compute effective effort. However, data on overall nominal effort are available, computed on the basis of the quantities of frozen bait imported and converted to number of hooks (one herring = one hook), as follows:

Year	Number of longliners	Number of hooks (millions)
1990	2	0.07
1991	8	0.65
1192	25	0.95
1993	50	3.65
1994	66	5.00
1995	65	5.90

3.2. Foreign flags

Fishery statistics for licensed longliners operating in the French Polynesian EEZ are heterogeneous. They include:

(i) Since 1980, Fishing Announcements, transmitted by radio to the French authorities on a weekly basis, expressed in day's fishing and weight of fish caught, by species. The geographical positions reported cover several days, and therefore are not very precise.

(ii) Since 1984, daily records in fishing logbooks, including precise data on geographical positions and catches, in numbers and weights of fish, by species, and effort, in numbers of hooks. These data should be sent by mail by the boat-owner's company, but only a fraction is received (Josse, 1992; Thiriez, 1995).

Fishery statistics for longliners operating outside the EEZ are available on a 5°x5° square basis, as follows:

- Taiwan: 1967-1992, by month;
- Korea: 1975-1987, by month, and 1988-1992, by quarter;
- Japan: 1962-1981, by month.

4. SPATIAL DISTRIBUTION OF CPUE IN THE EEZ

Using a combination of the detailed statistics available from foreign longliners, averaged over the 1984-1992 period, it has been possible to make maps of the catches per unit of effort (CPUEs), in kilograms of tuna per 100 hooks (Chabannes *et al*, 1993). Maps of such CPUEs for albacore are presented in Figure 1, and in Figure 2 for bigeye, and yellowfin. Albacore is the most abundant tuna south of 11°S; bigeye and yellowfin are more abundant north of that latitude, but clearly bigeye is found further offshore than yellowfin, which is concentrated around the islands in the north, and also in the central EEZ.

A map of the CPUE of bigeye caught by the French Polynesian longliners (Figure 3) shows that this fleet is fishing the same areas, but with less success. One possible reason is the fact that fishing trips in the northern part of the EEZ are not easy, even for the relatively-large French Polynesian longliners, since there is no suitable harbor for unloading in the Marquesas Islands.

5. SPECIFIC INFORMATION ON BIGEYE

5.1. Quality of the fishery statistics

Figure 4, provided by Dr. A. Fonteneau, shows clearly a continuity of the concentration of bigeye tuna caught in the northern part of the EEZ with the major fishing concentration of bigeye in the South Pacific, centered at roughly 10°S and 130°W. Bigeye caught on this particular fishing ground, which are called *seiki* by the Japanese fishermen, are considered to be of prime quality for *sashimi,* (Ashenden and Kitson, 1987). Consequently, fishing effort is believed to be high in this area. It is important for French Polynesia to have access to accurate fishery statistics in waters adjacent to its EEZ, as the fisheries are sharing a common resource. The quality of such statistics can be assessed as follows:

5.1.1. Foreign flags

In the EEZ itself, fishery statistics for the foreign longliners operating on bigeye concentrations in the north are apparently correct, and there is no reason to suspect misreporting of species, as higher prices are received for bigeye. However, as explained above, such statistics are not fully reported in logbooks on a daily basis by all the longliners operating in the EEZ, so there is a problem of rate of coverage, which could be estimated by comparing radio reports to the available logbooks. Such work was done for the period up to 1992 by Chabannes *et al.* (1993), but must be updated for recent years.

Outside the EEZ, where there is no legal obligation to report, only 5°x5 ° data are available, but not for all years and countries. Access to more precise data, if available, on a 1°x1°-month basis, for instance, would be very useful for two purposes:

(i) Studying in detail the apparent movements of tuna, as reflected by catches, to try to estimate the degree of interaction between fisheries inside and outside the EEZ;

(ii) Exploring the relationship between the fisheries and broad climatic events, such as El Niño-Southern Oscillation, inside and outside the EEZ.

Size frequencies of tuna caught by foreign longliners fishing in French Polynesia are not reported. Size frequencies seem to be recorded on Japanese longliners operating outside the EEZ. It is not clear if longliners operating inside the EEZs of various nations collect size frequencies which pertain to those nations individually.

5.1.2. French Polynesian longliners

The catches of bigeye seem to be correctly reported by large longliners, the only ones able to fish in the Marquesas Islands area, in the northern part of the EEZ. Such vessels unload their catches only at the Papeete Central Auction Market, where the tunas are correctly sorted by species. Minor confusion with yellowfin could exist for small longliners operating around the Society Islands, and particularly Tahiti, at the center of the EEZ, but apparently bigeye is rare in this area.

Size frequencies of bigeye tunas landed at Papeete are recorded by EVAAM (Etablissement pour la Valorisation des Activités Aquacoles et Maritimes). Figures 5a and 5b show size frequencies for 1995 and 1996. These should be raised to the total catch in the near future.

As a partial conclusion, there is a good potential for improving the precision of bigeye fisheries statistics in the EEZ. A combination of data, *e.g.* substitution of size frequencies among fleets by area, could be used for filling the gaps in a common data base.

5.2. Biology and ecology

The data on these topics are collected mainly by experimental fishing, using a longline rigged with depth recorders and hook timers (Josse *et al.*, 1995), conducted by the ORSTOM oceanographic vessel *Alis* within the general framework of program ECOTAP, extending from 1995 to 1997. Various physical oceanographic measurements are collected. Micronectonic pelagic trawl hauls are made regularly on planktonic layers detected with echosounders. The pelagic trawl opening is 15 m high, with 5-mm mesh in the codend, and the net is rigged with a trawl instrumentation system. The available results are as follows.

5.2.1. Environmental conditions

High availability of bigeye in the northern part of the EEZ seems to be linked to the abundance of forage associated with equatorial upwelling. Hydrological conditions are characterized by a sea-surface temperature ranging from 26° to 28°C, a marked thermocline at 100-150 m, and low levels of dissolved oxygen in deeper water, with values decreasing in the thermocline and as low as, or less than, 1 ml/l below the thermocline. Misselis (1996), using cladistic methods, showed two particular seasonal bodies of water, characteristic of bigeye (Figures 6 and 7).

5.2.2. Biology and ecology

Size frequencies of individual bigeye, by sex, caught during 1993 and 1995-1996 are shown in Figure 8. Similar quantities of large males and females can be seen, indicating a similar growth pattern for both sexes, which is not the case for yellowfin and albacore. This observation is not incompatible with the slight dimorphism in growth for very large bigeye shown by Shomura and Kaela (1963). Otoliths are collected from each fish. Determination of the age of the fish, using daily growth increments, has been undertaken by the South Pacific Commission.

The depths at which the tuna bite on the baited hooks have been computed with a new method of modelling the curve formed by a basket of 25 hooks on the monofilament main line between two buoys (Wendling, 1995). Using time-depth recorders (TDRs) at the middle of the basket permits adjustment of the curve, as done previously by Boggs (1992), who used a simple catenary curve. From these data the range of swimming depths of feeding tunas and associated species, summarized in Figure 9, are computed. For bigeye, observed values range from 120 m (26.5°C) to 450 m (9°C), with a mean value of 275 m (15.5°C). These values agree with those reported by Boggs. This indicates a deep feeding habitat for bigeye, shared with some sharks, swordfish, *opah* (*Lampris regius*), and pomfret (*Taractes longipinnis*). Such a habitat agrees with the hypothesis of Suda *et al.* (1969), and with the behavioral thermoregulation shown by Holland *et al.* (1992).

Feeding is studied in two ways:

(i) Observation of daily feeding patterns, using hook timers on the branch lines (Boggs, 1992);

(ii) Identification of stomach contents, compared with micronectonic catches caught by pelagic trawls in the vicinity of the longline set. Also, a continuous recording by echo-integration of the planctonic layers is made during longlining operations. From these, trophic indices will be computed and compared with tuna distribution.

Reproduction is studied by systematic recording of sexual state and weighing the gonads. A gonadosomatic index (GSI) is computed as:

$$GSI = (\text{Gonad weight} \times 10^4) / (\text{Fork length}^3),$$

after Miyabe (1994). Gonad weight is in grams, and fork length in centimeters.

Values for bigeye are displayed in Figure 10. It can be seen that the GSI of females over 100 cm (23 kg) is sometimes 3 or more, which is the generally accepted value for the GSI which indicates sexual maturity of tunas. Consequently, the Marquesas Islands area could be a spawning ground for bigeye. It is likely that the spawning area extends to the main fishing concentrations north and east of the Marquesas Islands (Figure 4).

An unexpected occurrence of young bigeye was observed north of the Marquesas Islands near 5°S, 140°W in January 1996, when 77 young bigeye associated with 7 young yellowfin were caught by trolling near a moored TOGA (Tropical Ocean and Global Atmosphere) weather buoy. Unfortunately, there were no conventional tags aboard the vessel, but one fish was tagged with a sonic tag and then tracked. The size frequencies of these fish are shown in Figure 11. A particular feature of all these fish is the unusual size of the swimming bladder, which was fully functional in fish over 40 cm long (Figure 12). This feature, which has not been reported in other areas where young bigeye occur, such as the eastern tropical Atlantic, could be interpreted as an unusual early development of an organ which improves the ability of the fish for diving and chasing in deeper waters, the only apparent source of food in this pelagic ecosystem. A similar feature has been suggested by Pereira (1995 and 1998) for young Atlantic bigeye in the area of the Azores Islands.

6. CONCLUSION

Clearly, a concentration of deep-swimming bigeye exists in the northern part of the French Polynesian EEZ. This concentration is continuous with the important international longline fishing ground east-northeast of the Marquesas Islands. It is a considerable shared resource, currently exploited mainly by the international fleet. The geographical situation of the Marquesas Islands, the land closest to this concentration, is *a priori* very convenient for establishing a flow of *sashimi*-grade tuna toward markets where it is in demand. Such an activity is profitably established in islands of the western central Pacific (Hanmet and Pintz, 1996). Unfortunately, there is currently no good harbor in the Marquesas Islands, and the main airstrip would have to be enlarged for wide-bodied aircraft. However, the government of French Polynesia is aware of this potential.

At the scientific level, it is expected that the ECOTAP program will provide information on the biology, ecology and environmental characteristics of tunas in the EEZ, and that this can be used for optimizing the new French Polynesian fishery. After 1998, studies in tuna fisheries biology will be carried out by EVAAM.

In regard to stock assessment, particularly for bigeye tuna, which seems to be heavily exploited, it is acknowledged that the ranges of most stocks of tunas probably extend over wide areas of the Pacific Ocean. Consequently, collaboration at international level is necessary. Such cooperation is already under way, and scientists from the South Pacific Commission and French Polynesia will work with a future international commission for the conservation of Pacific tunas.

7. REFERENCES

ABBES R., E. JOSSE, J.P. MAMA and S. YEN. 1993. Albacore fishery in French Polynesia. 5th South Pacific Commission Research Workshop, 13 p.

ASHENDEN G.P and G. W. KITSON. 1987 Japanese tuna fishing and processing companies. pp 233-254 *In* The Development of the Tuna Industry in the Pacific Islands Region: an Analysis of Options. East-West Center: D.J. DOULMAN Editor.

BOGGS C. 1992. Depth, capture time, and hooked longevity of longline-caught pelagic fish: timing bites of fish with chips. US Fish. Bull. 90(4): 642-658.

BRUN M. and W.L. KLAWE. 1968. Landings of skipjack and yellowfin tuna at Papeete market (Tahiti). Commer. Fish. Rev., 30(4): 62-63.

CHABANNES J., R. ABBES, and E. JOSSE. 1993. La pêche palangrière asiatique dans la ZEE de Polynésie Française. Analyse des données disponibles pour la période 1984-1992. ORSTOM Tahiti. Arch. Oceano. 93-4, 28 p.

HAMNET M.P. and W.S. PINTZ., 1996. The contribution of tuna fishing and transhipment to the economies of American Samoa, the Commonwealth of the Northern Mariana Islands, and Guam. Pelagic Fisheries Research Program, JIMAR Hawaii 1996.

HOLLAND K., R. BRILL, R. CHANG, J. SIBERT and D. FOURNIER. 1992. Physiological and behavioral thermoregulation in bigeye tuna (*Thunnus obesus*). Nature 358: 410-412.

JOSSE E. 1992. La pêche palangrière japonaise dans la ZEE de Polynésie Française de 1984 à 1990. ORSTOM Tahiti. Arch. Oceano. 92-7., 106 p.

JOSSE E., R. ABBES, P. BACH and B. WENDLING., 1995. Campagne ECOTAPP: Etude du comportement des thonidés par l'acoustique et la pêche à la palangre en Polynésie Française, 22 juin au 18 août 1993. Rapport de la Campagne ECOTAPP, Doc Int ORSTOM-IFREMER-EVAAM, 157 p.

MISSELIS C. 1996. Environnement et variabilité des captures thonières à la palangre. Etude dans la zone economique exclusive polynésienne au Nord de 20°S. Mémoire DAA ENSA Rennes, 94 p.

MIYABE N. 1994. A review of the biology and fisheries for bigeye tuna, *Thunnus obesus*, in the Pacific Ocean. In SHOMURA R.S., J. MAJKOWSKI and S. LANGI (editors), Interactions of Pacific tuna fisheries, FAO Fish. Tech. Pap., 336(2): 207-243.

MOARII G. and F. LEPROUX. 1996. The drop-stone technique used by artisanal fishermen in French Polynesia. SPC Fish Aggregating Device Bull. 1: 16-18.

PEREIRA J.G. 1995. A pesca do atum nos Açores e o atum patudo (*Thunnus obesus*) do Atlantico. Thesis Univ. Açores, 330 p.

PEREIRA, J.G. 1998. Bigeye tunas: the access to deep waters. Inter-Amer. Trop. Tuna Comm., Spec. Rep., 9: 243-249.

SHOMURA R.S. and B. A. KAELA 1963. Growth and sexual dimorphism in growth of bigeye tuna (*Thunnus obesus*). A preliminary report. FAO Fish. Rep 6(3): 1409-1427.

SUDA A., S KUME, and T. SHIHOHAMA. 1969. An indicative note on a role of permanent thermocline as a factor controlling the longline fishing ground for bigeye tuna. Bull. Far Seas Fish. Res. Lab 1: 99-114.

THIRIEZ G. 1995. La pêche palangrière des flottilles japonaise et coréenne dans la ZEE polynésienne au Nord du 16°S. Des sources de données aux analyses de l'activité de pêche et des prises par unité d'effort du thon obèse. (*Thunnus obesus*). Memoire DEA Univ. Française du Pacifique, 43 p.

WENDLING B. 1994. La pêche thonière polynésienne à la palangre monofilament. Comportement de l'engin: aide à la connaissance de la ressource. Mémoire DAA ENSA Rennes, 88 p.

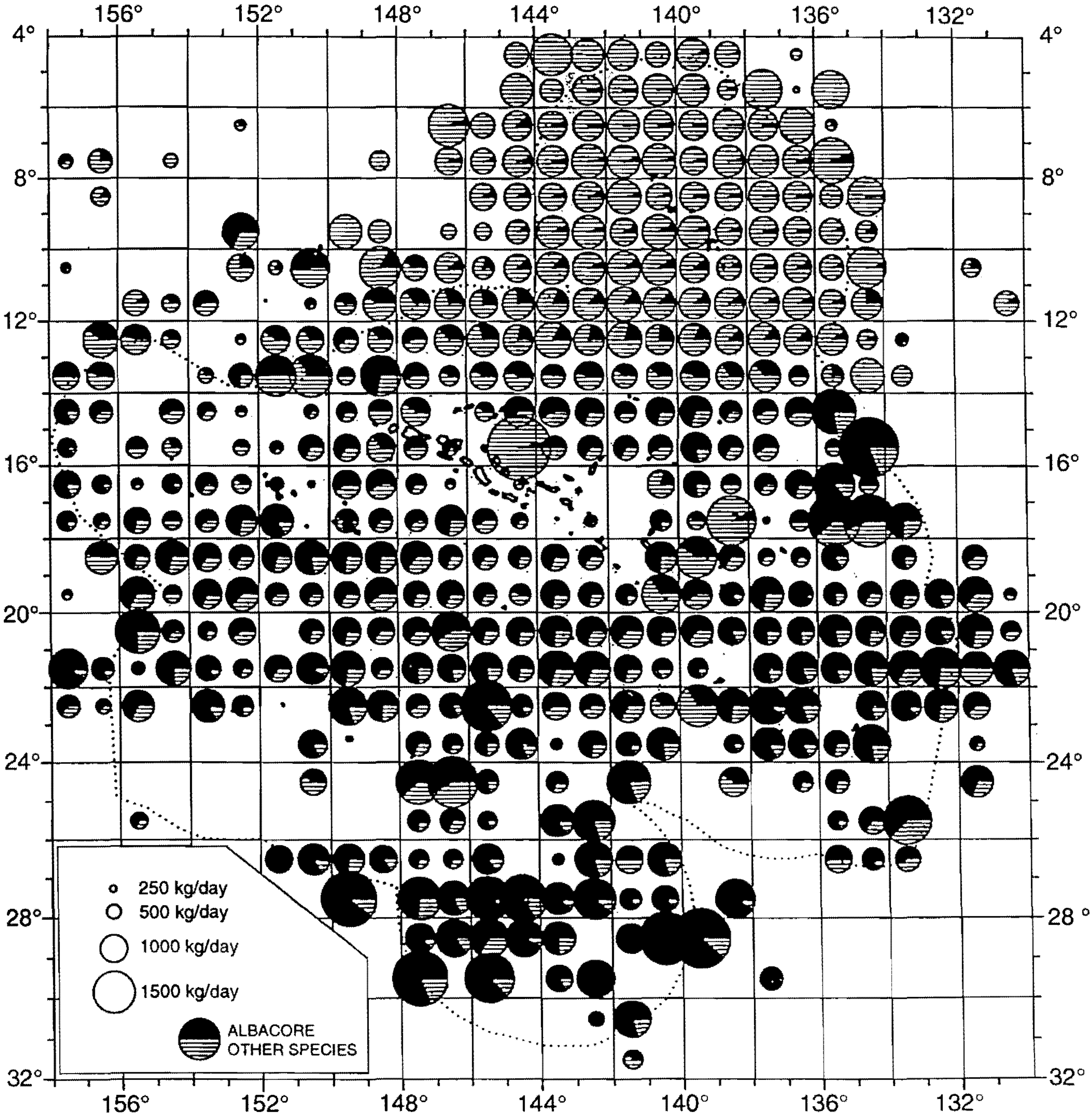

FIGURE 1: Ratios, for Korean longliners, of the CPUEs (kg/day) of albacore to those of all species combined in the EEZ of French Polynesia, computed from the average annual values for 1984-1992.

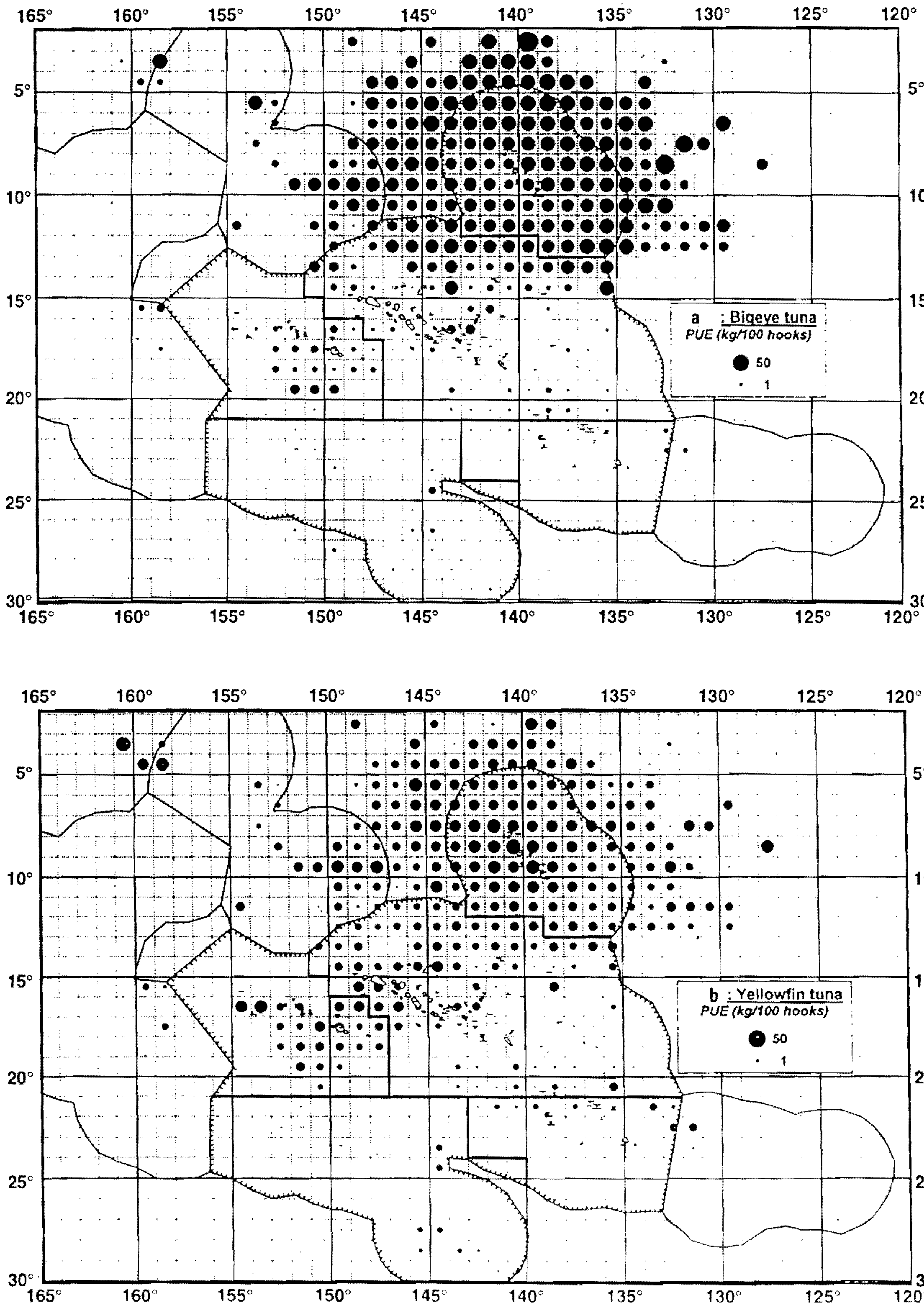

FIGURE 2: Geographical distributions of CPUEs (kg/100 hooks) of bigeye (upper panel) and yellowfin (lower panel) tuna in the EEZ of French Polynesia, computed from the average annual values for Japanese and Korean longliners during 1984-1992.

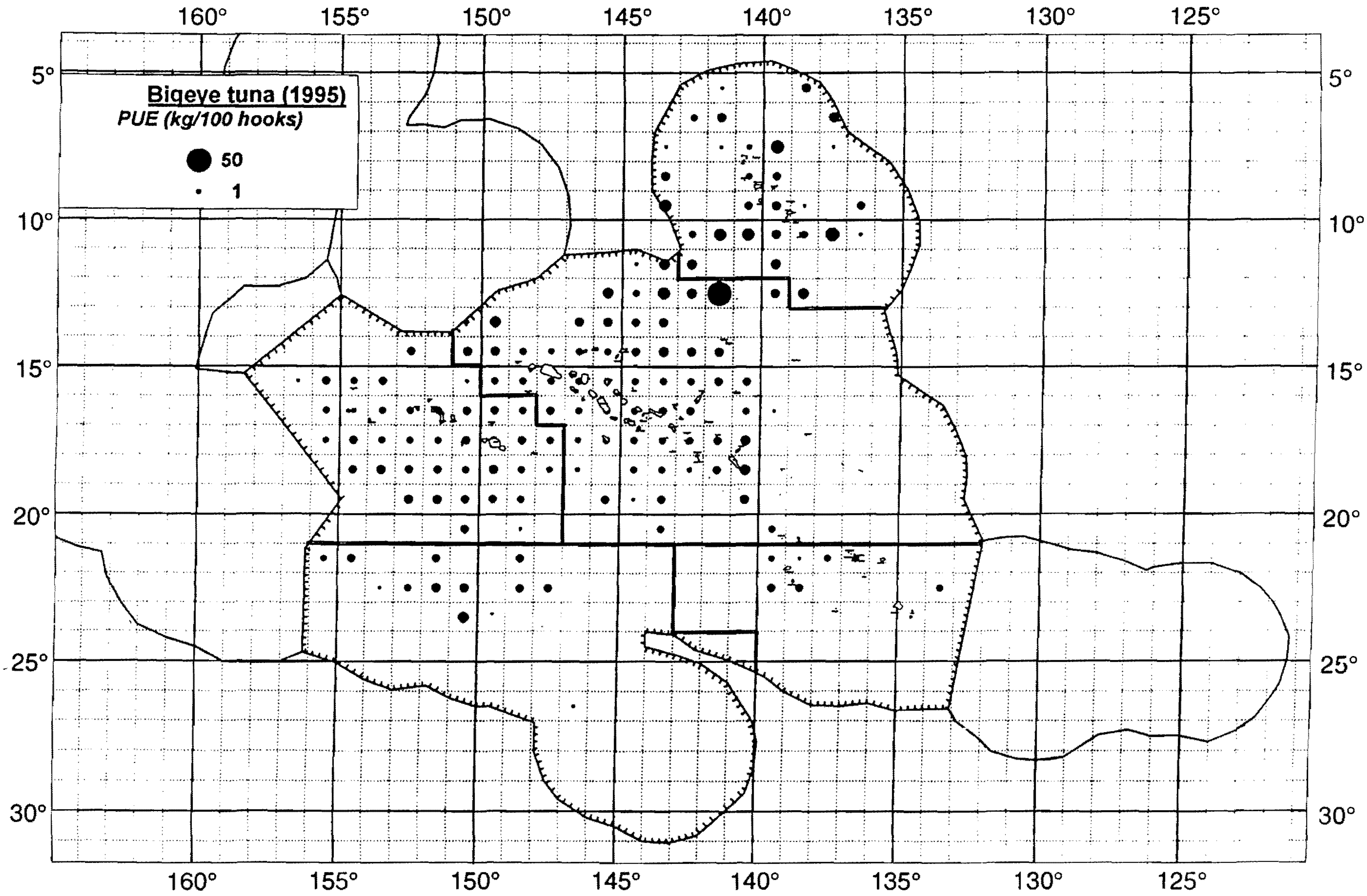

FIGURE 3: Geographical distribution of CPUEs of bigeye tuna for French Polynesian longliners during 1995.

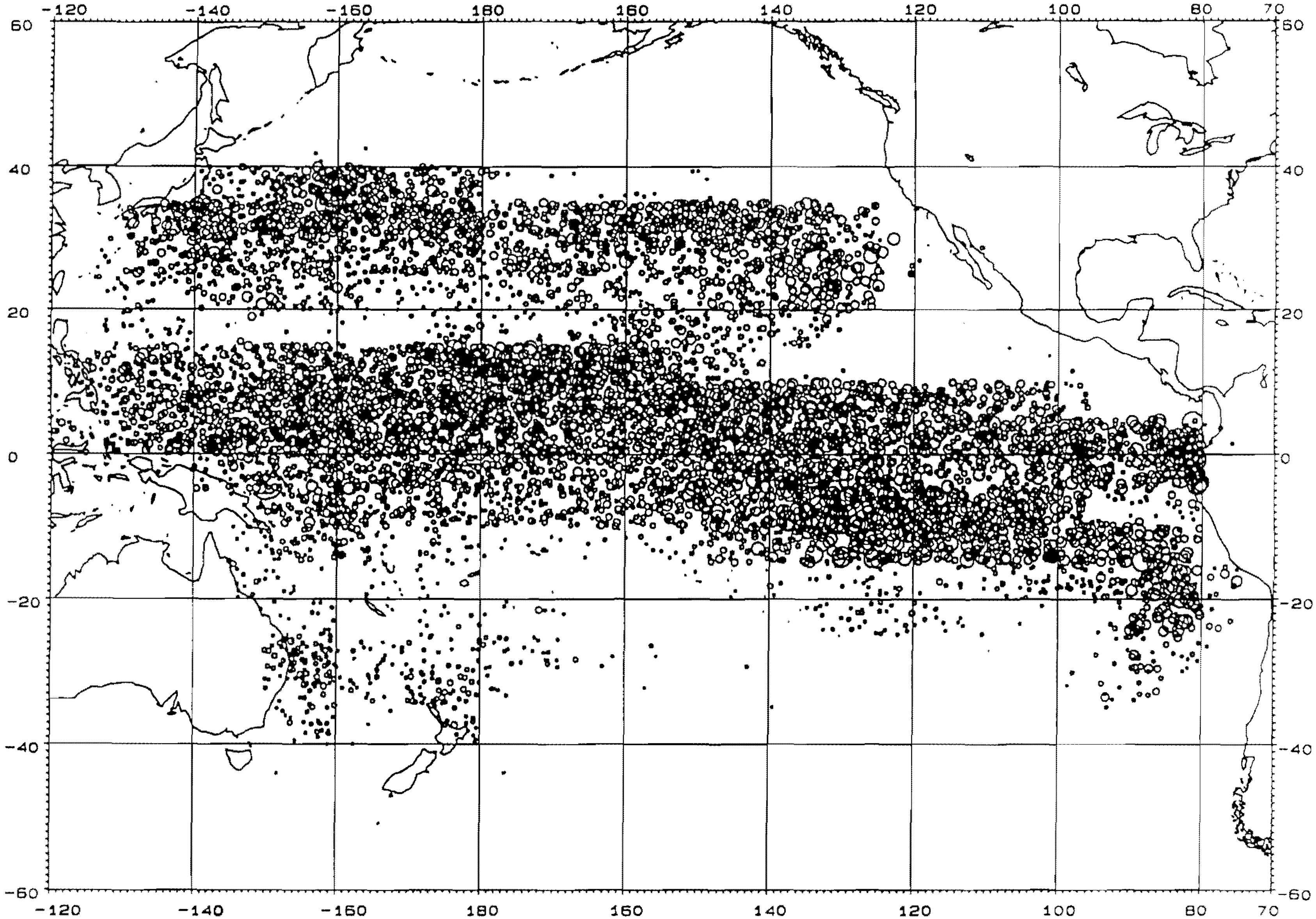

FIGURE 4: Geographical distribution of the total catches of bigeye tuna by all longline fleets in the Pacific Ocean, 1952-1993. Each circle represents a monthly catch, randomly distributed within the reported 5° square. Source: A. Fonteneau, World Tuna Data Base (TUCAW).

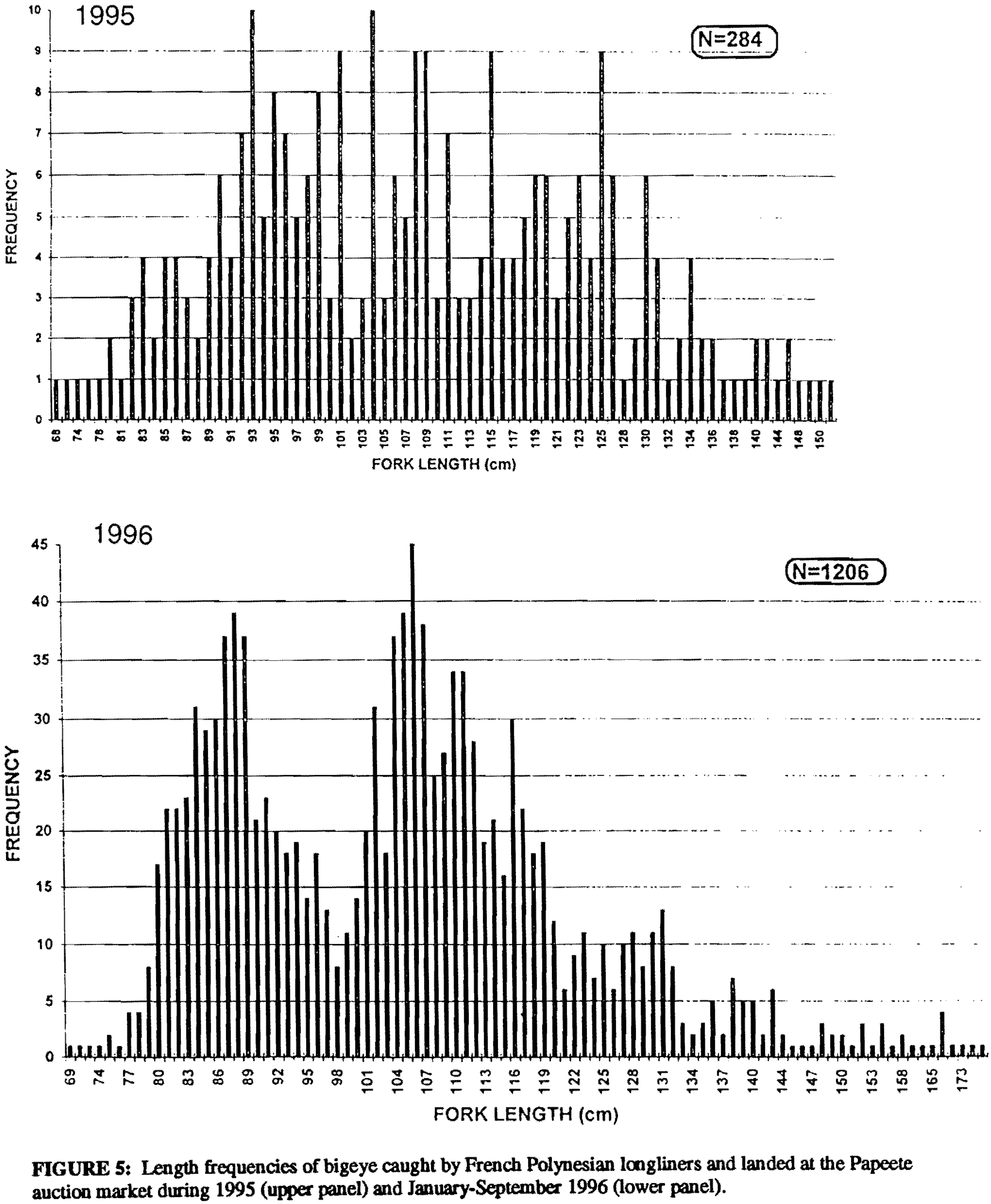

FIGURE 5: Length frequencies of bigeye caught by French Polynesian longliners and landed at the Papeete auction market during 1995 (upper panel) and January-September 1996 (lower panel).

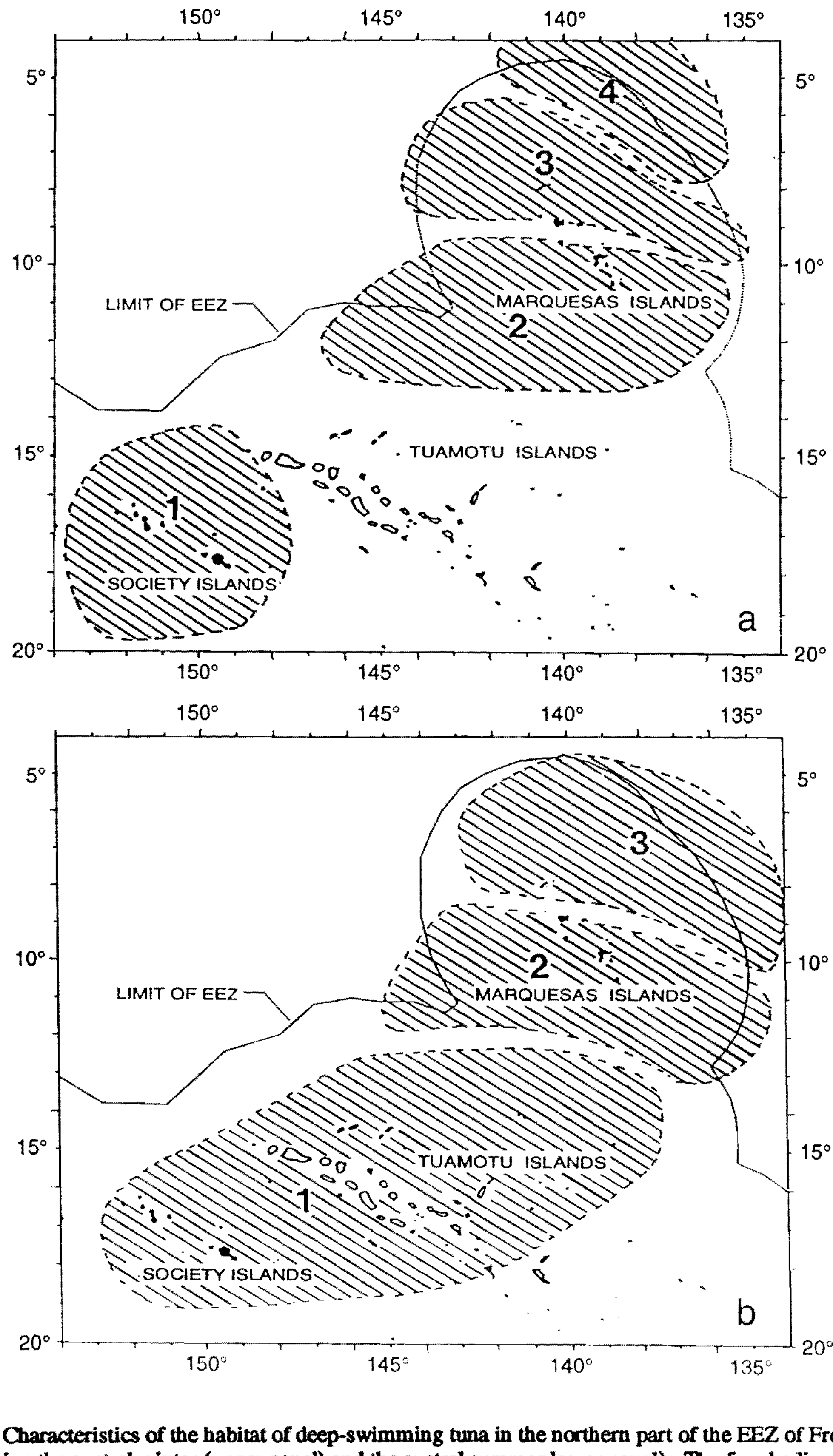

FIGURE 6: Characteristics of the habitat of deep-swimming tuna in the northern part of the EEZ of French Polynesia during the austral winter (upper panel) and the austral summer lower panel). The four bodies of water were separated by cladistic methods. Bigeye tuna is associated with bodies 3 and 4.

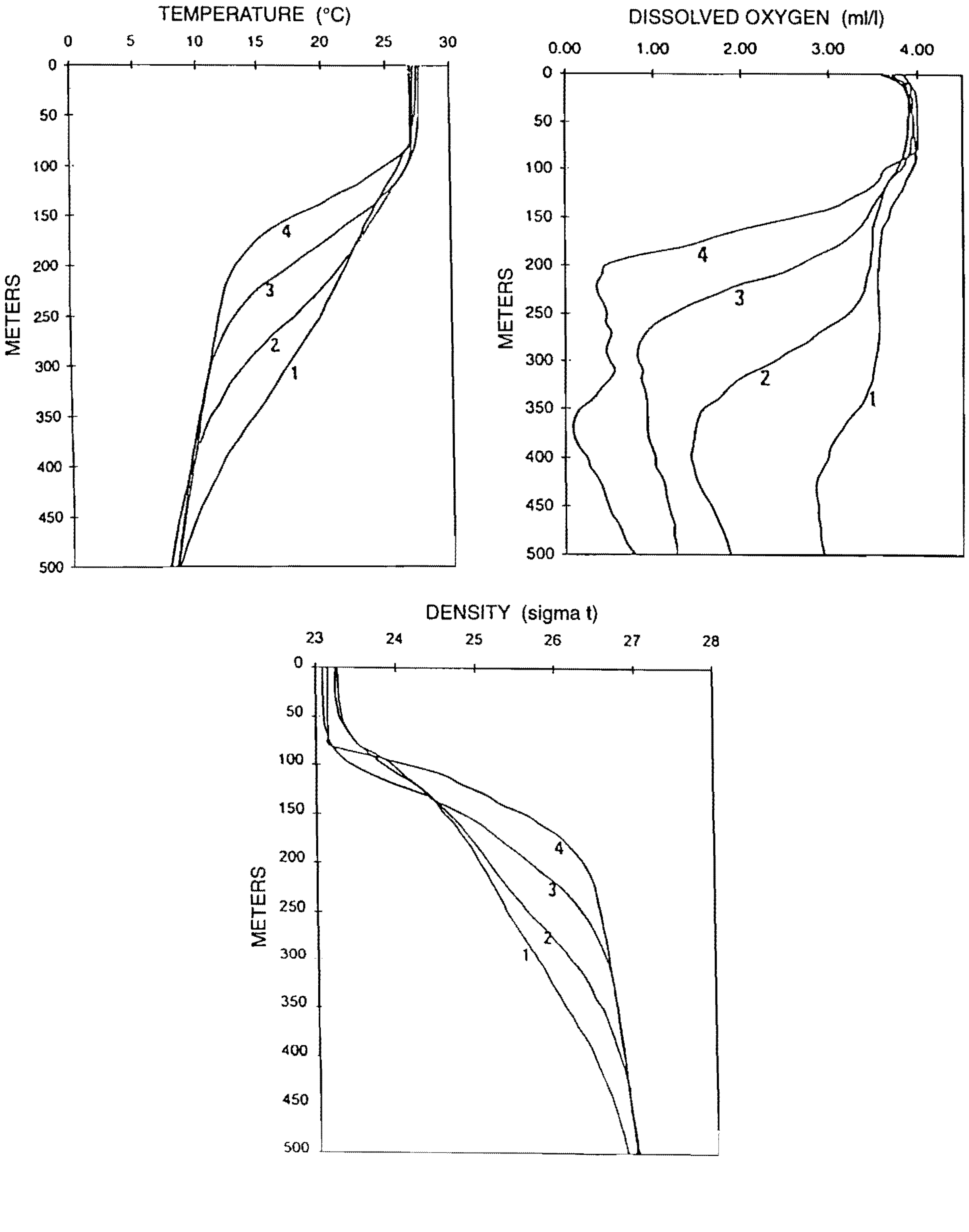

FIGURE 7: Profiles of temperature, dissolved oxygen, and density for the four bodies of water shown in Figure 6.

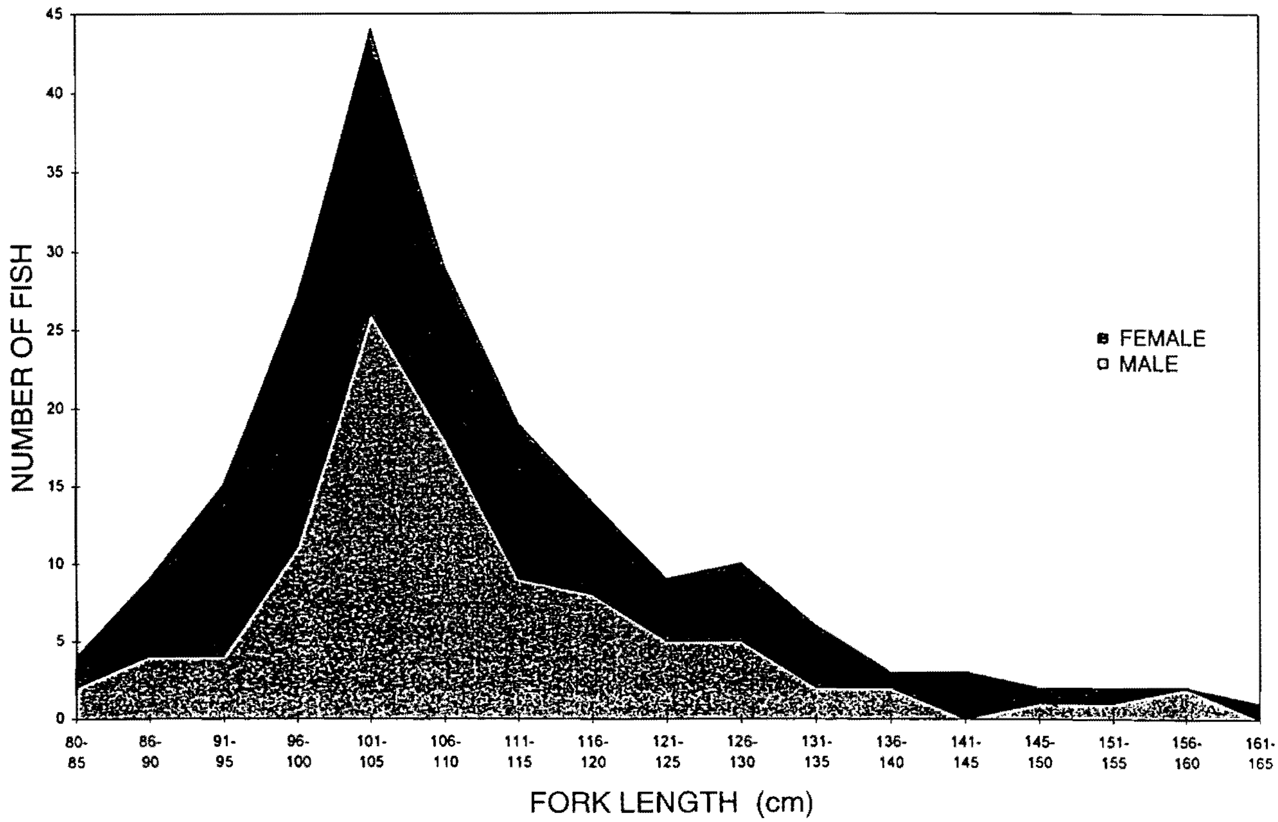

FIGURE 8: Length frequencies, by sex, of bigeye tuna caught by the N.O. *Ali* during 1993 and 1995-1996.

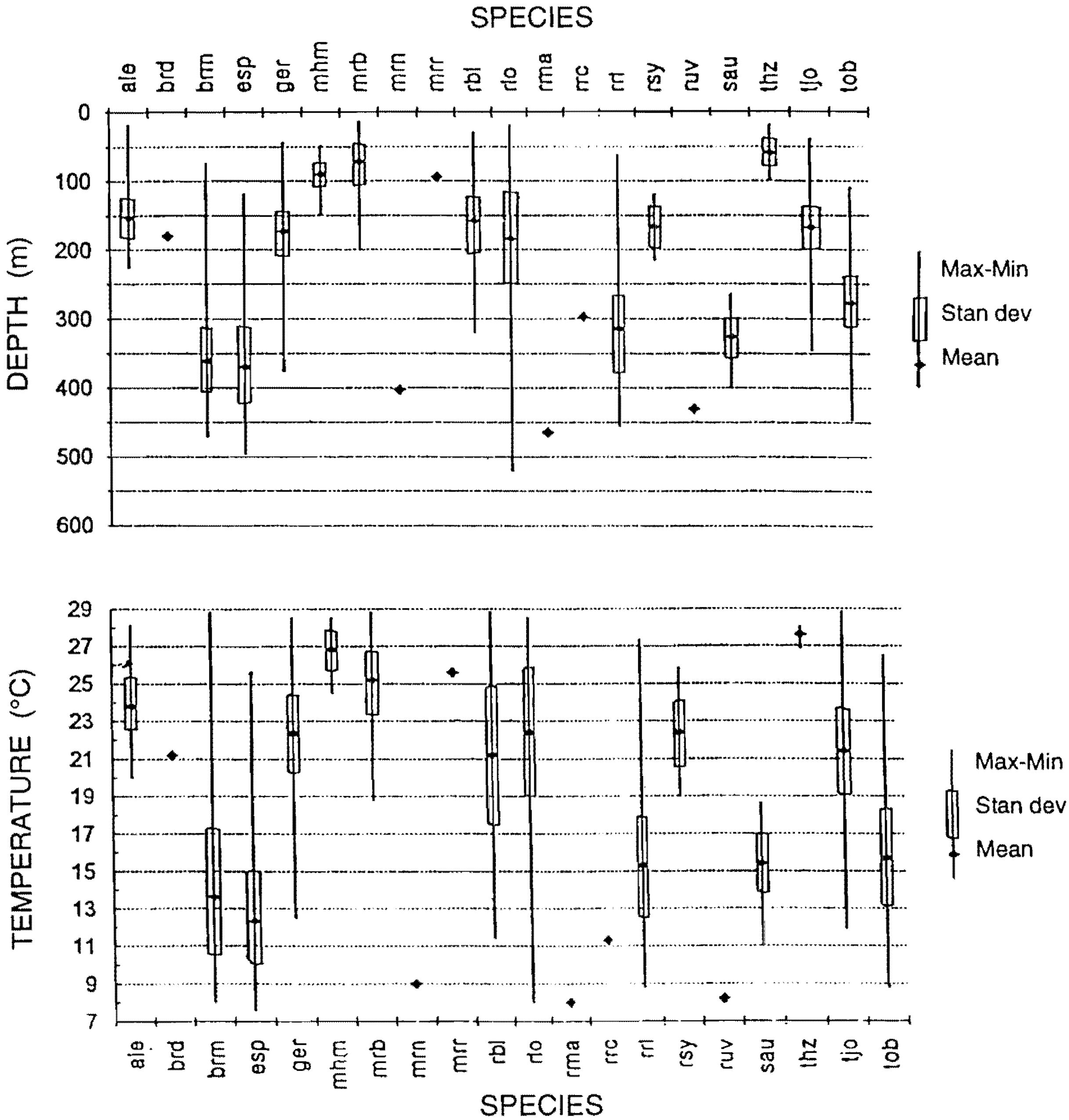

FIGURE 9: Ranges of depth and temperature for various tunas and associated species caught by the N.O. *Alis* in the EEZ of French Polynesia during 1993. The species are indicated by the letters on the far right, as follows: ale: *Alapisaurus ferox*; brd: barracuda; brm: *Taractes longipinnis*; esp: swordfish; ger: albacore; mhm: dolphinfish; mrb: blue marlin; mrn: black marlin; mrr: striped marlin; rbl: *Prionace glauca*; rlo: *Carcharinus longimanus*; rma: hammerhead shark; rrc: *Alopias superciliosus*; rrl: *Alopias* sp; rsy: *Carcharhinus falciformis*; ruv: *Ruvettus pretiosus*; sau: *Lampris opah*; thz: wahoo; tjo: yellowfin tuna; tob: bigeye tuna.

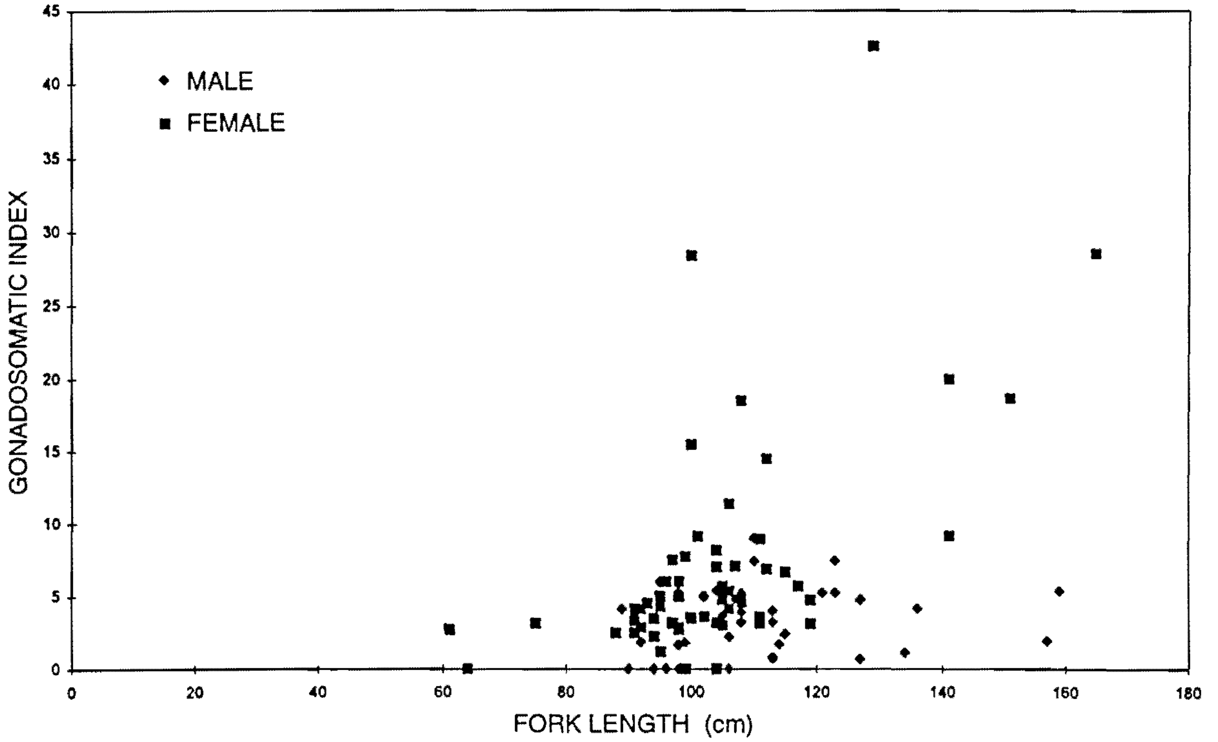

FIGURE 10: Gonadosomatic indices of male and female bigeye caught by the N.O. *Alis* during 1993 and 1995-1996.

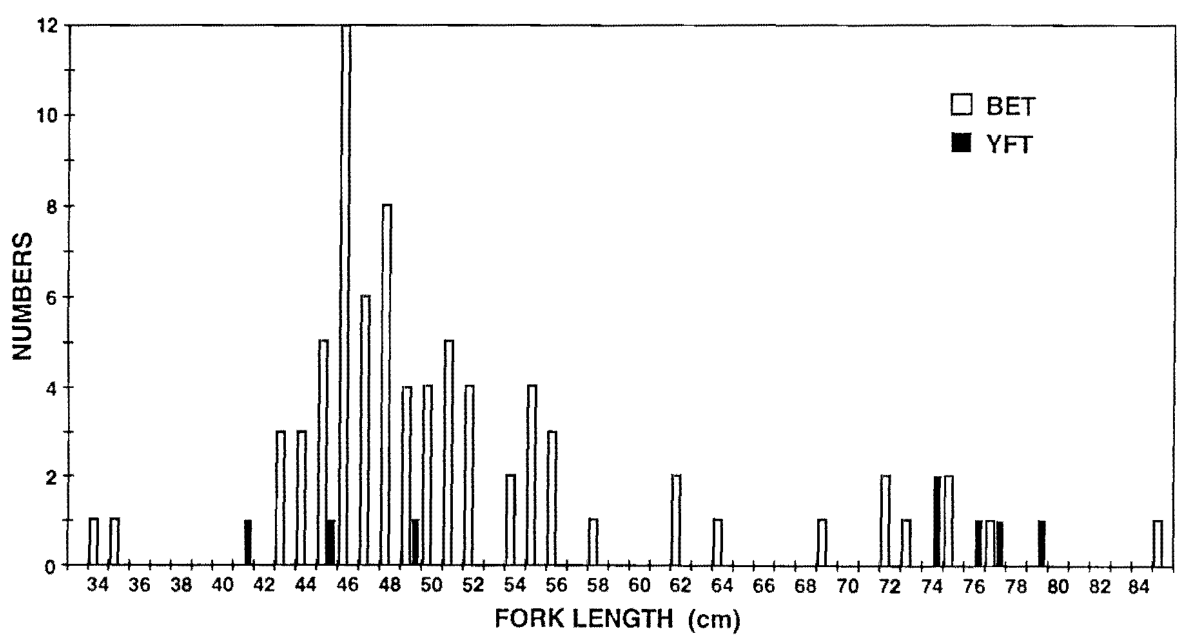

FIGURE 11: Length frequencies of juvenile bigeye and yellowfin tuna caught by trolling near 5°S-140°W during January 1996.

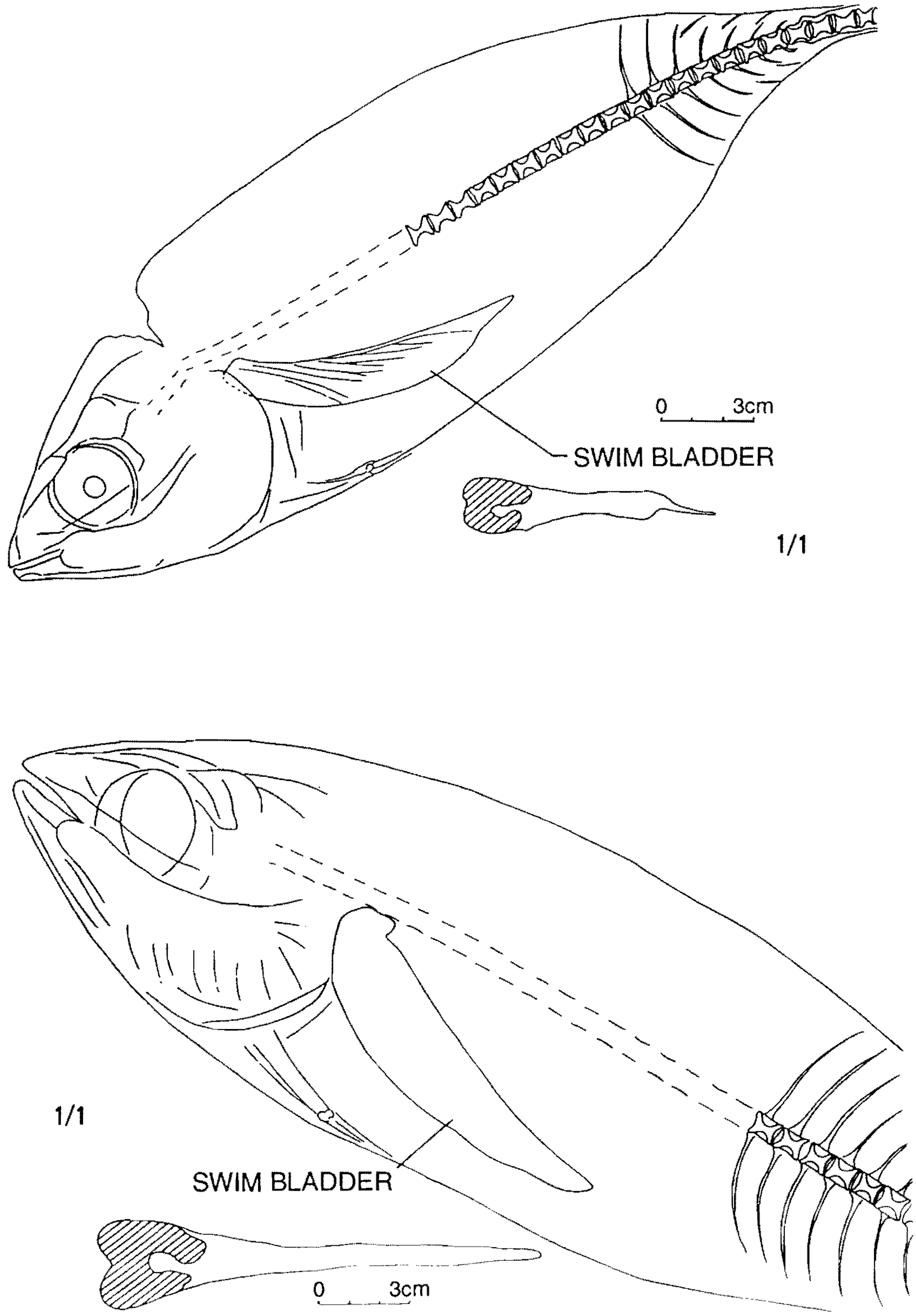

FIGURE 12: Drawings, from radiographs, of two young bigeye tuna caught by trolling, showing the unusual sizes of their functional swim bladders. Upper views of dissected and dried bladders are added. The upper fish is 43 cm FL, with a swim bladder volume of 55 cm^3; and the view shows a fully-developed swimming bladder. The lower fish is 34 cm FL, with a swim bladder volume of 25 cm^3. The upper view shows the"tail" of the swim bladder, which is not fully developed.

TABLE 1: Historical series of tuna catches, in metric tons, in the EEZ of French Polynesia. Catches by *poti marara* coastal craft, estimated at 200-500 MT per year, are not included. The values in parentheses are catches of bigeye tuna. J: Japan ; K: Korea, T: Taiwan. The 1996 values are for January-November only.

Year	Sales of skipjack and small tuna at Papeete market	Landings of skipjack and small tuna; all of French Polynesia	Catches of bigeye by French Polynesian longliners	Catches of bigeye by foreign longliners	Countries under license and reporting
1954	358				
1955	339				
1956	410				
1957	296				
1958	259				
1959	343				
1960	380				
1961	395				
1962	566				
1963	625				
1964	490				
1965	558				
1966	789				
1967	639				
1968	710				
1969	804				
1970	712				
1971	484				
1972	569			4023 (902)	J, T
1973	563			5659 (1110)	J, T
1974	535			5266 (1684)	J, T
1975	652			7044 (3330)	J, K, T
1976	658-844	1521-1902		7264 (2943)	J, K, T
1977	670-870	1774-2218			
1978	984-1230	2649-3313			
1979	805			1945 (819)	J
1980	992	1312		2944 (1618)	J
1981	1035	1468		4726 (1254)	J, K
1982	1067	1557		2631 (663)	J, K
1983	903	1491		1423 (291)	K
1984	1300	2344		2018 (822)	J, K
1985	903	1623		4774 (1931)	J, K
1986	981	1356		4293 (1967)	J, K
1987	907	1536		4467 (2184)	J, K
1988	750	1314		5187 (2790)	J, K
1989	986	1370		2901 1004)	J, K
1990	786	1400	55 (4)	4232 (1825)	J, K
1991	769	1472	250 (35)	5541 (3213)	J, K
1992	574	1406	820 (57)	2305 (1110)	K
1993	425		2400 (163)	1395 (750)	K
1994	479		2653 (165)	2130 (1231)	K
1995	343		2455 (182)	2023 (1321)	K
1996				3032 (1842)	K

Sources: Bard (1974); Bessineton (1976); Josse *et al.*, Rapport ECOTAPP (1995); EVAAM, Direction des Affaires Maritimes, Chabannes *et al.* (1993).

A COMPARISON OF BIGEYE STOCKS AND FISHERIES IN THE ATLANTIC, INDIAN, AND PACIFIC OCEANS

by

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SUMMARY

This paper presents a comparison of the fisheries exploiting bigeye tuna. First, the bigeye catch trends in each ocean are compared; this reveals a slow but constant increase in bigeye catches in all areas. A spectacular increase in the bigeye catches during recent years was noted in various areas. A comparison of the value of the landings of the various tuna species shows that the value of bigeye taken by longliners and sold in Japan is very high. The historical changes of the fishing zones of the various fisheries are analyzed, and the relationship between fishing success and various oceanographic parameters in each ocean are reviewed. The status of the bigeye stocks in the various oceans and the serious limitations and uncertainties on the status of all such stocks worldwide are discussed. It is strongly recommended that *ad hoc* scientific research on bigeye tuna, well-coordinated at a worldwide level, be developed.

1-OVERALL: BIGEYE TUNA WORLDWIDE

Worldwide, bigeye stocks and fisheries have until recently been under very little scrutiny by scientists, at least compared with other major tuna species such as yellowfin or skipjack, and consequently relatively little is presently known about this species in comparison with other tuna species. The catch statistics for many surface fisheries are still quite poor, with small bigeye often being classified as yellowfin in landing statistics and vessel logbooks. This lack of interest is surprising, considering the very high landing value of bigeye in the *sashimi* market (Figure 2): large bigeye taken by longliners are sold at a price approximately 10 times that of purse seine-caught yellowfin and skipjack (Figure 1). In recent years, catches of bigeye have accounted for about 40%, or about US$1.5 billion, of the total value of tuna landings worldwide; yellowfin accounts for 21%, and skipjack 18% (Figure 2).

Until recently, the bigeye stocks in the Atlantic, Indian and Pacific Oceans were in reasonably good condition: a steadily increasing trend in bigeye fishing effort and catches was observed in all three oceans (Figure 3). Production modeling, discussed below, indicated that these three stocks were reaching full exploitation during the early 1990s, but did not show any symptoms of overfishing (Figure 25). However, this same period saw a spectacular increase in the catches of small bigeye by surface fisheries (Tables 1-4), often associated with an increase in the catches of large bigeye by longliners (Figure 3). This increase has raised serious concerns about a possible overexploitation of the bigeye stocks. There is, therefore, an urgent need to review current knowledge and uncertainties, and to develop an active and well-coordinated research program on bigeye tuna, in order to obtain as soon as possible realistic assessments of the stocks of this species in the various oceans. These assessments should preferably use age-structured approaches because of the potential interactions between the purse-seine and longline fisheries. This paper presents a comparative overview of bigeye tuna stocks and fisheries worldwide, and discusses the major problems in the assessment of bigeye stocks.

2- BIGEYE FISHERIES: TRENDS BY OCEAN

The trends in bigeye catches in the three oceans are quite similar (Figure 3): a slow but constant increase until the early 1990s, followed by a spectacular increase in recent years, especially in the Atlantic and Pacific

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Oceans. However, catches of bigeye are often under-reported in the logbooks of surface-fishing vessels. Small bigeye (under about 3 kg) are frequently reported as skipjack or yellowfin, and only medium and large bigeye are consistently reported as such. The only way to obtain reliable estimates of the amounts of small bigeye landed is with specialized sampling programs aimed at identifying bigeye when it is landed.

The bigeye fisheries are quite different in the three oceans:

- In the Atlantic Ocean, bigeye has been targeted since the early 1960s by various fisheries (baitboat, purse-seine and longline), each one targeting a specific range of sizes (Pereira, 1995). The quality of bigeye catch statistics and size sampling is quite good, as systematic species-identification programs and size sampling have been conducted routinely for bigeye in most surface fleets since the late 1970s (ICCAT, 1985). Data on bigeye catches and sizes by gear are available from ICCAT. Tables 1 and 2 present annual estimates of the catches by species for various Atlantic fisheries, with the purse-seine catch classified by type of set (on free-swimming schools and log-associated schools).

- In the Indian Ocean, bigeye has been fished by longliners since the mid-1960s, but since the mid-1980s large amounts of small bigeye have been taken by purse seiners, primarily in sets on natural and artificial floating objects. The baitboat catches of bigeye, which are limited to the Maldive Islands, are insignificant. Sampling for species identification has been done routinely for the purse-seine fleet since the mid-1980s, and both the quantities and sizes taken are fairly well known. Table 3 gives annual estimates of the purse-seine catches, by species and fishing mode (on free-swimming schools and log-associated schools). The data on catches and sizes by gear are available from the IPTP (and from the IOTC in the near future).

- In the Pacific Ocean, bigeye has been taken primarily by longliners since the early 1950s, with a major increase in longline fishing effort and catches during the 1970s, due to the development of a deep-freezing method which made it possible to sell high-quality, high-priced bigeye on the Japanese *sashimi* market, and to the development of deep longlines during the same period. Since the late 1970s, bigeye have been taken by purse-seine fleets fishing on floating objects in the western Pacific (around the Philippines, in the "warm-pool" area (Picaut *et al.*, 1996)) and in the eastern Pacific, but the amount and the sizes of those catches of small bigeye are largely unknown. This major statistical uncertainty is a serious difficulty for any bigeye stock assessment in the Pacific Ocean, especially for the age-specific approaches. Table 4 gives annual estimates of the purse-seine catches, by species and fishing mode (on free-swimming schools and log-associated schools) in the eastern Pacific.

Figures 4, 5 and 6 show the average catches from bigeye fishing zones in the three oceans by the surface and longline fisheries during 1969-1978, 1979-1988 and 1989-1993, respectively. No adjustments are made for incomplete reporting of bigeye in the logbooks in the Pacific. Figure 7 shows the average catches made by the surface fishery in the Atlantic, Indian and Pacific Oceans during the above periods, and also during 1994-1995. These maps clearly illustrate the relative importance of the longline fisheries, and the changes in the bigeye fishing areas. In the areas in which bigeye now predominates in the catches, yellowfin tuna was, until the late 1960s, often the main species targeted and caught. This change is due in part to the use of deep longlines and the present high value of bigeye. Since the late 1950s the size of the fishing zones exploited by the longliners has been relatively stable in the Atlantic and eastern Pacific Oceans, but has decreased in the western Pacific and increased in the Indian Ocean (Figures 8 and 9). The recent increase in the catches by surface gear is apparent in various areas, for instance in the Atlantic and in the eastern Pacific (Figure 7), and is due mainly to the increasing use of artificial floating objects by purse seiners and possibly to other technological factors, such as sonar. In the Pacific it may also be due, to some extent, to better species identification of bigeye in the catches. It should be noted that in the Atlantic and Indian Oceans, where identification of bigeye is good, bigeye are almost always caught with small yellowfin, in both free-swimming and log-associated schools. In free-swimming schools the percentage of bigeye is relatively low: in 1990-1994 it accounted for between 6.8 and 6.0% of the total catches of yellowfin and bigeye in these two oceans, whereas the corresponding figures for log-associated schools are 43.6 and 21.4%.

The areas in which the surface fisheries catch bigeye have been quite variable over time, with a tendency to expansion during recent years, partly due to the increasing use of artificial logs.

Figures 10 and 11 show the average catches of bigeye by the surface and longline fisheries in four ocean areas, by 5° squares, during 1989-1993. The patterns of longline productivity by 5° square are similar in all four areas, although the eastern Pacific shows higher values for many squares. For the surface fisheries, however, large differences in the catches by 5° square are observed, with very low catches in both the eastern and western Pacific. These differences may be real, and reflect high average catches in some areas *e.g.* the Canary Islands, Azores Islands, and Madeira in the Atlantic, where various baitboat fisheries target bigeye, or they may be due to underreporting of bigeye catches, as is probably the case in the Pacific Ocean.

Another overview of the areas in which adult bigeye are most abundant is given in Figure 26, which shows 5° squares in which catches greater than 100 tons of bigeye were made in each month during the 1952-1993 period. This illustrates the major areas where the bigeye biomass was predominantly concentrated and exploited during the history of the fisheries.

3- BIGEYE STOCKS AND THEIR OCEANOGRAPHIC ENVIRONMENT

The major oceanographic parameters important for determining the distribution and movements of bigeye worldwide are shown in Figures 12 to 17: average sea-surface temperature (SST) (Figure 12); thermocline depth (Figure 13); average subsurface temperatures (Figures 14 and 15); and oxygen concentration (Figures 16 and 17). The habitat of bigeye tuna is similar in all three oceans: adults live in deep tropical waters, whereas small bigeye (less than 5 kg) are caught in warm surface waters in multispecies schools, most often with yellowfin and skipjack. In both the longline fisheries targeting adult fish and the surface fisheries, a large majority of the catches is taken in tropical waters with quite high SSTs (Figures 19 and 20). The percentage of bigeye taken in waters with average quarterly SSTs greater than 20°C, by 5° squares, is as follows:

	Longline	Surface
Eastern Pacific Ocean	91.7%	89.2%
Western Pacific Ocean	92.5%	100.%
Indian Ocean	77.6%	90.8%
Atlantic Ocean	85.8%	97.1%

However, the adult bigeye are taken predominantly in the deep and cold layers of the ocean, at depths between 200 and 500 meters, most often in the areas with relatively low levels of oxygen (Figures 16, 17, and 23). This specific distribution is well explained by the low metabolism of large bigeye and their low requirements for oxygen.

The predominance of the intertropical areas is well shown by the average percentage of the bigeye catches taken by longliners between 20°N and 20°S in each ocean during the 1983-1993 period:

Eastern Pacific Ocean	89.0%
Western Pacific Ocean	78.3%
Indian Ocean	90.0%
Atlantic Ocean	86.5%
Total	86.0%

Bigeye tuna can also feed significantly in the northern and southern temperate zones, between 30°S and 40°S in the Indian Ocean, and reaching 45°N in the warm waters of the Kuroshio Current in the western Pacific and in the Gulf Stream in the Atlantic, where bigeye are seasonally exploited with other tuna species, primarily by longliners (Figures 4-6).

Bigeye spawn in warm waters (Nikaido *et al.*, 1991), like yellowfin and skipjack, so the seasonal concentrations of bigeye exploited by longliners in warm waters in the sub-equatorial areas are probably made up of spawning fish. Figure 24 shows those seasonal areas of potential spawning (as quarterly catches with SSTs >25°C), and of potential feeding (areas with SSTs <25°C). Adult bigeye probably migrate extensively between these spawning and feeding zones.

In the Atlantic, Indian, and western Pacific Oceans, bigeye "nursery" areas (with concentrations of recently-hatched bigeye, of less than 3 kg) are located in the warm waters (SST >25°C) close to the equator, where they are exploited in mixed schools with small yellowfin and skipjack by purse-seine and baitboat fisheries. This location of the bigeye nurseries is probably linked with the lack of efficient thermoregulation in small bigeye (Brill 1994).

4- DIFFICULTIES IN BIGEYE STOCK ASSESSMENT

Production modeling

The status of the bigeye stocks in the Pacific, Indian and Atlantic Oceans has been assessed with production models, which estimate the structural relationship between total catches and effective fishing effort. These analysis have shown very similar patterns in all three oceans (Figure 25): a slow but constant increase in fishing effort, producing a slow increase in bigeye catches. It appears that most of these catches were probably quite close to the equilibrium productivity of each stock, because the increase in the effort was usually very slow. The large amounts of small bigeye taken in the Indian, Atlantic and western Pacific Oceans since the late 1970s and early 1980s apparently did not result in a decline in the productivity of the stocks. The results obtained from those production models (for instance, using the exponential PRODFIT model (Fox, 1975) with $k = 5$ years, and the most recent general linear model (GLM) indices calculated for bigeye in each ocean) were that all three stocks were reaching their maximum sustainable yields during recent years. The large catches taken during recent years in the Atlantic and Pacific Oceans are interpreted to be an overexploitation of these two stocks.

These global analyses have serious limitations, as the catches are often poorly known and fishing effort is estimated indirectly, using a single index of abundance calculated from the longline fisheries and tentatively adjusted for the development of deep longlines since the 1970s (most often a GLM index). The effects of the sudden large increase in the longline and purse-seine catches in recent years are unknown, and are difficult to estimate using production models, because these catches consist primarily of small bigeye. These effects will be seen when the stock and the fisheries reach equilibrium, after about 5 to 8 years (the life span of bigeye after their recruitment to the surface fisheries).

Age-structured analyses

A stock exploited simultaneously by surface fleets catching juvenile fish and by longline fleets catching adults should preferably be analyzed using age-structured models, for example virtual population analyses (VPA). However, applying these analyses to bigeye is difficult, because they require:

- Data on the size distributions of the total catches by all gears;
- Estimates of growth rates, necessary to transform the catch-at-size data into catch-at-age data;
- An estimate of age-specific natural mortality (M_i);
- Various indices of age-specific abundance or of fishing mortalities, needed to tune the analyses.

In the Indian and Pacific Oceans these data are often incomplete or are not yet available, so it is not possible to apply age-structured analyses. For the Atlantic Ocean, the ICCAT data base on bigeye is fairly complete and available for study, so it was possible to conduct this type of analyses with some positive results (Pereira, 1995; Pallarés *et al.*, 1998). However these VPA analyses of bigeye done routinely in the Atlantic are still hampered by major uncertainties, primarily those regarding age-specific M.

If natural mortality is high for juvenile bigeye (*M* is assumed to be 0.8 for ages 0 and 1, and 0.4 for older fish), the potential negative effects on the adult stock of the catches of juveniles by surface fleets are small or very small (a very high *M* implies a very large population, and a low subsequent fishing mortality (*F*), but if this natural mortality is low, the effects may be very large.

The Scientific Committee for Research and Statistics (SCRS) assumption about *M* (0.8 for juveniles, 0.4 for adults) may seem reasonable, and it is also reasonable to assume that *M* is similar for juvenile yellowfin, skipjack and bigeye, since they live in mixed schools in the same equatorial area. However, this *M* for juvenile is very hypothetical, and the real *M* may be much higher, as suggested recently by the analysis of tag recovery data done by the South Pacific Commission (Hampton *et al.*, 1998).

VPA analyses conducted by Tomlinson (1998) for the eastern Pacific with different trial values of *M* confirm the type of uncertainties found in the Atlantic.

Further research on bigeye biology is required in order to obtain reliable estimates of age-specific *M* and the other parameters used in the VPA analysis.

5- FUTURE RESEARCH ON BIGEYE WORLDWIDE

Worldwide, bigeye tuna appear to be in danger of being overfished, for two reasons: (1) the high value of longline-caught bigeye on the *sashimi* market and (2) the recent spectacular development of the purse-seine fisheries on artificial floating objects. Until recently little research had been done on bigeye anywhere, and there is a need for an intensive and well-coordinated large-scale research program on this species. The Bigeye Year Program, a four-year research program recently approved by the SCRS for the Atlantic, is an example of the type of research necessary, and similar research in the Indian and Pacific Oceans should be developed and coordinated with the Atlantic program, taking into account the different systems and the statistical and biological data available in each area. For instance, in the Pacific priority should be given to obtaining reliable estimates of the amount and sizes of bigeye taken by all the purse-seine fisheries in each area, by means of systematic species-sampling programs. Corrected figures of bigeye catches should also be estimated for the historical fisheries. Catch-and-effort and size data on bigeye, vital to the quality of the data base and the stock analyses, should be made easily available. The structure of the various bigeye stocks is poorly understood for all three oceans, and further research is needed to establish hypothetical stock structures based on scientific information. The FAO should play an active role in coordinating this worldwide bigeye research, which should be carried out as soon as possible by the various organizations responsible for tunas in the different oceans.

6- CONCLUSION ON BIGEYE PROSPECTS: RESEARCH, FISHERIES, AND MANAGEMENT:

In the new context of "responsible fishing," nations involved in fisheries for bigeye tuna are responsible for:

(1) reducing their bigeye catches to sustainable levels, since the recent sharp increases in catches may pose a serious conservation risk for the bigeye stocks in the Atlantic and eastern Pacific Oceans.

(2) developing extensive and well-coordinated research programs on bigeye worldwide, in order to improve the basic knowledge of the various stocks and fisheries, and estimate the species' potential to sustain catches by the various surface and longline fisheries in all three oceans.

Given the very high value of the bigeye landings, it should be possible to obtain funds for these large research programs from government and industry sources.

ACKNOWLEDGMENTS

This worldwide comparison of bigeye tuna fisheries was made possible by extensive cooperation between various fishing agencies. I thank the chief scientists and statisticians who cooperated in building the worldwide data base used in this paper. Special thanks should be given to Papa Kebe of ICCAT, David Ardill and Alejandro

Anganuzzi of the IPTP, Tony Lewis and Tim Lawson of SPC, and Michael Hinton of the IATTC for their efficient and constant help.

LITERATURE CITED

BRILL (R.W.) 1994. A review of temperature and oxygen tolerance studies of tunas pertinent to fisheries oceanography, movement models and stock assessment. Fisheries Oceanography, Vol. 3, No. 3, pp 204-216.

FOX, (W.W, Jr.) 1975 Fitting the generalized production model by least squares and equilibrium approximation. Fish. Bull. U.S., Vol. 73, No. 1, pp 23-36.

HAMPTON, (J.), LEWIS, (A.), and WILLIAMS, (P.) 1998. Estimates of western and central Pacific bigeye tuna catch and population dynamics. Inter-Amer. Trop. Tuna Comm., Spec. Rep., No. 9, pp 212-234.

ICCAT 1997. Report for biennial period, 1996-97, Part I (1996).

NIKAIDO (H.), MIYABE (N.), and UEYANAGI (S.) 1991. Spawning time and frequency of bigeye tuna, *Thunnus obesus*. Bull. Natl. Res. Inst. Far Seas Fish., No. 28, pp 47-73.

OKAMOTO (H.) and MIYABE (N.) 1996. Updated standardized CPUE of bigeye caught by the Japanese longline fishery in the Indian Ocean and stock assessment by production model. Proceedings of the Sixth Expert Consultation on Indian Ocean Tunas, pp 225-231.

PALLARES (P.) and FONTENEAU (A.) 1996. Patudo Atlántico: consideraciones sobre la evaluación analítica del stock. Documento ICCAT SCRS/96/87.

PALLARES, (P.), PEREIRA, (J.), MIYABE, (N.), and FONTENEAU, A.) 1998. Atlantic bigeye tuna: overview of present knowledge (November 1996). Inter-Amer. Trop. Tuna Comm, Spec. Rep., No. 9, pp 20-80.

PEREIRA (J.) 1995. A pesca do atum nos Acores e o atum patudo (*Thunnus obesus*, Lowe 1839) do Atlântico. Tese de doutoramento. Universidade dos Acores, Horta, Janeiro de 1995, 330 p.

PICAUD, (J.), IOUALALEN, (M.), MENKES, (C.), DELACROIX, (T.), and McPHADEN, (M.J.) 1996. Mechanisms of the zonal displacements of the Pacific warm pool: implications for ENSO. Science, Vol. 274, No. 5292, pp 1486-1489.

TOMLINSON, (P. K.) 1998. Assessment studies of bigeye tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm, Spec. Rep., No. 9; pp 250-290.

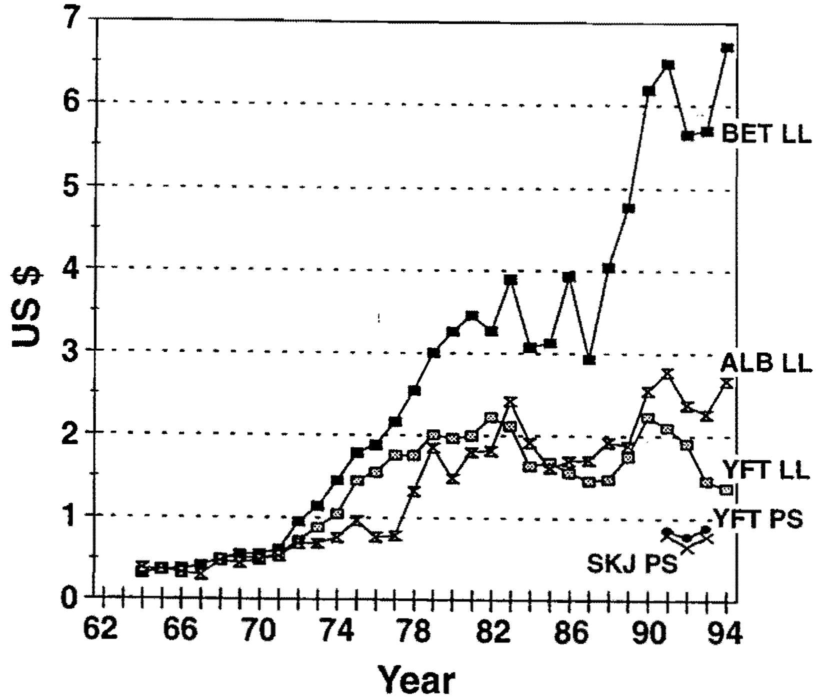

FIGURE 1. Average prices of bigeye, yellowfin, skipjack, and albacore landed in Tokyo for the *sashimi* market, and average prices of skipjack and yellowfin taken by purse seiners in the U.S. market. YFT LL, BET LL, and ALB LL: yellowfin, bigeye, and albacore taken by longliners; YFT PS and SKJ PS: yellowfin and skipjack taken by purse seiners.

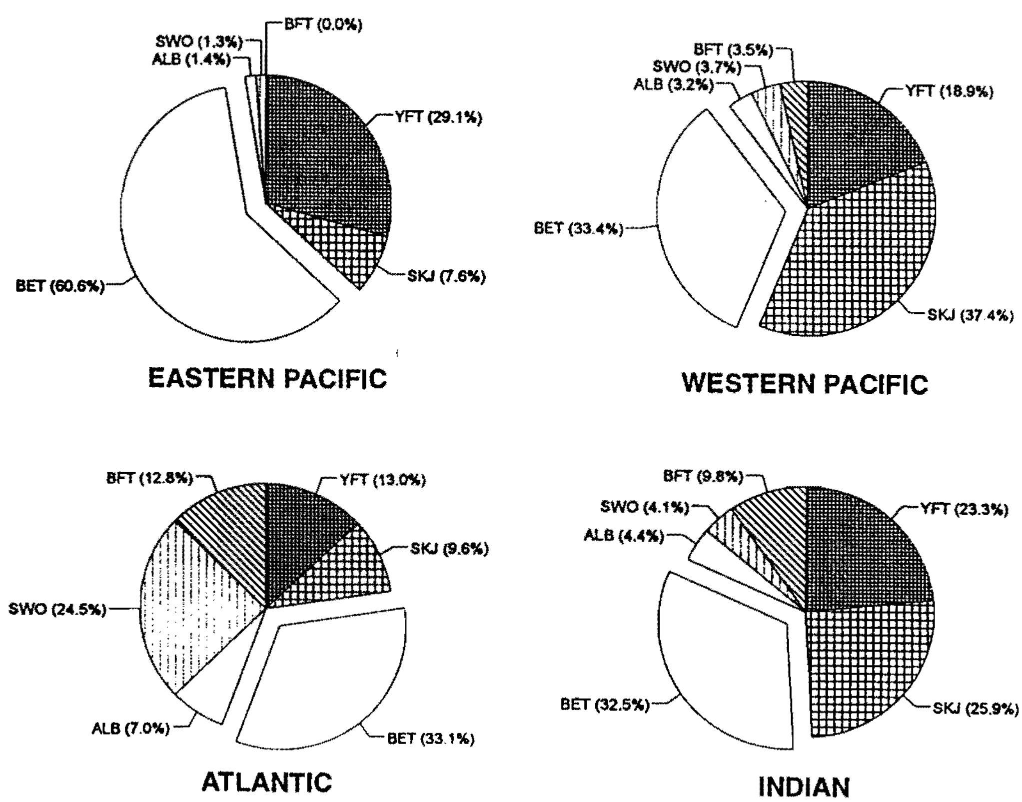

FIGURE 2. Estimated landing values of yellowfin, skipjack, bigeye, swordfish, albacore, and bluefin catches during the 1989-1993 period, based on their average prices in the longline and surface fisheries. BET: bigeye; YFT: yellowfin; SKJ: skipjack; BFT: bluefin; SWO: swordfish; ALB: albacore.

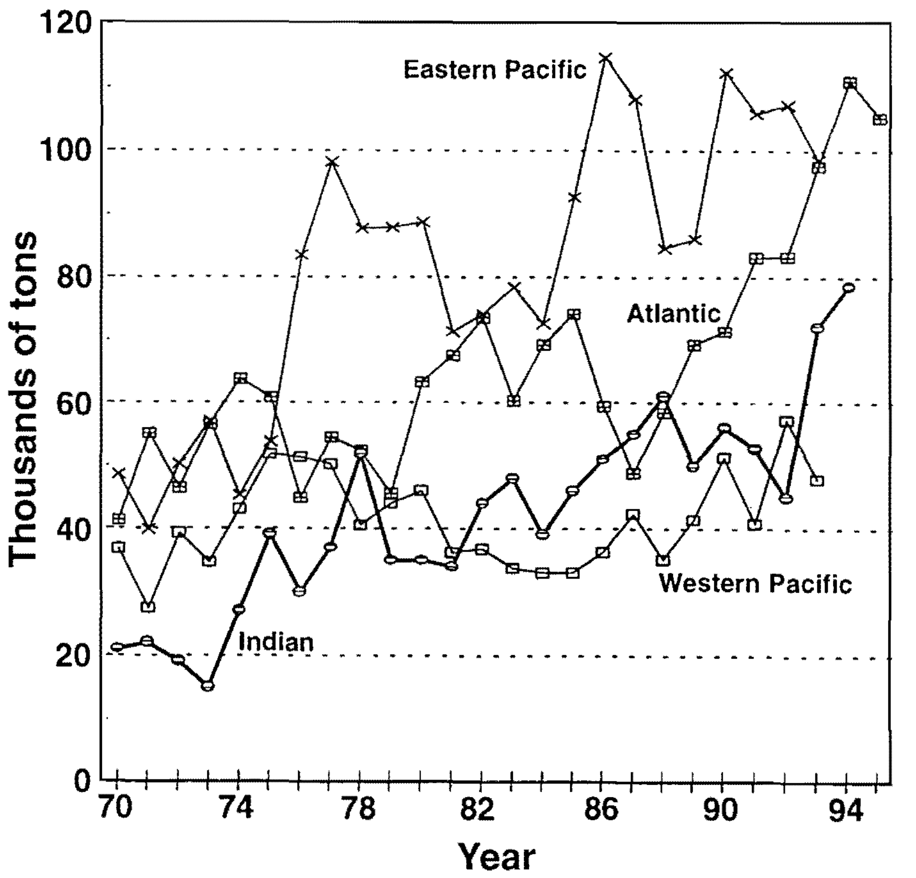

FIGURE 3. Annual catches of bigeye, by ocean.

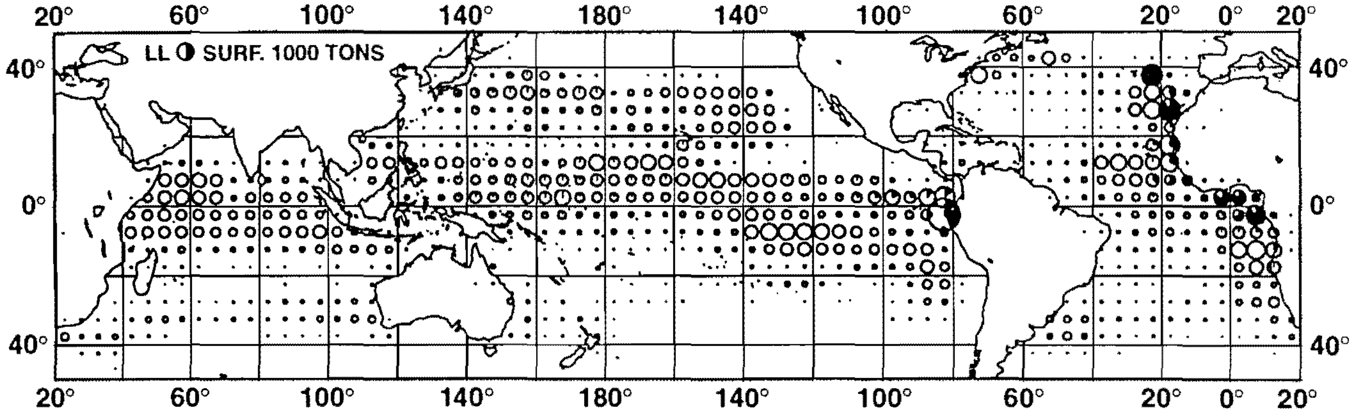

FIGURE 4. Average catches of bigeye by surface and longline fisheries, 1969-1978. LL: catches by longliners; SURF.: catches by surface gears.

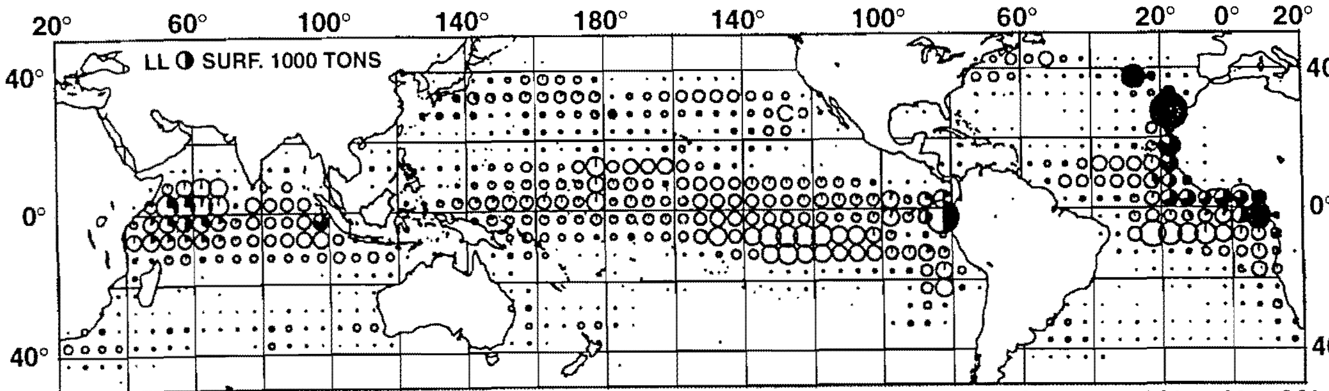

FIGURE 5. Average catches of bigeye by surface and longline fisheries, 1979-1988. LL: catches by longliners; SURF.: catches by surface gears.

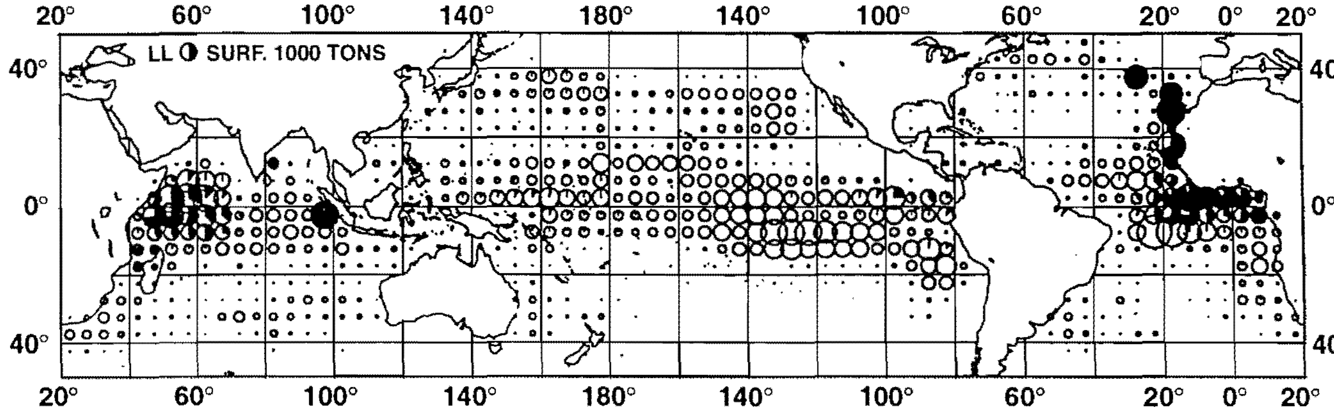

FIGURE 6. Average catches of bigeye by surface and longline fisheries, 1989-1993 . LL: catches by longliners; SURF.: catches by surface gears.

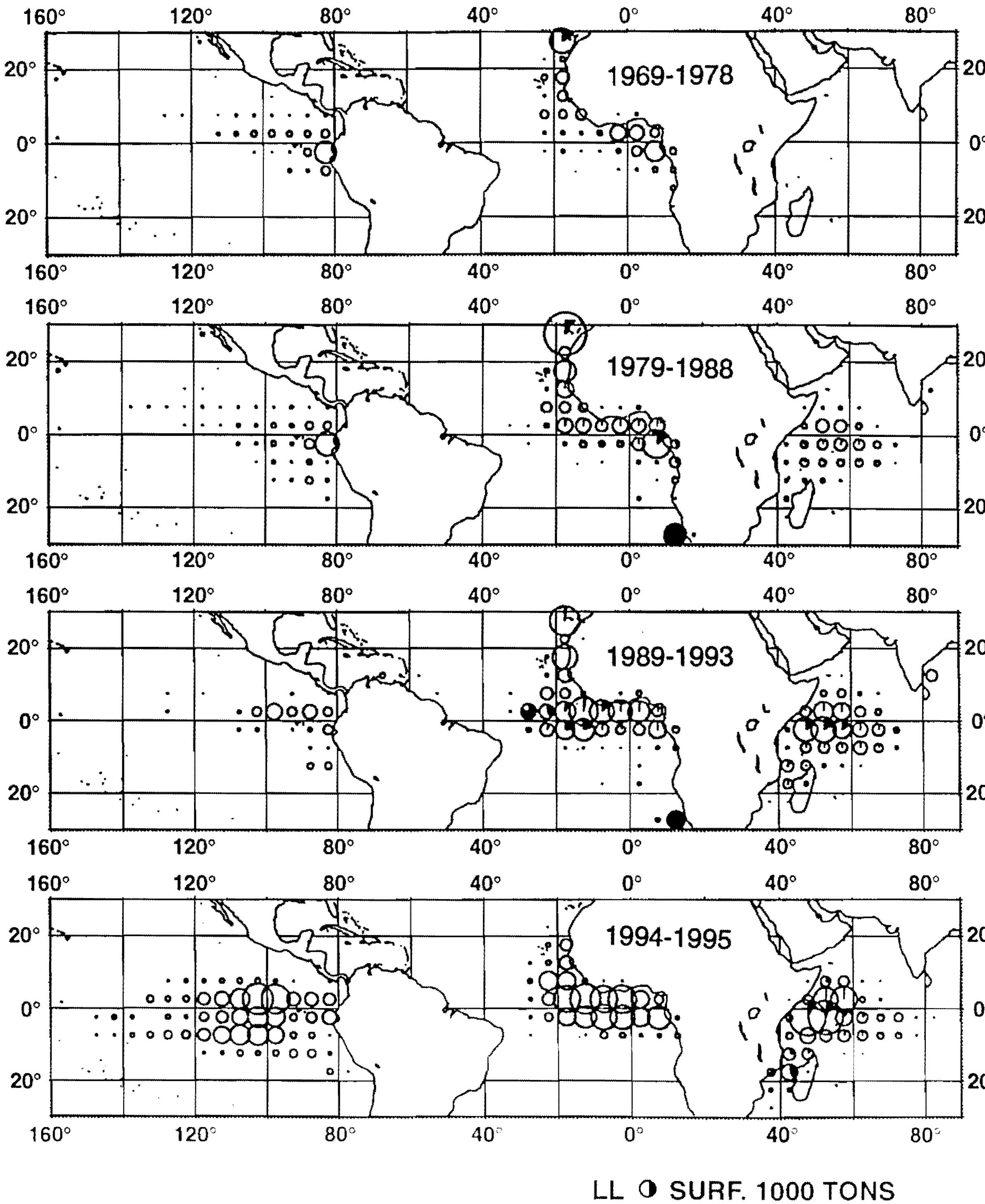

FIGURE 7. Average catches of bigeye by the surface fisheries during four periods in the Atlantic, Indian and eastern Pacific Oceans. LL: catches by longliners; SURF.: catches by surface gears.

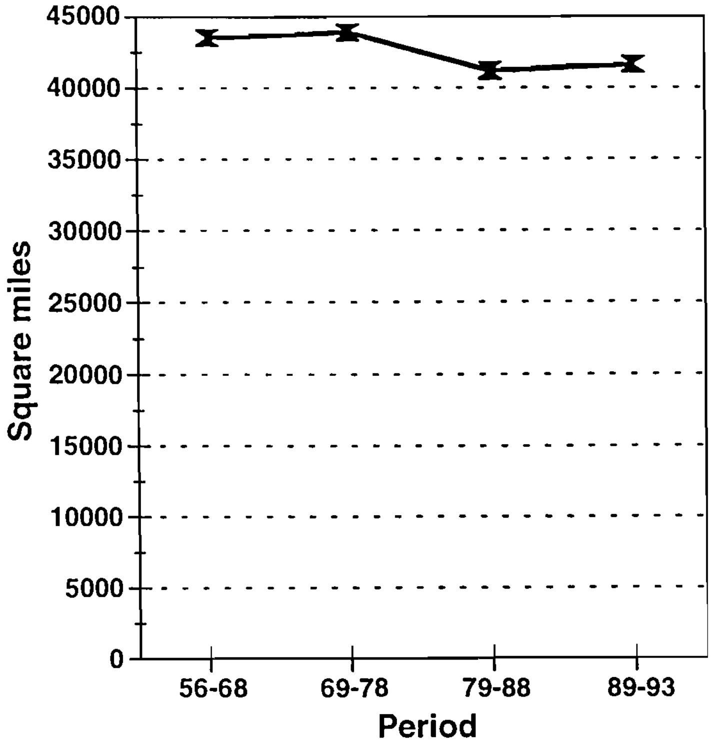

FIGURE 8. Size of the fishing areas exploited by longline fisheries worldwide with significant catches of bigeye (>10 tons/annual/5° square), during four periods between 1956 and 1993.

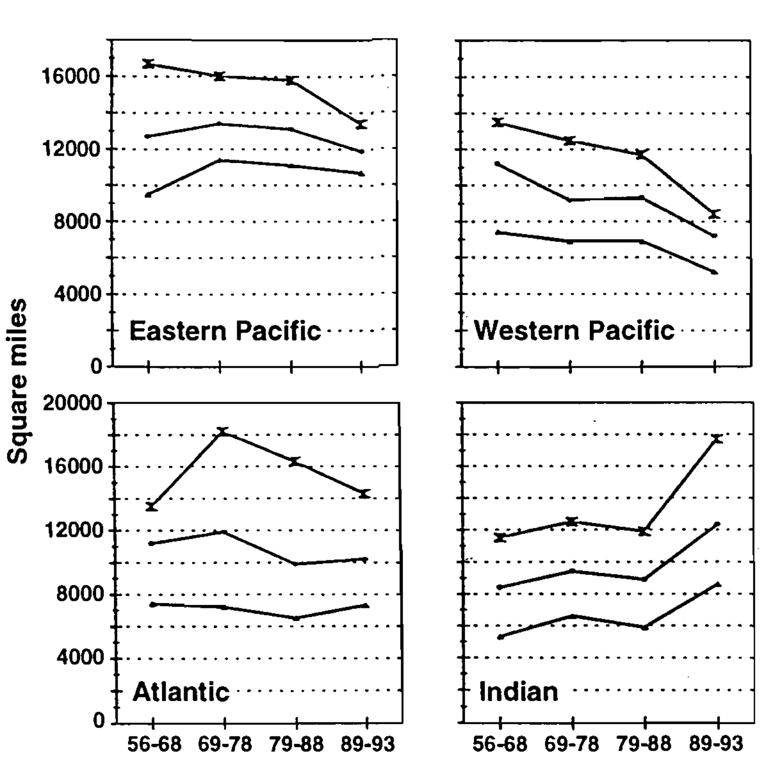

FIGURE 9. Size of the fishing areas with significant catches of bigeye (at three levels: >1 t, >10 t, >50 tons/year/5° square) exploited in four ocean areas (Atlantic Ocean, Indian Ocean, eastern and western Pacific Ocean)annual, during four periods between 1956 and 1993.

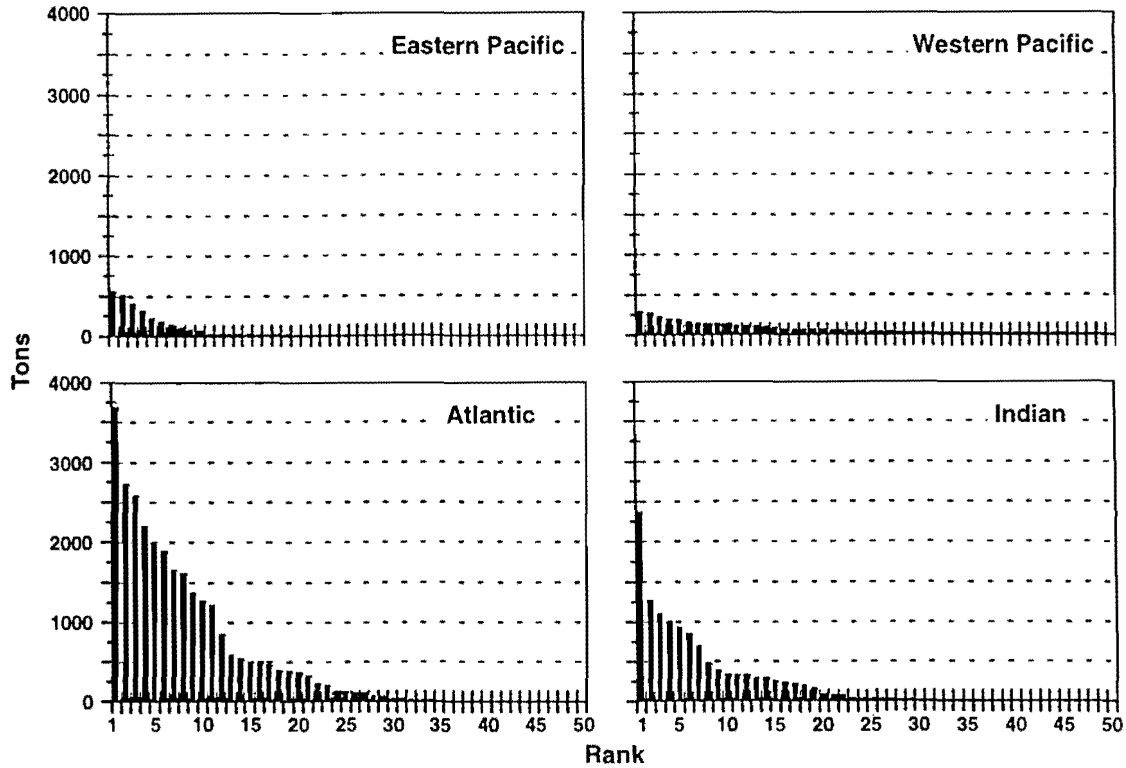

FIGURE 10. Average catches of bigeye by surface gears, by 5° area, in decreasing order, during 1984-1993 in four ocean areas. (The low average catches of bigeye in the Pacific Ocean may be partly due to an underestimation of the catches of small bigeye in the surface fisheries.)

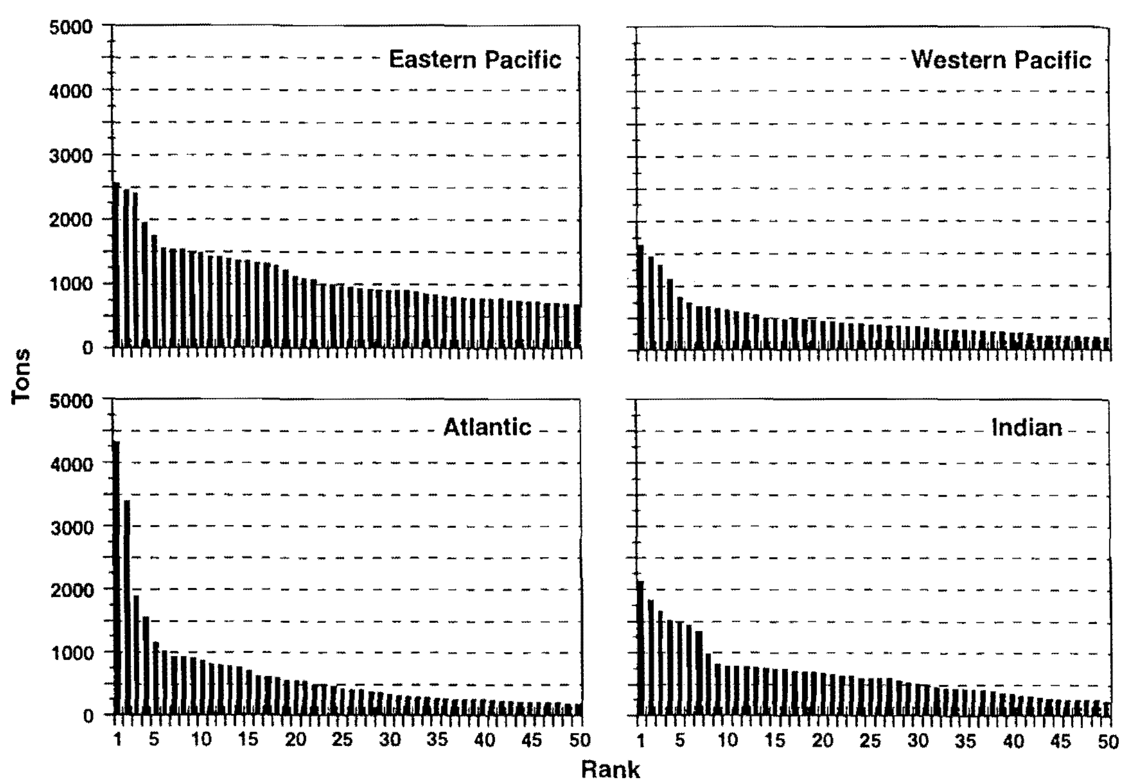

FIGURE 11. Average longline catches of bigeye by 5° area, in decreasing order, in four ocean areas during 1984-1993.

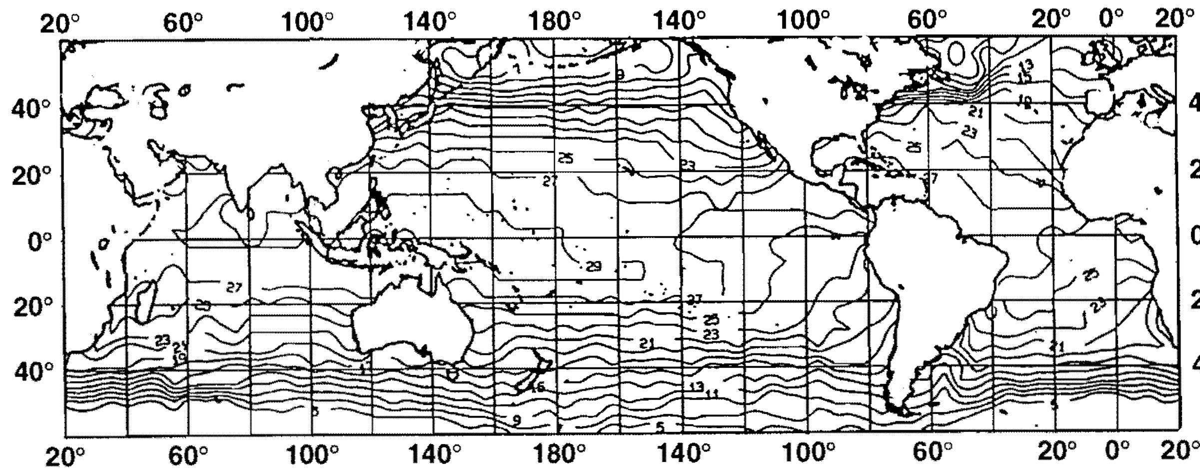

FIGURE 12. Average annual sea-surface temperatures (°C).

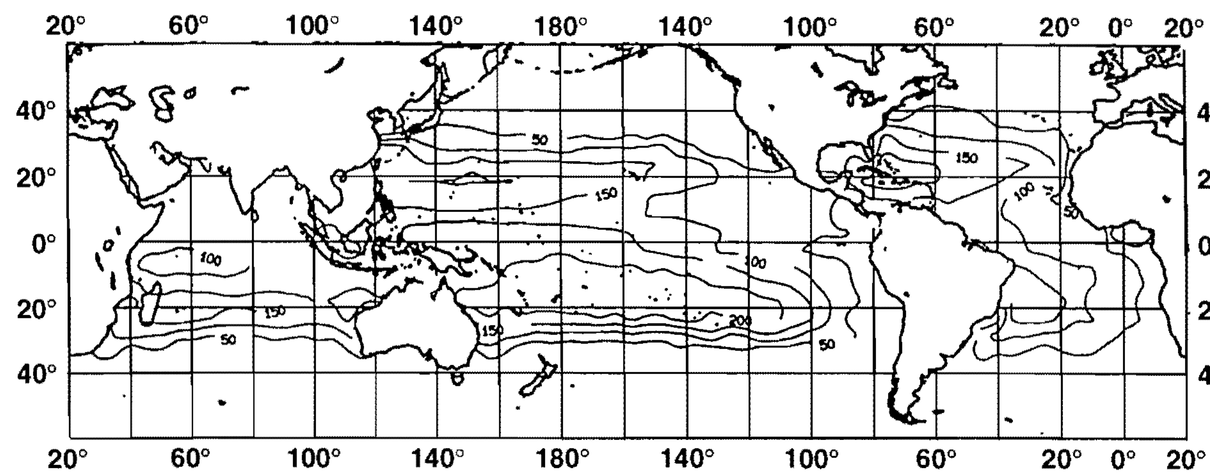

FIGURE 13. Average depth of the thermocline in the intertropical area, estimated from the average depth of the 20°C isotherm.

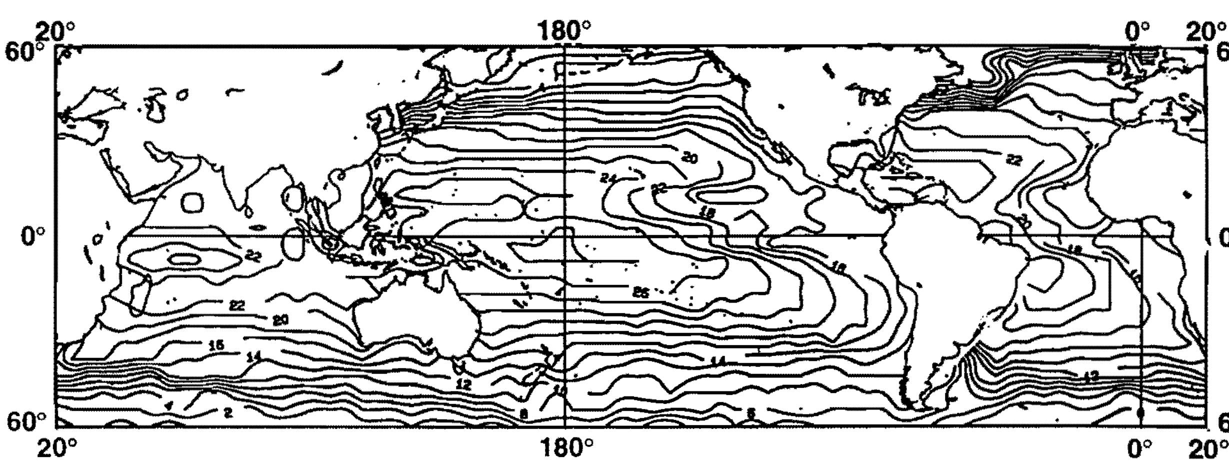

FIGURE 14. Average annual temperature (°C) at a depth of 100 meters (average depth of conventional longlines).

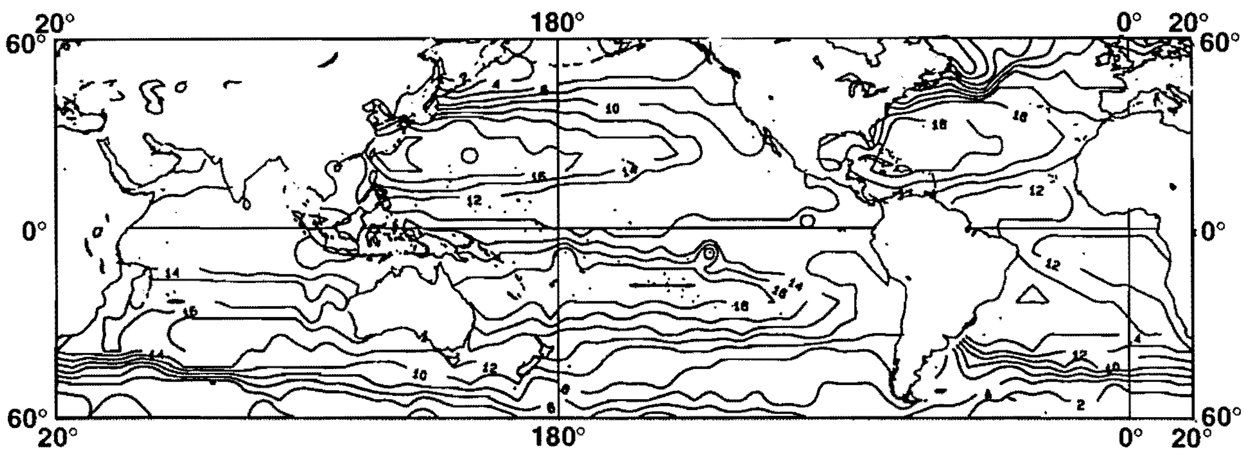

FIGURE 15. Average annual temperature (°C) at a depth of 250 meters (average depth of deep longlines).

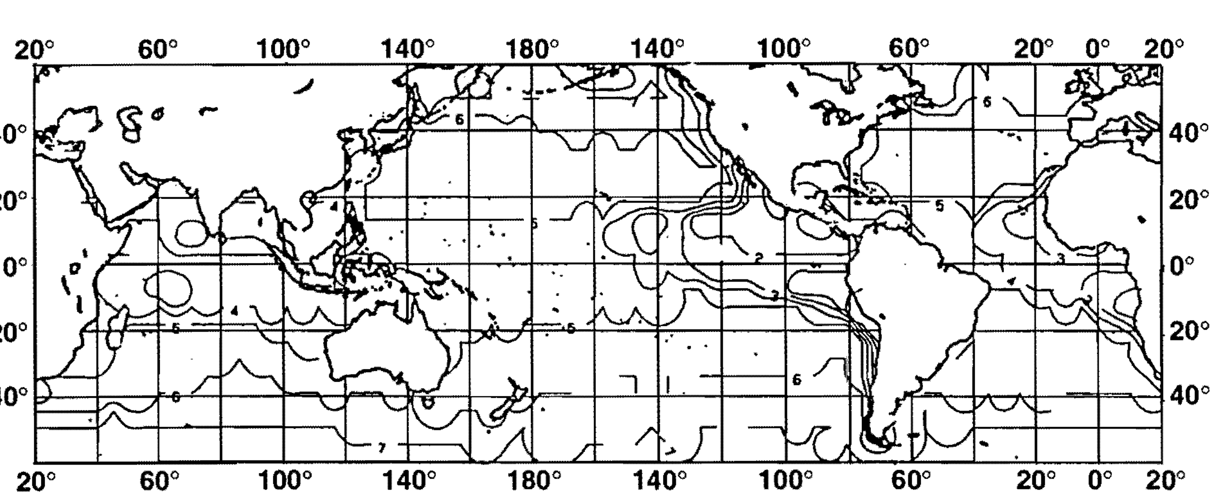

FIGURE 16. Average concentration (ml/l) of oxygen at a depth of 100 meters (average depth of conventional longlines).

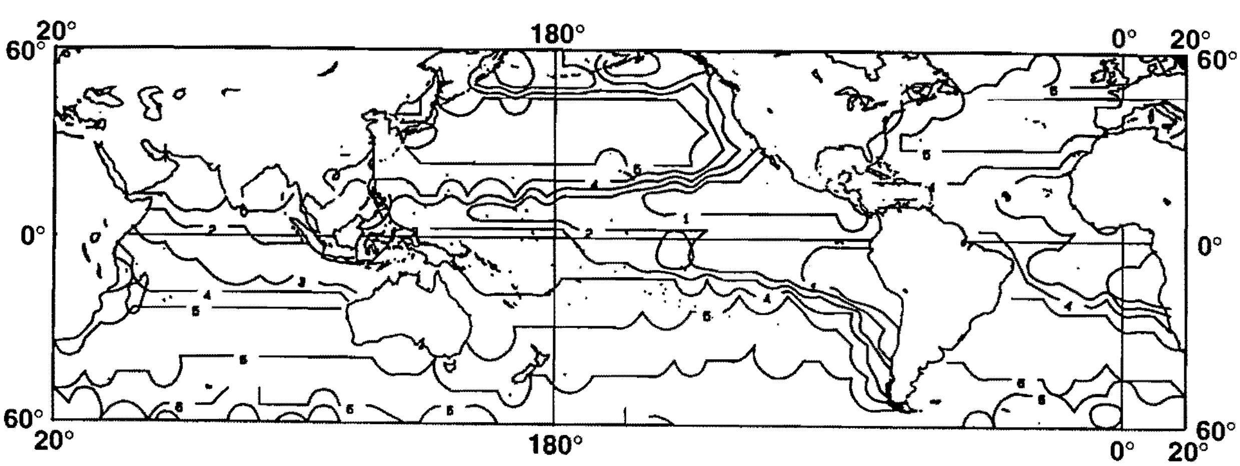

FIGURE 17. Average concentration of oxygen (ml/l) at a depth of 250 meters (average depth of deep longlines).

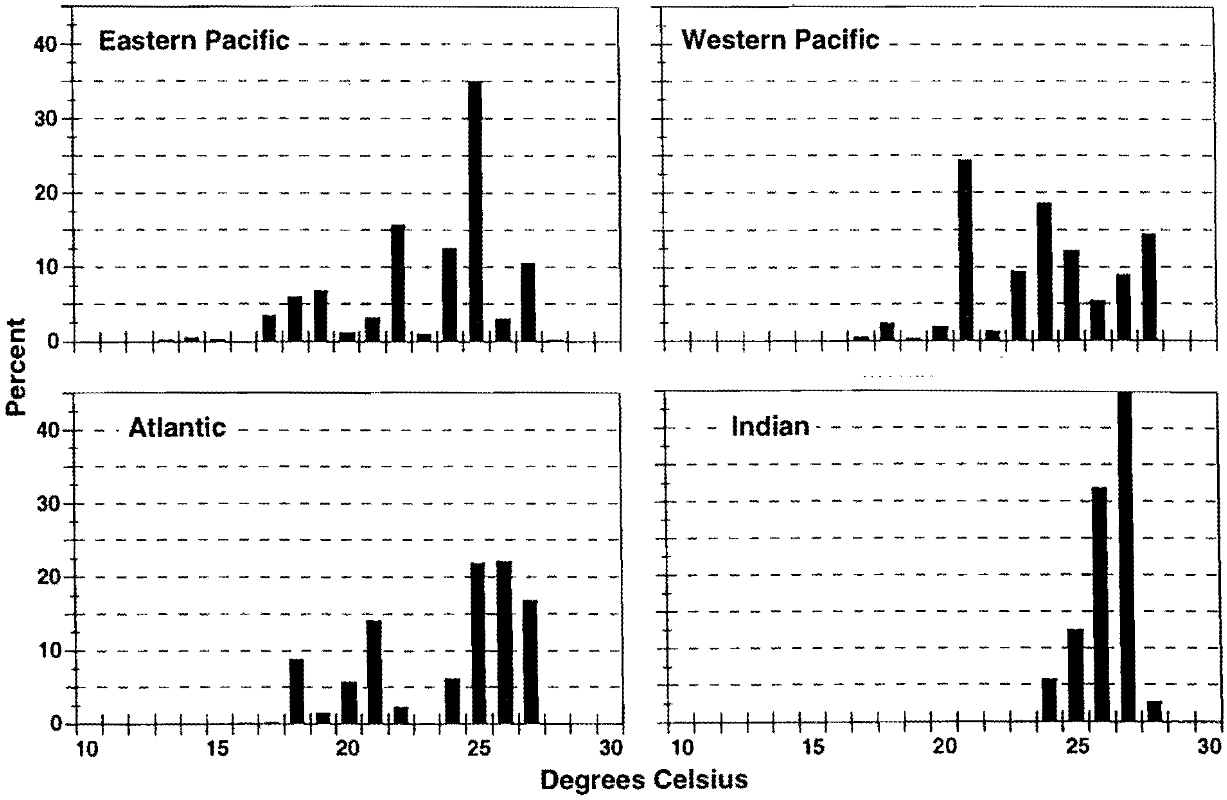

FIGURE 18. Catches of bigeye by surface fisheries as a function of the average surface temperature in each of the four ocean areas.

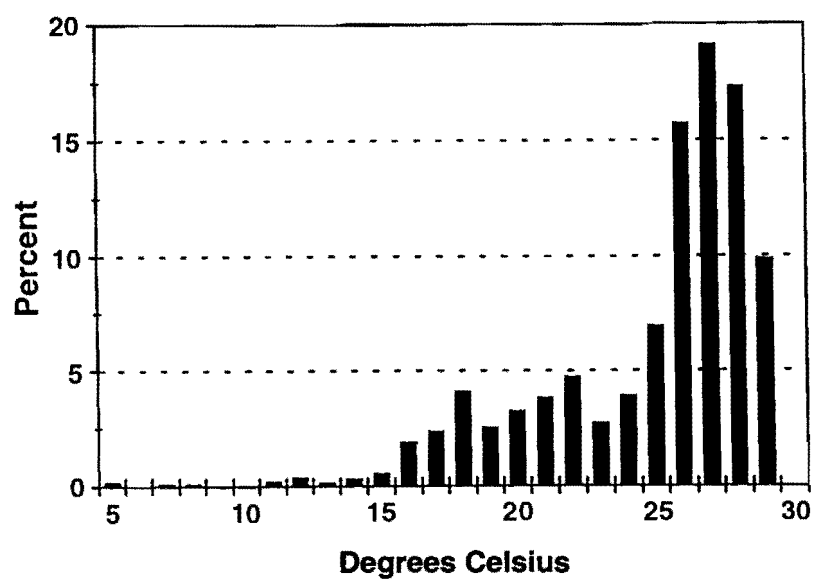

FIGURE 19. Worldwide catches of bigeye by longline fisheries as a function of the average sea-surface temperature.

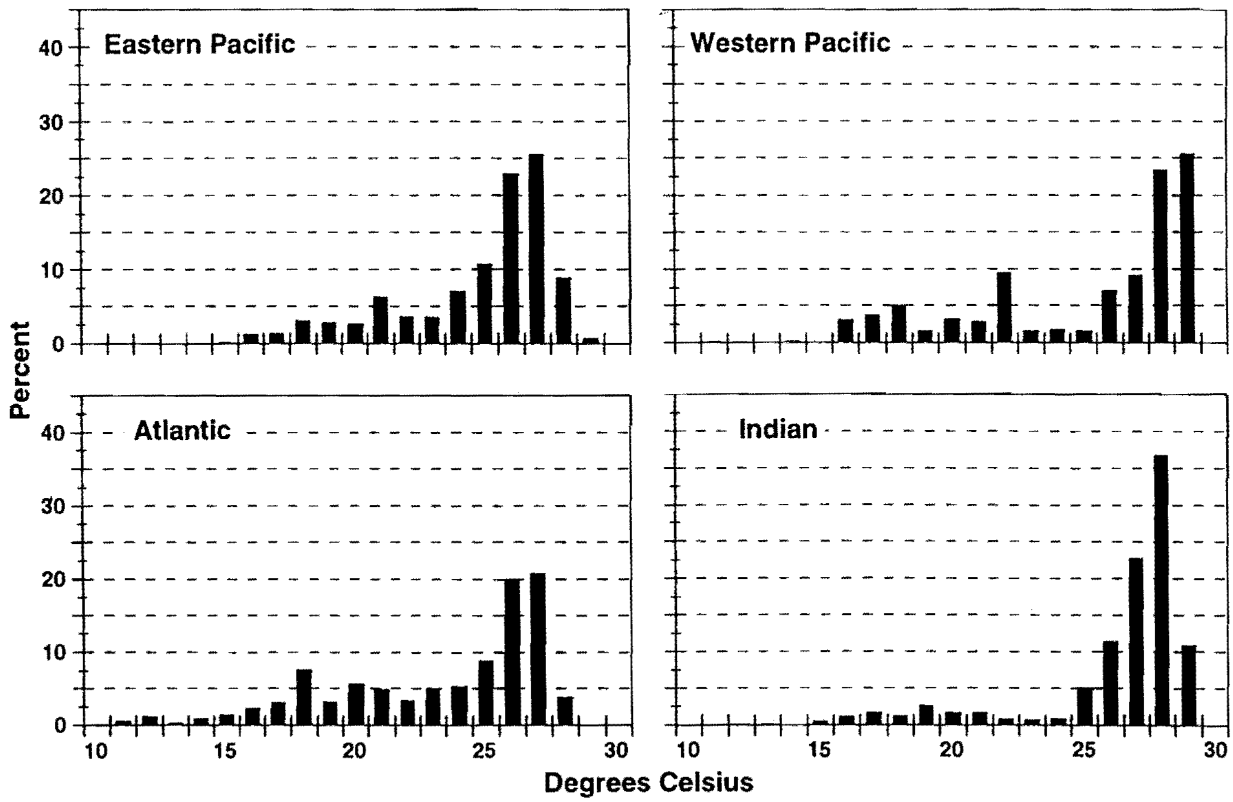

FIGURE 20. Catches of bigeye by longline fisheries as a function of the average sea-surface temperature in each of the four ocean areas.

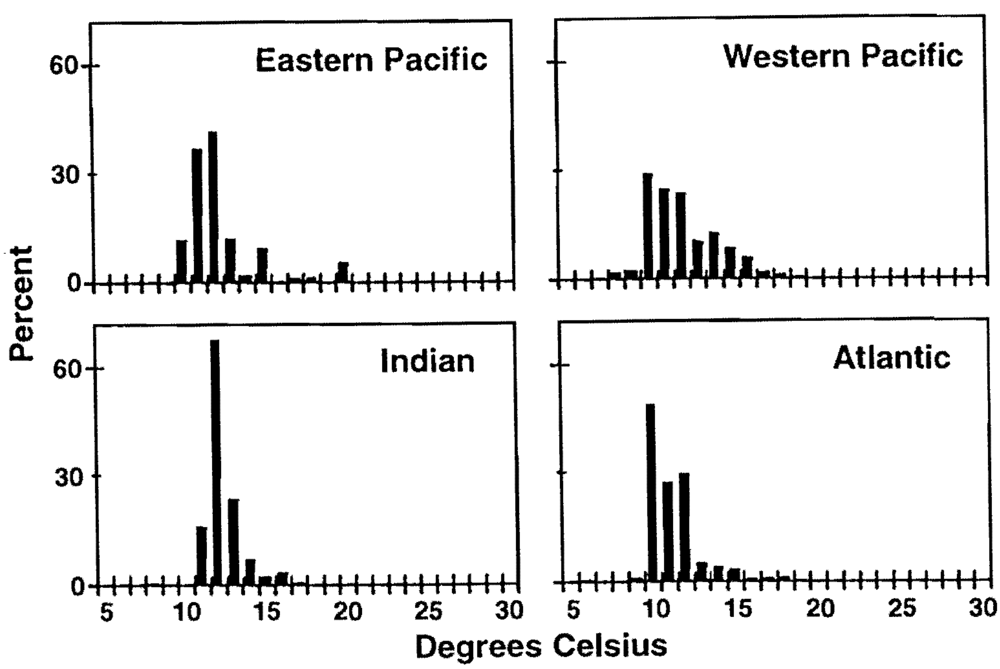

FIGURE 21. Catches of bigeye by longline fisheries as a function of the temperature at a depth of 250 meters.

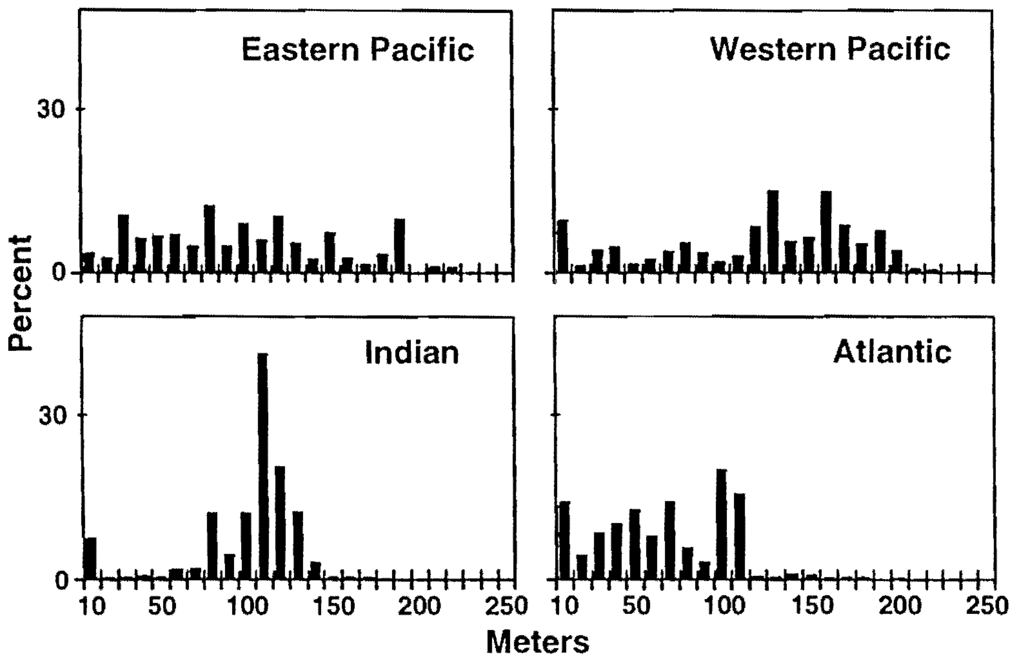

FIGURE 22. Catches of bigeye by longline fisheries as a function of the depth of the 20°C isotherm.

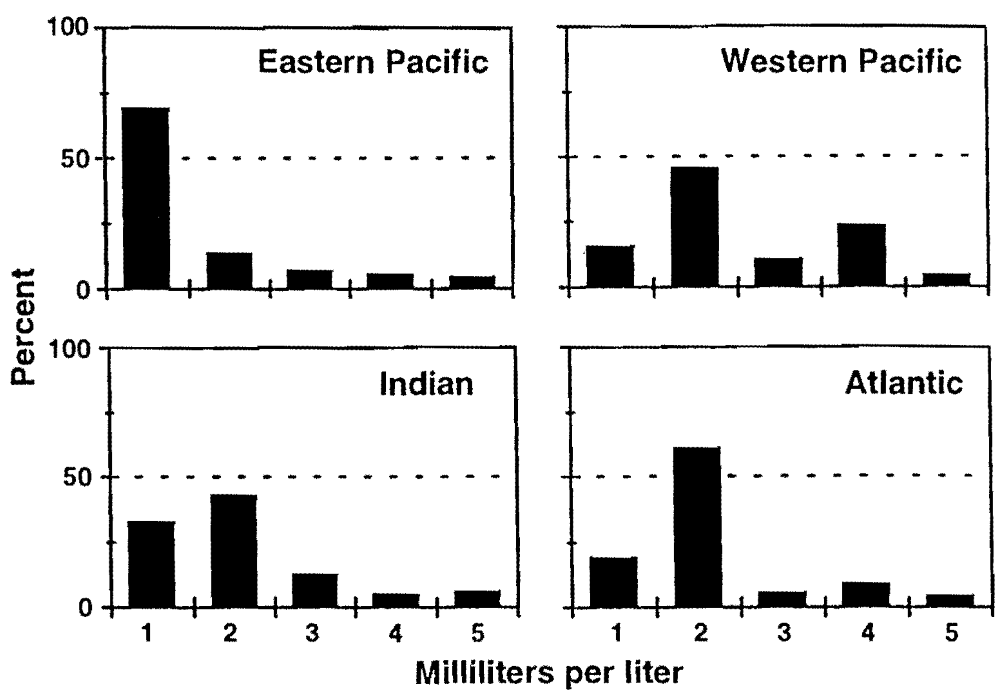

FIGURE 23. Catches of bigeye by longline fisheries as a function of the concentration of oxygen at a depth of 250 meters.

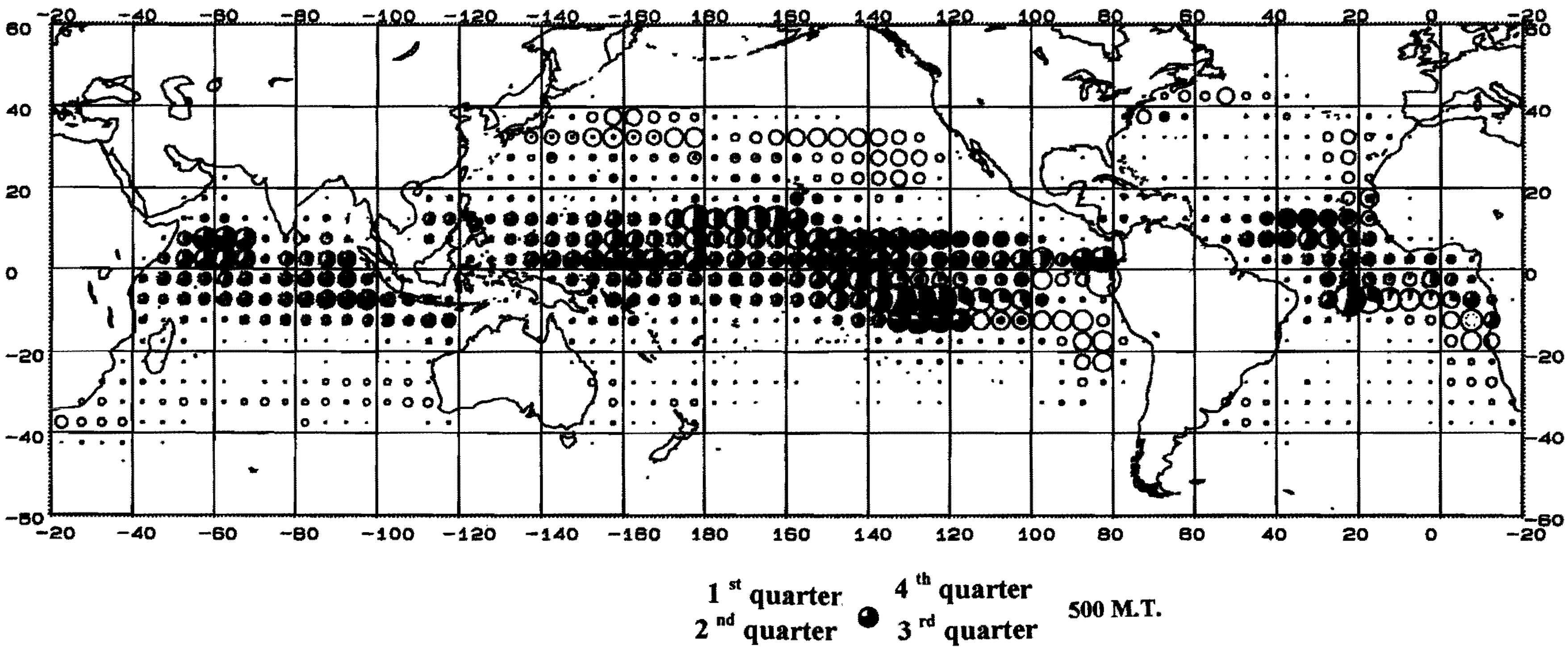

FIGURE 24. Map of the average catches of bigeye by longline vessels, total catches, and catches as a function of surface temperature, for all catches made in strata with warm (>26°C) surface water, by 5° area-quarter. NB: This figure attempts to illustrate both the global distribution of the species (by the average catches at all sea-surface temperatures), and the catches in warm waters, which very often correspond to strata potentially favorable for spawning. In these illustrations of catches in warm waters, the seasonality of the catches shown allows the periods of potential spawning to be clearly seen.

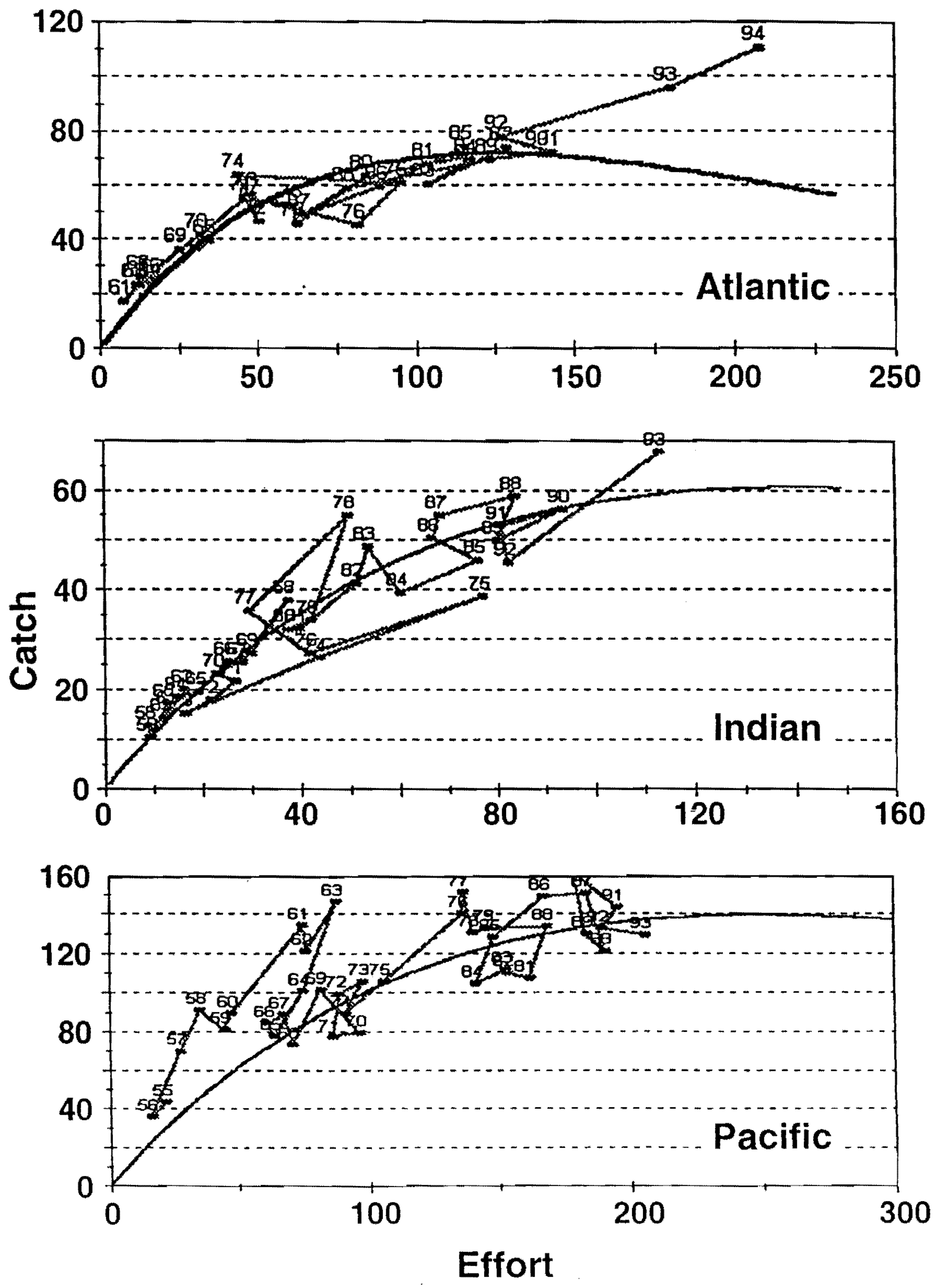

FIGURE 25. Production modeling of the bigeye stocks in the Atlantic, Indian, and Pacific Oceans: observed relationship between catches and effort, and estimated potential underlying equilibrium of the stock productivities (estimated by PRODFIT, using a value of 1.0 for m (exponential model) and $k = 5$ years).

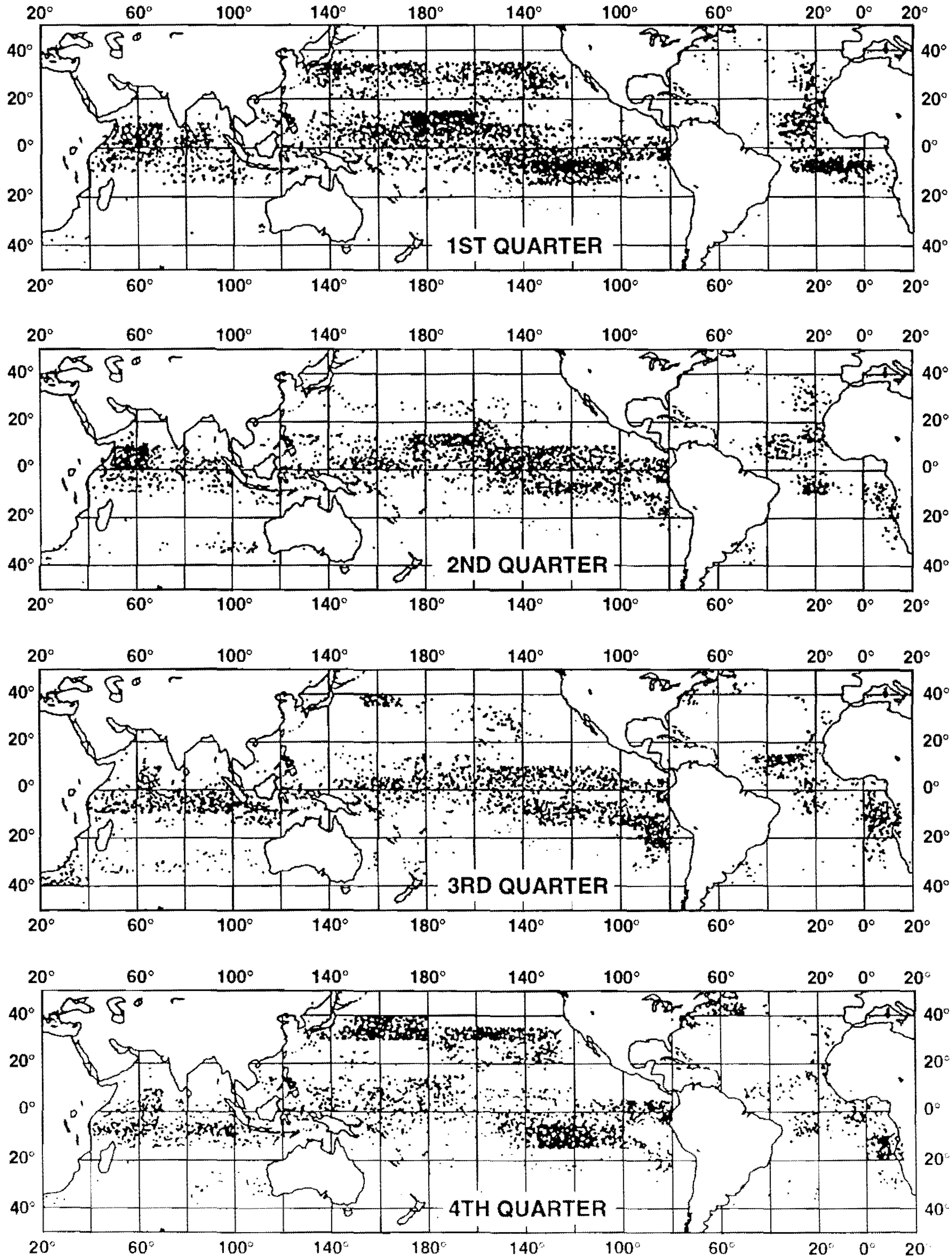

FIGURE 26. Major fishing zones for bigeye during each quarter: quarterly maps of the longline fisheries, showing all monthly catches greater than 100 tons during the 1952-1993 period (by 5° square, with a random latitude and longitude in each 5° area). The area of each circle is proportional to each monthly catch of more than 100 tons observed in the area. NB: In this type of map, a 5° fishing area, permanently fished and producing large catches each month, may potentially have 42 years x 3 months = 126 circles, but only if large catches were always made in the area. An area seldom fished will have far fewer circles (or no circles) if large catches have never been made in the area, since as any catch of less than 100 tons/month will not be shown in this map. The goal of this type of map is to show the relative importance for bigeye of each 5° area and the seasonality of the major bigeye fisheries worldwide.

TABLE 1. Catches by purse seiners in the Atlantic Ocean.

Year	Catches in log-associated schools				Catches in free-swimming schools			
	Effort	Yellowfin	Skipjack	Bigeye	Effort	Yellowfin	Skipjack	Bigeye
1990	10434	14500	34167	2921	37319	104227	31254	3443
1991	22929	18063	92295	11809	37662	84705	40151	4685
1992	23240	20544	70534	13956	32991	81220	19302	4952
1993	20171	19994	65144	20808	27531	67447	31814	9591
1994	22165	22172	62308	24192	31185	69216	28746	6847

TABLE 2. Catches by the Tema baitboat fleet.

Year	Effort	Yellowfin	Skipjack	Bigeye
1969	1123	992	4928	268
1970	1234	813	7480	212
1971	1606	1956	11730	522
1972	1654	3500	10147	935
1973	3415	7355	14450	1945
1974	5065	10243	22626	2396
1975	2417	4815	9825	558
1976	3627	6727	19092	1187
1977	4295	4435	23937	1721
1978	4213	3129	25617	1214
1979	4906	6011	30710	1095
1984	3286	5846	17268	1406
1985	3761	8954	16370	1418
1986	3369	8203	19180	1432
1987	4252	8937	22846	1112
1988	5147	8371	26006	1212
1989	4285	6857	22162	2151
1990	5752	8235	26599	4162
1991	5976	7117	30331	3658
1992	4708	7186	23164	2807

TABLE 3. Catches by purse seiners in the Indian Ocean.

Year	Catches in log-associated schools				Catches in free-swimming schools			
	Effort	Yellowfin	Skipjack	Bigeye	Effort	Yellowfin	Skipjack	Bigeye
1982	218	390	911	13	0	643	114	0
1983	1189	3624	8118	150	0	7577	1714	27
1984	6373	10902	30771	1239	0	46737	12667	613
1985	7963	17228	55207	2326	0	43304	11349	306
1986	6947	13585	59265	3922	0	45233	19751	1492
1987	6661	21914	61026	4299	0	42026	31703	1258
1988	8080	26729	75126	6751	0	82788	23388	4520
1989	10052	36379	78409	7620	0	51884	45131	3133
1990	10174	23813	85943	7678	0	74988	21111	3177
1991	10282	33981	90484	13552	0	70095	12488	5083
1992	11552	54276	101588	13882	0	63403	18347	1936
1993	11897	42236	81342	9161	0	80355	43643	5353
1994	10568	37542	102851	9272	9190	72436	27566	5897
1995	11781	79780	96579	20469	9762	50576	21855	5522

TABLE 4. Catches by purse seiners in the Pacific Ocean.

Year	Catches in log-associated schools				Catches in free-swimming schools			
	Effort	Yellowfin	Skipjack	Bigeye	Effort	Yellowfin	Skipjack	Bigeye
1968	115	7240	10685	1443	9297	47060	38058	0
1969	19	1433	942	357	8819	24266	30410	0
1970	21	1247	1847	77	11569	44571	26404	0
1971	35	3696	14958	1739	12679	36641	66705	0
1972	50	7289	5397	1975	11034	28013	14424	0
1973	98	9635	7814	1791	13787	57197	20636	0
1974	111	32004	31426	613	17287	51984	33511	0
1975	214	16720	31977	3540	18576	49890	57188	0
1976	560	36133	50986	7657	23453	60366	48507	0
1977	390	19114	21508	4983	20762	57361	35204	0
1978	398	44738	100171	9175	26956	55121	46307	0
1979	739	34099	76427	4648	29944	59953	39601	0
1980	1311	27923	70930	11920	27194	49713	35575	0
1981	483	24852	65063	8193	24790	60459	35341	0
1982	813	24654	57213	3369	18798	28066	31451	0
1983	1973	12151	26962	2040	12429	39200	22949	0
1984	668	8943	34320	3625	12613	47432	16032	0
1985	152	11389	22462	2799	13964	35457	26091	0
1986	417	33956	35975	975	11085	37747	14962	0
1987	268	25618	27821	509	13490	45222	23606	0
1988	220	22139	31976	736	17834	91567	35828	0
1989	150	27114	36278	880	17063	57203	40591	0
1990	241	34853	34797	3948	16417	55798	34424	0
1991	682	23193	35754	2968	13473	50311	21011	0
1992	608	14834	45557	4307	13128	50629	32107	0
1993	231	17056	47103	4536	15528	97037	31670	0
1994	658	18229	47488	22928	14738	64205	19713	0
1995	2091	23096	78846	30891	15836	64351	42035	0

ESTIMATES OF WESTERN AND CENTRAL PACIFIC OCEAN BIGEYE TUNA CATCH AND POPULATION PARAMETERS

by

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1. INTRODUCTION

Bigeye tuna (*Thunnus obesus*) occur in the western Pacific from approximately 45^0 N to 45^0 S, and are captured by a variety of gears, including longline (as adults), purse seine and pole-and-line. They are however primarily taken by longline gear, for which they are a major target species. Smaller but still substantial amounts are taken by the purse seine fishery, particularly in sets on logs or other floating objects. Such catches, typically of juvenile bigeye, are not normally recorded as such, but are combined with the yellowfin catch in logsheet records and landing statistics.

In this paper, we compile estimates of annual bigeye catch by gear type for the Western and Central Pacific (WCPO), the area west of 150^0 W, and including eastern Indonesia and the Philippines (Figure 1), and present a summary of available data on the size composition of these catches. Secondly, some analyses of bigeye tagging data are presented, giving preliminary estimates of bigeye growth rates, movements and mortality rates.

2. ESTIMATES OF BIGEYE CATCH IN THE WCPO

Catch estimates are developed for longline and purse seine gear, based mainly on data held in the Regional Tuna Fisheries Database (RTFD), and the multi-gear Philippines and eastern Indonesian fisheries.

2.1 Longline

The longline fishery has operated over a wide area of the WCPO since the early 1950s, first involving Japanese longliners, then progressively Taiwanese and Korean vessels, with Pacific Island countries and the PRC more recent entrants to the fishery. Bigeye have always been a significant component of the catch, but with increased targeting of the species by deep longlining beginning in the late 1970s.

Estimates of bigeye longline catch in recent years by Japan, Korea, Taiwan and the People's Republic of China (PRC) (Table 1) were based on the best estimates available (i.e. Lawson, 1996 and Japanese aggregated data). Bigeye catch estimates for the Hawaiian longline fishery were obtained from Boggs and Ito (1993) (1988-1990 data), Curran et al. (1996) (1991-1994 data), and Bigelow (pers. comm.) (1995 data). Catches listed under "Other" in Table 1 are mainly from fleets based in various Pacific Island countries. These estimates exclude longline catches in the Philippines and Indonesia, which are provided in separate sections (see below).

The WCPO bigeye longline catch has represented about 30% of the total Pacific bigeye longline catch in most years. The majority of the catch is taken in two longitudinal bands (Figure 2) — in equatorial waters between 5^0S and 15^0N, and in temperate waters north of 30^0N— areas where shallower thermoclines in association with optimal water temperatures at the thermocline render bigeye more vulnerable to longline gear (Suda, 1969). Very little bigeye catch is taken from WCPO waters south of 5^0S, other than in some domestic longline fisheries, e.g. Fiji.

2.2 Purse Seine

Few estimates of purse seine catches of mainly juvenile bigeye have been available for the WCPO; bigeye are not separated from yellowfin of similar size in the catch, and are not readily distinguishable to the untrained eye. Tanaka (1989), in Miyabe (1994), suggests that, based on sampling of Japanese purse seine unloadings at Yaizu port for the period 1976 to 1985, between 1 and 4 % of the total catch weight was bigeye, and between 3 and 14 % of the bigeye/yellowfin catch was bigeye. More recently, sampling of the catches of US purse seiners fishing in WCPO and unloading at Pago Pago since June 1988 by National Marine Fisheries Service (NMFS) has allowed species and size composition to be obtained. No comprehensive data exist for other fleets, other than that of Japan (Miyabe, pers com.), so the data for the US fleet has been extrapolated to produce estimates of the catch of bigeye for all purse seine fleets operating in the WCPO. As considerably more bigeye are taken in log-associated sets, it is necessary to have data for each fleet by set type.

Several assumptions were made when determining these estimates:

1. For each year, the species composition of bigeye compared to yellowfin taken in school sets made by other fleets is similar to that of US purse seine vessels, based on the NMFS port sampling data (Table 2).

2. For each year, the species composition of bigeye compared to yellowfin taken in associated (log and FAD) sets made by other fleets is similar to that of log sets made by US purse seine vessels, based on the NMFS port sampling data (Table 2).

3. For each year, the size composition of bigeye taken in unassociated sets made by other fleets is similar to that of US purse seine vessels, based on the NMFS port sampling data.

4. For each year, the size composition of bigeye taken in associated (log and FAD) sets made by other fleets is similar to that of log sets made by US purse seine vessels, based on the NMFS port sampling data.

Given these assumptions, a percentage of the logsheet-reported yellowfin catch was allocated to bigeye for year, flag and school type strata. The raising factors used to expand the catches of yellowfin reported on logsheets to the total regional estimates of yellowfin catch (Lawson, 1996) were then used to expand the bigeye catches apportioned from the reported yellowfin catches.

Estimates of the annual bigeye catch by the international purse seine fleet operating in the WCPO range from 1,139 t to 17,872 t for the period 1980 to 1995 (Table 3). There is little opportunity to corroborate these estimates. However, a recent estimate of the bigeye catch by the Japanese purse seine fleet (2,800 t in 1995, N. Miyabe, pers. comm.), based on independent sampling of that fleet, is very close to the estimate derived here, i.e. 2,688 t.

2.3 Philippines

Significant quantities of bigeye are known to be taken in the multi-gear Philippines tuna fishery, but again bigeye are not routinely separated from small yellowfin in the catch and are not reported separately in published FAO statistics. Miyabe et al. (1995) confirmed the species identification of bigeye, based on external morphological characters, by mtDNA analysis, and made some attempt to estimate catch-at-size for bigeye and yellowfin for 1993. The LCEM (Landed Catch and Effort Monitoring) Programme carried out during 1993 and 1994, as part of the Philippines Tuna Research Project (PTRP), at 18 landing sites throughout the Philippines, has since provided the opportunity to further this process. This sampling produced raised catch estimates at the landing sites, chosen to provide maximum coverage of the landings of oceanic species (skipjack, yellowfin and bigeye), which represent 55% and 30% respectively of the Bureau of Agricultural Statistics (BAS) estimates of total catch of these species for 1993 and 1994.

Estimated bigeye catches in Philippine waters were determined by applying an estimated percentage of bigeye expected, given the catch of yellowfin (from Lawson, 1996). Estimated percentages were determined for each gear type as described in Table 4. Where the PTRP LCEM data was used in this estimation process, 1994 was preferred to 1993 as it was believed that sampling protocol had stabilized after one years' data collection.

The proportion of bigeye in catches is similar for all gears at around 10%. Raised annual bigeye catches range from several thousand tonnes to almost 10,000 t.

2.4 Indonesia

Very few tuna catch data, apart from estimated landings, are available from Indonesia. It has therefore been necessary to extrapolate from data for adjacent Philippines waters. Estimated bigeye catches in Indonesian waters were determined by applying an estimated percentage of bigeye expected, given the declared landings by gear of yellowfin (from Lawson, 1996). Estimated percentages from the LCEM data (adjacent fishing grounds) were used in the estimation procedure (see Table 6).

The estimated catch of mostly juvenile bigeye from eastern Indonesia and the Philippines exceeds that from the WCPO purse seine fishery for several years, and constitutes around 15% of the WCPO total catch of bigeye (see later).

2.5 Estimated total bigeye catch for the WCPO

Total bigeye catches for the WCPO, summed over the foregoing sources, are given in Table 8. The catch peaked in 1990 at an estimated 82,843 t. The international longline fleet provides approximately 70% of the total catch by weight, with the domestic fisheries of eastern Indonesia and the Philippines, and the purse seine fishery each contributing approximately 15% on average. WCPO catches exceed those for the Indian Ocean and, until recent years, the Atlantic Ocean (Fonteneau, this volume). Catches are still considerably less than for the eastern Pacific, where the bulk of the Pacific longline catch is taken.

2.6 Catch rates

Data on catch per unit effort (CPUE) of bigeye for the WCPO are available only for the longline fishery, and primarily for the Japanese fleet which takes most of the catch. Unadjusted CPUEs for the WCPO have been relatively stable since 1970, whereas those for the eastern Pacific, where the main longline fishery operates, have been trending steadily downwards since that time (Figure 3). Standardized CPUE time series show essentially the same pattern for both areas.

2.7 Sex ratio

Data on sex ratio of larger longline-caught fish have been collected by observer programmes operated by Federated States of Micronesia and the SPC. For this sample (n = 2,877), males are dominant at most size classes, but at sizes larger than 125 cm LCF, this becomes more than 2:1 (Table 9).

2.8 Size composition of the bigeye catch, by gear

Bigeye size composition data have been collected by SPC observers and port samplers (longline and purse seine), NMFS port samplers (purse seine) and Philippines port samplers over the past several years.

The longline size data are unimodal, with the mode at approximately 140 cm (Figure 5). The size composition of purse seine caught bigeye is similar for unassociated and associated sets, with most sampled fish being in the range 40-90 cm (Figure 6). However, unassociated sets have some incidences of larger bigeye (110-140 cm), which have not been recorded in samples from associated sets. Bigeye catches in the Philippines by the purse seine/ringnet and handline gears are predominantly of small fish (20-50 cm), although larger fish to 170 cm are also caught in smaller numbers by handline (Figure 7).

3. BIGEYE TAGGING IN THE WESTERN AND CENTRAL PACIFIC

The SPC's Regional Tuna Tagging Project tagged 8,074 bigeye during 1990-1992. As at 30 September 1996, 937 tagged bigeye had been recaptured and reported to SPC. Most of the releases were made in three locations: the Philippines (small fish), the Coral Sea off north-eastern Australia (medium-sized fish) and in the vicinity of the Gilbert Islands (Kiribati) (medium-sized fish). Fish were tagged over a wide size range, with several modes apparent in the release length frequency (Figure 8). The tagging data provide valuable information on bigeye population dynamics. In the following sections, summary information is presented on growth, movements and mortality, as derived from the tagging data.

3.1 Growth

Of the RTTP bigeye tag recoveries, 269 were recorded as having accurate release and recapture lengths and dates. Subsequently, 15 of these returns were omitted from the analysis because of obvious inconsistencies in the data. Inspection of tag returns with short times at liberty indicated that either the length at release, the length at recapture, or both lengths were measured with error, which resulted in a number of negative observed length increments. The standard deviation of this error was approximately 1.4 cm. A von Bertalanffy model incorporating measurement errors and individual variation in L_∞ is as follows:

$$\delta_i = (L_\infty - L_i)\left[1-\exp(-Kt_i)\right] - \varepsilon_{1,i}\exp(-Kt_i) + \varepsilon_{2,i} + \varepsilon_{L,i}\left[1-\exp(-Kt_i)\right]$$

where
- δ_i is the length increment of return i,
- L_i is the length at tagging of return i,
- t_i is the time at liberty of return i,
- $\varepsilon_{1,i}$ is the release length measurement error of return i,
- $\varepsilon_{2,i}$ is the recapture length measurement error of return i, and
- $\varepsilon_{L,i}$ is the deviation from mean L_∞ of return i.

Without further information, there is no way to discriminate between the two measurement error terms. However, the effect of release length measurement error declines with time at liberty. We therefore eliminated returns less than 50 days at liberty from the analysis, and assumed that all measurement error was due to error in the measurement of recapture length. The final data set then consisted of 192 tag returns. Initial fits (maximum likelihood) of the above model (with $\varepsilon_{1,i}$ set to zero) provided the parameter estimates given in Table 9.

Examination of the standardized residuals from this fit suggested that the model did not provide an adequate fit over the range of time at liberty - growth appeared to be approximately linear for times at liberty of 50-500 days, and showed a more typical von Bertalanffy form for longer periods at liberty. A second fit was therefore carried out with parameters estimated separately for <500 and >500 days at liberty. These parameter estimates are given in Table 10.

The segmented model has an overall log likelihood of 654.0, which is a highly significant improvement in fit over the unsegmented model. The plot of observed length increments against time at liberty, and the segmented fitted model, is shown in Figure 9. The model appears to provide a reasonable description of the data.

Plots of residuals are shown in Figure 10. There are dome-shaped patterns in the residuals plotted against time at liberty and expected length increment. This might suggest deficiencies in the model, or that there is heterogeneity (such as geographical variation) in the data that is not accounted for.

Despite these shortcomings, the fitted models provide a preliminary indication of bigeye growth rates in the western and central Pacific. SPC is now sampling bigeye otoliths (currently 181 sets of otoliths covering a length range of 45-165 cm) for analysis of daily growth rings. It is expected that analysis of these data in conjunction with the tag return data will eventually provide more reliable estimates of bigeye growth.

3.2 Movements

Many of the tagged bigeye were observed to move extensively throughout the western and central Pacific (Figure 11A). Several bigeye tagged in the Coral Sea off north-eastern Australia were recaptured in the central Pacific east of 180°. Two such recoveries occurred in the vicinity of 130°W (displacements of >4,000 nmi in 4 yr and 1.8 yr), in the main bigeye fishing area for Japanese and other longliners. Two recaptures of fish released in Kiribati waters (Gilbert Islands) were recovered in Hawaii by local longliners. Bigeye clearly have the capacity for long-distance movement. Approximately 25% of observed displacements were greater than 200 nmi, with about 5% greater than 1,000 nmi (Figure 11B).

However, in some locations, notably in the Coral Sea off north-eastern Australia (where most bigeye were tagged during the RTTP), considerable numbers (213 out of a total of 260 returns from Coral Sea releases — 82%) of tagged bigeye have now been recaptured in the release area up to five years later. Some bigeye it seems show a high degree of residency in some locations. This is evident in the plot of displacement versus time at liberty (Figure 12).

3.3 Mortality

Many tagging data sets can be used to obtain estimates of fishing and natural mortality. The full bigeye data set is ill-suited to this purpose because of the apparently limited mixing of many tagged fish (e.g. the Coral Sea releases) throughout the region. However, three sets of releases (in the Philippines, Coral Sea and the western equatorial Pacific bounded by 10°N-10°S, 130°E-180°, i.e. the primary purse seine fishing ground) can be analyzed independently on local geographical scales, i.e. only considering recaptures within the release area. These three release sets are well suited to a tag attrition analysis because a high proportion of the recoveries in each case came from the release area. However, it must be recognized that the estimates of "natural mortality" may be inflated to some extent by movement away from the area of the fishery.

3.3.1 Philippines tagging

The Philippines data set consists of 1,269 bigeye tagged during the period July-October 1992. Of these, 357 (28%) were recovered in the Philippines domestic fishery, mostly by small purse seine or ringnet vessels. The fish tagged were of small size, almost all <40 cm (Figure 13). Estimates of natural mortality (M) and fishing mortality (F) rates were derived assuming reporting rates of 0.5-1.0 (Table 11). A plot of observed and expected tag returns for one of these fits is shown in Figure 14. Estimates of M and F are very high over the range of assumed reporting rates, in keeping with the high tag return rate (28%) and the rapid attrition of tagged fish. As no returns of these tagged fish were reported from outside the Philippines, it is likely that mortality of the tagged fish, rather than movement away from the Philippines, resulted in the high estimates of M. It is possible that a component of this mortality was tag induced; however we feel that high predation mortality of small tunas in the vicinity of fish aggregation devices is the most likely explanation in this instance.

3.3.2 Coral Sea tagging

The Coral Sea data set consists of 3,716 bigeye releases in October-November 1991. The fish were captured from large subsurface tuna aggregations that regularly form off the coast of Cairns, North Queensland, on the October-November full moon periods. In contrast to the Philippines releases, the Coral Sea releases were of medium to large sized bigeye, primarily >60 cm (Figure 15). Discounting short-term recaptures by the tagging vessel, 192 tagged fish have been recaptured to the end of 1996, most (154) by Australian longline and other vessels fishing in the area in which the bigeye were released. In contrast to the Philippines data set, these recaptures have occurred steadily over the subsequent five years.

The recapture of tagged bigeye and longline CPUE in this area is highly seasonal. We therefore fitted a model that incorporates seasonally variable catchability. It is likely that such changes in catchability are associated with seasonal changes in bigeye vertical distribution. Two models were fitted, one in which F in any particular season was assumed to be proportional to the level of nominal local longline effort (model 1), and one in which "effective" effort was determined to take account of suspected changes in targeting of bigeye by the longline fleet (model 2). An example of the fit of both models to the data is shown in Figure 16.

Parameters were estimated for a range of assumed reporting rates. The estimates of M are strongly sensitive to which model is applied — 0.22-0.23 yr^{-1} for model 1 and 0.52-0.59 yr^{-1} for model 2. The model 2 estimates are reasonably consistent with previous estimates of M in the literature. The model 1 estimates are much lower than typically associated with bigeye. Similarly, estimates of F for 1996 range from 0.03-0.06 yr^{-1} for model 1 to 0.14-0.24 yr^{-1} for model 2. Further analysis is required to estimate changes in targeting and to develop an appropriate index of effective effort for use in analysis of the tagging data. However, given other information from the fishery, we feel that the assumptions used in model 2 are probably more accurate than those used in model 1.

3.3.3 Western equatorial Pacific tagging

The western equatorial Pacific data set consists of 2,454 bigeye releases during the period December 1989-December 1992. The fish were captured from log-associated, FAD-associated and unassociated schools throughout the area 10°N-10°S, 130°E-180°. The releases were of small-medium sized bigeye, primarily 45-65 cm (Figure 17). Of these releases, 316 (12.9%) have been recaptured, most (297) by purse seine vessels. Most of the recaptures occurred over a two-year period following release, during which these sized bigeye would have remained vulnerable to purse seining.

A tag-attrition model was fit to the purse seine returns, assuming that F during any particular time period was proportional to purse seine fishing effort in that period. The parameters estimated are therefore M and the catchability coefficient, q. The fit of the model to the data is shown in Figure 18. The general pattern of returns is well estimated by the model, although high numbers of returns in several months (April 1990, February 1991 and July 1991) were not predicted by the model. This is due to the capture of unmixed tagged bigeye soon after release. The effect of this lack of mixing on the parameter estimates is to slightly bias upwards the estimate of q.

Parameters have been estimated for a range of assumed reporting rates (Table 12), although the reporting rate for purse seiners in the region has been estimated to be approximately 0.6 (Hampton 1997). The estimates of M are intermediate to those obtained from the Philippines data and the Coral Sea data, possibly reflecting the relative sizes of the tagged fish in each of these release groups. Fishing mortality is moderate, representing an annual exploitation rate at the estimated reporting rate (0.6) of approximately 18%. This is slightly lower than similar estimates for skipjack and yellowfin tuna (20%) in the same area.

4. FUTURE SPC RESEARCH ON BIGEYE

SPC's research on bigeye in the immediate future will largely involve refinement of the catch statistics and population parameter estimates given in this paper. During 1997, it is intended to examine several stock assessment methodologies, including biomass dynamics models and length-based age-structured models, to assess their suitability for application to bigeye.

LITERATURE CITED

Boggs, C.H. and R.Y. Ito. 1993. Hawaii's pelagic fisheries. Mar. Fish. Rev. 55(2):69-82.

Curran, D.S., C.H. Boggs and Xi He. 1996. Catch and Effort from Hawaii's longline fishery summarized by quarters and five degree squares. Honolulu Lab., Southwest Fish. Sci. Cent., National Marine Fisheries Service, NOAA, Honolulu, Hawaii. NOAA Technical Memorandum NMFS. NOAA-TM-NMFS-SWFSC-225.

Hampton, J. 1997. Estimates of tag-reporting and tag-shedding rates in a large-scale tuna tagging experiments in the western tropical Pacific Ocean. Fish. Bull. 95:68-79.

Lawson, T. 1996. South Pacific Commission tuna fishery yearbook 1995. Oceanic Fisheries Programme, South Pacific Commission, Noumea, New Caledonia. 92 p.

Miyabe, N. 1994. General review paper of Pacific bigeye tuna *Thunnus obesus*. P. 207-243 in Shomura, R., J. Majkowski, and S. Langi (editors) Interactions of Pacific tuna fisheries, Vol. 2. FAO Fisheries Technical Paper 336/2.

Miyabe, N. 1995. Follow-up study on the stock status of bigeye tuna in the Pacific Ocean. Western Pacific Yellowfin Research Group 5, Working paper 12. 21-23 August 1995, Noumea, New Caledonia.

Suda, A., S. Kume and T.Shiohama 1969. An indicative note on the role of permanent thermocline as a factor controlling the longline fishery for bigeye tuna. Bull. Far Seas Fish. Res. Lab., (1): 99-114.

Tanaka, H. 1989.Shift of the fishing ground and features of shoals caught by purse seine fishery in the tropical seas of the western Pacific Ocean. Bull. Tohoku Fish. Res. Lab., 51:75-88.

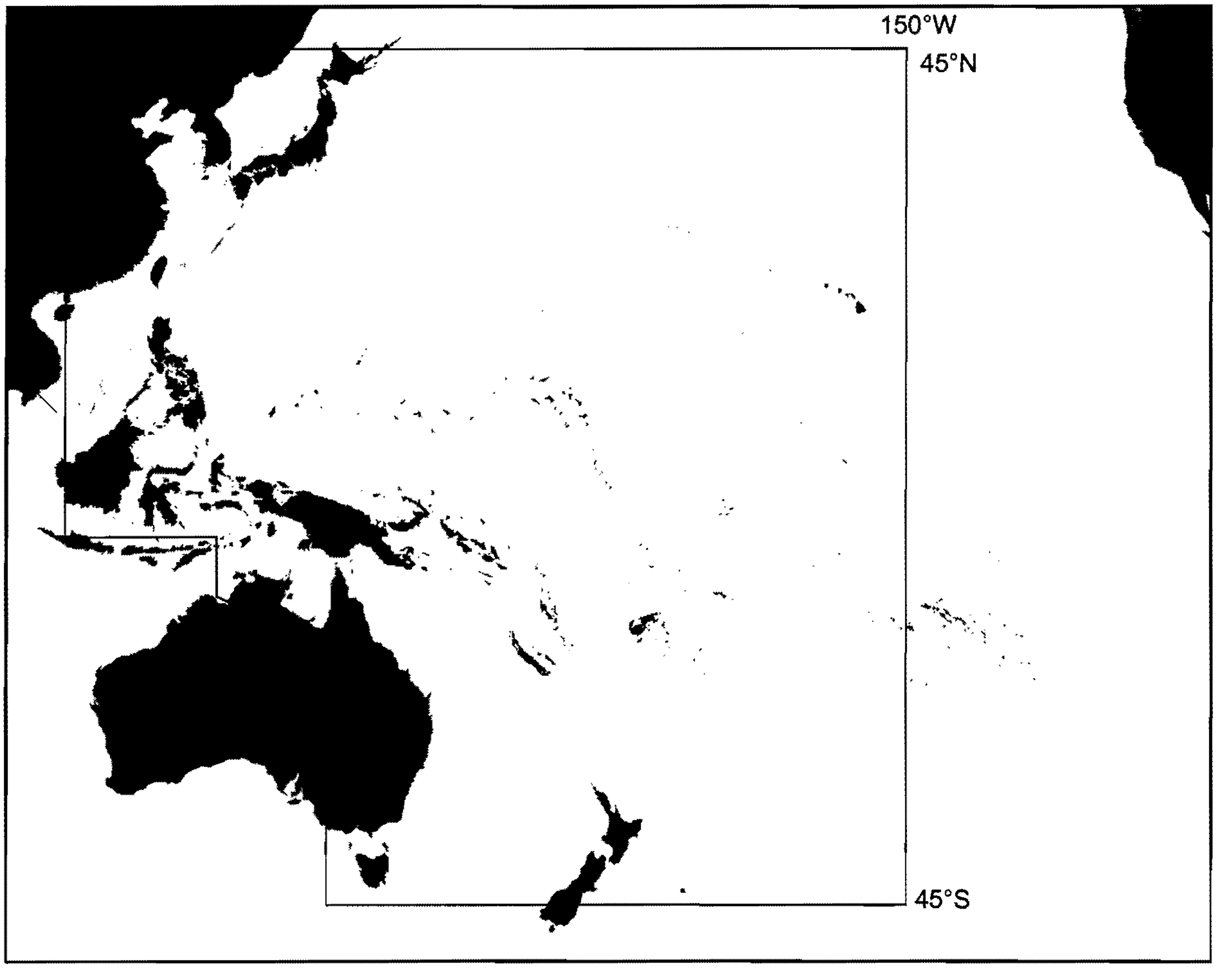

FIGURE 1. Area used in estimation of bigeye tuna catch.

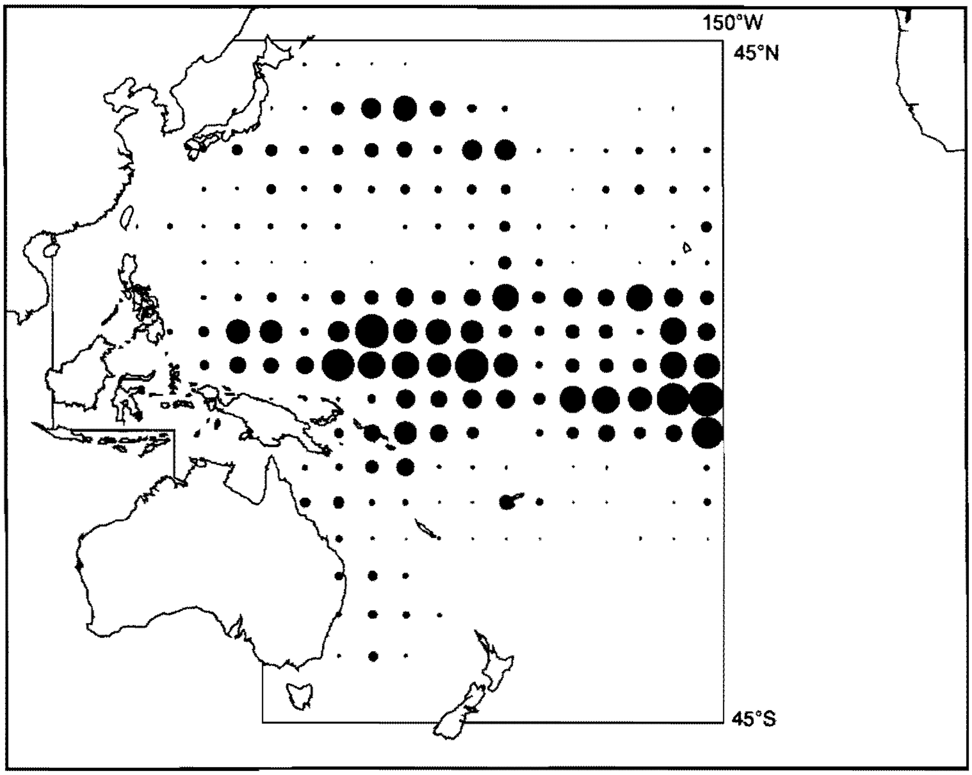

FIGURE 2. Distribution of bigeye longline catch.

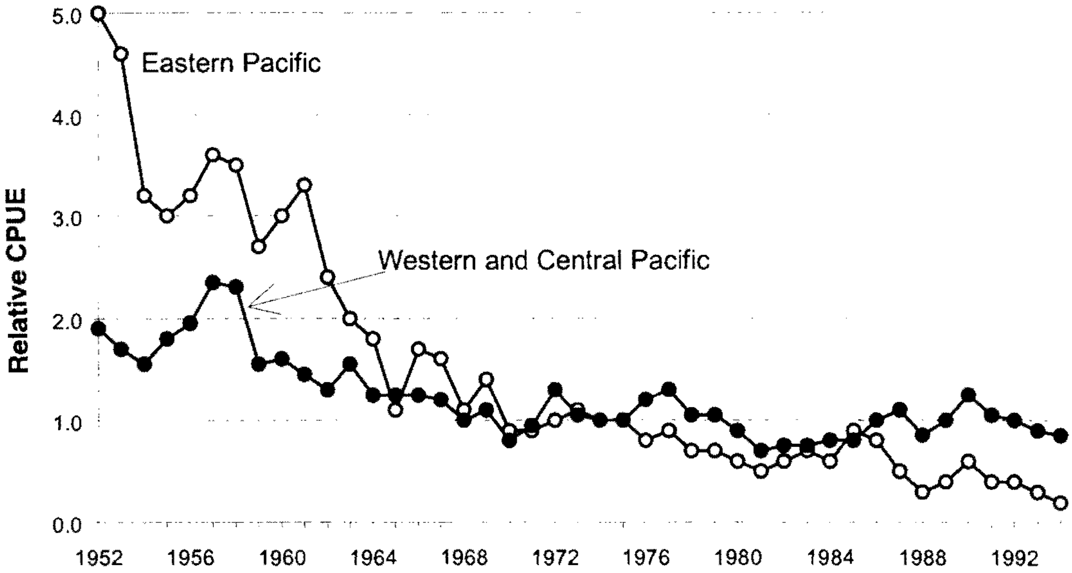

FIGURE 3. Bigeye CPUE by Japanese longliners. Eastern and western Pacific refer to areas east and west of 150°W. (After Miyabe 1995)

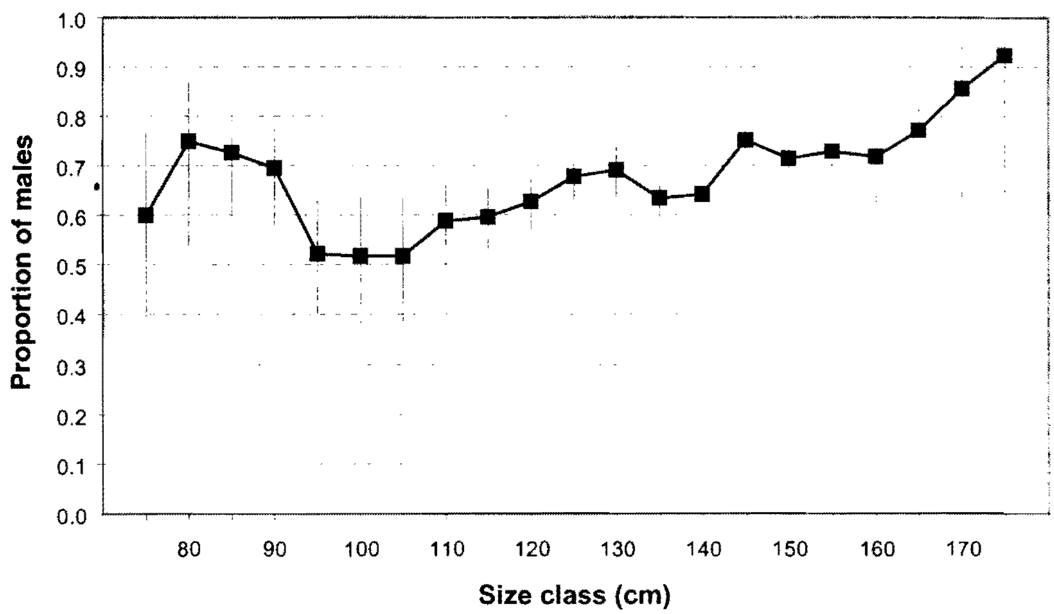

FIGURE 4. Proportion of male bigeye, by size class, from a sample of 2,977 bigeye collected by scientific observers on longliners in the WCPO. The error bars represent 95% confidence intervals on the proportions.

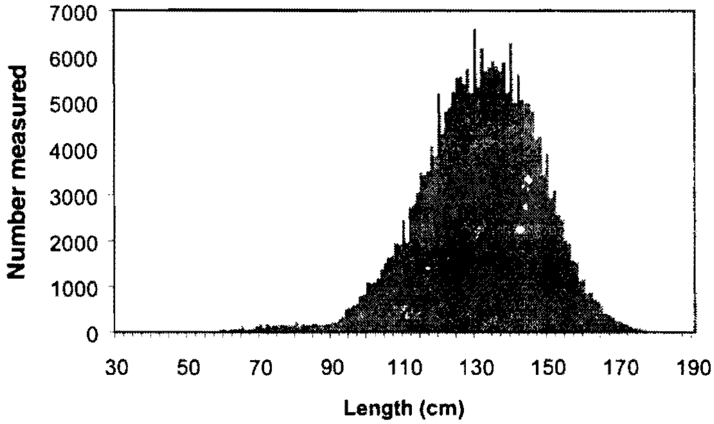

FIGURE 5. Size composition of bigeye in the longline catch. (Source: SPC port sampling data; 1992-1996)

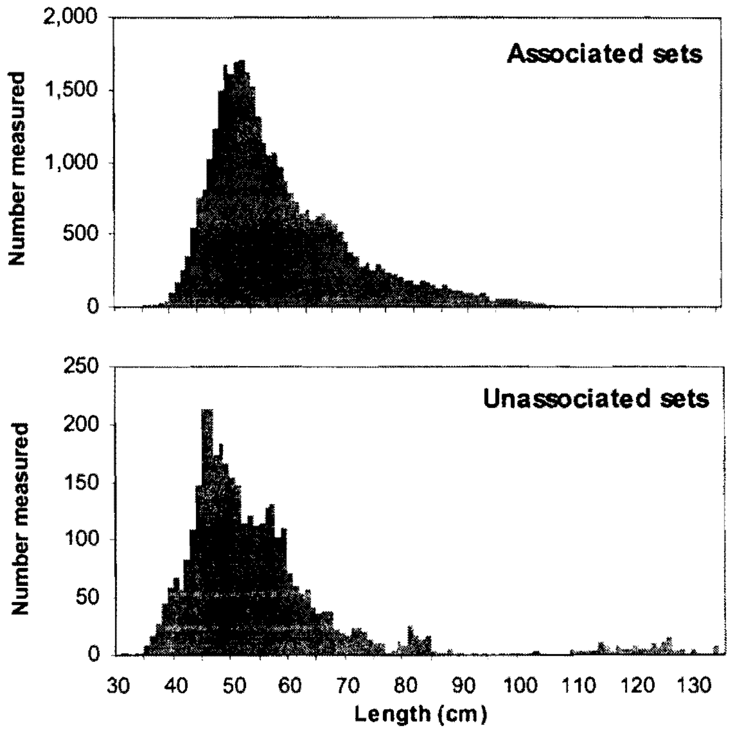

FIGURE 6. Size composition of bigeye in the US purse seine catch. (Source : NMFS port sampling data; 1988-1996)

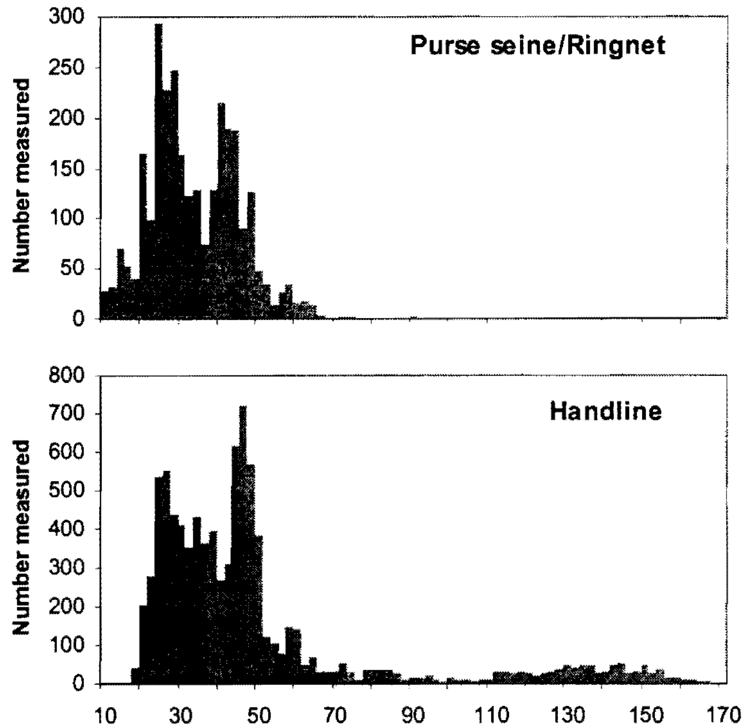

FIGURE 7. Size composition of purse seine/ringnet and handline caught bigeye sampled in the Philippines in 1994. (Source: Philippines Landed Catch & Effort Monitoring Program)

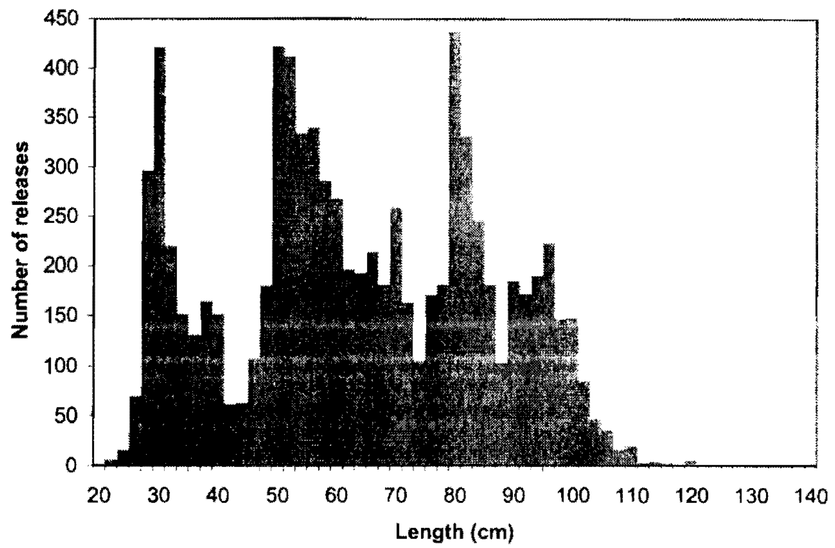

FIGURE 8. Size distribution of bigeye tag releases during the RTTP.

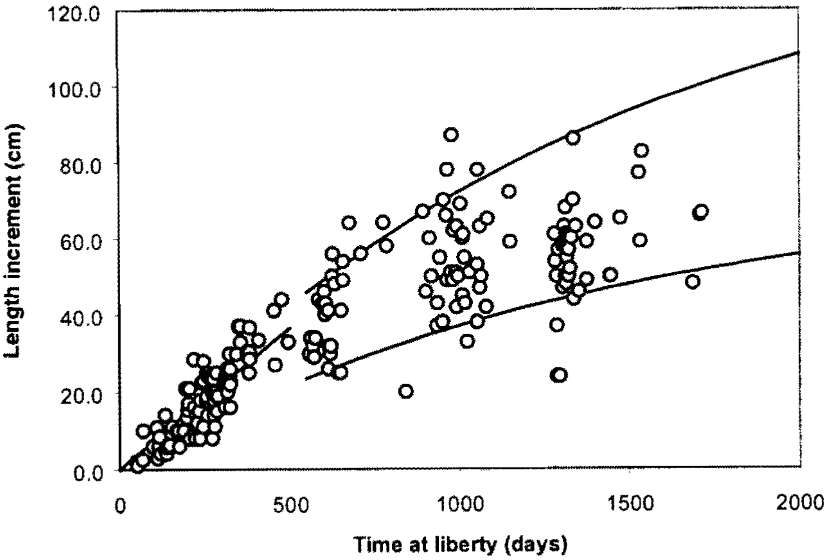

FIGURE 9. Observed length increments by time at liberty (dots) and model fits (lines). The two lines for >500 days at liberty represent predicted length

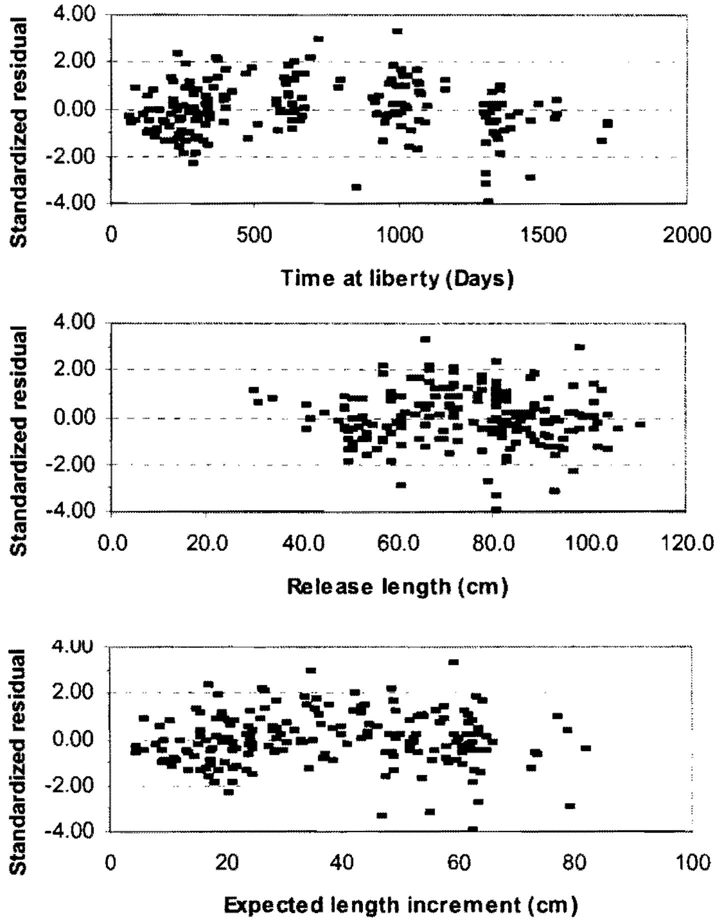

FIGURE 10. Standardized residuals plotted against time at liberty, release length and expected length increment.

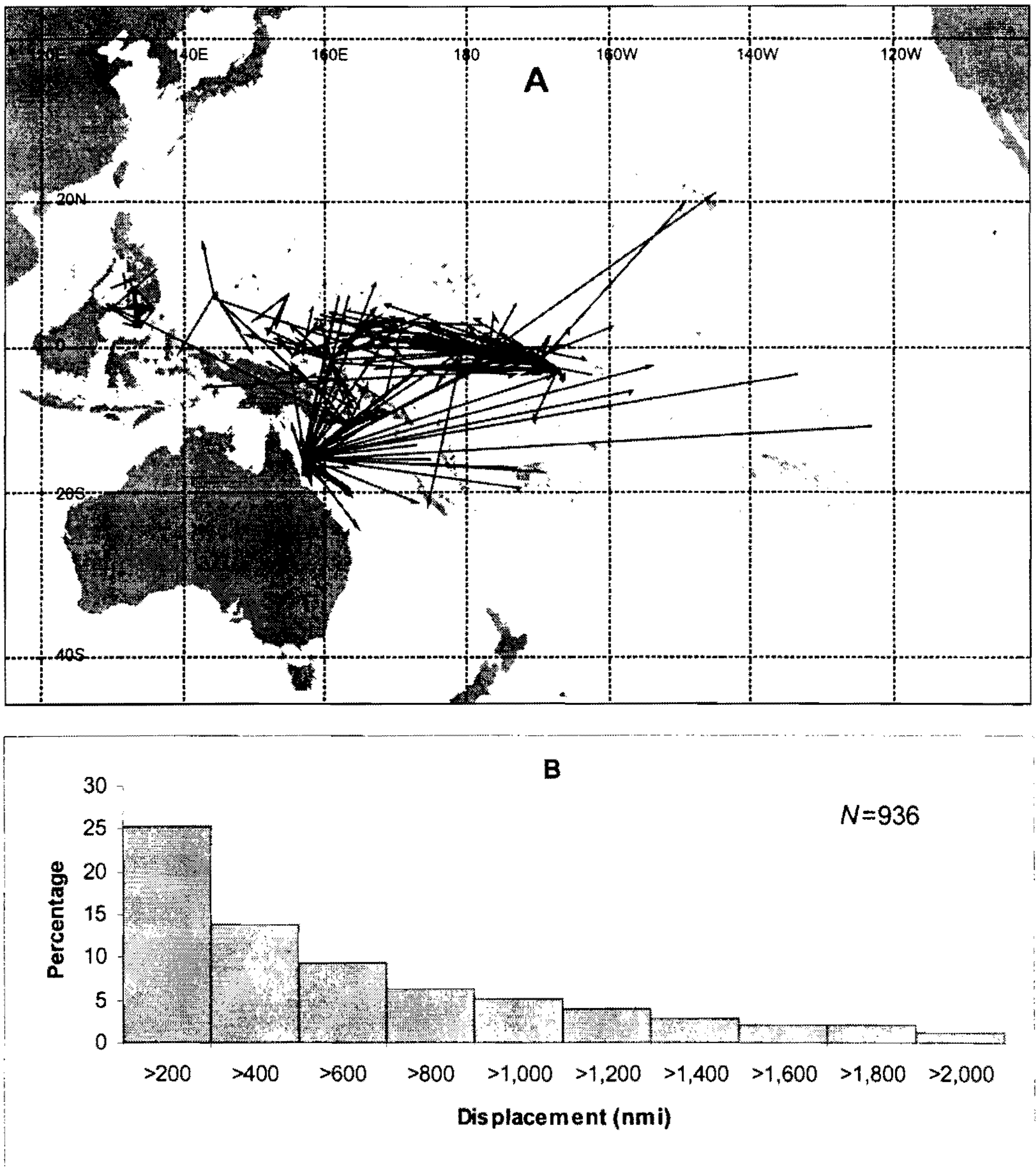

FIGURE 11. A. Displacements >100 nmi of bigeye tuna tagged by the South Pacific Commission's Regional Tuna Tagging Project (RTTP). B. The cumulative distribution of all RTTP tagged bigeye displacements having accurate location data.

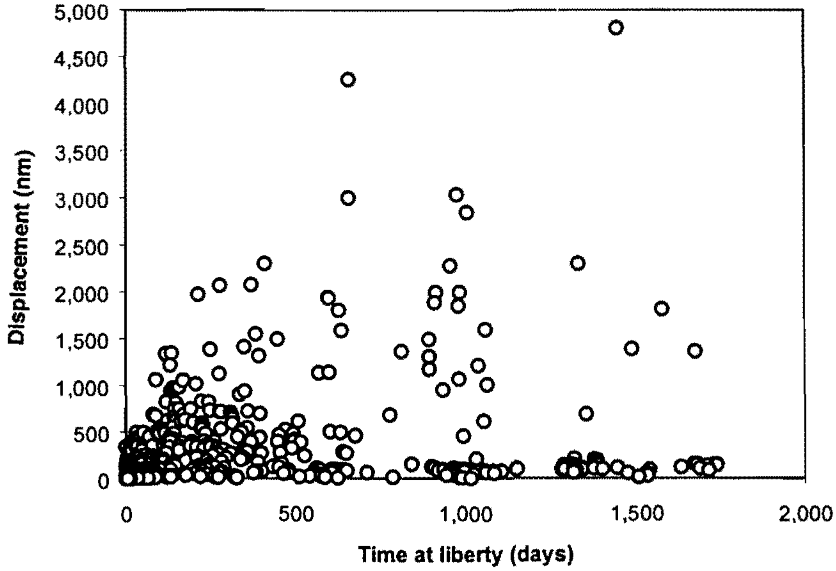

FIGURE 12. Plot of displacement versus time at liberty for RTTP tagged bigeye.

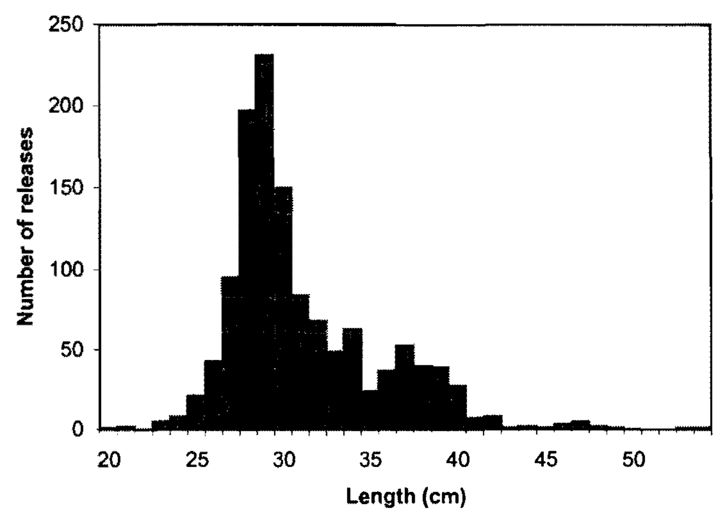

FIGURE 13. Size distribution of bigeye tag releases in the Philippines in July-October 1992.

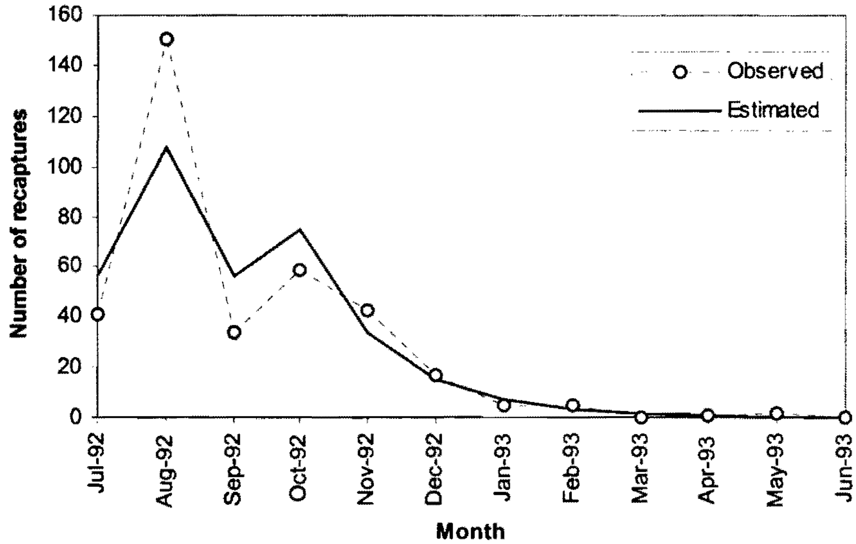

FIGURE 14. Observed and predicted tag returns for bigeye tagging in the Philippines in July-October 1992.

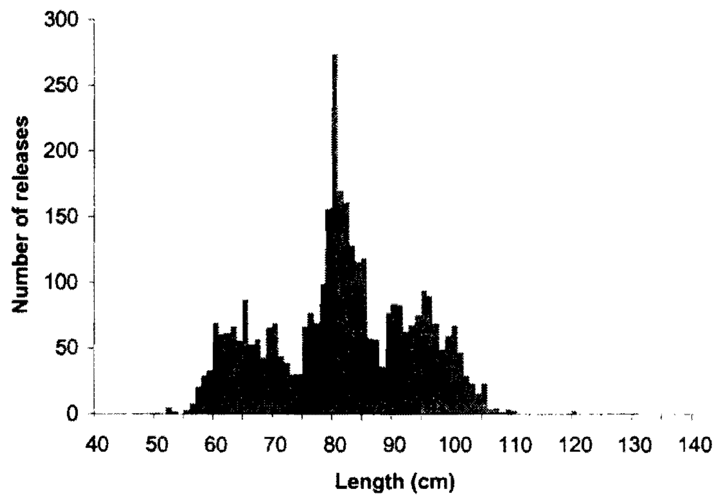

FIGURE 15. Size distribution of bigeye tag releases in the Coral Sea in October-November 1991.

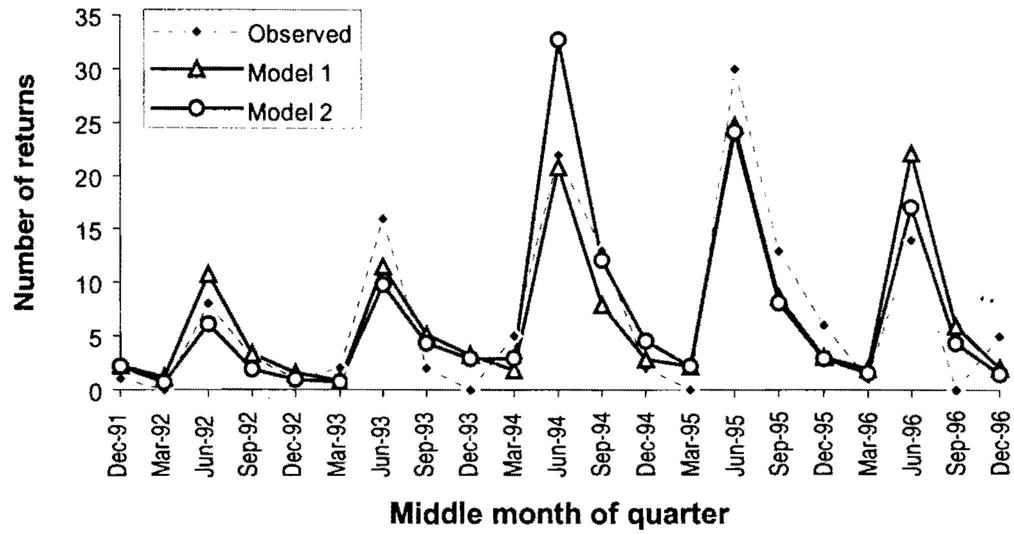

FIGURE 16. Observed and predicted tag returns for bigeye tagging in the Coral Sea in October-November 1991. In Model 1, bigeye fishing mortality in a given season is proportional to nominal effort; in Model 2, bigeye fishing mortality in a given season is also influenced by targeting efficiency, assumed to be proportional to catch per unit effort.

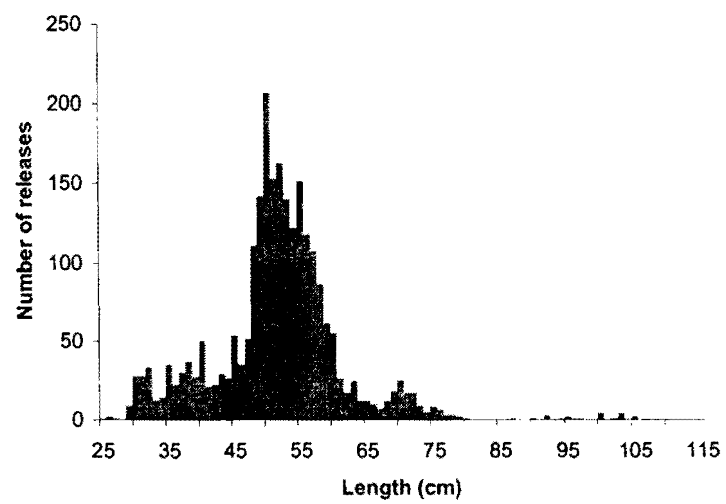

FIGURE 17. Size distribution of bigeye tag releases in the western equatorial Pacific in December 1989-December 1992.

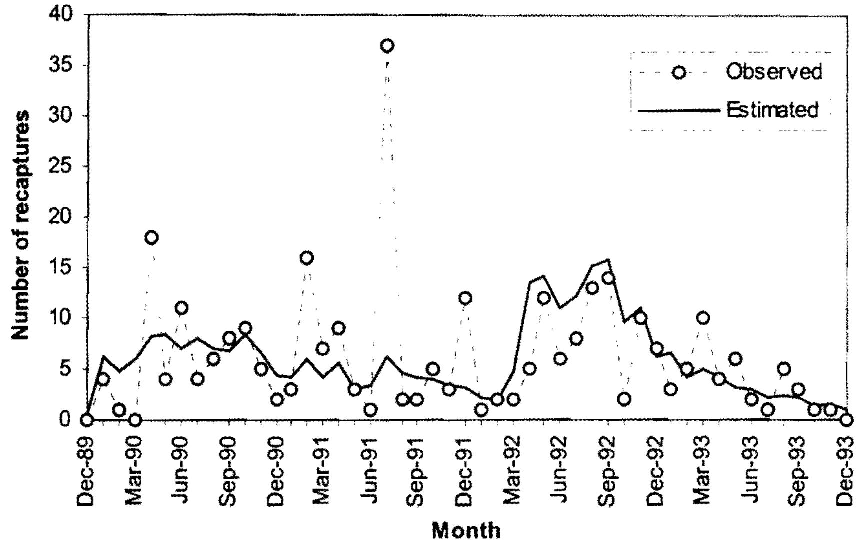

FIGURE 18. Observed and predicted tag returns for bigeye tagging in the western equatorial Pacific during the period December 1989-December 1992. Bigeye fishing mortality is assumed proportional to purse seine fishing effort.

TABLE 1. Estimated bigeye catch (t) from longline vessels operating in western and central Pacific tuna fisheries (excluding Indonesia and Philippines).

Year	Japan	Korea	Taiwan	People's Republic of China	Hawaii	Other	Total
1970	21,570	0	1,673	0	250	0	23,493
1971	22,360	0	1,429	0	250	0	24,039
1972	30,311	0	1,704	0	250	0	32,265
1973	21,243	0	1,653	0	250	16	23,161
1974	24,173	0	1,496	0	250	0	25,919
1975	22,789	15,203	901	0	250	0	39,143
1976	27,048	14,889	801	0	250	25	43,013
1977	30,544	13,874	1,073	0	250	34	45,775
1978	26,066	7,543	1,000	0	250	36	34,894
1979	29,148	12,029	1,241	0	250	86	42,754
1980	33,755	10,740	1,468	0	300	98	46,361
1981	27,974	6,381	943	0	380	25	35,704
1982	32,501	7,020	468	0	420	42	40,452
1983	30,640	4,462	295	0	490	52	35,939
1984	35,628	6,428	475	0	600	94	43,226
1985	39,108	9,149	298	0	700	76	49,331
1986	31,979	6,137	181	0	800	31	39,127
1987	40,824	11,760	220	0	816	113	53,734
1988	35,872	11,491	186	0	1,500	68	49,118
1989	37,353	11,564	347	0	1,600	69	50,933
1990	40,184	14,077	3,899	0	1,700	116	59,976
1991	32,113	6,360	2,379	380	1,680	223	43,135
1992	32,501	13,060	5,076	1,226	1,597	538	53,999
1993	30,667	10,647	3,396	3,131	2,161	720	50,721
1994	27,904	13,754	4,870	7,764	1,886	918	57,096
1995	23,330	12,625	3,627	4,890	2,300	1,102	47,875

TABLE 2. Percentage of bigeye (by weight) expected in the purse-seine logsheet-reported catch of yellowfin, based on NMFS port sampling data 1988-1995 (A. Coan, pers. comm.). Estimates for 1980-1987 are based on averages of the 1988-1995 estimates.

	Percentage bigeye			Percentage bigeye	
Year	School	Log	Year	School	Log
1980	0.64	12.70	1988	3.04	8.88
1981	0.64	12.70	1989	0.48	16.02
1982	0.64	12.70	1990	0.34	11.62
1983	0.64	12.70	1991	1.01	10.12
1984	0.64	12.70	1992	0.66	13.92
1985	0.64	12.70	1993	0.91	12.94
1986	0.64	12.70	1994	0.44	11.59
1987	0.64	12.70	1995	0.98	16.30

TABLE 3. Estimated purse seine catch (t) of bigeye and the percentage of bigeye in the combined yellowfin-bigeye purse seine catch in the WCPO.

Year	Japan		Korea		Taiwan		US		Other		Total	
	Bigeye	%	Bigeye	%	Bigeye	%	Bigeye	%	Bigeye	%	Bigeye	%
1980	1,026	10.9	6	8.7			73	6.7	34	7.5	1,139	10.4
1981	2,648	12.3	51	8.7			1,087	6.7	101	7.5	3,887	9.8
1982	3,024	10.5	213	10.4			1,533	6.7	105	5.5	4,875	8.7
1983	2,820	10.8	96	12.1	265	12.3	4,745	8.7	373	13.5	8,299	9.6
1984	2,944	9.5	52	12.6	410	10.7	4,258	9.3	575	12.4	8,239	9.6
1985	3,431	9.9	155	9.6	487	10.9	1,696	7.0	602	8.7	6,371	8.9
1986	3,779	9.5	164	6.8	694	12.4	2,483	7.5	649	11.3	7,769	9.0
1987	3,385	8.4	1,412	8.1	915	12.6	4,035	6.3	1,677	12.7	11,424	8.1
1988	2,125	8.3	1,077	7.0	780	8.5	1,510	6.0	927	8.8	6,418	7.5
1989	3,914	11.7	2,046	12.8	2,268	14.2	2,374	5.1	2,536	16.0	13,139	9.0
1990	1,502	7.1	2,084	9.0	2,546	11.0	1,448	2.5	2,531	11.2	10,111	6.4
1991	2,434	5.4	2,604	7.4	3,175	9.0	1,301	3.2	1,769	10.0	11,284	5.8
1992	2,956	6.3	4,621	9.1	4,331	8.6	3,092	6.8	2,872	12.6	17,872	7.7
1993	3,116	5.7	2,586	4.2	2,733	4.5	3,503	6.6	2,583	10.8	14,521	5.9
1994	2,132	5.8	2,277	5.1	1,758	3.9	1,142	1.8	1,642	9.0	8,951	4.2
1995	2,688	6.9	2,829	9.5	1,309	4.4	2,382	6.5	3,250	13.0	12,458	6.9

TABLE 4. Estimated percentage of bigeye in the declared yellowfin catch by gear for vessels fishing in Philippine waters.

Gear	Percentage bigeye	Comments
Bagnet	10.0	Not enough information available from the LCEM database. Therefore, species composition was assumed to be similar to purse seine/ringnet vessels operating in the Philippines (i.e. 1994 LCEM data).
Gillnet	10.0	Not enough information available from the LCEM database. Therefore, species composition was assumed to be similar to purse seine/ringnet vessels operating in the Philippines (i.e. 1994 LCEM data).
Handline	8.6	Species composition was determined from 1994 LCEM data.
Longline	8.6	No data are available for the longline fishery. Assumed to be similar to the handline proportion.
Purse seine	10.0	Species composition was determined from 1994 LCEM data.
Ringnet	9.9	Species composition was determined from 1994 LCEM data.
Seine net	10.0	Not enough information available from the LCEM database. Therefore, species composition was assumed to be similar to purse seine/ringnet vessels operating in the Philippines (i.e. 1994 LCEM data).
Unclassified	10.0	Assumed to be primarily a mixture of purse seine, ringnet and handline. Therefore, the estimate of 10% applied.

TABLE 5. Estimated catch (t) of bigeye by gear in the Philippines.

Year	Bagnet	Gillnet	Handline	LL	PS	Ringnet	Seine net	Uncl.	Total
1980	65	230	2,761	0	1,246	0	7	43	4,353
1981	51	266	2,821	92	1,455	364	1	95	5,143
1982	12	139	2,557	163	1,635	133	5	106	4,749
1983	32	126	3,086	0	2,078	0	14	366	5,701
1984	75	216	2,666	110	2,299	0	8	65	5,440
1985	133	204	3,053	156	1,675	484	68	133	5,907
1986	35	214	3,112	207	1,267	492	1	82	5,411
1987	42	216	2,271	325	1,517	292	9	87	4,758
1988	0	0	0	0	0	0	0	5,706	5,706
1989	0	0	0	0	0	0	0	6,215	6,215
1990	69	81	236	18	2,157	819	0	4,687	8,069
1991	1	2	1,967	22	2,398	298	0	4,548	9,236
1992	12	176	2,080	105	1,211	272	112	181	4,147
1993	65	114	2,271	90	445	157	0	294	3,435
1994	54	425	3,248	121	944	773	0	294	5,859
1995	5	166	3,026	114	1,864	105	0	278	5,558

TABLE 6. Estimated percentage of bigeye in the declared catch of yellowfin by gear for vessels fishing in Indonesian waters.

Gear	Percentage bigeye	Comments
Handline	8.6	Philippines estimate for handline (Table 4)
Longline	8.6	Philippines estimate for longline (Table 4)
Purse seine	10.0	Philippines estimate for purse seine (Table 4)
Pole-and-line	10.0	Assumed to be similar to other surface gears in this area
Unclassified	10.0	Philippines estimate for Unclassified (Table 4)

TABLE 7. Estimated catch (t) of bigeye by gear in Indonesia.

Year	Pole-and-line	Handline	Longline	Purse seine	Unclassified	Total
1980	0	0	0	0	1,755	1,755
1981	0	0	0	0	2,189	2,189
1982	96	0	310	143	1,834	2,384
1983	0	0	0	0	2,020	2,020
1984	228	0	144	211	2,039	2,622
1985	234	0	212	211	2,267	2,924
1986	228	0	210	165	2,787	3,390
1987	232	0	0	168	2,843	3,244
1988	244	0	0	177	2,985	3,406
1989	471	234	441	252	3,135	4,532
1990	443	275	474	267	3,229	4,687
1991	547	330	521	250	3,446	5,094
1992	532	412	537	220	3,677	5,378
1993	559	433	537	460	3,861	5,849
1994	583	529	396	490	3,765	5,763
1995	0	0	0	0	5,913	5,913

TABLE 8. Estimated catch (t) of bigeye in the western and central Pacific Ocean, west of 150°W.

Year	Longline	Purse seine	Philippines	Indonesia	Total
1980	46,361	1,139	4,353	1,755	53,609
1981	35,704	3,887	5,143	2,189	46,923
1982	40,452	4,875	4,749	2,384	52,460
1983	35,939	8,299	5,701	2,020	51,960
1984	43,226	8,239	5,440	2,622	59,527
1985	49,331	6,371	5,907	2,924	64,533
1986	39,127	7,769	5,411	3,390	55,697
1987	53,734	11,424	4,758	3,244	73,160
1988	49,118	6,418	5,706	3,406	64,648
1989	50,933	13,139	6,215	4,532	74,819
1990	59,976	10,111	8,069	4,687	82,843
1991	43,135	11,284	9,236	5,094	68,748
1992	53,999	17,872	4,147	5,378	81,396
1993	50,721	14,521	3,435	5,849	74,527
1994	57,096	8,951	5,859	5,763	77,669
1995	47,875	12,458	5,558	5,913	71,804

TABLE 9. Parameter estimates for a von Bertalanffy model with individual variation in L_∞ applied to bigeye tag return data (192 observations).

Parameter	Estimate	SD
L_∞ (cm)	184.0	7.885
K (yr^{-1})	0.2536	0.02515
Variance of $\varepsilon_{L,i}$	316.2	104.2
Variance of $\varepsilon_{2,i}$	27.23	6.832
Function value	674.0	

TABLE 10. Parameter estimates for a segmented model applied to bigeye tag return data (192 observations). For data <500 days at liberty, a linear model is applied. For data >500 days at liberty, a von Bertalanffy model with individual variation in L_∞ is applied.

Parameter	Estimate	SD
t_i <500 days		
Rate (cm per yr)	26.63	0.8249
Variance of $\varepsilon_{2,i}$	26.61	4.209
Function value	244.77	
t_i >500 days		
L_∞ (cm)	. 156.82	4.616
K (yr^{-1})	0.4272	0.04679
Variance of $\varepsilon_{L,i}$	180.4	70.20
Variance of $\varepsilon_{2,i}$	7.972	25.79
Function value	409.23	

TABLE 11. Estimates of M and F (per month) from the Philippines data, assuming different reporting rates.

Reporting rate	M	F
0.5	0.3435	0.4420
0.6	0.4172	0.3683
0.7	0.4698	0.3157
0.8	0.5093	0.2762
0.9	0.5400	0.2455
1.0	0.5645	0.2210

TABLE 12. Estimates of M and F (per month) from the western equatorial Pacific data, assuming different levels of reporting rate.

Reporting rate	M	F
0.5	0.0875	0.0345
0.6	0.0969	0.0288
0.7	0.1036	0.0248
0.8	0.1086	0.0217
0.9	0.1125	0.0193
1.0	0.1157	0.0174

HAWAII TUNA TAGGING PROJECT

by

David G. Itano
University of Hawaii, Pelagic Fisheries Research Program

1. Introduction

The Pelagic Fisheries Research Program (PFRP) of the University of Hawaii funds several projects on the pelagic fishery resources of the central and western Pacific. Dr. Kim Holland is the active principal investigator to a small-scale mark and recapture study for bigeye and yellowfin tuna in Hawaiian waters funded by the PFRP. The Hawaii Tuna Tagging Project (HTTP) was originally requested by a small group of fishermen who exploit tuna on a highly-productive seamount and near offshore anchored fish-aggregation devices (FADs). The project is restricted in release sites to the Cross Seamount, located 160 nautical miles south of Honolulu, Hawaii, and the offshore FADs located between 150 and 180 miles from shore. The PFRP has also funded a modeling study to optimize the design of a larger-scale tuna tagging project for the entire Hawaii EEZ.

The participants in the fishery target juvenile bigeye and yellowfin tuna that aggregate to the Cross Seamount and offshore FADs. The fishery consists of small vessels of 10 to 30 meters in length that use simple handline or troll gear to take bigeye and yellowfin in the 6- to 25-kg range. The area near the seamount has also been historically exploited by Hawaii-based longline vessels targeting larger bigeye and yellowfin tuna. Initial concern by the handline fishermen regarding gear interaction and sustainability issues drove the initial funding of this project.

2. Project design

The HTTP was designed to address interaction issues and to investigate the local movement of tuna in the Hawaii EEZ, retention rates on seamounts and FADs and local catch rates. Over 70 percent (by weight) of landings from the offshore handline fishery consist of bigeye tuna, with yellowfin and a small amount of dolphinfish and wahoo making up the remainder. Standard plastic dart tags manufactured by Hallprint are utilized by the HTTP.

One full-time field technician is employed to conduct the tagging operations and coordinate tag recapture and reward systems. A part-time technician maintains a release and recapture database, utilizing software developed by the South Pacific Commission for its Regional Tuna Tagging Project. A part-time consultant to the project designed tag release and recapture forms and procedures and assists the field officer.

The project has utilized commercial fishing vessels in semi-opportunistic arrangements to release bigeye and yellowfin tuna, using simple handline and troll gear. Recently, a more satisfactory system has been instituted to reimburse fishermen for tagged fish based on estimated weights of fish calculated from lengths taken at the time of tagging. Utilizing this system, the total number of tag releases achieved in a year were more than doubled in a single month.

3. Collaborative projects

The Inter-American Tropical Tuna Commission (IATTC) is collaborating with the PFRP project to conduct an age and growth study specific to bigeye tuna. The study is primarily an oxytetracycline (OTC)-based age validation study that will determine the time interval of growth increments on the otoliths of bigeye tuna in Hawaiian waters. Standard tags of the HTTP are orange in color, with OTC-injected bigeye marked with green tags.

4. Releases and recaptures

Immediately prior to the World Bigeye Meeting held in La Jolla, California (November 11, 1996), the project had released approximately 683 bigeye and 348 yellowfin (1,030) during more than a year of tagging effort, with a recapture rate of 6.01% and 8.05% for each species, respectively. During November 1996, an additional 1,378 tuna releases were achieved, which raised the total number of releases to 2,408 (1,581 bigeye, 827 yellowfin). The majority of the bigeye releases (1,011) have been injected with OTC for the age validation study. All of the November releases were made using handline or troll gear on a commercial fishing vessel engaged in the fishery. Table 1 lists HTTP releases by area.

As of December 3, 1996, 141 tagged tuna have been recaptured and reported to the HTTP (60 bigeye and 81 yellowfin), including 24 recaptures from OTC-injected bigeye. Most of these have been short-term recoveries by commercial participants in the offshore handline fishery, but 12 recoveries by longline and a few sport troll catches have been reported. Recovery rates to December 3, 1996, were 3.8% (bigeye), 9.8% (yellowfin) and 5.9% (both species combined). These figures are expected to change substantially during December 1996 and January 1997, with high recapture rates anticipated from the seamount fishery. Table 2 lists HTTP recoveries by area.

5. Summary

The HTTP is a small-scale project designed primarily to address issues of local-scale movement, interaction and vulnerability of bigeye and yellowfin through releases on highly-productive offshore fishing grounds. The field component of the project is ongoing, but all indications are that the project will have very high recapture rates. Most of the recaptures have been at the points of release, as would be expected for tuna schools aggregated to structures. However, some very interesting movements between the Cross Seamount and the offshore buoys and inshore FADs near the main Hawaiian Islands have been confirmed. Recaptures of juvenile bigeye highlight their strong aggregation behavior and relatively high vulnerability near seamounts and FADs. Interaction has already been demonstrated by recaptures by longline and troll gear, and the evidence is expected to increase as the tagged fish mature and leave the seamount aggregations and fully recruit to longline and other surface and sub-surface fisheries. The documentation of large-scale movement was not a main objective of this project, but it is possible that some recaptures will demonstrate this as time allows a wider dispersal of the tag releases.

A tuna tagging workshop was convened in Honolulu, Hawaii on November 1, 1996, with participation from a broad mix of representatives of Hawaii-based and international fishery organizations, including experts on tuna tagging projects. The objective of the workshop was to assist the design of an optimal tuna tagging project for the entire Hawaii EEZ to address local and international management concerns. The conclusion of the workshop was that a wider-scale bigeye/yellowfin tuna tagging project be developed for the Hawaii region, as it is the only way to directly address many pressing management concerns. A proposal to develop an EEZ-wide bigeye tagging project has been developed, utilizing the results of the workshop, and funding is being sought.

TABLE 1. Tag releases of the Hawaii Tuna Tagging Project by release area, as of December 3, 1996.

Area	Bigeye			Yellowfin			Total
	OTC	Non-OTC	Sub-total	OTC	Non-OTC	Sub-total	
Cross Seamount	537	268	805	1	457	458	1263
FAD 2	474	48	522	2	183	185	707
FAD 4	0	199	199	0	98	98	297
FAD 5	0	55	55	0	86	86	141
Total	1011	570		3	824		2408
Species totals		1581 (65.7%)			827 (34.3%)		

TABLE 2. Tag recaptures of the Hawaii Tuna Tagging Project by area as of December 3, 1996.

Area	Bigeye			Yellowfin			Total
	OTC	Non-OTC	Sub-total	OTC	Non-OTC	Sub-total	
Cross Seamount	11	22	33	0	65	65	98
FAD 2	10	6	16	0	10	10	26
FAD 4	0	2	2	0	0	0	2
FAD 5	0	6	6	0	4	4	10
Other	3	0	3	0	2	2	5
Total	24	36	60	0	81	81	141
Species totals		60 (42.6%)			81 (57.4%)		

PRELIMINARY ANALYSIS OF AGE AND GROWTH OF BIGEYE TUNA (*THUNNUS OBESUS*) IN THE WESTERN PACIFIC OCEAN, BASED ON OTOLITH INCREMENTS

by

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Bigeye tuna (*Thunnus obesus*) inhabit the warm waters of the Indian, Pacific and Atlantic oceans, and are found across the entire Pacific between northern Japan and the North Island of New Zealand in the west, and from about 40°N to 30°S in the east (Calkins, 1980). Bigeye are caught mainly by longlines, but also by purse-seine and pole-and-line fisheries. In recent years, about 250,000 metric tons have been landed annually from the three oceans, with more than half being caught by the Japanese fisheries.

So far, age and growth studies of this species have been done by reading rings on scales (Nose *et al.*, 1957; Yukinawa and Yabuta, 1963) or modal progressions in length-frequency data (Tatsuki *et al.*, 1960). However, it is generally difficult to count increments in scales, especially for fish larger than 130 cm (Yukinawa and Yabuta, 1963).

There are few studies on aging of bigeye based on otoliths, although there are many studies of other tunas, for instance, yellowfin (*Thunnus albacares*) (Uchiyama and Struhsaker, 1981; Wild, 1986; Yamanaka, 1990; Stequert *et al.*, 1996), albacore (*T. alalunga*) (Laurs *et al.*, 1985), and northern bluefin(*T. thynnus*) (Radtke, 1984; Foreman, 1996), based on daily increments in the otoliths (sagitta). In this paper some preliminary analysis of aging of bigeye tuna based on otolith microstructure is presented.

MATERIALS AND METHODS

The samples, which were caught by Japanese purse seiners in the western Pacific Ocean approximately between 11°N and 2°S, 130°E and 170°E, from May to October, 1996, were collected at Yaizu fishing port in Shizuoka Prefecture, Japan. About 20 to 40 fish a month were sampled. A total of 160 individuals, ranging from 27.2 to 67.5 cm in fork length (FL), were collected, of which capture dates are known for 84.

All fish were measured to the nearest 0.1 cm and weighed to the nearest l g, and otoliths (sagittae) were extracted in the laboratory. At the same time, gonads were extracted and frozen to identify sex.

After removing tissue, the otoliths were cleaned in sodium hypochlorite (household bleach) and dried. Then they were etched with 3N hydrochloric acid (HCl), checking the surface microstructure at frequent intervals under a light microscope, rinsed in water and immersed in 0.2M ethylenediaminetetraacetic acid (EDTA) for about 5 minutes, dried, ion coated and examined under a scanning electron microscope (SEM) at 100 to 400X magnification. The methods of preparation are similar to those of Yamanaka (1990). The microstructure of the otoliths was observed, using the photographs of the SEM images (Figure 2); the increments were identified and counted. Increments are counted along the axis from primordium to postrostrum tip, as shown in Figure 1.

RESULTS

At first it was difficult to identify all increments on an otolith due to insufficient or excess etching, but with more experience in etching it became less difficult to identify them. The increments were visible on the surface of etched otoliths (Figure 2). After preliminary analyses, nine otoliths, from fish of 33.4 to 57.9 cm FL caught in June and July, 1996, were successfully counted through the whole axis (Figure 3), but nine other specimens could be counted only partially, due probably to inappropriate etching. Generally, increments are comparatively clear and easy to identify around the primordium and the postrostrum, but less clear at the intermediate zone. The clarity of increments differed among the individuals.

The relationship between number of increments and fork length is shown in Figure 3. A clear positive correlation was observed. From the relationship, bigeye measure about 40cm FL when the number of increments is 200, and about 55cm when it is 400.

DISCUSSION

From the present study, it has been proved that increments on the otoliths of bigeye are formed as in other tunas and can be tracked using similar methods, although there are some difficulties to be solved in the technique, such as etching and counting.

Some reports confirmed that the increments on the otoliths of northern bluefin and yellowfin tunas are deposited daily (Wild and Foreman, 1980; Foreman, 1996; Uchiyama and Struhsaker, 1981; Yamanaka, 1990), but this was not validated for bigeye in this study. This validation should also be done in a future study. If each increment is deposited daily, as in bluefin and yellowfin tunas, bigeye grow to about 40 cm FL in six months and 55 cm in one year (Figure 3). This growth pattern in this period is very similar to that of yellowfin (Yamanaka, 1990; Stequert *et al.*, 1996). This estimate of early growth is greater than those of Nose *et al.* (1957) and Yukinawa and Yabuta (1963), who estimated about 35-40cm FL for one-year-old fish.

The results of present study indicate that aging by otoliths is promising for fish smaller than 60 cm. It is hoped that this method can be extended to fish of larger sizes.

LITERATURE CITED

Calkins, T. P. 1980. Synopsis of biological data on the bigeye tuna, *Thunnus obesus* (Lowe, 1839), in the Pacific Ocean. Inter-Am. Trop. Tuna Comm., Spec. Rep., 2: 213-259.

Foreman, T. J. 1996. Estimates of age and growth, and an assessment of ageing techniques, for northern bluefin tuna, *Thunnus thynnus*, in the Pacific Ocean. Inter-Am. Trop. Tuna Comm., Bull., 21(2), 71-123.

Laurs, R. M., R. Nishimoto, and J. A. Wetherall. 1985. Frequency of increment formation on sagittae of North Pacific albacore (*Thunnus alalunga*). Can. J. Fish. Aquat. Sci., 42(9), 1552-1555.

Nose, Y., H. Kawatsu, and Y. Hiyama. 1957. Age and growth of Pacific tunas by scale reading (in Japanese with English summary). *In* Suisan Gaku Shusei, Tokyo Univ. Press: 701-716.

Radtke, R. 1984. Scanning electron microscope evidence for yearly growth zones in giant bluefin tuna (*Thunnus thynnus*) otoliths from daily increments. Fish. Bull., 82(2), 434-440.

Stequert, B., J. Panfili, and J. M. Dean. 1996. Age and growth of yellowfin tuna, *Thunnus albacares*, from the western Indian Ocean, based on otolith microstructure. Fish. Bull., 94(1), 124-134.

Tatsuki, K., M. Uno, T. Okuda, and K. Kitamura. 1960. Ecological study of tunas in the Kinan Area- II Annual changes of hooked rate and size composition of bigeye tuna. Report of Nankai Regional Fisheries Research Laboratory, 12, 58-62.

Uchiyama, J. H. and P. Struhsaker. 1981. Age and growth of skipjack tuna, *Katsuwonus pelamis*, and yellowfin tuna, *Thunnus albacares*, as indicated by daily growth increments on sagittae. Fish. Bull., 79(1), 151-162.

Wild, A. 1986. Growth of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean based on otolith increments. Inter-Am. Trop. Tuna Comm., Bull., 18(6), 421-482.

Wild, A. and T. J. Foreman. 1980. The relationship between otolith increments and time for yellowfin and skipjack tuna marked with tetracycline. Inter-Am. Trop. Tuna Comm., Bull., 17 (7), 507-560.

Yamanaka, K. Y. 1990. Age, growth and spawning of yellowfin tuna in the southern Philippines. IPTP Working Paper, 21, 1-87.

Yukinawa, M. and Y. Yabuta. 1963. Age and growth of bigeye tuna, *Parathunnus mebachi* (Kishinouye). Report of Nankai Regional Fisheries Research Laboratory, 19, 103-119.

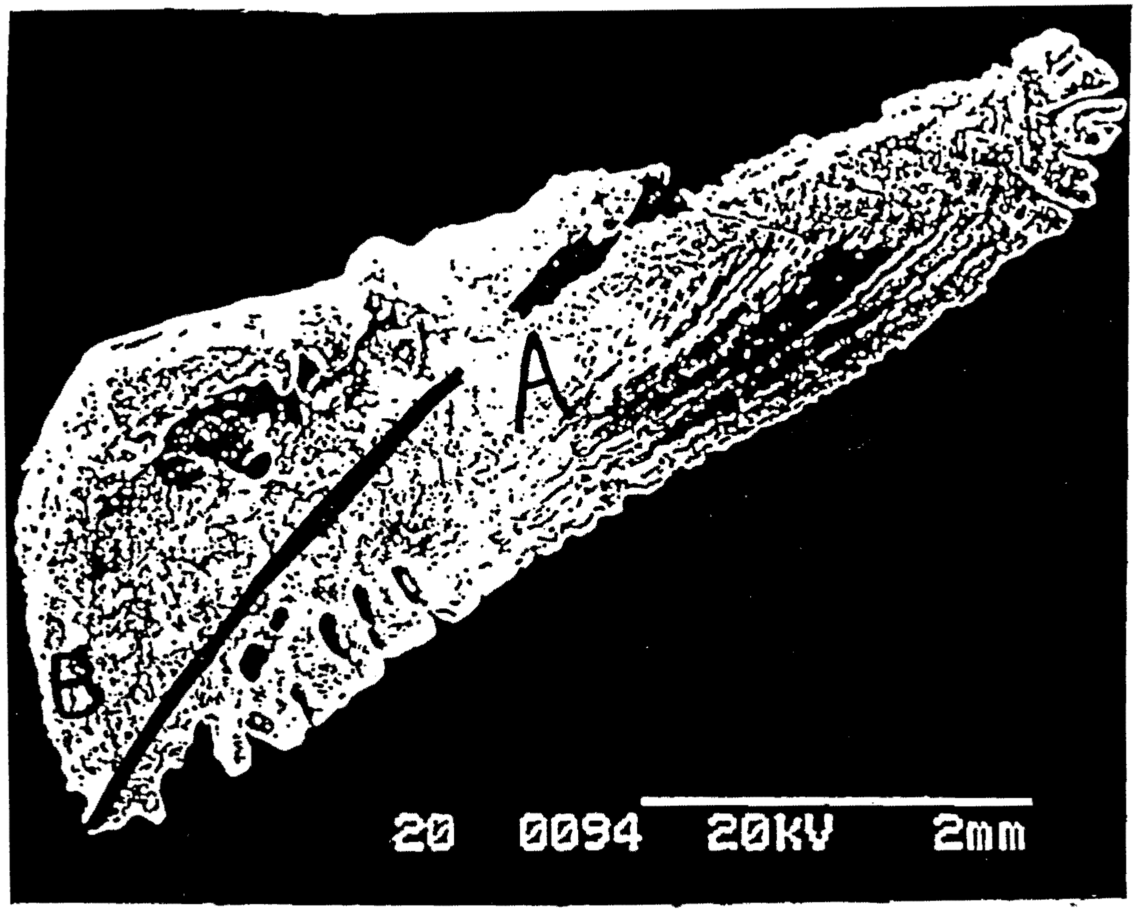

FIGURE 1. Photograph of whole otolith of bigeye (SEM image). FL = 38.2 cm. The line from A (primordium) to B (postrostrum tip) denotes the axis along which the increments were counted.

FIGURE 2. Microstructure of the otolith surface near the primordium (left) and near the postrostrum tip (right).

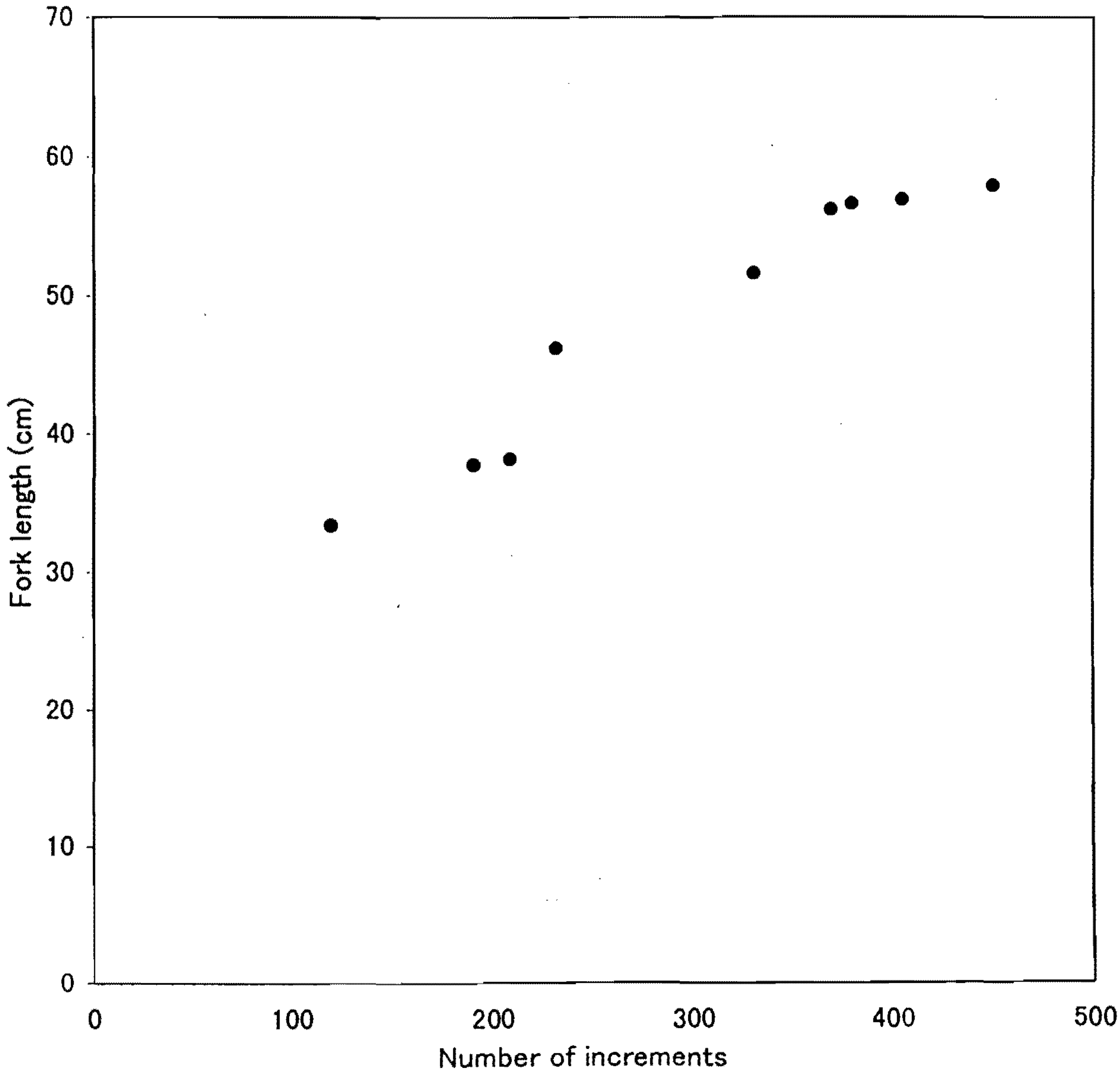

FIGURE 3. Relationship between number of otolith increments and fork length of bigeye.

BIGEYE TUNA: ACCESS TO DEEP WATERS

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Bigeye tuna (*Thunnus obesus*), in its adult phase, is considered the tuna species that lives at the greatest depths. This is demonstrated by the fact that longlines capture this species with hooks deployed at depths below 300 meters. In fact, Saito (1975) observed bigeye tuna at depths between 300 and 400 meters. Also, Saito and Sasaki (1974), in a survey using vertical longlines in the Pacific, obtained greater bigeye captures at depths between 330 and 382 meters. In experiments using longlines in Hawaii, Boggs (1990, 1992) obtained greater bigeye catches at depths between 391 and 446 meters. This is also the depth interval that several investigators studying the vertical distribution of bigeye indicate as the greatest depth at which this species can be found.

Several explanations for the capacity of bigeye tuna to live at greater depths than any other species of tuna have been given. These include physiological and anatomical adaptations that allow them to explore deeper habitats in the ocean and to have access to the mesopelagic and bathypelagic fauna which, according to Grandperrin (1975), exist at depths below 450 meters. Furthermore, in order to be able to dive to such depths, bigeye tuna must have particular anatomical characteristics such as 1) well-developed pectoral fins and swim bladder, which permit the fish to balance its weight in the water at greater depths; and 2) very good adaptation of their visual organs to the light changes with depth, since they use their vision to hunt, and light at those depths is substantially reduced.

Holland *et al.* (1990) observed that bigeye with attached sonic tags spend most of the day at depths between 200 and 400 meters, in waters with temperatures of 14 to 17°C. The same specimens were found at night at depths between 70 and 90 meters, in water temperatures of about 23 to 25°C. These specimens ranged between 72 and 74 cm in length (10 to 12 kg in weight), whereas adult bigeye captured with longlines weigh more than 30 kg.

Several studies have shown that bigeye is more abundant in the eastern Atlantic, in the region between 5°N and 20°N and 5°S and 20°S, corresponding to two regions where the dissolved oxygen content is low at depths between 150 and 500 meters, being less than 2ml/l in the northern region to the east of 20°W and in the southern region to the east of 0°. Also, in the central and equatorial Atlantic, where bigeye is abundant, the dissolved oxygen content at 150 meters ranges from 2 to 3 ml/l (Merle, 1978). This capacity for tolerating low oxygen concentrations makes it possible for bigeye to have access to deep regions of the ocean, where other species of tuna, such as skipjack (*Katsuwonus pelamis*) and yellowfin (*Thunnus albacares)* are not found, thereby reducing the competition for food with other species of tuna.

The large pectoral fins of bigeye tuna, with an area of more than 500 cm^2 in adults, provide the vertical thrust necessary to their hydrodynamic equilibrium, while their well-developed swim bladder functions as a hydrostatic organ, balancing their weight in the water.

These two adaptations make it possible for bigeye to live at greater depths with lower consumption of energy. Also, their vision is adapted to the low light conditions found in deep waters. The presence of the *tapetum lucidum* in the large eyes of this species functions as a mirror, reflecting the light to the visual cells and reducing the minimum light necessary for them to see (Kawamura *et al.*, 1981). The retina has almost exclusively double cones, denser in the ventral region of the retina, which are more sensitive to the light than the simple cones that are displayed in parallel lines. The first type indicates the importance of movement in prey recognition. The density of the cones in the different regions of the retina indicates that the visual axis is from bottom to top (Pereira, 1995).

1. THE PECTORAL FIN

The Scombridae are pelagic fishes with negative buoyancy that swim continuously with their pectoral fins extended, producing a lifting effect that balances their weight in the water, while their swim bladder adjusts the hydrostatic equilibrium (Magnuson, 1973). Albacore (*Thunnus alalunga*) have the longest pectoral fins of all the tunas, and bigeye are next (Gibbs and Collette, 1967).

Analysis of the pectoral fins of bigeye tuna captured in the Azores showed that the lengths of these fins are approximately 18 to 38 percent of their body lengths (Figure la, b). Magnuson (1973) observed that a bigeye tuna with a fork length of 125 cm has a pectoral fin area of over 500 cm^2. This would permit the fish to not only make extensive vertical movements, required for hydrodynamic reasons, but also to swim slowly.

2. THE SWIM BLADDER

Some species of fish achieve their equilibrium in the water through the swim bladder, which works as a hydrostatic organ by changing the gas content inside the fish to give it a certain hydrostatic equilibrium (Steen, 1970). The presence of a swim bladder helps to reduce the weight of the body in the water and to reduce the minimum swimming speed, resulting in a lower energy consumption. According to Magnuson (1973), these two adaptations, large pectoral fins and the presence of a swim bladder, tend to occur together in some of the species of Scombridae, permitting them to live either 1) at greater depths, where quick vertical movements have a very small effect on the expansion of gas in the swim bladder; or 2) near the surface, where they do not make quick vertical movements. Steen (1970) stated that a fish with a certain quantity of gas in the swim bladder is at equilibrium only at a certain depth, which can be a disadvantage for active fishes, which make quick changes of depth when hunting. Using longlines to capture different tuna species, Yamaguchi (1989) found several bigeye tuna with their swim bladders ruptured and their stomachs coming out of their mouths as a result of gas expansion in the bladder. He also observed that this did not happen with yellowfin captured nearer the surface.

The swim bladders of 359 bigeye tuna captured in the Azores region between April and August in 1986 and 1987 were examined immediately after the fish were landed to study the relationship between the growth of this organ and with body length.

The fork length of each fish was measured to the next-lowest centimeter. After removing the contents of the abdominal cavity, the maximum length and width of the swim bladder were measured to the next-lowest millimeter.

The relationship between the lengths and the widths of the swim bladders and the fork lengths are shown in Figures 2 and 3, respectively.

A distinct group of bigeye with a smaller swim bladders, relative to their fork lengths, can be seen in Figure 2. A detailed analysis of these specimens showed that they were all captured during July and Augus, in mixed schools with skipjack tuna. The size frequencies of the bigeye and skipjack in these mixed schools are shown in Figure 4. From this sample, subsamples were taken for the study of the swim bladder.

The lengths of the swim bladders of the bigeye with fork lengths less than 90 cm during April-June and July-August are shown in Figure 5. This graph shows that there were two distinct groups of bigeye, with different stages of development of the swim bladder.

Data on the growth of the swim bladder, relative to the lengths of the fish, are shown in Table 1 for two groups of fish.. From these data, it is possible to infer possible allometrics in the growth of the swim bladder for these two groups. The swim bladders of the specimens captured between April and June show positive allometric growth in both length and width. For the specimens captured in mixed schools with skipjack during July and August, the growth in length of the swim bladder is isometric, and the growth in width is allometrically positive.

These results indicate that bigeye tuna in the same length range could be in different stages of development of the swim bladder, with those which associate with skipjack developing more slowly than those which do not associate with skipjack. Skipjack do not have a swim bladder, and live mostly in surface waters, and yet they can make frequent dives to depths of more than 200 meters (Cayré, 1985). The small bigeye that live with skipjack probably have the same type of swimming behavior as skipjack, and therefore show a late development of the swim bladder. Bigeye tuna of the same size range, but living only with other bigeye, probably have a much more rapid development of the swim bladder, showing a positive allometry in the growth of the swim bladder when compared with bigeye living in mixed schools with skipjack. This more rapid development may be an evolutionary adaptation, permitting for them to dive to greater depths and remain there for long periods of time.

LITERATURE CITED

BOGGS (C. H.), 1990. Longline research on tuna and marlin. *Relatório, X Semana das Pescas dos Açores*: 249-252. Sec. Regional Agric. Pescas, Horta, Açores.

BOGGS (C.H.), 1992. Depth, capture time, and hooked longevity of longline-caught pelagic fish: timing bites of fish with chips. *Fish. Bull. U. S.* **90** (4): 642-658.

CAYRÉ (P.), 1985. Contribution à l'étude de la biologie et de la dynamique du listao (*Katsuwonus pelamis*, Linnaeus 1758) de l'Océan Atlantique. *Thése doctorat Université Paris 6.* Tome 1: 181 p.

GIBBS (R.H.) & COLLETTE (B.B.), 1967. Comparative anatomy and systematics of the tunas, genus *Thunnus. Fish. and Wildl. Ser. Fish. Bull.*, **66** (1): 65-130.

GRANDPERRIN (R.), 1975. Structures trophiques aboutissant aux thons de longue ligne dans le Pacifique Sud Ouest. *Thèse Doc. Etat. Université de Marseille*, 295 p.

HOLLAND (K.N.); BRILL (R.W.) & CHANG (R.K.), 1990. Horizontal and vertical movements of yellowfin and bigeye tuna associated with fish aggregation devices. *Fish Bull. US.* **88** (3): 493-507.

KAWAMURA (G.), NISHIMURA (W.), UEDA (S.) & NISHI (T.), 1981. Vision in tunas and marlins. *Mem. Kagoshima Univ. Res. Center S. Pacific* 2 (1): 3-47.

MAGNUSON (J.J), 1973. Comparative study of adaptations for continuous swimming and hydrostatic equilibrium of Scombroid and Xiphoid fishes. *Fish. Bull. U.S.*, **71** (2): 337-356.

MERLE (J.), 1978. Atlas hydrologique saisonier de l'océan Atlantique intertropical. *Travaux de Documents de l'ORSTOM*, **82:** 134 p.

PEREIRA (J), 1995. A pesca do atum nos Açores e o atum patudo (*Thunnus obesus*, Lowe 1839) do Atlântico. Tese de Doutoramento. Universidade dos Açores, Horta, Janeiro de 1995. 330 pp.

SAITO (S.), 1975. On the depth of capture of ;b9igeye tuna by fgurther imporved longline in tropical Pacific. *Bull Jpn. Soc. Sci. Fish.*, **41** (8): 831-841.

SAITO (S.) & SASAKI (S.), 1974. Swimming depth of large sized albacore in south Pacific Ocean - II. Vertical distribution of albacore catch by an improved vertical longline. *Bull. Jpn. Soc. Sci. Fish.* **40** (7): 643-649. [Engl. Transl. N°9 by Tamio Otsu, 1974, 12p.; NMFS Honolulu Lab.]

STEEN (J.B.), 1970. The swim bladder as a hydrostatic organ. *Fish Physiology IV*, pp: 413-443. Academic Press, New York.

YAMAGUCHI (Y.), 1989. Tuna longline fishing IV: Fish ecology in the context of tuna longline fishing. *Mar Behav. Physiol.* **15**: 45-73.

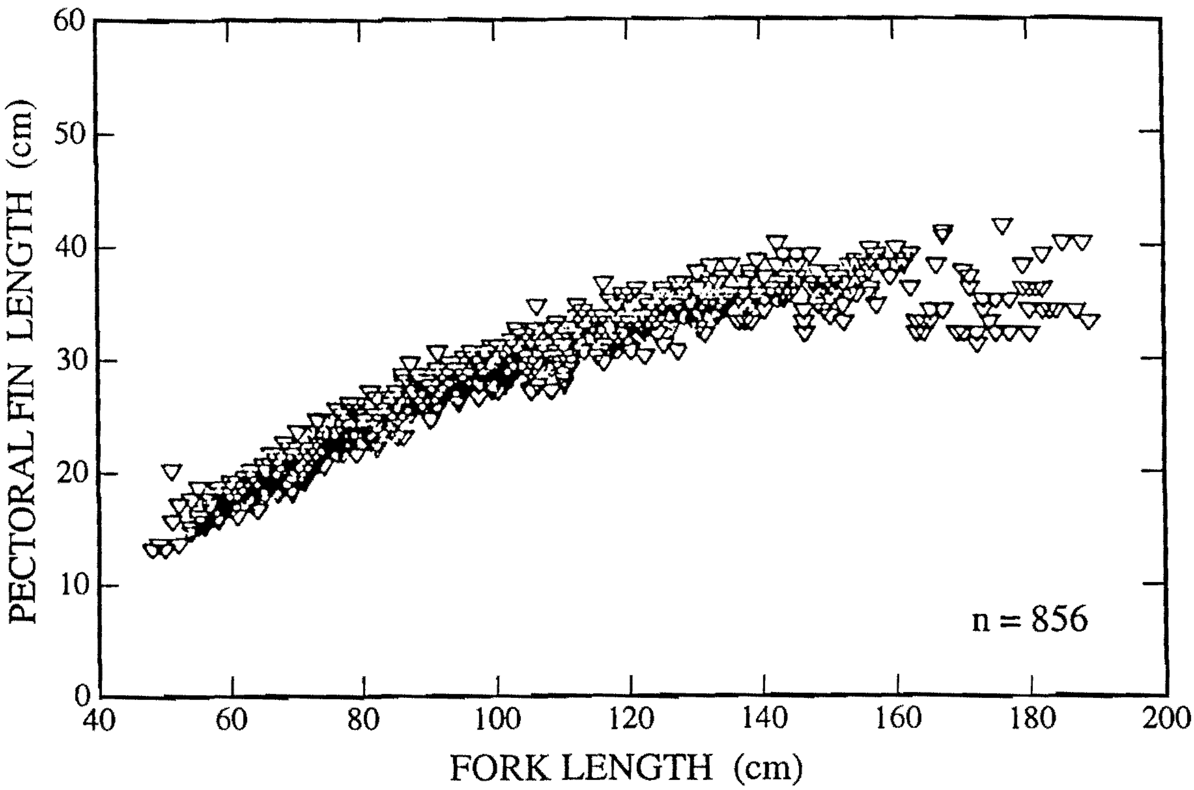

FIGURE 1a. Relationship between pectoral fin lengths and fork lengths of bigeye tuna in the Azores region.

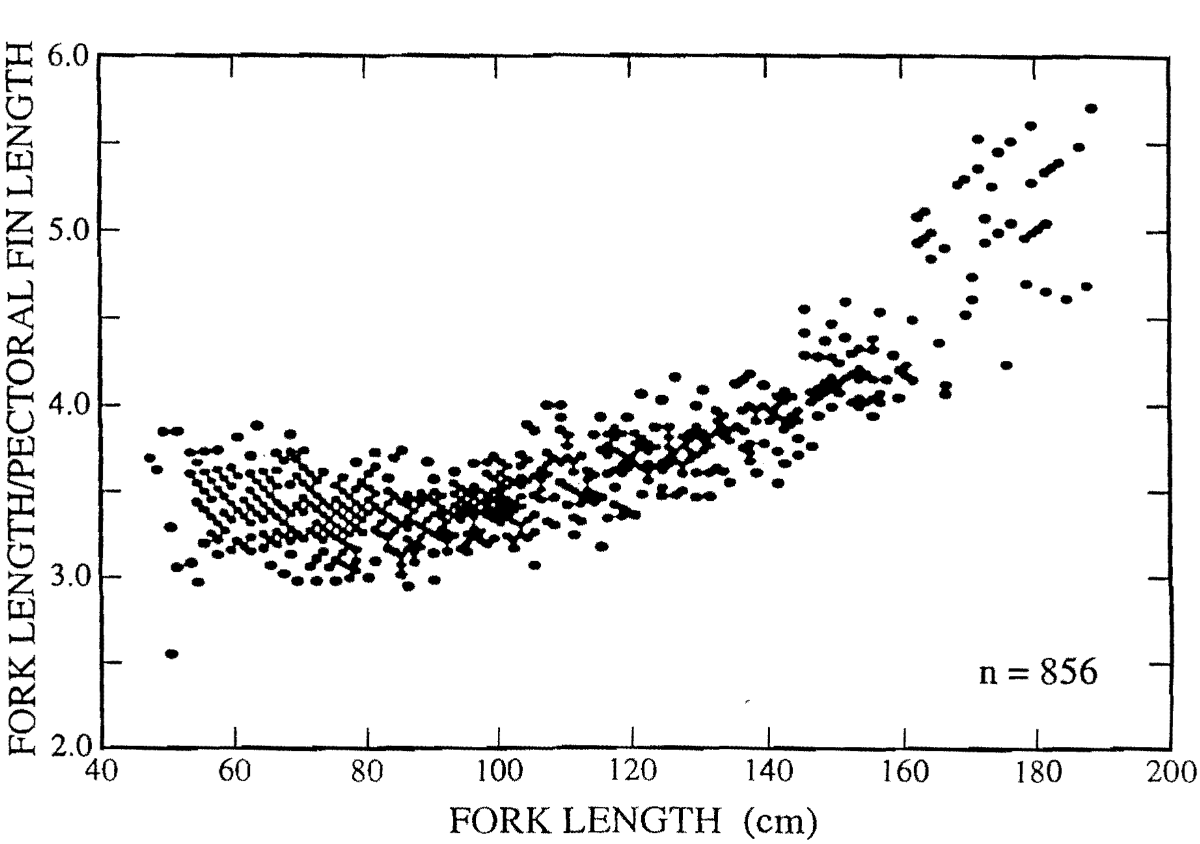

FIGURE 1b. Relationship between fork lengths divided by pectoral fin lengths and fork lengths of bigeye tuna in the Azores region.

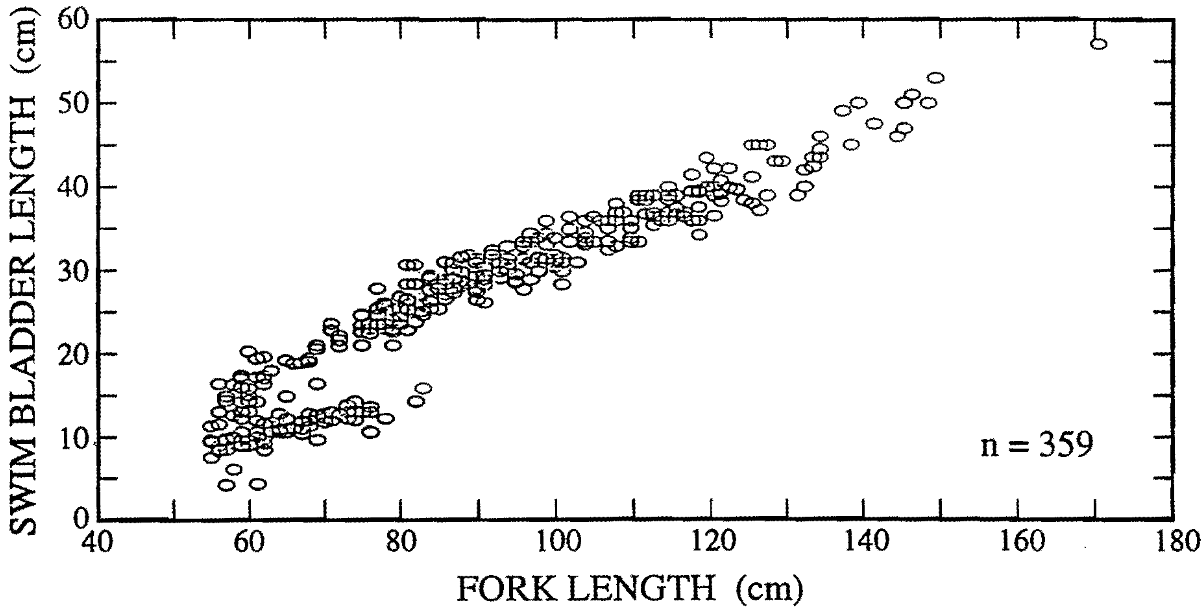

FIGURE 2. Relationship between lengths of the swim bladder and fork lengths of bigeye tuna in the Azores region.

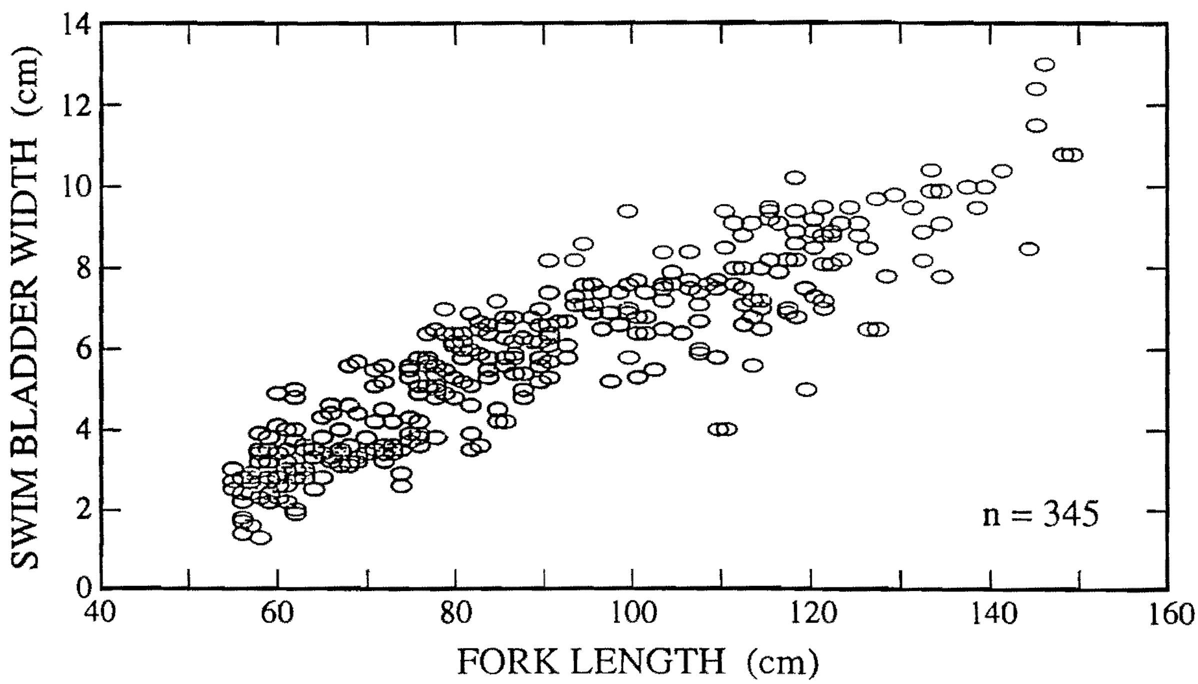

FIGURE 3. Relationship between widths of the swim bladder and fork lengths of bigeye tuna in the Azores region.

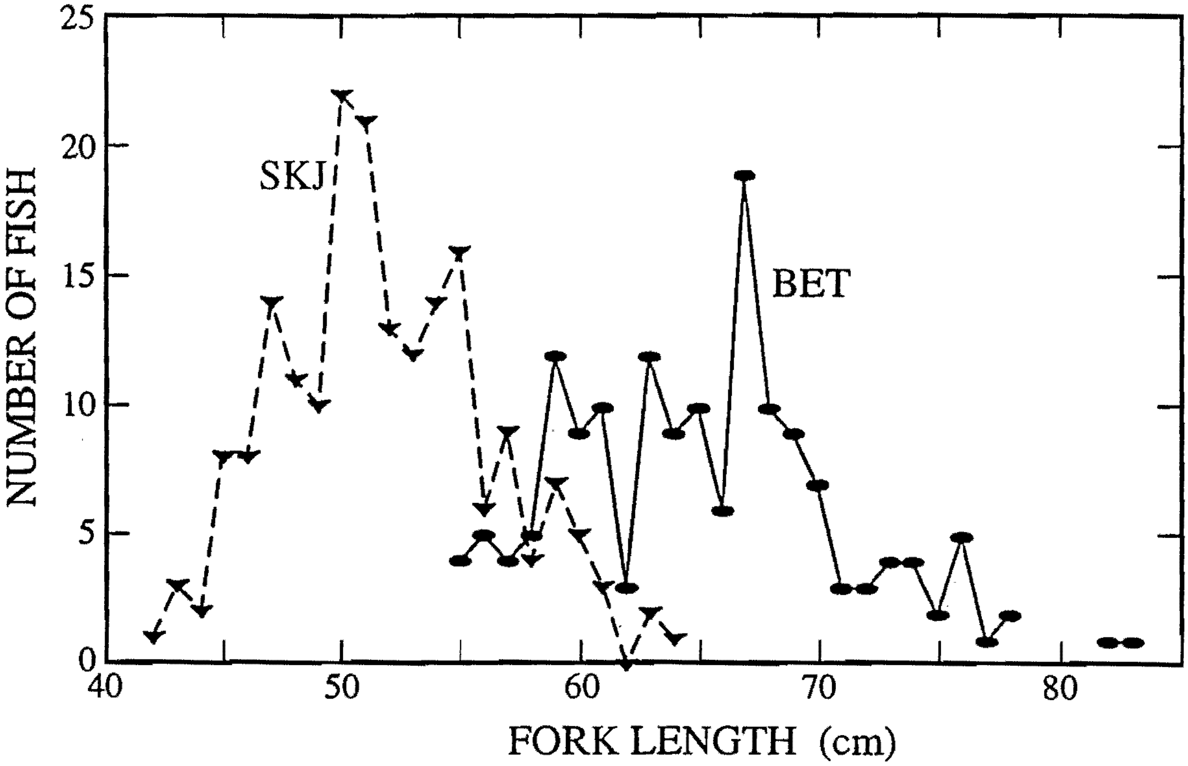

FIGURE 4. Size frequencies of bigeye (BET) and skipjack (SKJ) tuna captured in mixed schools in the Azores region during July and August.

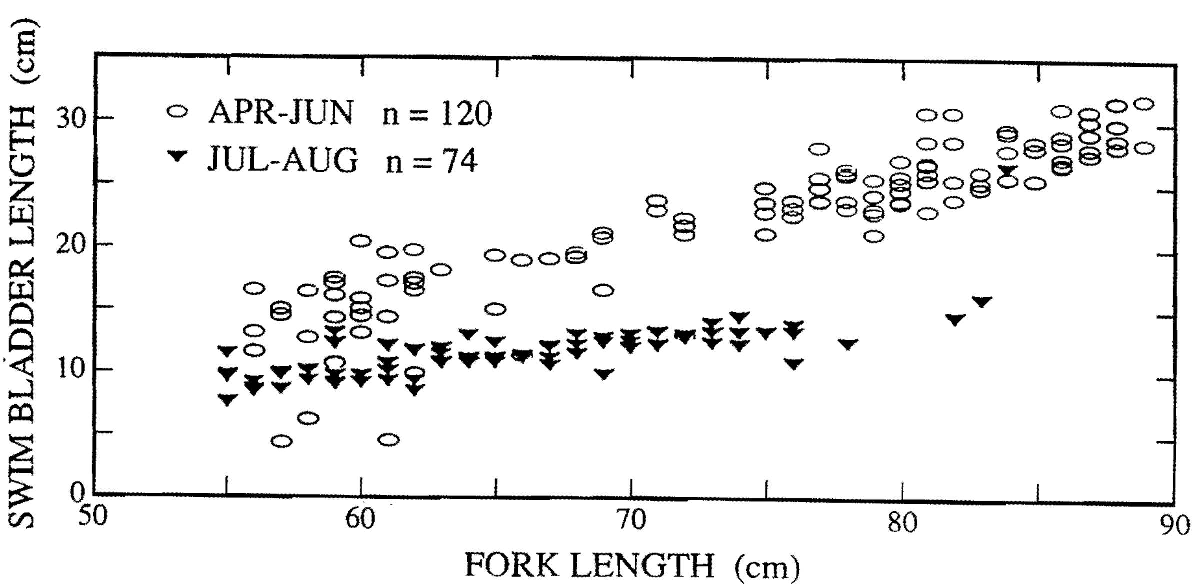

FIGURE 5. Relationships between lengths of the swim bladder and fork lengths of bigeye tuna in the Azores region during April-June and July-August.

TABLE 1. Summary of the adjustments of the relationship between fork length (FL) and length (Lsb) and width (Wsb) of the swim bladder of bigeye tunas sampled in the Azores region.

Sample	Number of fish	*a*	*b*	*r*
Lsb (April-June)	285	0.136777	1.185465	0.965415
Lsb (July-August)	74	0.119196	1.089926	0.780926
Wsb (April-June)	271	0.025126	1.214613	0.836813
Wsb (July-August)	74	0.020171	1.203353	0.631410

ASSESSMENT STUDIES OF BIGEYE TUNA IN THE EASTERN PACIFIC OCEAN

by

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INTRODUCTION

During the mid-1950s, Japanese longline vessels began to fish in the eastern Pacific Ocean east of 150° W (EPO) and their catches of bigeye increased over time, reaching a peak of 97 thousand metric tons in 1986 (Table 1). In the 1965-1993 period, 24 to 43 percent of the world catches of bigeye came from the EPO and were caught mostly by longlines (Table 1). During late 1993 purse seine vessels operating in the EPO discovered that bigeye associated with floating objects, but well beneath the surface of the water, can be detected with sonar, and they developed methods for catching them. Many of these floating objects were fish-aggregating devices (FADs) placed in the water by the fishermen. Most of these purse-seine catches of bigeye were taken between 5°N and 10°S. Accordingly, beginning in 1995, the IATTC staff further increased its studies on bigeye, principally to estimate the effects of increased catches by the surface fishery on the longline fishery and on the sustainable yield.

FISHERIES

The surface fishery

Bigeye are caught near the surface of the water by purse seiners, baitboats, trollers, and recreational fishing vessels (Barrett and Kume, 1965; Calkins *et al.*, 1993). The catches of bigeye by purse seiners are much greater than those of all other types of surface-fishing vessels combined. The purse-seine catches increased during the late 1960s and the 1970s, declined after 1981, and then rose dramatically in 1994, 1995, and 1996 (Table 1). The distributions of the logged catches of bigeye by purse seiners in the EPO during 1981-1995 and 1996 are shown in Figures 1 and 2. The catches southwest of the Galapagos Islands were much greater during 1996 than during 1994 and 1995 (Anonymous, 1997: Figures 7 and 8).

The increased purse-seine catches of bigeye during the late 1960s and the 1970s were apparently due to two factors. First, the actual catches probably increased because there were restrictions on the catches of yellowfin, but not bigeye, during the 1966-1979 period, which in some instances caused fishermen to seek out bigeye in preference to yellowfin. Concurrently with this, the fishermen's skill in catching bigeye probably increased. Second, the statistics collected after the mid-1960s are more accurate. Bigeye and yellowfin caught by the surface fishery have, in most years, brought the same price to the fishermen, so bigeye have often been reported as yellowfin. Since the advent of regulations, however, the two species have more often been reported separately, and in locations where they are not there has been better coverage by IATTC employees, who estimate the proportions of the two species in mixed landings. Two recent studies (Anonymous, 1992: 34-35; Anonymous, 1998) indicate that misidentification of bigeye as yellowfin has not been a serious problem during recent years.

As stated above, the increased catches of bigeye during 1994-1996 were apparently due to the development of new methods for catching bigeye associated with floating objects.

During the 1971-1991 period about 62 percent of the purse-seine catches of bigeye was taken in unassociated schools, 33 percent in schools associated with floating objects, and 5 percent in schools associated with whales, sharks, or dolphins (Calkins *et al.*, 1993). There was considerable overlap in the lengths of the bigeye taken by the surface and longline fisheries. The average catch of bigeye per successful bigeye set was 21 metric tons (20, 26, and 16 metric tons for unassociated schools, floating-object schools, and schools associated with whales, sharks, or dolphins, respectively). (A "successful" bigeye set is defined as a set in which 0.5 short ton or more of bigeye was caught, regardless of the catch of other species in the same set.)

During the 1990-1993 period less than half of the sets in which bigeye were caught were made on fish associated with floating objects, and about half of the bigeye caught were taken in such sets (Anonymous, 1997: Table 4). During 1994-1996, however, much greater portions of the bigeye sets were made on floating objects, and 90 to 95 percent of the bigeye caught came from such sets.

During 1994-1996 most of the sets in which bigeye were taken included yellowfin, skipjack, or both.

The length distributions of bigeye caught in the EPO by surface gear during each year of the 1991-1996 period are shown in Figure 3. Those caught during 1994-1996 (especially 1996) were smaller than those caught during 1990-1993. Data on the length frequencies of bigeye caught in free-swimming schools and in floating-object schools are shown in Figure 4. (Very few bigeye are caught in association with dolphins.) The fish from the floating-object schools tend to be smaller than those from free-swimming schools, and the number of floating-object sets with bigeye has increased substantially more than that of sets on free-swimming schools with bigeye.

The longline fishery

Studies of the Japanese longline fishery conducted jointly by Japanese and IATTC scientists (Suda and Schaefer, 1965; Kume and Joseph, 1966; Kume and Schaefer, 1966; Kume and Joseph, 1969; Shingu *et al*., 1974; Miyabe and Bayliff, 1987; Nakano and Bayliff, 1992) include analyses of data on trends in effort and catches, horizontal, vertical, and temporal distributions of catches, trends in apparent abundance, size composition, and maturity of bigeye.

The distributions of the effort, in numbers of hooks, and the catches per unit of effort (CPUEs; numbers of fish caught per 100 hooks) of bigeye by Japanese longliners in the EPO, averaged over the 1988-1992 period, are shown in Figures 5 and 6. There were almost no catches in the area north of about 10°N and east of about 125°W during any quarter. The greatest CPUEs were recorded (1) between Ecuador and 120°W and 10°S and 5°N throughout the year, (2) northeast of Hawaii between 20°N and 33°N and 122°W and 140°W during the first and fourth quarters, and (3) off southern Peru and northern Chile between 18°S and 25°S and 80°W and 90°W during the third quarter.

The distribution of effort did not coincide well with the areas of greatest CPUEs of bigeye, even though bigeye was the most important species of fish caught by Japanese longliners. For example, heavy concentrations of effort are apparent in equatorial waters (8°N to 15°S and west of 100°W), but the CPUEs of bigeye in this area were not particularly high. Furthermore, although the CPUEs for bigeye were fairly high northeast of Hawaii and off southern Peru and northern Chile, not much effort was exerted in these areas. This may be because in the equatorial region bigeye could be caught throughout the year and the fish tended to be large, whereas in the higher latitudes the occurrence of bigeye was more seasonal and the fish tended to be smaller.

Punsly and Nakano (1992) used general linear models GLMs) to standardize the CPUEs of bigeye in the EPO. The effects of years, seasons, areas, and depths of fishing were considered, and all were found to have significant effects on the CPUEs. More recently, a modification of the GLM method has been used with longline CPUE data for bigeye to produce standardized estimates of the relative abundance of that species in the EPO during the 1975-1994 period.

Length-frequency data for bigeye caught by longlines in the EPO between 40°N and 35°S during 1987-1992 are shown in Figure 7. The length compositions and average weights did not vary much during this period, but the average weights (Table 2) showed greater variation during years prior to 1987.

CATCH STATISTICS

Data on the Japanese longline fishery for tunas, including catches by species, location (5-degree areas), date (year and month), and length and/or weight frequencies of sampled fish are made available to the IATTC by the NRIFSF. In addition, the Tuna Research Center, Institute of Oceanography, National Taiwan University, and the National Fisheries Research and Development Agency of Korea, furnish data on the catches of fish of each species by longline vessels of the Republic of China (ROC) and the Republic of Korea (ROK) in the EPO. Data on the longline fisheries of Western Hemisphere nations are obtained from various government organizations and from industry sources.

Data on the catches, in numbers and weights of fish, and average weights of the fish are shown in Tables 2-4. Most of the longline catches of bigeye in the EPO are made by Japanese vessels (Table 2). The catches by surface gear during 1994-1996 were much greater than those of previous years (Table 3), and in 1996, for the first time, the purse-seine catch may have exceeded the longline catch (Table1). The total catch of bigeye by all gears (Tables 4 and 10) averaged 60 thousand metric tons per year for the 1971-1985 period and 85 thousand metric tons per year for the 1986-1996 period.

The average sizes of fish caught by Japanese longline vessels declined from the early 1970s to the early 1980s (Table 2). In 1983 and 1984 the average size was greater, and then it was less from 1985 through 1995, except for 1987. These changes in average size might be related to increasing use of deeper-fishing longlines, with 12 or 13 hooks per basket, which began during the early 1980s (Nakano and Bayliff, 1992: Figure 7). The average weights of bigeye caught by the surface fishery have been highly variable (Table 3), but the numbers of samples taken were small, except during 1994-1996. The average weight for 1996 was the lowest since 1977.

INDICES OF ABUNDANCE

The simplest index of abundance of bigeye in the EPO is the catch, in numbers of bigeye, by longline gear divided by the numbers of hooks fished, either for the entire EPO or for the areas within the EPO in which the catches of bigeye are greatest (Nakano and Bayliff, 1992).

During the mid-1970s, Japanese longliners began to use gear with wider spacing between buoys and more hooks per basket, particularly in equatorial waters, and the use of longlines with this configuration spread poleward during the ensuing years. These are called deep longlines. The hooks which are furthest from the buoys of deep longlines hang at greater depths than do any of the hooks of conventional longlines. Bigeye spend more time in and below the thermocline than do most other species (Brill, 1994), so the shift to deep longlines should have increased the fishing power of longlines for bigeye. (It should be noted, however, that the numbers of hooks fished per day remained about the same, and that many of the hooks of deep longlines fish at the same depths as those of the conventional longlines.) As stated previously, general linear modeling has been used to compensate for differences in the longline CPUEs of bigeye in various area, season, and depth strata. Two models have been employed. The year effects in each model were used as annual indices of abundance, standardized by the other factors. The first model used the computer program SAS GLM, with the natural logarithm of the CPUE (defined as 1 + number of bigeye caught per thousand hooks) as the dependent variable. The second model used the computer program SAS GENMOD, employing the Poisson distribution of bigeye catch with an offset of the natural logarithm of the fishing effort in number of hooks. The analyses showed significant interactions between years and areas, so separate analyses were run for each area. Similar results were obtained for the two models for each area, with years, bimonthly periods, maximum depths at which the hooks fished, and interactions between bimonthly periods and maximum depths at which the hooks fished being significant in every case. CPUEs for the entire EPO (Figure 8) were calculated from weighted averages of the CPUEs for the individual areas.

STOCK ASSESSMENT

In general, there are three approaches to the analysis of the effects of fishing on a population of fish, age-structured modeling, spawner-recruit modeling, and production modeling. Application of these to bigeye tuna in the EPO is discussed below. These analyses should be considered as preliminary, as little is known about the rate of exchange of fish between the EPO and the central and western Pacific. Also, there is insufficient information on important parameters, such as age- and sex-specific growth and natural mortality, size at which the fish reach sexual maturity, *etc.* In addition, there are problems with spatiotemporal stratification of the size data and standardization of the longline effort and CPUE data. As will become apparent below, the results obtained with various trial values of natural mortality differ considerably, so more precise estimates of this parameter would be of great value.

Age-structured modeling

Some assumptions have been made to facilitate the age-structured analyses. These include: (1) there is a single stock (as defined by Suzuki *et al.*, 1978) of bigeye in the EPO, and the rate of exchange of fish between the EPO and other parts of the Pacific Ocean has remained the same over the study period; (2) the natural mortality is constant after the fish are recruited into the fishery, is the same for both sexes, and does not vary from year to year; (3) the growth rates are the same for both sexes and vary from year to year only to the extent permitted by the constraints required for fitting normal length-frequency distributions, as described below.

Tagged bigeye released in the Coral Sea, near Australia, have been recaptured as far away as Hawaii, but most of the fish recaptured had travelled much shorter distances. The same is probably the case for bigeye in the EPO. Actually, the ratio of males to females tends to be significantly greater than 1 for larger fish (Kume, 1969a and 1969b), implying that older females grow more slowly than do older males or that older females have a higher rate of natural mortality than do older males. The amount of information available is insufficient to incorporate differential growth or mortality into the calculations, however.

Cohort analyses

The basic data used for the cohort analyses of bigeye tuna in the EPO are: (1) catches of bigeye, in numbers of fish, by longline vessels of Japan, the ROC, and the ROK, by area (Figure 9), year (1971-1992), and month; (2) length-frequency data for bigeye caught in the EPO by longline vessels of Japan, by area, year, and month; (3) catches of bigeye, in metric tons, by purse seiners and baitboats, by area (Figure 10), year (1971-1996), and month; (4) length-frequency data for bigeye caught in the EPO by purse seiners and baitboats, by area, year, and month; (5) weight-length equations for longline- and purse seine-caught bigeye. The data for the purse-seine and baitboat fisheries were collected by the IATTC staff. The analyses of length-frequency data were carried out by the methods described by Tomlinson *et al.* (1992). The catch data for the Japanese, ROC, and ROK longline vessels were combined with length-frequency data for the Japanese longline vessels to estimate the catches (stratified by area (Figure 9) and time) by the longline fishery, by 1-cm intervals, for 1971-1992. The average weights of the fish were estimated from the length-frequency distributions and the weight-length equation $w = (3.661 \times 10^{-5})l^{2.90182}$, where w = weight in kilograms and l = length in centimeters (Nakamura and Uchiyama, 1966). Equivalent estimates of the length frequencies of the fish caught with longlines during 1993-1995 were made by averaging the data for 1990 through 1992 and adjusting these to the total catch, in numbers of fish, supplied by the NRIFSF. The 1996 catch was assumed to be the same as that of 1995. Likewise, the catch and length-frequency data for the purse-seine and baitboat fisheries were used to estimate the surface catches, stratified by area (Figure 10) and time, by 1-cm intervals, for 1975-1996. Equivalent estimates of the surface catches for 1971-1974 were made by combining catch data for those years and average length-frequency data for the surface fishery for 1975-1993. The longline and surface data were then combined to provide monthly estimates of the catches in all areas combined, in numbers of fish and in metric tons, by 1-cm intervals. The length-frequency distributions indicate that there are two cohorts, the X cohort, recruited in July at about 30 cm, and the Y cohort, recruited in January, also at about 30 cm.

If the maximum life span of the fish is about 10 years, which seems to be the case, there could be as many as 20 cohorts present in the catch of each month. The length frequencies were converted to age frequencies by fitting a distribution composed of 20 normal distributions to each monthly length-frequency distribution. The estimation of the 20 means for each month was constrained by the growth curve (estimated from modal progressions), and the estimation of the 20 standard deviations for each month was constrained by the ranges demonstrated by modal groups within the length distribution. The catch frequencies, by age, of the combined X and Y cohorts for 1971 through 1996 are shown in Figure 11.

The monthly catch-at-age data for each cohort present in the fishery during the 1971-1996 period (X62 through X96 and Y62 through Y96 cohorts) were analyzed. Since the annual natural mortality rate (M) is believed to be between 0.4 and 0.8, the analyses were performed with values of 0.4, 0.6, and 0.8 assigned to M. Each analysis was begun by guessing the rate of annual instantaneous fishing mortality (F) for the last month in which fish of each cohort were caught. These initiating values of F were then adjusted until estimates of the numbers of fish in the population which were compatible with the standardized longline CPUEs (Punsly and Nakano, 1992)) were obtained (Figure 12). The final choice for each cohort permits the estimation of the number of bigeye in that cohort at the beginning of each month and estimation of F for that cohort for each month. The estimated average numbers of fish of each age group of each cohort in the population during July of each year are shown in Table 5, and some average values of *F* for various years are shown in Table 6. (In Table 5 the first line lists the estimated populations of age-0 through age-9 fish in 1971, so the age-0 fish are members of the X71 and Y71 cohorts, the age-1 fish are members of the X70 and Y70 cohorts, and so on. In Table 6 the columns headed by 1971-79, 1980-87, 1988-93, and 1994-96 list estimates of average *F* for fish of ages 0 through 9 during those periods.) The average weights at age were estimated from the estimates of the catches in numbers and weights of fish; estimates at quarterly intervals are listed in Table 7. Estimates of the biomass of the population calculated from the estimates of the population sizes (Table 5) are shown in Figure 13.

The results of these analyses are not as accurate as desired because, although fish of different cohorts can usually be distinguished from one another when they are young, this becomes increasingly difficult as they grow older, so older fish are probably often assigned to the wrong cohorts. In addition, the estimates of *M* are little more than guesses. Also, the catchability of the fish varies according to age, area, season, weather, oceanographic conditions, and other circumstances, the growth rates vary, and the times of recruitment vary. All of these introduce "noise," and possibly bias as well, into the calculations.

Cohort analysis also provides estimates of the recruitment for each cohort for each value of *M* and each set of initiating *F* values; those for the initiating values of *F* which produced the estimates in Figure 13 are shown in Figure 14.

Yield-per-recruit analyses

Estimates of growth and mortality rates are required for yield-per-recruit (YPR) analyses. Estimates of age-specific *F*s for each month and estimates of recruitment (Figure 14) obtained from the cohort analyses, estimates of the average weights of fish of each age (Table 7), and values of *M* of 0.4, 0.6, and 0.8 were used to calculate estimates of the YPRs for the 1971 through 1986 cohorts, for which complete life history data are available (Table 8). Estimated YPRs obtainable with various multiples of the fishing effort of 1982 and 1994 and three estimates of *M* are shown in Figure 15. The YPRs obtainable with different estimates of *M* differ considerably, particularly in the right panel of the figure.

Spawner-recruit relationships

Data on relative abundances of fish of ages 3 through 9, which are presumed to be spawners, and recruits (age-0 fish) obtained from the cohort analyses are shown in Figure 16. There is no evidence from these data that these two variables are correlated, which is not surprising in view of the fact that the abundance of spawners did not vary much over the period in question. This relationship should continue to be monitored, however, particularly if the abundance of spawners becomes reduced.

Production modeling

The only data required are catch and standardized CPUE. Standardization of CPUE data is nearly always a problem for multispecies fisheries, as vessels fishing in different area-time-gear configuration strata may be concentrating on different species, even though they may catch individuals of several species. The CPUEs listed in Table 9 and abundance indices computed with the logarithmic model (Figure 8), both adjusted to means of 1.0 for the 1975-1994 period, are shown in Figure 17. The two indices are nearly the same, despite the fact that, as pointed out above, the vulnerability of bigeye to capture should have increased with the switch from conventional to deep longline gear. As mentioned previously, in late 1993 purse-seine fishermen learned how to detect bigeye associated with floating objects, but well below the surface, with sonar, and catch them, so purse-seine effort for the 1971-1993 period is not equivalent to purse-seine effort for the 1994-1996 period. This does not create a problem in estimating the total effort, as only longline CPUE data were used in the production analyses described here. However, the productivity of the stock has almost certainly changed due to the increased exploitation of younger fish.

For this study, it was assumed (1) that there is a single stock of bigeye in the EPO and no exchange of fish between the EPO and other parts of the Pacific Ocean, (2) that all longline effort in the EPO has the same probability of catching bigeye of the EPO stock and that the efficiency of the longline gear did not change during the

1964-1995 period, and (3) that the longline CPUEs are indicative of the relative abundance of bigeye of all ages taken by the surface and longline fisheries. (The last assumption is not satisfied, of course.)

Data on the total catches and on the CPUEs by Japanese longline vessels are given in Tables 9 and 10. The total catches, in numbers of fish, were divided by the CPUEs, also in numbers of fish, to obtain estimates of the total effort (Table 9). In addition, the total catches, in weight, were divided by the CPUEs, also in weight, to obtain estimates of the total effort (Table 10). The effort data from Table 10 were used for production modeling.

The data were fit to the equation for the production model by minimizing the sums of squares between the observed amounts of effort and those predicted by the fitted model (Pella and Tomlinson, 1969). The fitting was done for a single value, 0.8, of *m*, the shape parameter, since this produces a production curve which is similar to the YPR curves (Figure 15). The results are shown in Table 11 and Figures 18-20. Two cases are shown, one with the minimum sums of squares ("best") and the other ("alternate") restrained to optimum effort greater than 400 million hooks. The predicted values of CPUE corresponding to the two values of optimum effort are virtually the same (Figure 20.) In the "best" case the recent effort exceeds the optimum effort, whereas for the "alternate" case the recent effort has been less than the optimum effort.

The estimates of the parameters (Table 11) for the production models for these data are not very reliable, as shown by the comparison in Figure 20. Different criteria for estimation gave different results for two important parameters, optimum effort and maximum sustainable yield (MSY). There is considerable variation between the observed CPUE and the values predicted by the model (Figure 20). Most of the variation in the CPUE was the result of changes in recruitment, rather than changes in population size caused by removal by the fisheries. Recent changes in the surface fishery, which catches fish which are younger than those caught by the longline fishery, will complicate the use of the production models in the future by changing the catchability of the population.

INTERACTION BETWEEN THE LONGLINE AND SURFACE FISHERIES

The age-specific estimates of the catches of fish obtained from the cohort analyses (Figure 11) were partitioned into separate estimates for the longline and surface fisheries (Figure 21). Likewise, the estimates of total *F* (Table 6) were partitioned into separate estimates for longlines and surface gear by calculating the portions of the total catches at each age made by each gear.

The interaction between two types of gear can be estimated by simulation of catch histories, using estimates of recruitment, natural mortality, and relative distribution of fishing mortality among fish of different ages obtained from cohort analyses with various multipliers of the vectors of *F* (which are directly proportional to the vectors of fishing effort) for one or both gears. This was done for bigeye in the EPO by (1) changing the estimates of *F* for the surface fishery, while leaving those for the longline fishery the same, or leaving both unchanged.

Simulation studies were carried out to predict what the catches for 1997-2006 would be with the following patterns of effort. The values of *F* for the surface fishery for 1997-2006 were set equal to that for 1996. Values of *F* for the longline fishery for 1993, 1994, and 1995 were calculated by multiplying the average value of *F* for the longline fishery for 1990-1992 by the amounts of fishing effort for 1993, 1994, and 1995 and then dividing by the average effort for 1990-1992. The values of *F* for the longline fishery for 1996 through 2006 were set equal to that for 1995. Then the values of *F* for the surface fishery for 1997 through 2006 were multiplied by either 0.1 (Pattern A), 1.0 (Pattern B), or 1.5 (Pattern C), while those for the longline fishery remained unchanged. The results are shown in Table 12 and in Figure 22 (for both types of gear combined) and Figure 23 (with separate estimates for the two types of gear).

DISCUSSION

The uncertainty about the natural mortality rate makes interpretation of the cohort analyses difficult. Different values of *M* produce different estimates of catch, amount of interaction between the surface and longline fisheries, and amount of effort necessary to achieve the MSY. The biomass of the stock has been relatively stable, although it declined after the mid-1980s (Figure 13). Similarly, the annual recruitment appears to have been relatively constant during the 1971-1996 period, fluctuating between lows in 1981 and highs in 1983 (Figure 14).

The YPR analyses indicate that effort at the 1982 level (multiplier of 1 in Figure 15) was less than optimum for all values of M. The YPRs are much greater for $M = 0.4$ than for $M = 0.8$, however. YPR analyses with effort at the 1994 level produce substantially different results, especially for the surface fishery. With $M = 0.4$ the effort was greater than optimum, with $M = 0.6$ it was slightly less than optimum, and with $M = 0.8$ it was substantially less than optimum.

Based on the simulations, estimates of the catches by gear of bigeye during the 1997-2006 period, with the three patterns of fishing effort described above, are shown in Figure 22. The surface fishery has little effect on the longline fishery with Pattern A, corresponding to the purse-seine fishery previous to 1994, regardless of M (Figure 23). With Patterns B and C, however, corresponding to the current and possible future purse-seine fishery, there is considerable effect on the longline fishery, especially at higher levels of effort and lower values of M.

Clearly, if M is low (about 0.4) and the effort of the surface fishery remains at the 1996 level the total catch will be reduced, and if the effort of the surface fishery increases further the total catch will be further reduced. However, if M is about 0.8, and the effort of the surface fishery remains at the 1996 level, or increases no more than 50 percent, the total catch will probably increase, although the catch of the longline fishery would be less than if the surface fishery were at the 1982 level. If M is about 0.6, the surface catch at current or slightly higher levels will not change the total catch very much. It is not clear at this time what effect reducing effort for either fishery would have on the total catch, except for the cases described above.

Production modeling, which does not require assumptions about natural mortality, does not indicate whether the present level of effort is less than or greater than optimum (Figure 18).

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LITERATURE CITED

Anonymous. 1992. Annual Report of the Inter-American Tropical Tuna Commission 1991: 271 pp.

Anonymous. 1997. Annual Report of the Inter-American Tropical Tuna Commission 1995: 334 pp.

Anonymous. 1998. Annual Report of the Inter-American Tropical Tuna Commission 1996: in preparation.

Barrett, I., and S. Kume. 1965. Observations on bigeye tuna caught in the surface tuna fishery in the eastern Pacific Ocean, 1951-1964. Calif. Fish Game, 51 (4): 252-258.

Brill, R. W. 1994. A review of temperature and oxygen tolerance studies of tuna pertinent to fisheries oceanography, movement models and stock assessments. Fish. Ocean., 3 (3): 204-216.

Calkins, T. P., M. Yamaguchi, and N. Miyabe. 1993. Some observations on bigeye tuna (*Thunnus obesus*) caught by the surface and longline fisheries for tunas in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 20 (8): 441-499.

Kume, S. 1969a. Ecological studies on bigeye tuna--V. A critical review on distribution, size composition and stock structure of bigeye tuna in the North Pacific Ocean (north of 16°N). Far Seas Fish. Res. Lab., Bull., 1: 57-75.

Kume, S. 1969b. Ecological studies on bigeye tuna--VI. A review on distribution and size composition of bigeye tuna in the Equatorial and South Pacific Ocean. Far Seas Fish. Res. Lab., Bull., 1: 77-98.

Kume, S., and J. Joseph. 1966. Size composition, growth and sexual maturity of bigeye tuna, *Thunnus obesus* (Lowe), from the Japanese long-line fishery in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 11 (2): 45-99.

Kume, S., and J. Joseph. 1969. The Japanese longline fishery for tunas and billfish in the eastern Pacific Ocean east of 130°W, 1964-1966. Inter-Amer. Trop. Tuna Comm., Bull., 13 (2): 275-418.

Kume, S., and M. B. Schaefer. 1966. Studies of the Japanese long-line fishery for tuna and marlin in the eastern tropical Pacific Ocean during 1963. Inter-Amer. Trop. Tuna Comm., Bull., 11 (3): 101-170.

Miyabe, N., and W. H. Bayliff. 1987. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1971-1980. Inter-Amer. Trop. Tuna Comm., Bull., 19 (1): 1-163.

Nakamura, E. L., and J. H. Uchiyama. 1966. Length-weight relations of Pacific tunas. *In* Manar, T. A. (editor), Hawaii, Governor's Conf. Cent. Pacif. Fish Resources, Proc.: 197-201.

Nakano, H., and W. H. Bayliff. 1992. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1981-1987. Inter-Amer. Trop. Tuna Comm., Bull., 20 (5): 183-355.

Pella, J. J., and P. K. Tomlinson. 1969. A generalized stock production model. Inter-Amer. Trop. Tuna Comm., Bull., 13 (3): 419-496.

Punsly, R., and H. Nakano. 1992. Analysis of variance and standardization of longline hook rates of bigeye (*Thunnus obesus*) and yellowfin (*Thunnus albacares*) tunas in the eastern Pacific Ocean during 1975-1987. Inter-Amer. Trop. Tuna Comm., Bull., 20 (4): 165-184.

Suzuki, Z., P. K. Tomlinson, and M. Honma. 1978. Population structure of Pacific yellowfin tuna. Inter-Amer. Trop. Tuna Comm., Bull., 17 (5): 273-441.

Shingu, C., P. K. Tomlinson, and C. L. Peterson. 1974. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1967-1970. Inter-Amer. Trop. Tuna Comm., Bull., 16 (2): 65-230.

Suda, A., and M. B. Schaefer. 1965. General review of the Japanese tuna long-line fishery in the eastern tropical Pacific Ocean 1956-1962. Inter-Amer. Trop. Tuna Comm., Bull., 9 (6): 305-462.

Tomlinson, P. K., S. Tsuji, and T. P. Calkins. 1992. Length-frequency estimation for yellowfin tuna (*Thunnus albacares*) caught by commercial fishing gear in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 20 (6): 357-398.

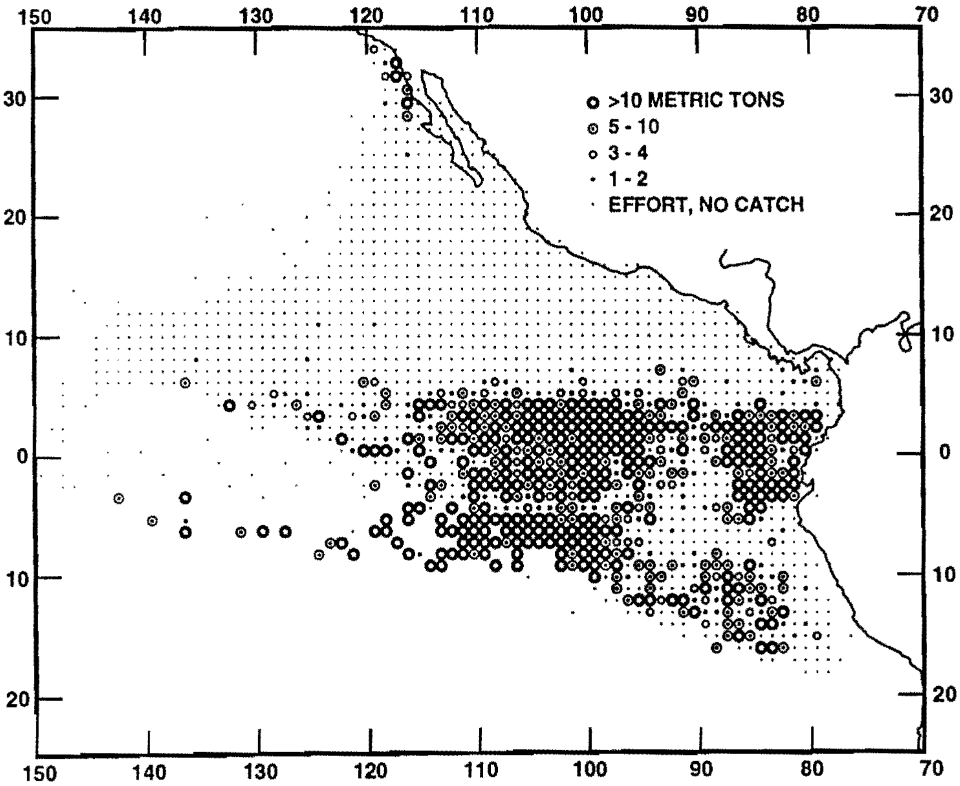


FIGURE 1. Catches of bigeye tuna in the EPO during 1981-1995 for all purse-seine trips for which usable logbook data were obtained. The averages were calculated only for 1-degree areas for which two or more years of data were available.

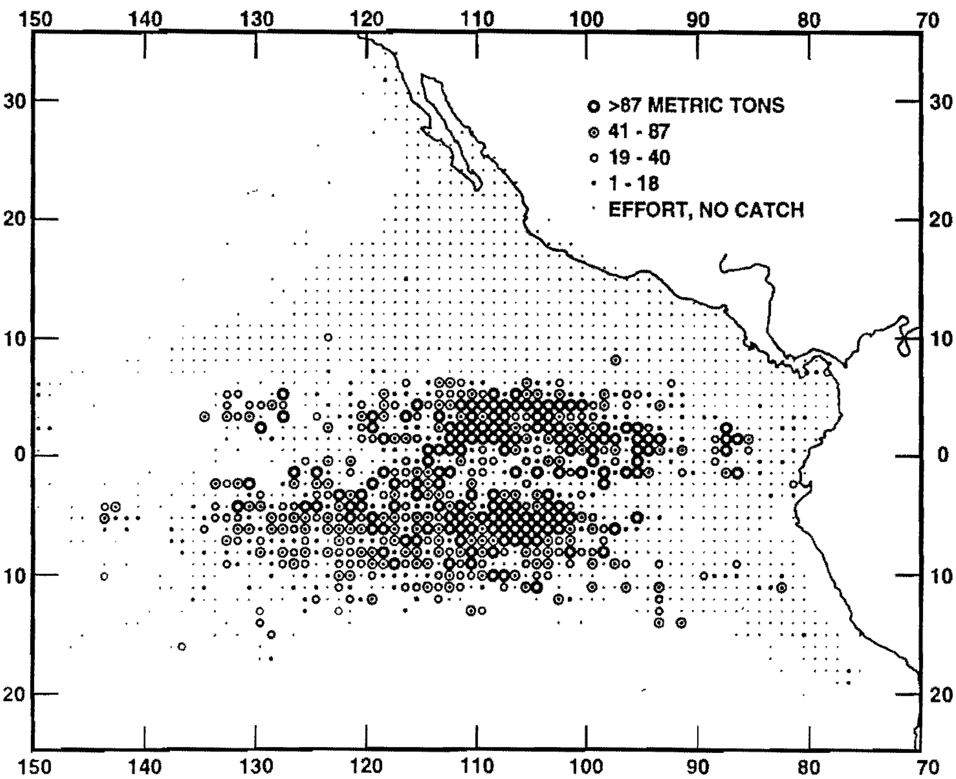


FIGURE 2. Catches of bigeye tuna in the EPO during 1996 for all purse-seine trips for which usable logbook data were obtained.

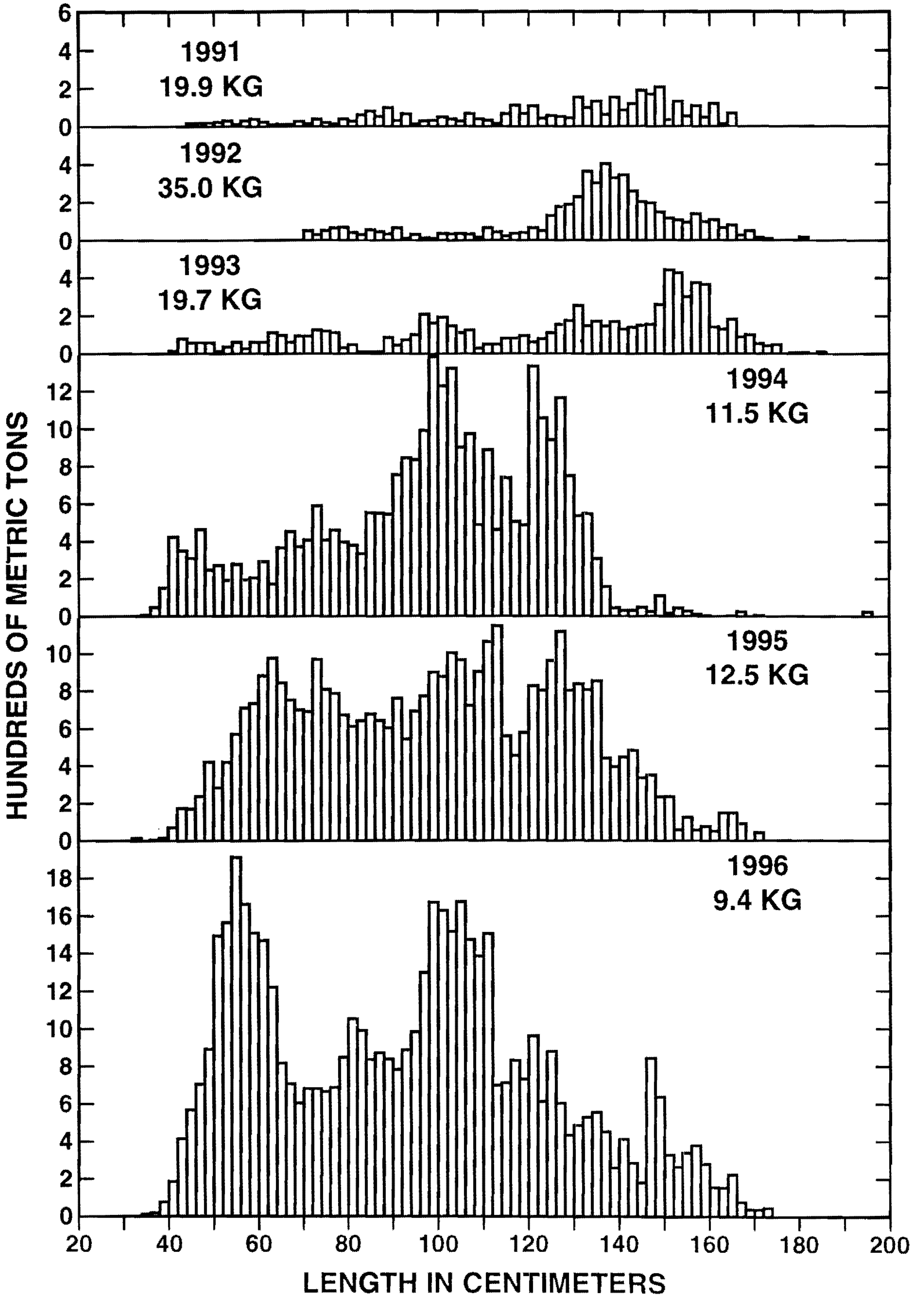


FIGURE 3. Estimated catches of bigeye by surface gear in the eastern Pacific Ocean. The values in the upper left or right corners of the panels are the average weights.

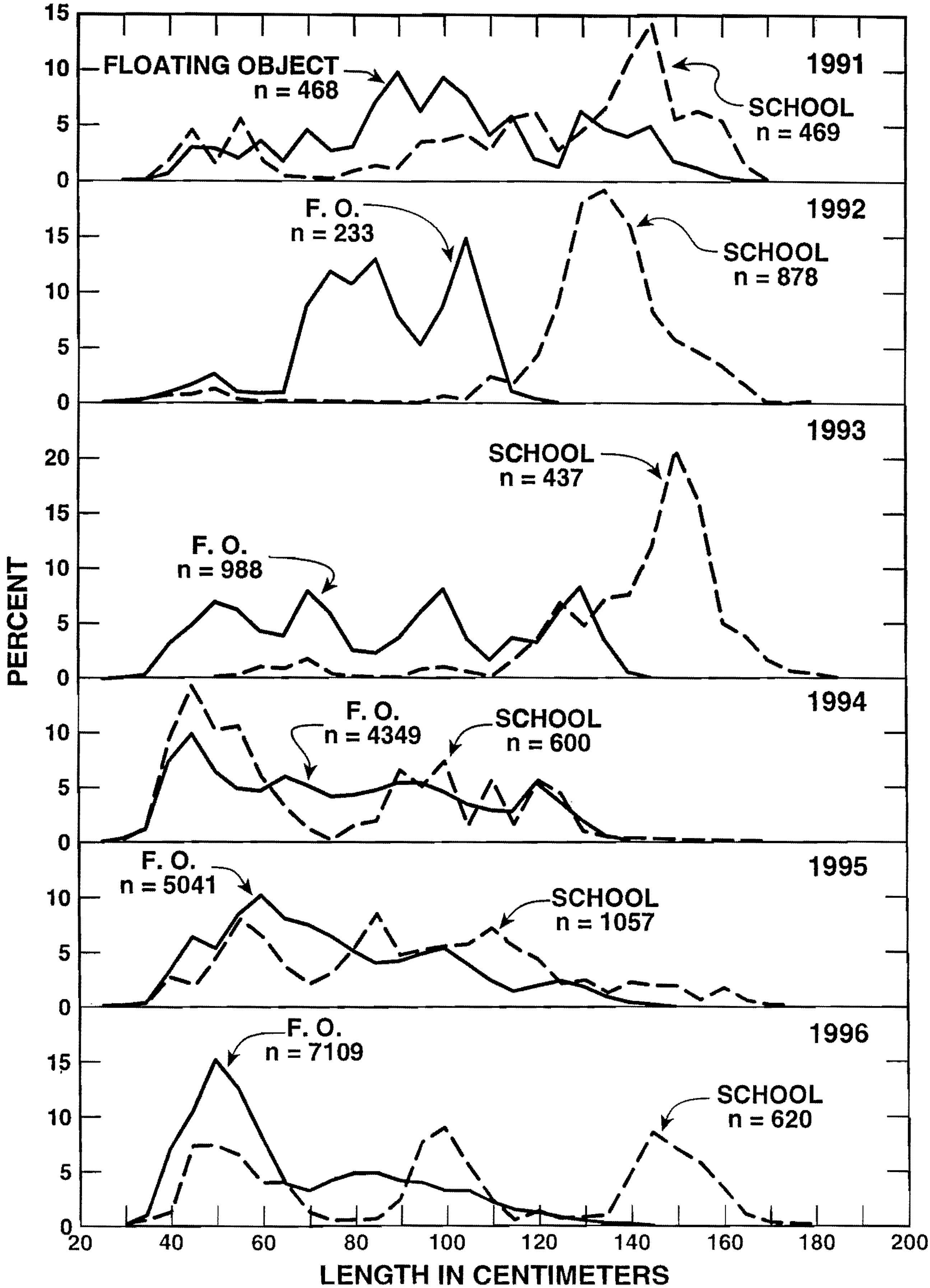


FIGURE 4. Length-frequency distributions, in percentages of numbers of fish, for bigeye tuna caught in sets made on schools of fish associated with floating objects and sets made on free-swimming schools of fish.

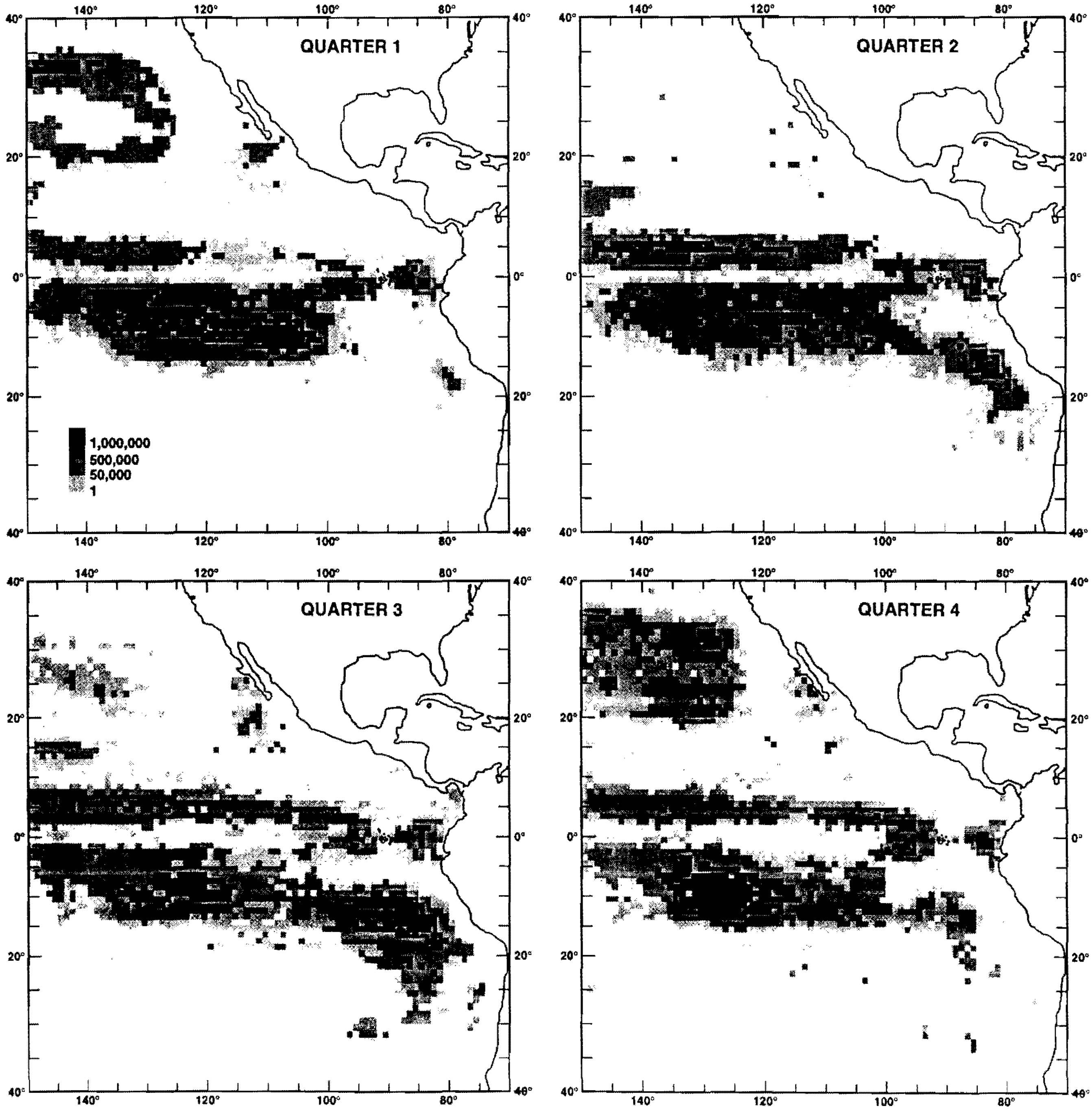


FIGURE 5. Quarterly distributions of effort, in numbers of hooks, by Japanese longline vessels in the EPO during 1988-1992.

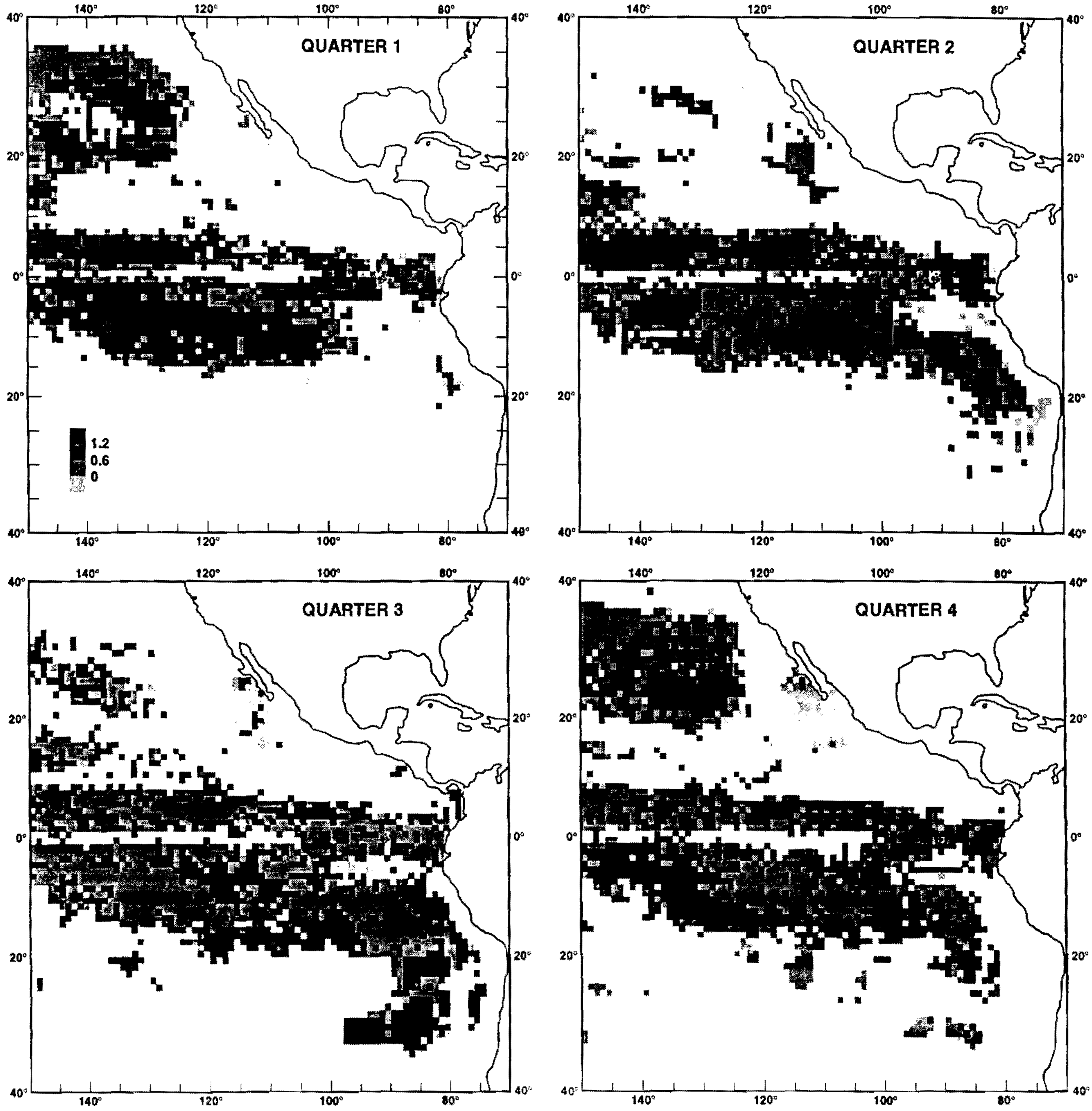


FIGURE 6. Quarterly distributions of average CPUEs of bigeye tuna, in numbers of fish per hundred hooks, by Japanese longline vessels in the EPO during 1988-1992.

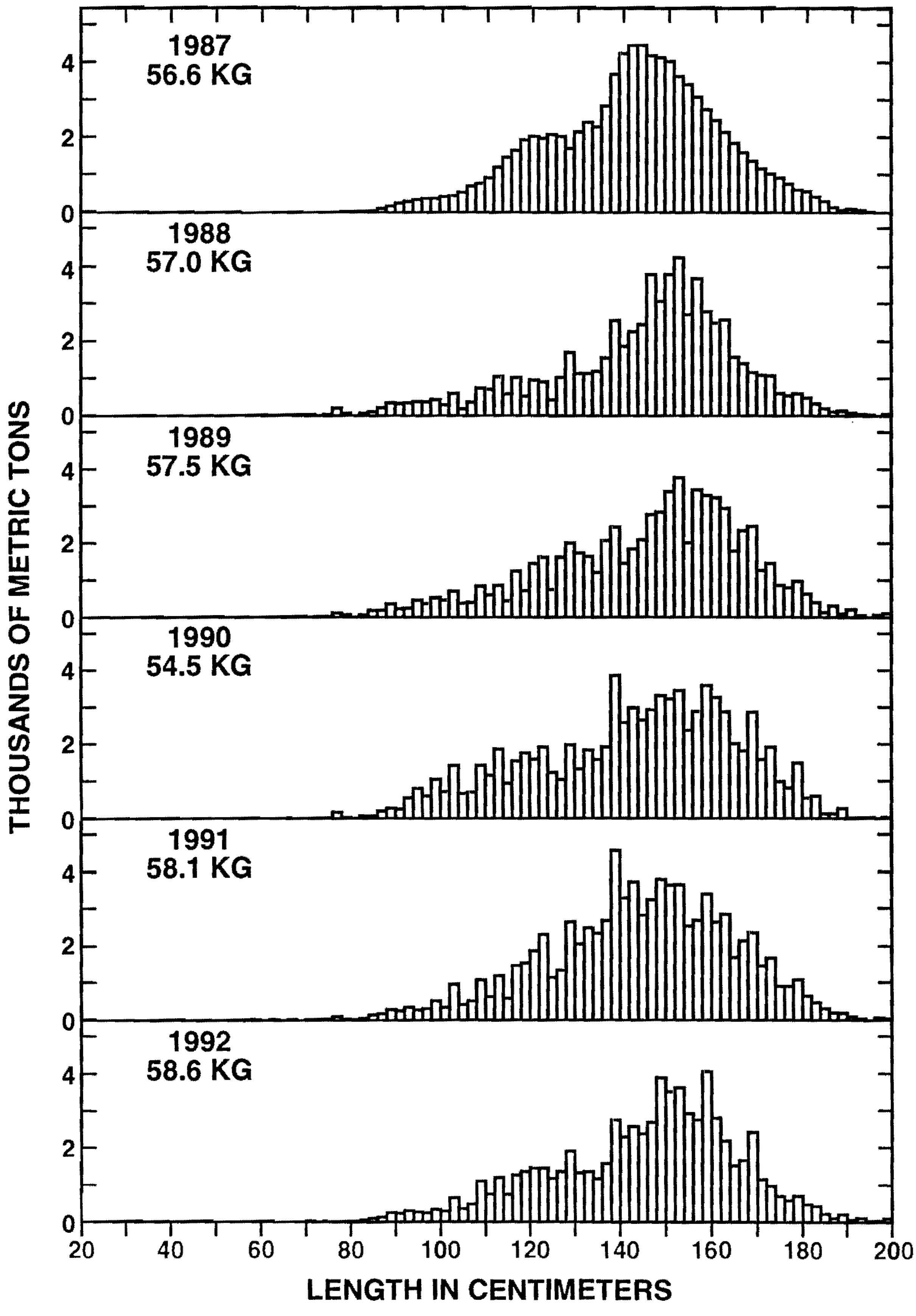


FIGURE 7. Length-frequency distributions of bigeye tuna caught by Japanese longline vessels in the EPO. The values in the upper left corners of the panels are the average weights.

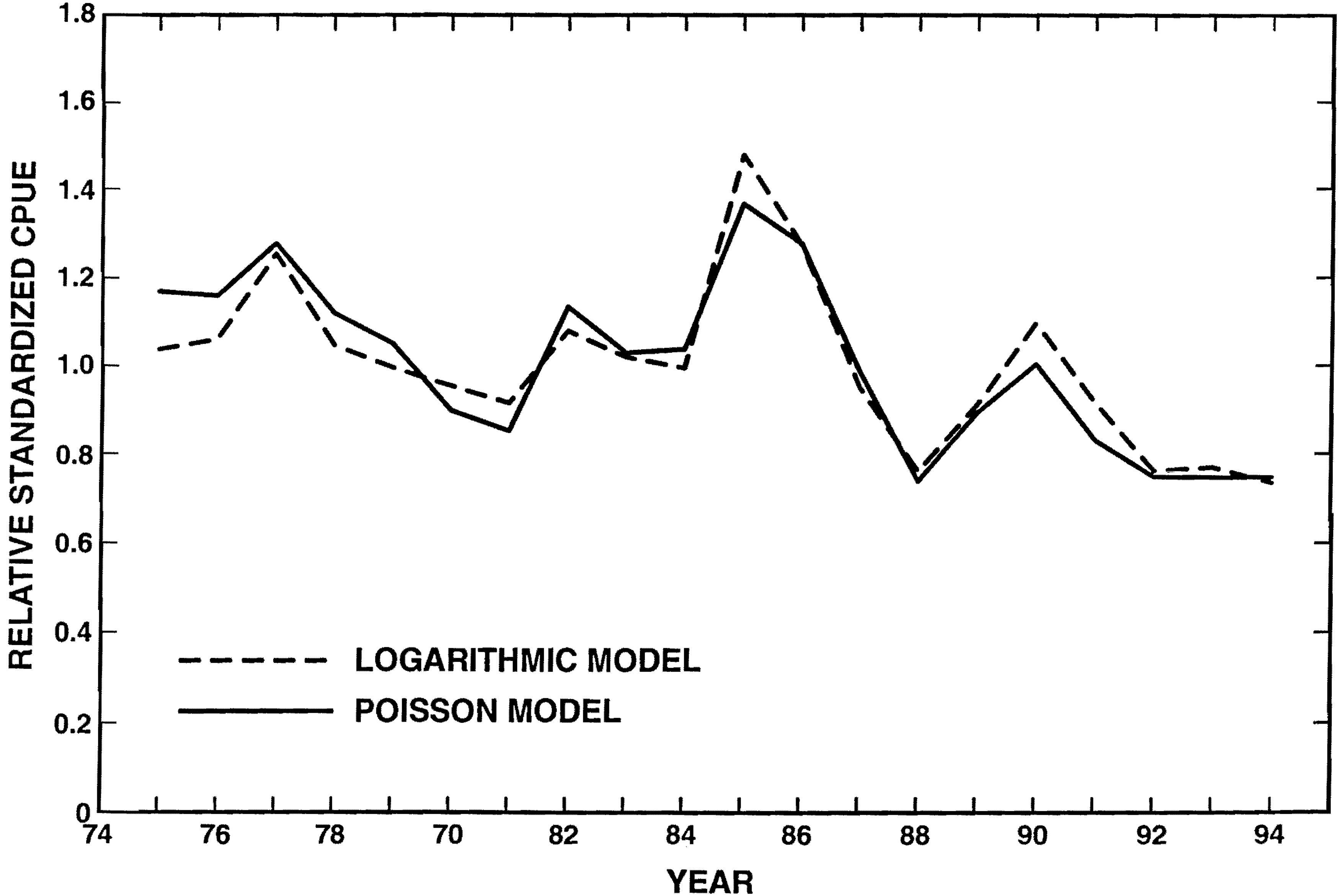


FIGURE 8. Estimates of standardized CPUEs of bigeye in the EPO.

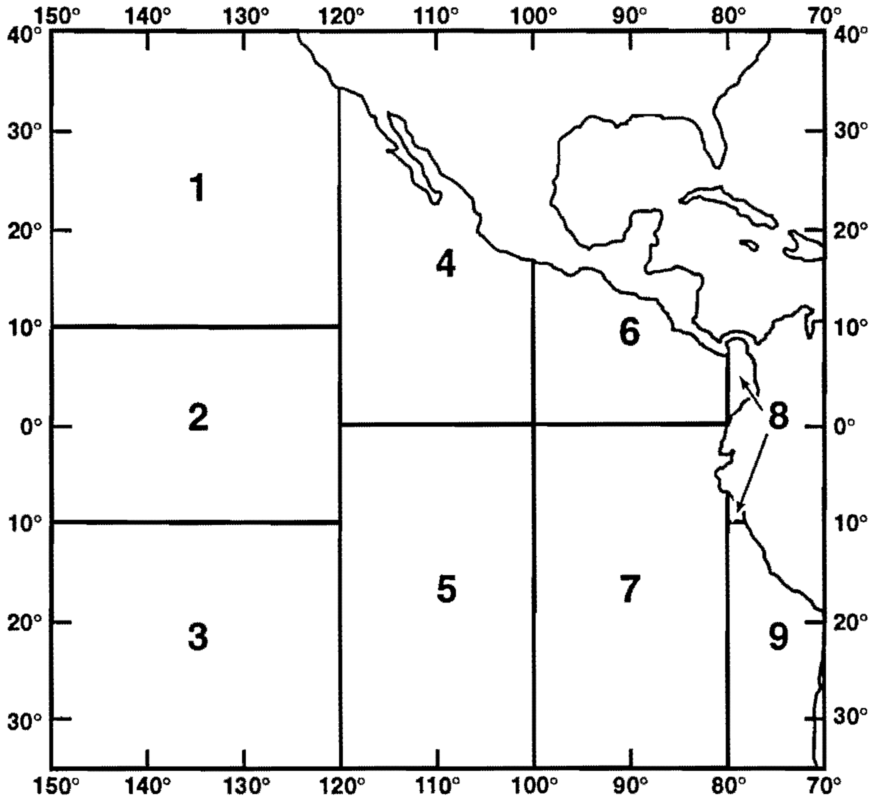


FIGURE 9. Areas used for stratification of catches and length frequencies of longline-caught bigeye tuna in the EPO.

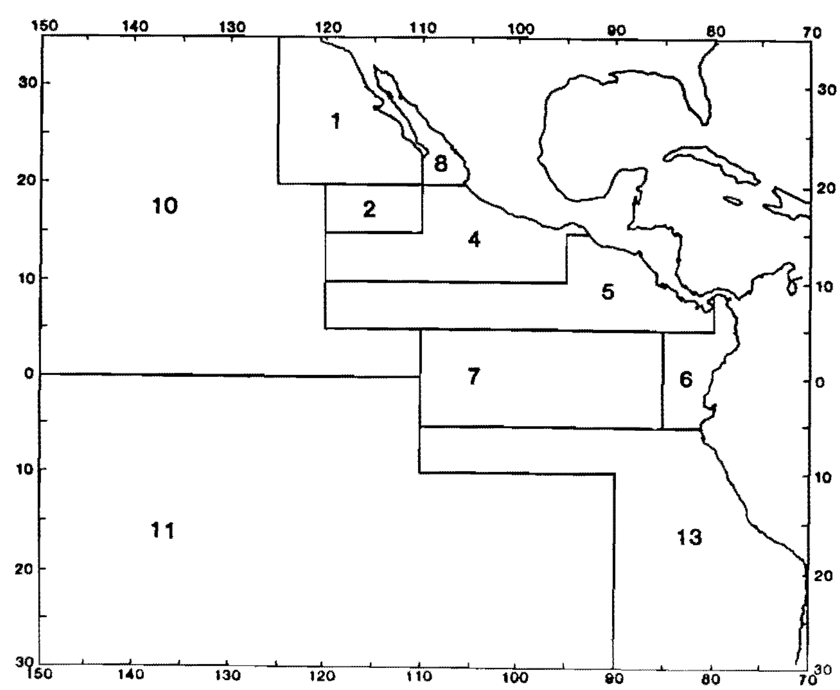
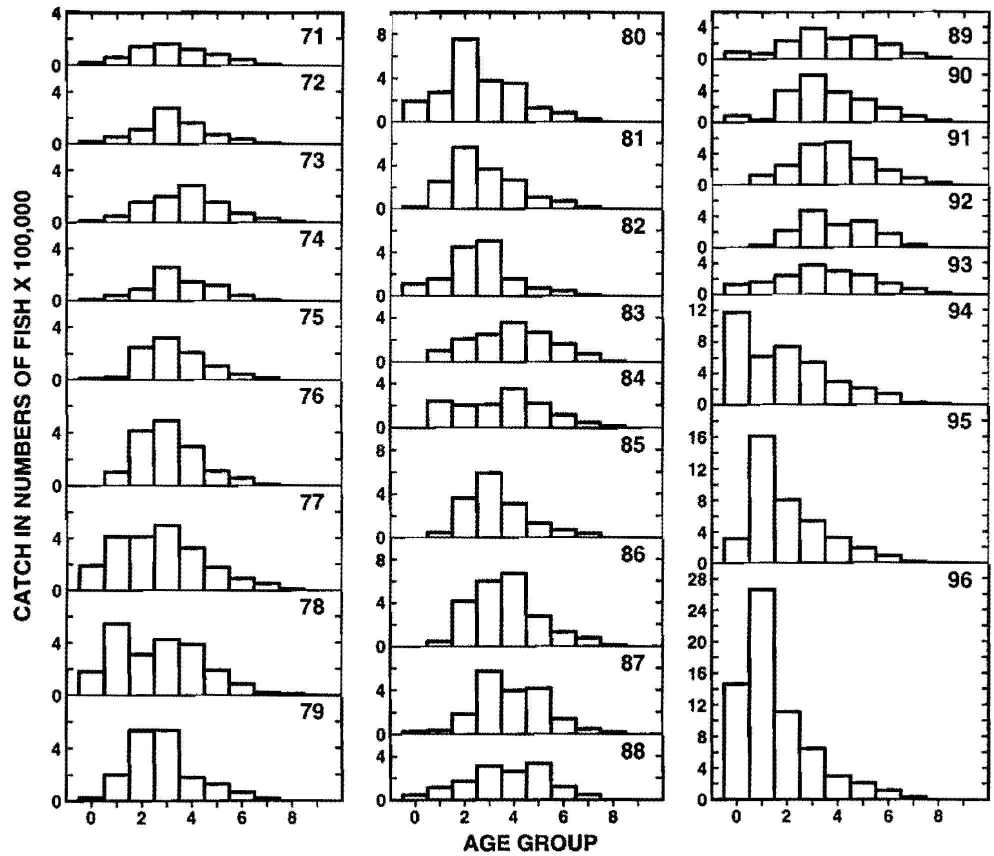


FIGURE 10. Areas used for sampling lengths of tunas in the eastern Pacific Ocean.



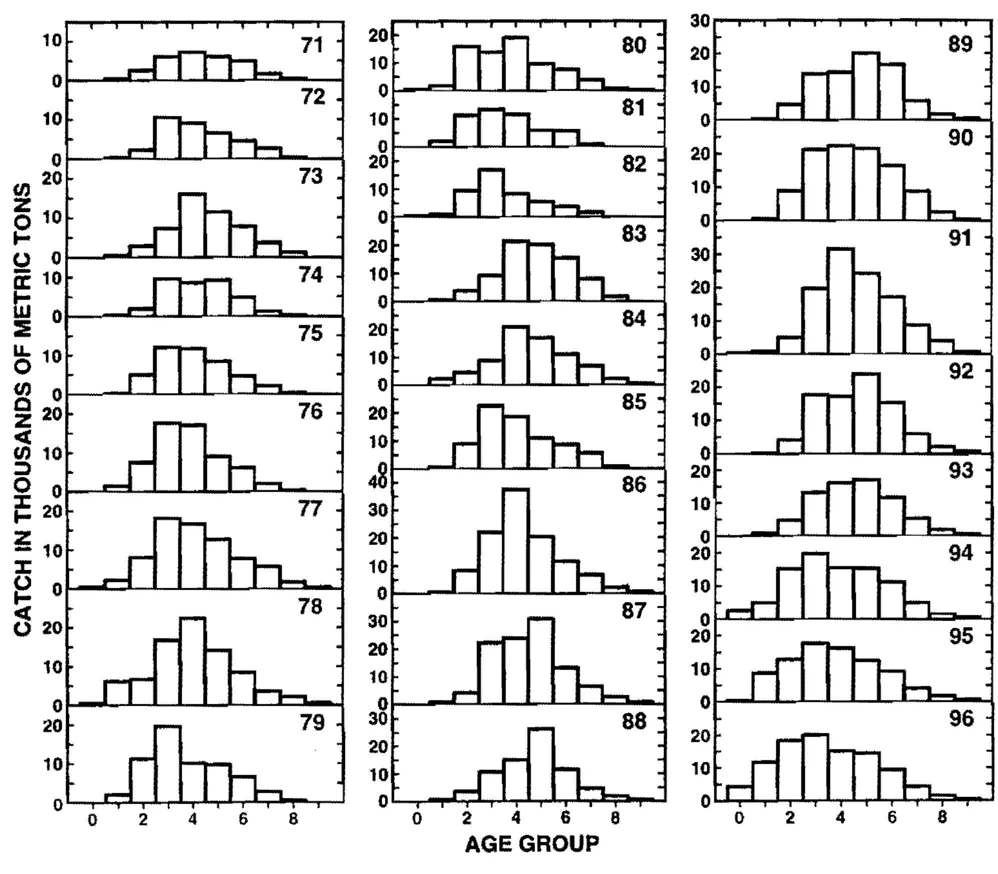


FIGURE 11. Estimated catches of bigeye tuna of ages 0 through 9 in the EPO.

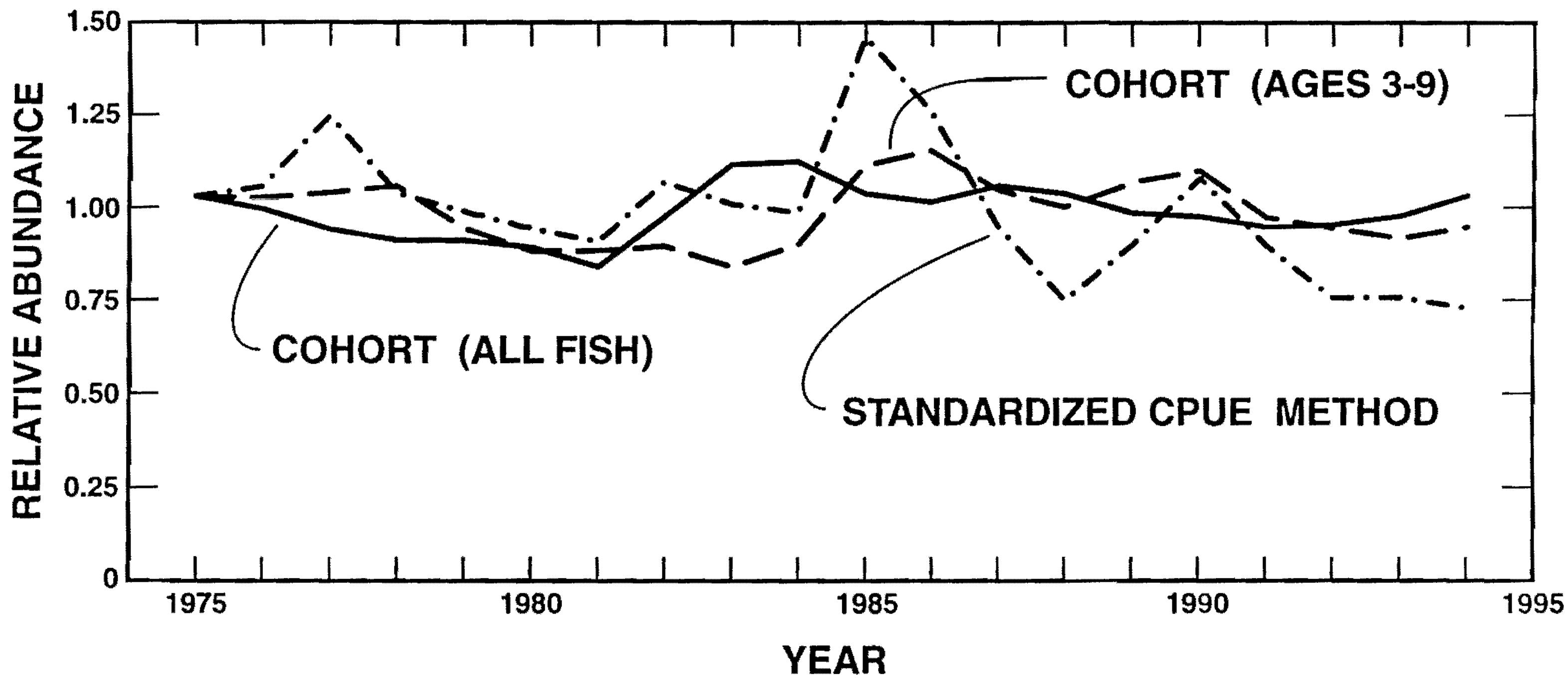


FIGURE 12. Comparison of two estimates of the relative abundance of bigeye tuna in the EPO, in numbers of fish, obtained by cohort analyses with $M = 0.6$, to data for standardized CPUEs. All three indices were adjusted to averages of 1.0.

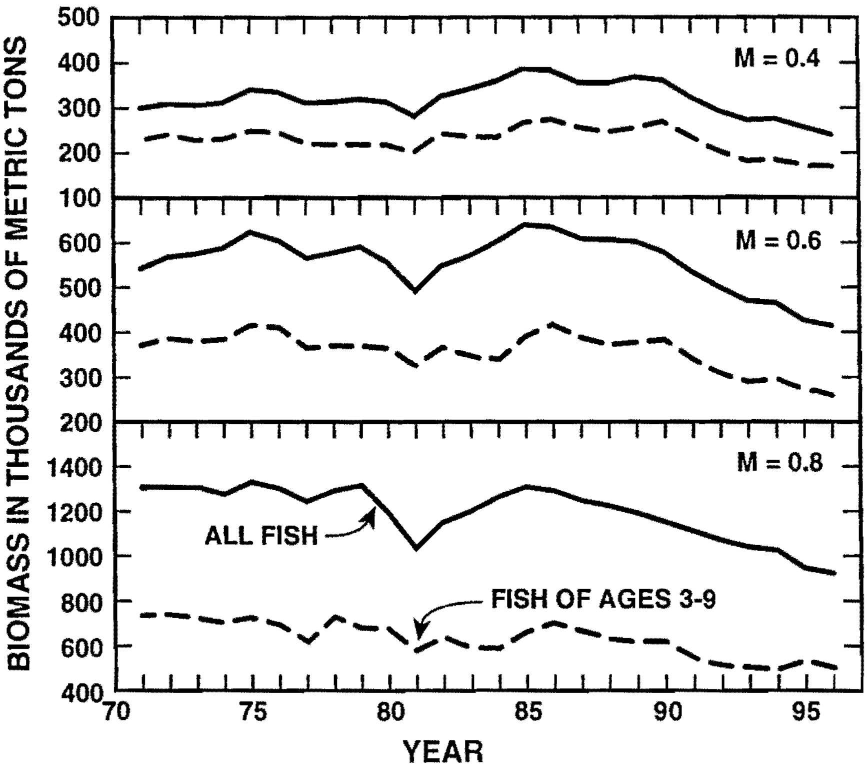


FIGURE 13. Estimates, obtained from cohort analyses, of average biomasses of bigeye tuna.

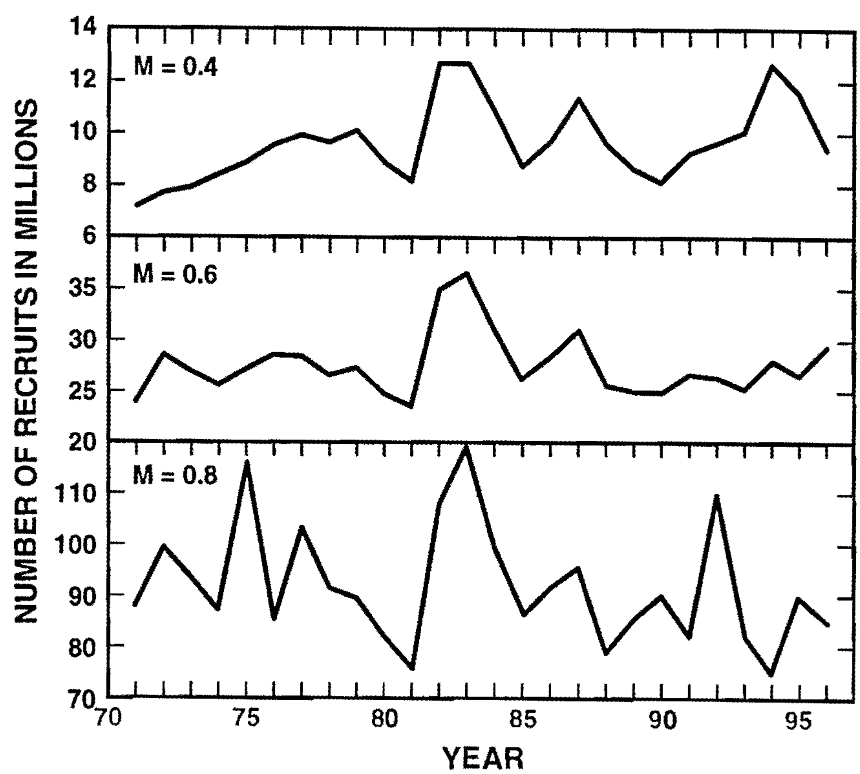


FIGURE 14. Estimates, obtained from cohort analyses, of recruitment of bigeye tuna, of the X and Y cohorts combined, in the EPO.

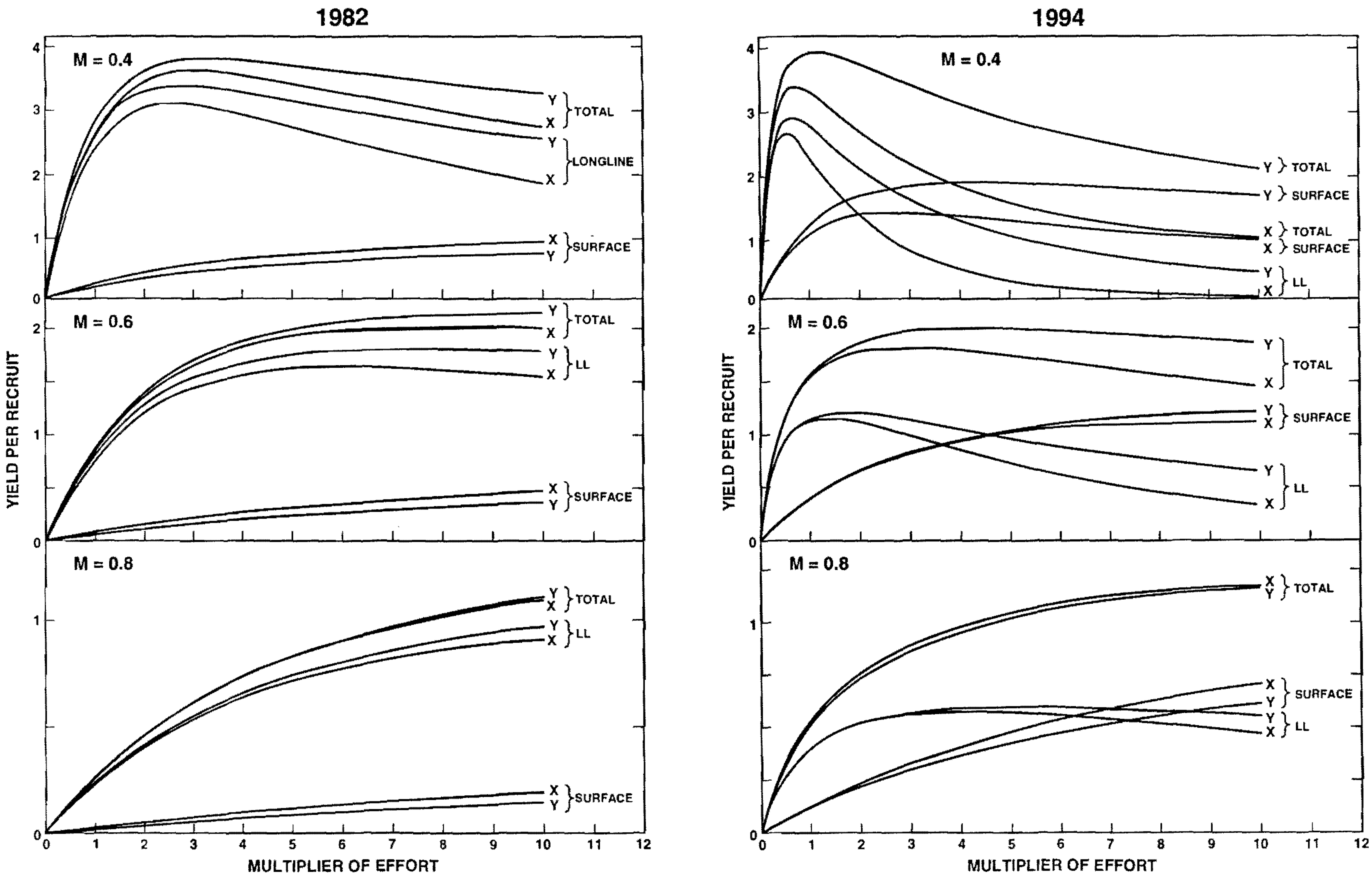


FIGURE 15. Yields per recruit for bigeye tuna with various multiples of the fishing effort of 1982 and 1994.

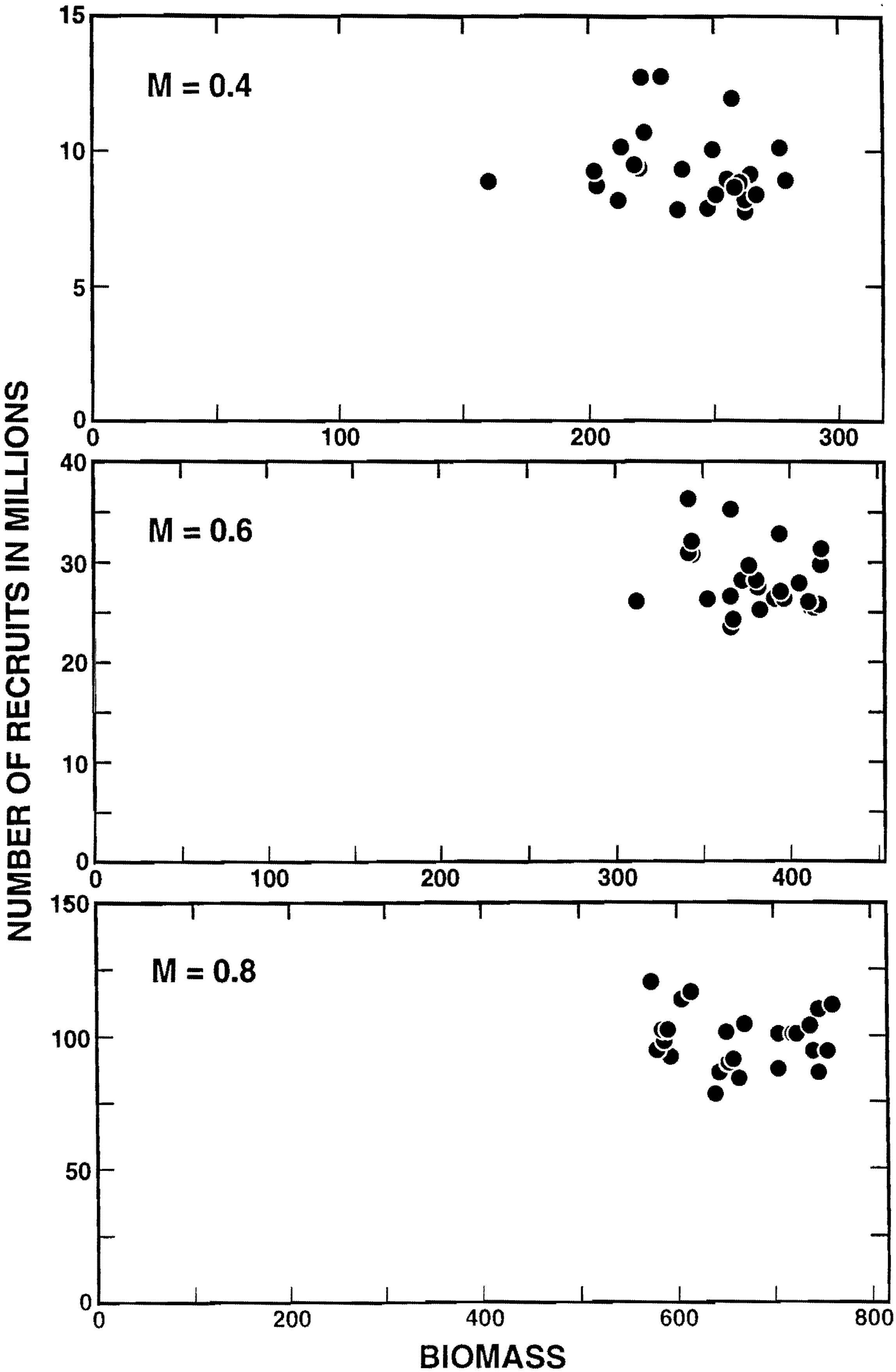


FIGURE 16. Relationships between estimates of recruitment and biomass of bigeye tuna of ages 3-9 in the EPO, obtained from cohort analyses, 1971-1995.

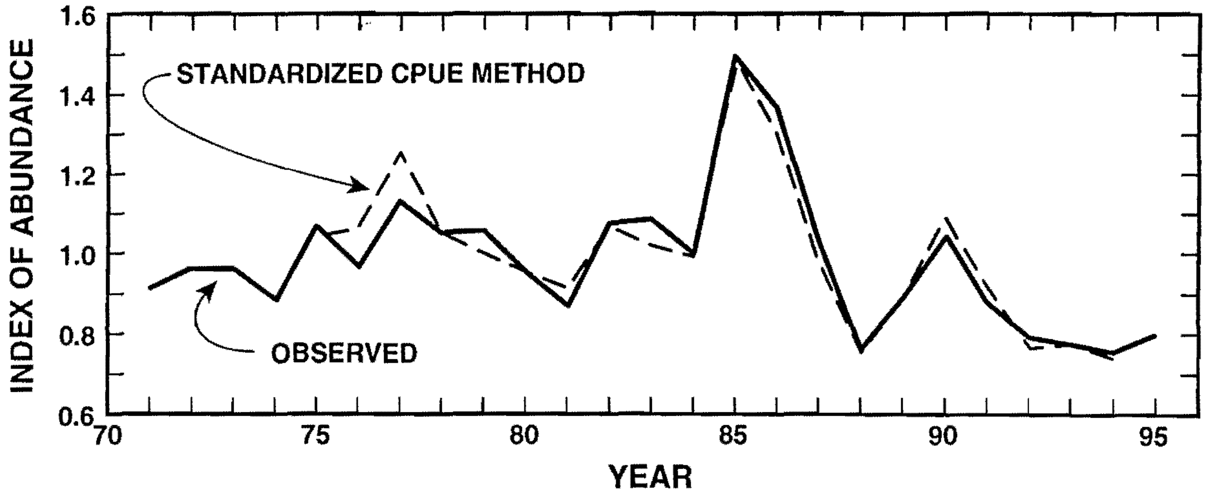


FIGURE 17. Indices of abundance of bigeye tuna in the EPO derived from catches per hook and from a generalized linear model. Both sets of values are adjusted to a mean of 1.0.

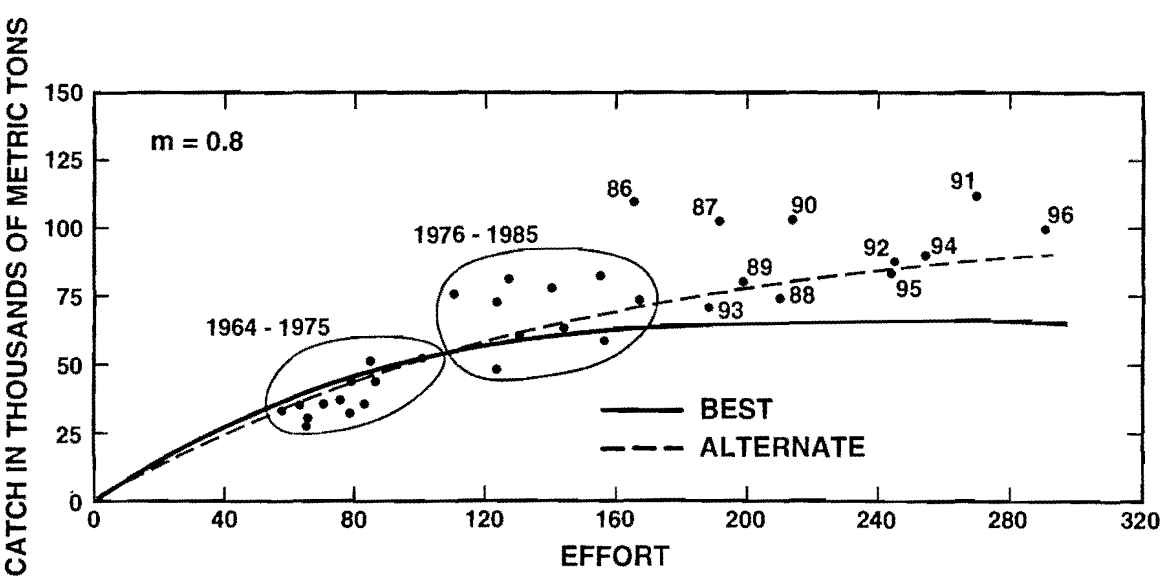


FIGURE 18. Estimates, from production modeling, of the relationships between the total catch of bigeye tuna and the total effort, standardized to longline effort in millions of hooks, for two values of optimum effort. The dots indicate observed values, and the curves indicate expected catches under equilibrium conditions.

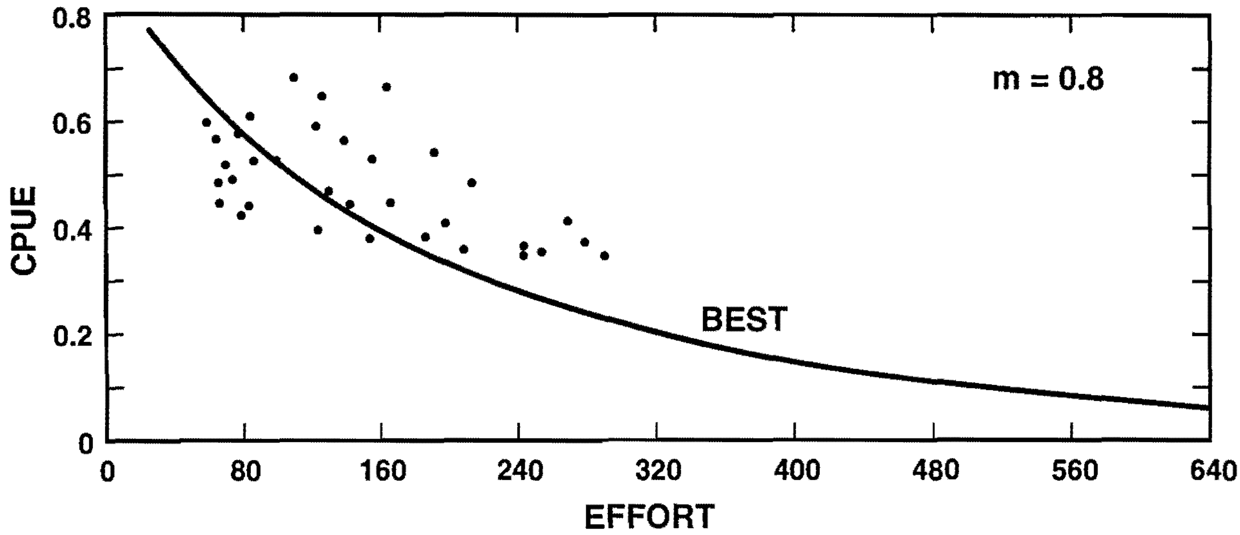


FIGURE 19. Estimates, from production modeling, of the relationships between longline CPUE of bigeye tuna, in metric tons per thousand hooks, and total effort, standardized to longline effort in millions of hooks, for the best fit with $m = 0.8$. The dots indicate observed values, and the curves indicate expected catches under equilibrium conditions.

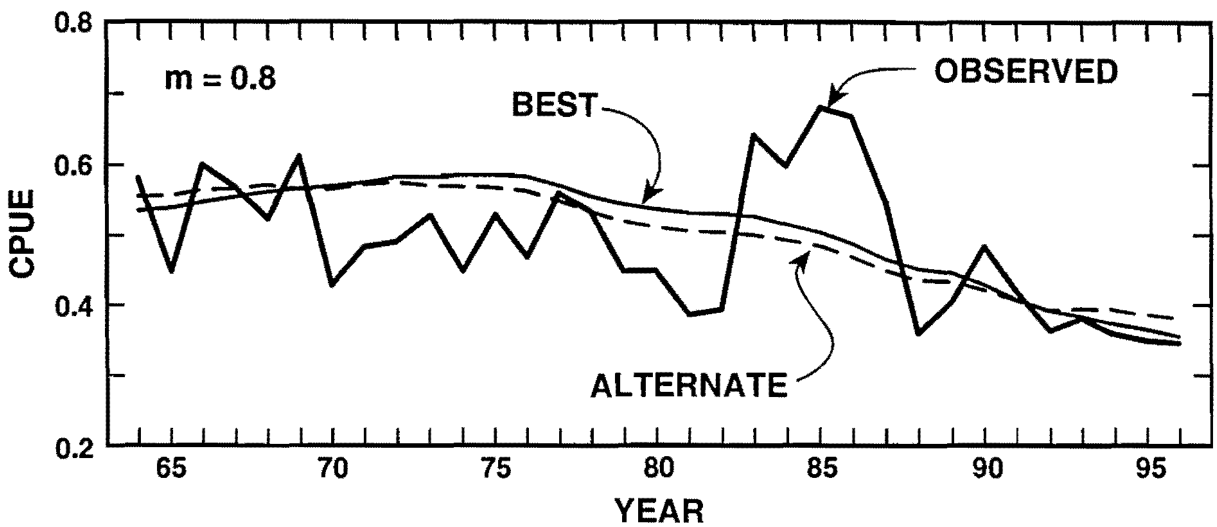


FIGURE 20. Temporal trends for the longline CPUE of bigeye tuna, in metric tons per thousand hooks, in the EPO, and trends predicted with production modeling for the best fit and the alternate fit.

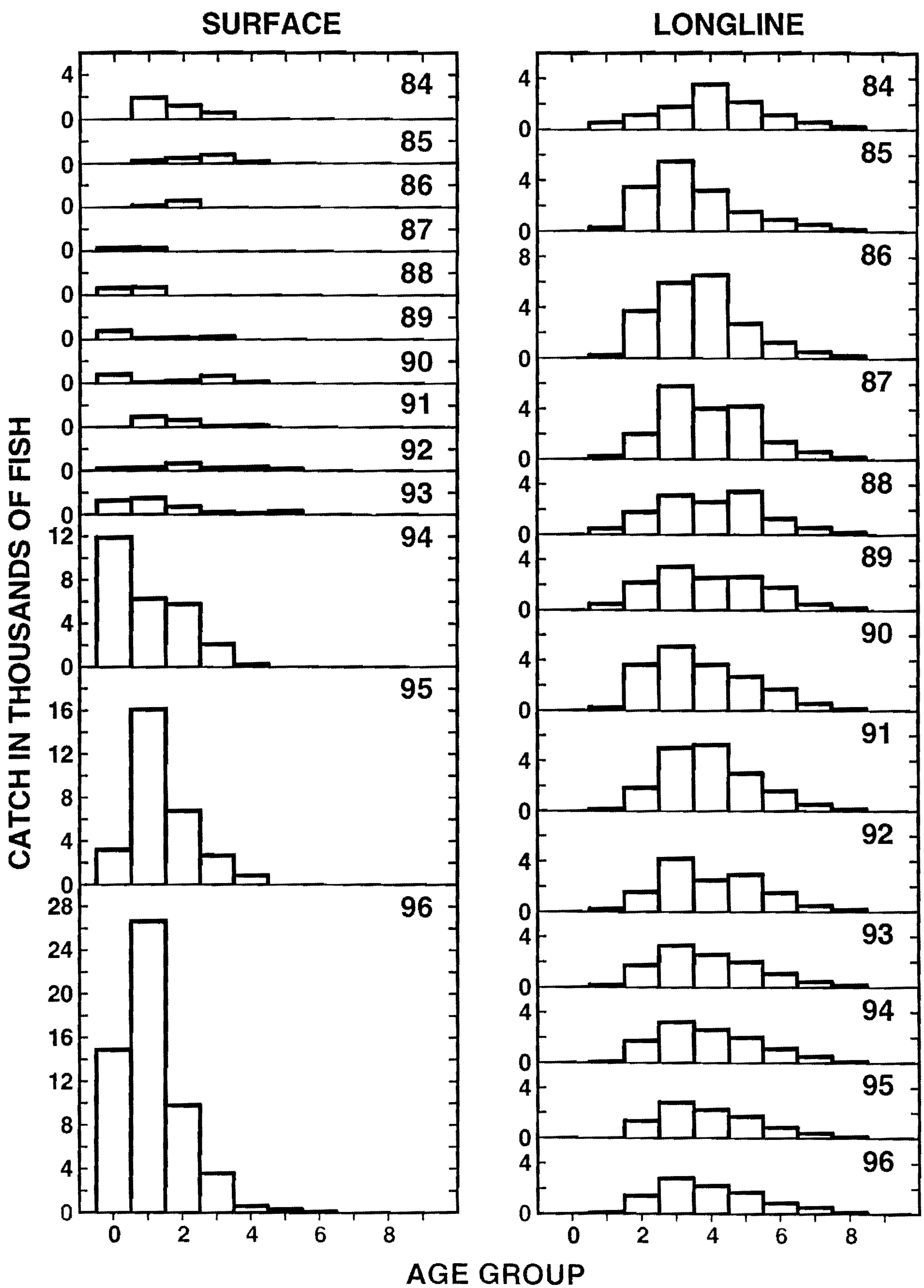


FIGURE 21. Estimated catches of bigeye tuna of ages 0 through 9, in thousands of fish, in the EPO by the surface and longline fisheries.

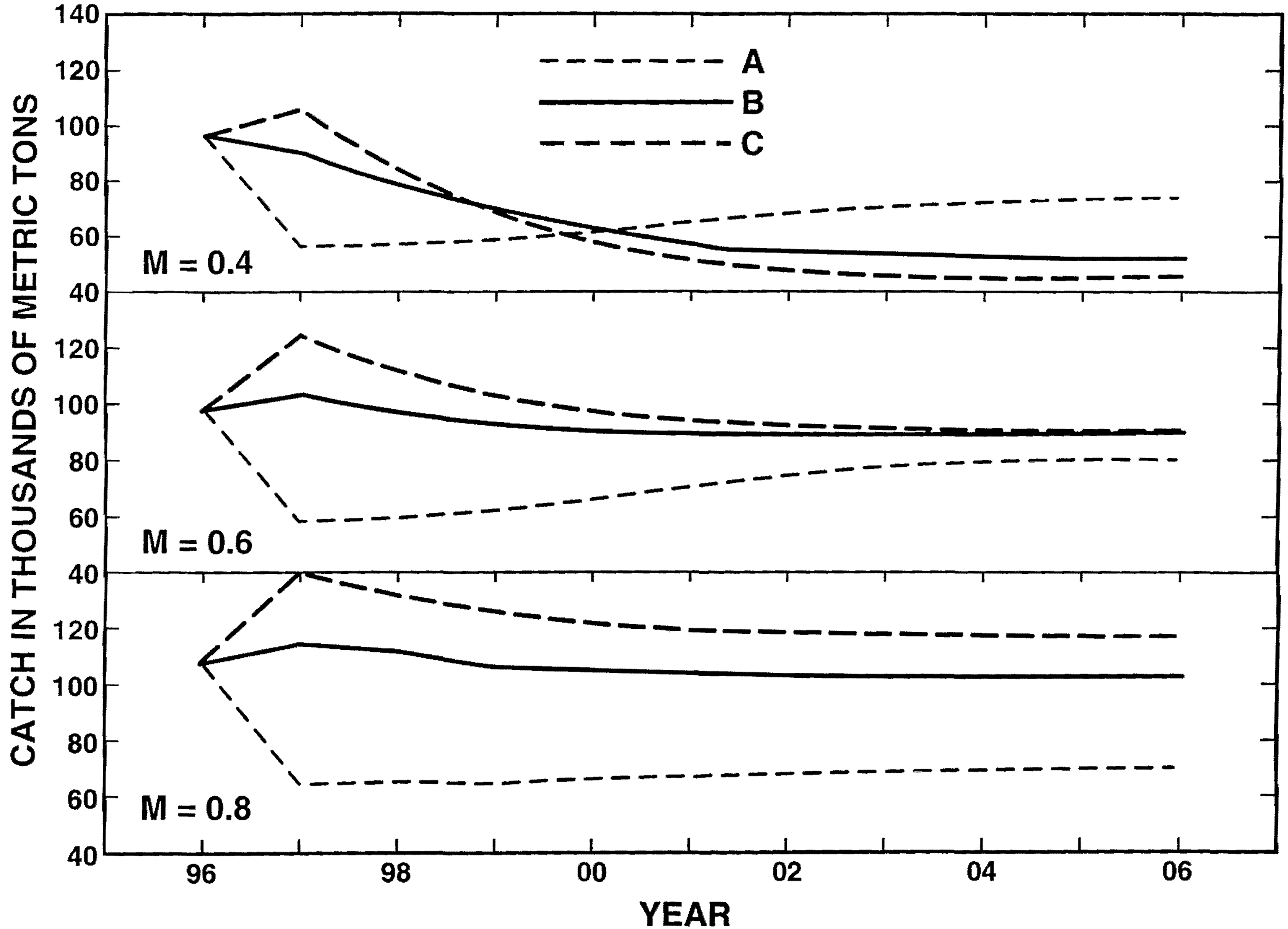


FIGURE 22. Estimated total catches of bigeye tuna with the three patterns of fishing described in the text.

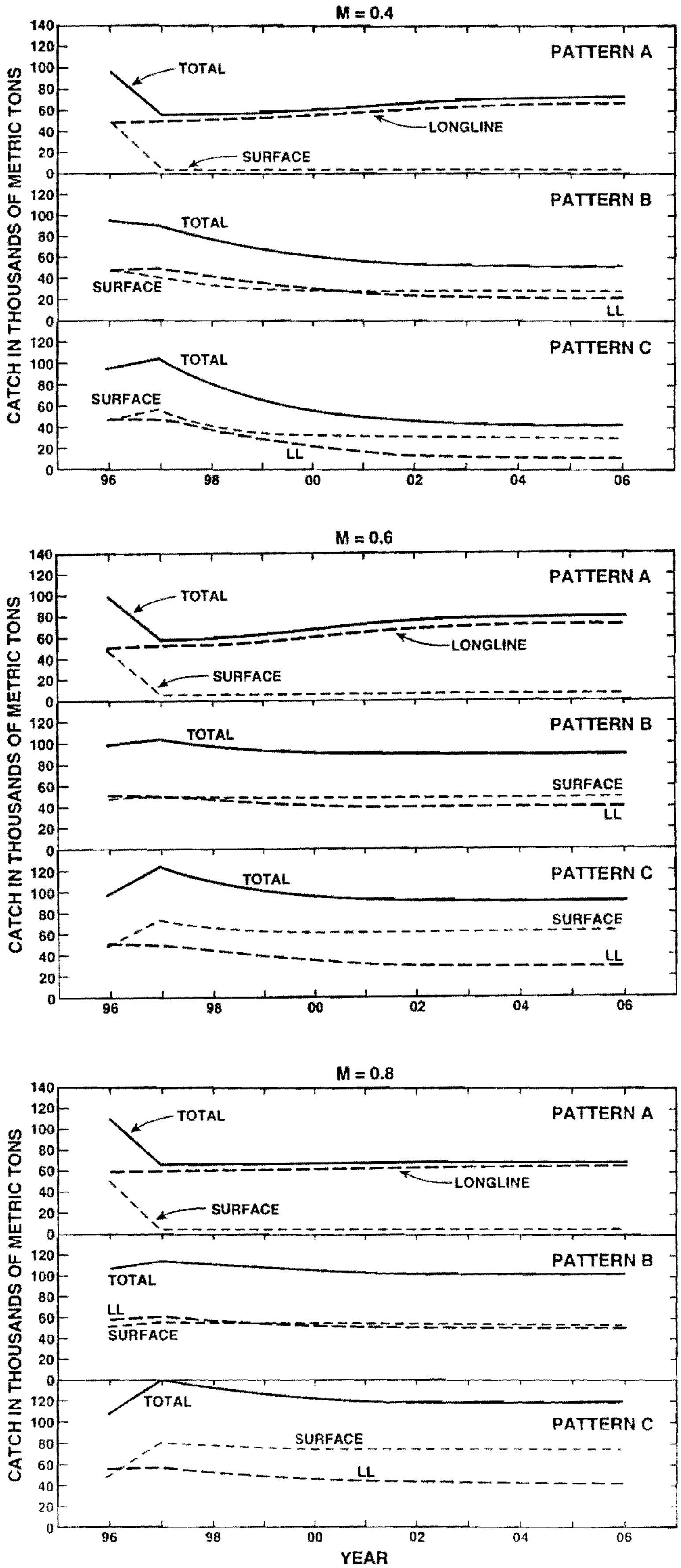


FIGURE 23. Estimated total catches of bigeye tuna with the three patterns of fishing described in the text and M = 0.4, 0.6, and 0.8.

TABLE 1. Annual catches of bigeye tuna, in thousands of metric tons. ROC and ROK stand for Republic of China and Republic of Korea, respectively.

Year	EPO						Western Pacific Ocean[3]	Total Pacific Ocean[4]	Atlantic and Indian Oceans[4]	Total[4]
	Surface[1]	Longline				Total				
		Japan[2]	ROC[2]	ROK[2]	Total					
Año	OPO						Océano Pacífico occidental[3]	Total Océano Pacífico[4]	Océanos Atlantico e Indico[4]	Total[4]
	Superficie[1]	Palangre				Total				
		Japón[2]	ROC[2]	ROK[2]	Total					
1954	0.3	1.5	*	*	1.5	1.8	*	*	*	*
1955	0.1	1.8	*	*	1.8	1.9	*	*	*	*
1956	0.0	2.4	*	*	2.4	2.4	*	*	*	*
1957	0.1	9.5	*	*	9.5	9.6	*	*	*	*
1958	0.3	10.3	*	*	10.3	10.6	*	*	*	76.8
1959	0.2	11.2	*	*	11.2	11.4	*	*	*	76.8
1960	0.2	17.3	*	*	17.3	17.5	*	*	*	74.8
1961	0.2	51.3	*	*	51.3	51.5	*	*	*	116.8
1962	0.4	44.2	*	*	44.2	44.6	*	*	*	129.7
1963	0.1	65.3	*	*	65.3	65.4	*	*	*	133.7
1964	0.1	45.4	*	*	45.4	45.5	38.2	83.7	38.8	122.6
1965	0.1	28.6	*	*	28.6	28.7	40.2	68.9	46.2	115.1
1966	0.3	34.1	*	*	34.1	34.4	42.7	77.1	43.1	120.2
1967	1.6	34.2	*	*	34.2	35.8	45.8	81.6	49.5	131.1
1968	2.6	33.8	*	*	33.8	36.4	30.6	67.0	58.2	125.2
1969	0.6	50.8	*	*	50.8	51.4	28.3	79.7	61.9	141.6
1970	1.3	31.8	*	*	31.8	33.1	51.1	84.2	58.4	142.6
1971	2.6	29.2	*	*	29.2	31.8	34.2	66.0	71.1	137.0
1972	2.2	34.7	*	*	34.7	36.9	50.8	87.7	60.1	147.8
1973	2.0	51.0	*	*	51.0	53.0	37.4	90.4	66.5	156.8
1974	0.9	35.3	*	*	35.3	36.2	51.7	87.9	83.3	171.3
1975	3.7	41.2	*	0.6	41.8	45.5	57.6	103.1	93.8	196.9
1976	10.2	49.5	0.4	1.1	51.0	61.2	67.8	129.0	71.9	200.8
1977	7.1	67.4	0.3	3.3	71.0	78.1	66.9	145.0	86.2	231.1
1978	11.7	67.3	0.2	3.0	70.5	82.2	39.4	121.6	101.2	222.8
1979	7.5	55.0	0.2	0.8	56.0	63.5	65.5	129.0	78.9	207.9
1980	15.4	55.6	0.7	2.0	58.3	73.7	58.8	132.5	94.0	226.5
1981	10.1	45.2	0.5	2.7	48.4	58.5	45.8	104.3	98.0	202.2
1982	4.1	41.3	0.1	2.4	43.8	47.9	61.5	109.4	112.1	221.6
1983	3.3	74.1	0.1	4.2	78.4	81.7	29.7	111.4	104.1	215.5
1984	5.9	64.1	0.1	2.6	66.8	72.7	30.5	103.2	104.4	207.6
1985	4.5	65.8	0.1	4.9	70.8	75.3	49.0	124.3	117.7	242.0
1986	1.9	96.6	0.1	10.7	107.4	109.3	40.9	150.2	106.8	257.0
1987	0.8	91.6	0.4	10.1	102.1	102.9	45.9	148.7	99.9	248.5
1988	1.1	58.7	0.4	5.0	64.1	65.2	55.2	120.4	111.1	231.5
1989	1.5	62.8	0.6	2.6	66.0	67.5	58.4	125.9	114.2	240.1
1990	4.7	78.2	0.4	10.9	89.5	94.2	68.4	162.6	113.1	275.7
1991	3.7	74.8	0.4	20.0	95.2	98.9	45.2	144.1	117.3	261.5
1992	5.5	62.3	0.6	7.2	70.1	75.6	77.5	153.1	120.4	273.5
1993**	8.1	54.8	*	*	*	*	*	129.3	167.2	296.5
1994**	29.4	52.9	*	*	*	*	*	141.2	177.7	318.8
1995**	36.9	40.0	*	*	*	*	*	127.4	198.7	326.1
1996**	52.1	*	*	*	*	*	*	*	*	*

TABLE 1. (continued)

1 Source: Anonymous, 1998: Table 3

2 Sources: published and unpublished data from the National Research Institute of Far Seas Fisheries, Shimizu, Japan, Institute of Oceanography, National Taiwan University, Taipei, Taiwan, ROC, and National Fisheries Research and Development Agency, Republic of Korea. The data were converted from numbers of fish to weight in metric tons with the average weight data in Table 2

3 Total Pacific Ocean minus eastern Pacific Ocean

4 Sources: 1958-1969 - Yearbooks of fisheries statistics of the Food and Agriculture Organization (FAO) of the United Nations; 1970-1995 - FAO data base

* not available

** preliminary

TABLE 2. Catches of bigeye tuna by longline gear in the eastern Pacific Ocean, and average weights of the fish.

Year	Catch in numbers of fish			Catch in metric tons			Average weight in kilograms[7]
	Japan[1]	Other[2]	Total[3]	Japan[4]	Other[5]	Total[6]	
Año	Captura en número de pescados			Captura en toneladas métricas			Peso promedio en kilogramos[7]
	Japón[1]	Otros[2]	Total[3]	Japón[4]	Otros[5]	Total[6]	
1971	526,836	0	526,836	29,176	0	29,176	55.38
1972	650,240	0	650,240	34,703	0	34,703	53.37
1973	886,464	0	886,464	50,954	0	50,954	57.48
1974	678,216	0	678,216	35,321	0	35,321	52.08
1975	792,340	11,796	804,136	41,194	613	41,807	51.99
1976	974,674	30,877	1,005,551	49,523	1,569	51,092	50.81
1977	1,296,738	70,700	1,367,438	67,404	3,675	71,079	51.98
1978	1,261,057	61,513	1,322,570	67,277	3,282	70,559	53.35
1979	1,250,050	23,605	1,273,655	54,965	1,038	56,003	43.97
1980	1,122,300	53,365	1,175,665	55,610	2,644	58,254	49.55
1981	981,725	69,269	1,050,994	45,169	3,187	48,356	46.01
1982	1,061,288	65,677	1,126,965	41,337	2,558	43,895	38.95
1983	1,193,849	69,637	1,263,486	74,114	4,323	78,437	62.08
1984	1,027,340	43,218	1,070,558	64,106	2,697	66,803	62.40
1985	1,378,671	103,230	1,481,901	65,804	4,927	70,731	47.73
1986	1,865,733	208,694	2,074,427	96,589	10,804	107,393	51.77
1987	1,619,020	184,649	1,803,679	91,604	10,448	102,052	56.58
1988	1,187,317	110,392	1,297,709	58,725	5,460	64,185	49.46
1989	1,321,219	67,843	1,389,062	62,824	3,226	66,050	47.55
1990	1,604,247	231,141	1,835,388	78,223	11,270	89,493	48.76
1991	1,496,669	407,990	1,904,659	74,833	20,400	95,233	50.00
1992	1,304,131	164,166	1,468,297	62,259	7,837	70,096	47.74
1993*	1,062,018	150,000	1,212,018	54,768	7,736	62,504	51.57
1994*	1,069,057	150,000	1,219,057	52,940	7,428	60,368	49.52
1995*	863,642	150,000	1,013,642	40,013	6,950	46,963	46.33
1996*	800,000	125,000	925,000	40,000	6,250	46,250	50.00

1 from data supplied by the NRIFSF of Japan
2 from data supplied by the TRC of the ROC and the NFRDA of the ROK
3 Column 2 + Column 3
4 (Column 2 x Column 8)/1,000
5 (Column 3 x Column 8)/1,000
6 Column 5 + Column 6
7 calculated from NRIFSF data bases
* preliminary

TABLE 3. Catches of bigeye tuna by surface gear in the eastern Pacific Ocean, and average weights of the fish. The latter were obtained from length-frequency data and the weight-length equation given in the text.

Year	Catch in numbers of fish[1]	Catch in metric tons[2]	Average weight in kilograms[3]
Año	Captura en número de pescados[1]	Captura en toneladas métricas[2]	Peso promedio en kilogramos[3]
1971	157,372	2,566	16.31
1972	137,256	2,238	16.31
1973	121,297	1,979	16.32
1974	54,467	890	16.34
1975	178,907	3,723	20.81
1976	504,694	10,186	20.18
1977	749,690	7,055	9.41
1978	881,057	11,714	13.30
1979	406,799	7,532	18.52
1980	1,003,549	15,421	15.37
1981	596,989	10,091	16.90
1982	359,323	4,102	11.42
1983	191,718	3,260	17.00
1984	369,509	5,936	16.06
1985	169,523	4,532	26.73
1986	75,276	1,939	25.76
1987	55,559	776	13.97
1988	132,939	1,053	7.92
1989	123,368	1,470	11.92
1990	230,304	4,712	20.46
1991	188,326	3,740	19.86
1992	156,961	5,497	35.02
1993	409,098	8,069	19.72
1994	2,553,628	29,375	11.50
1995	2,953,936	36,941	12.51
1996	5,541,466	52,132	9.41

1 from IATTC data base

2 from Table 1

3 (Column 3 x 1,000)/Column 2

TABLE 4. Catches of bigeye tuna by all types of gear in the eastern Pacific Ocean, and average weights of the fish.

Year / Año	Catch in numbers of fish[1] / Captura en número de pescados[1]	Catch in metric tons[2] / Captura en toneladas métricas[2]	Average weight in kilograms[3] / Peso promedio en kilogramos[3]
1971	684,208	31,742	46.39
1972	787,496	36,941	46.91
1973	1,007,761	52,933	52.53
1974	732,683	36,211	49.42
1975	983,043	45,530	46.31
1976	1,510,245	61,278	40.58
1977	2,117,128	78,134	36.90
1978	2,203,627	82,273	37.34
1979	1,680,454	63,535	37.81
1980	2,179,214	73,675	33.81
1981	1,647,983	58,447	35.47
1982	1,486,288	47,997	32.29
1983	1,455,204	81,697	56.14
1984	1,440,067	72,739	50.51
1985	1,651,424	75,263	45.58
1986	2,149,703	109,332	50.86
1987	1,859,238	102,828	55.30
1988	1,430,648	65,238	45.60
1989	1,512,430	67,520	44.64
1990	2,065,692	94,205	45.61
1991	2,092,985	98,973	47.29
1992	1,625,258	75,593	46.51
1993*	1,621,116	70,573	43.54
1994*	3,772,685	89,743	23.79
1995*	3,967,578	83,904	21.15
1996*	6,466,466	98,382	15.21

1 (Table 2, Column 2) + (Table 3, Column 2)
2 (Table 2, Column 3) + (Table 3, Column 3)
3 (Column 3 x 1,000)/Column 2
* preliminary

TABLE 5a. Average population of bigeye tuna of ages 0-9, in thousands of fish, during July, for $M = 0.4$.

Year	X cohort										Y cohort									
Año	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1971	3,509	2,442	1,490	875	439	239	138	84	61	44	2,915	1,694	1,236	756	424	235	84	77	51	19
1972	3,735	2,332	1,612	863	481	244	135	77	52	40	3,255	1,941	1,110	761	448	246	136	48	50	34
1973	4,079	2,486	1,533	977	463	249	122	67	46	34	3,078	2,169	1,261	674	361	239	130	80	28	33
1974	4,299	2,723	1,643	898	579	243	126	65	40	29	3,287	2,054	1,424	783	393	179	134	80	51	18
1975	4,374	2,875	1,765	1,014	493	314	125	72	41	25	3,532	2,196	1,295	851	429	237	99	81	53	34
1976	5,503	2,909	1,835	955	508	267	173	66	42	26	3,222	2,355	1,395	734	450	234	133	57	50	35
1977	4,932	3,532	1,916	1,004	517	239	127	69	33	25	4,008	2,147	1,397	774	299	230	112	77	31	32
1978	5,237	3,225	2,230	1,062	469	252	107	63	31	17	3,423	2,580	1,374	763	318	125	117	59	43	20
1979	5,394	3,491	1,935	1,202	571	221	105	49	35	19	3,792	2,191	1,303	756	405	140	49	62	35	28
1980	4,063	3,569	2,268	1,172	556	308	104	40	26	21	3,726	2,497	1,327	656	355	221	37	18	37	22
1981	4,442	2,538	2,251	1,074	594	319	174	63	25	16	2,948	2,428	1,533	678	330	188	111	19	11	24
1982	6,843	2,933	1,662	1,110	591	338	187	101	38	16	4,647	1,963	1,413	841	365	186	95	63	11	6
1983	5,695	4,483	1,879	955	571	296	164	87	58	24	5,609	3,066	1,230	774	428	157	68	45	37	7
1984	4,778	3,758	2,972	1,190	534	262	115	73	46	36	4,673	3,719	2,019	744	346	154	48	15	19	24
1985	4,401	3,202	2,477	1,793	629	258	120	37	38	29	3,430	3,118	2,292	1,150	382	158	56	19	3	12
1986	5,008	2,949	2,100	1,522	863	299	113	40	9	23	3,811	2,295	1,981	1,175	532	166	63	19	6	1
1987	5,734	3,357	1,941	1,172	871	314	99	34	10	2	4,468	2,549	1,465	1,077	567	200	46	18	3	2
1988	4,265	3,832	2,230	1,144	639	437	102	29	11	2	4,019	2,978	1,661	889	535	219	65	11	6	1
1989	4,168	2,857	2,500	1,364	642	328	169	32	6	2	3,472	2,652	1,933	1,018	486	224	77	24	3	2
1990	4,089	2,789	1,884	1,466	764	322	138	49	9	1	3,224	2,266	1,672	1,095	516	220	79	29	5	1
1991	4,661	2,645	1,832	1,039	743	328	105	34	10	1	3,738	2,115	1,459	886	525	192	56	15	5	1
1992	5,087	3,112	1,727	1,059	553	287	95	27	8	2	3,604	2,499	1,361	834	420	182	60	15	2	1
1993	5,173	3,381	2,068	1,032	551	253	97	27	7	1	3,942	2,394	1,640	783	401	169	55	16	3	1
1994	5,712	3,323	2,117	1,215	551	243	78	25	6	1	5,529	2,588	1,527	909	390	161	51	15	3	1
1995	6,747	2,713	1,733	998	607	257	91	20	6	1	3,618	3,329	1,473	743	422	167	57	15	3	1
1996	4,694	3,409	1,047	807	526	288	105	28	4	1	3,547	2,250	1,728	671	331	182	62	21	4	1

TABLE 5b. Average population of bigeye tuna of ages 0-9, in thousands of fish, during July, for $M = 0.6$.

Year	X cohort										Y cohort									
Año	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1971	11,548	6,749	3,383	1,564	1,035	498	181	99	56	3	8,763	5,171	2,634	1,113	683	340	118	73	41	16
1972	13,682	6,319	3,681	1,733	763	523	250	86	51	30	10,628	4,798	2,814	1,384	558	340	167	58	38	22
1973	14,220	7,492	3,440	1,925	845	351	248	116	41	27	8,912	5,822	2,596	1,480	624	250	155	81	28	20
1974	12,283	7,793	4,091	1,770	988	403	156	122	59	21	9,294	4,883	3,168	1,368	759	287	114	79	42	14
1975	14,019	6,736	4,219	2,165	873	474	187	74	65	31	9,229	5,094	2,603	1,639	664	394	139	54	42	23
1976	15,072	7,673	3,611	2,107	1,032	422	227	87	36	34	9,491	5,053	2,725	1,306	790	316	192	68	26	23
1977	14,712	8,130	4,178	1,776	1,044	474	184	82	38	16	9,546	5,197	2,605	1,347	542	369	133	94	31	13
1978	13,938	8,001	4,340	2,092	792	488	212	81	32	16	8,790	5,145	2,793	1,270	557	229	168	57	44	16
1979	13,926	7,632	4,186	2,113	1,021	351	212	96	38	15	9,482	4,737	2,437	1,382	602	241	94	78	28	23
1980	11,491	7,600	4,123	2,186	934	491	153	88	47	19	9,202	5,163	2,473	1,140	621	284	80	39	38	14
1981	12,530	6,137	4,043	1,868	1,021	466	239	78	47	25	7,761	4,988	2,705	1,168	528	295	121	39	20	21
1982	17,946	6,835	3,332	1,860	909	506	232	118	39	25	11,970	4,247	2,543	1,315	562	258	135	56	20	10
1983	17,055	9,755	3,671	1,684	866	406	219	91	56	20	13,790	6,524	2,252	1,245	596	227	89	57	26	11
1984	13,711	9,304	5,323	1,953	826	366	147	87	40	28	11,890	7,530	3,548	1,164	523	207	74	22	21	14
1985	12,764	7,524	5,067	2,738	915	364	151	45	38	19	9,403	6,512	3,948	1,757	534	220	72	28	5	10
1986	14,139	7,004	4,085	2,654	1,193	391	145	46	10	19	10,145	5,156	3,473	1,833	746	210	82	23	10	2
1987	15,164	7,759	3,810	2,031	1,322	415	123	42	10	2	11,246	5,562	2,763	1,673	804	268	57	23	4	4
1988	11,429	8,312	4,240	1,948	984	592	130	34	13	2	9,900	6,156	3,008	1,430	752	295	85	14	7	1
1989	11,853	6,271	4,502	2,208	956	447	212	39	6	2	9,218	5,398	3,320	1,562	684	289	99	29	3	2
1990	12,244	6,500	3,412	2,278	1,077	425	170	59	10	1	8,929	5,007	2,865	1,635	707	278	94	34	6	1
1991	12,870	6,633	3,532	1,671	1,032	425	132	40	12	1	9,687	4,858	2,692	1,357	709	248	70	17	6	1
1992	12,409	7,052	3,597	1,783	788	378	120	33	9	2	9,775	5,310	2,613	1,345	590	236	74	18	3	1
1993	11,748	6,782	3,853	1,859	836	326	121	33	8	1	9,470	5,343	2,882	1,314	596	222	69	19	4	1
1994	12,448	6,312	3,583	1,958	893	346	96	31	7	1	10,840	5,147	2,860	1,404	601	230	66	18	4	1
1995	11,485	5,823	3,016	1,590	887	389	125	24	7	1	10,618	5,606	2,585	1,314	604	245	81	19	4	1
1996	13,940	5,241	2,517	1,332	745	379	152	39	4	2	10,729	5,669	2,615	1,131	572	239	89	29	5	1

TABLE 5c. Average population of bigeye tuna of ages 0-9, in thousands of fish, during July, for $M = 0.8$.

Year	X cohort										Y cohort									
Año	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1971	37,731	21,349	8,244	3,196	1,899	861	290	141	63	25	31,858	13,833	7,655	1,912	1,548	603	219	105	58	19
1972	42,164	16,937	9,573	3,591	1,349	812	366	117	60	28	36,279	14,305	6,194	3,382	811	664	253	92	46	26
1973	40,472	18,931	7,584	4,213	1,517	544	329	145	48	26	33,467	16,292	6,393	2,724	1,397	313	269	104	38	20
1974	40,136	18,176	8,487	3,301	1,831	627	212	135	61	20	29,589	15,031	7,295	2,821	1,176	578	120	115	45	16
1975	72,096	18,029	8,112	3,740	1,394	761	251	85	59	26	27,076	13,289	6,682	3,183	1,189	508	244	47	51	20
1976	31,584	32,376	8,021	3,454	1,538	575	312	99	34	25	34,241	12,156	5,906	2,890	1,330	490	207	102	18	23
1977	49,164	14,063	14,516	3,416	1,450	606	214	102	35	12	34,002	15,375	5,306	2,516	1,140	538	183	82	40	7
1978	43,581	22,024	6,211	6,339	1,370	574	229	78	34	12	30,066	15,196	6,853	2,236	965	450	211	68	30	17
1979	46,163	19,568	9,711	2,544	2,734	542	208	84	30	14	27,265	13,436	6,476	2,942	920	376	174	82	27	12
1980	38,334	20,703	8,732	4,263	938	1,164	207	67	32	11	27,373	12,214	5,923	2,731	1,198	370	121	66	33	11
1981	39,379	17,069	9,188	3,574	1,750	380	495	87	29	14	22,859	12,243	5,370	2,493	1,139	496	134	50	28	15
1982	52,720	17,656	7,636	3,804	1,501	737	150	210	36	13	34,960	10,260	5,325	2,259	1,050	483	198	51	21	12
1983	57,152	23,602	7,860	3,300	1,570	588	276	34	86	15	38,956	15,667	4,539	2,260	899	396	168	73	19	10
1984	44,552	25,627	10,577	3,475	1,391	607	196	94	6	37	33,871	17,468	7,011	1,975	867	295	132	51	23	8
1985	41,327	20,017	11,479	4,583	1,415	545	227	56	33	1	28,424	15,206	7,679	2,971	792	330	95	49	17	10
1986	44,100	18,568	8,951	5,042	1,776	534	195	69	12	13	29,920	12,768	6,740	3,142	1,135	280	113	27	17	7
1987	45,076	19,815	8,312	3,833	2,144	579	158	54	17	2	31,821	13,439	5,676	2,811	1,226	382	74	31	5	6
1988	34,179	20,245	8,886	3,603	1,605	842	173	41	15	4	28,262	14,284	5,997	2,470	1,115	417	117	17	9	1
1989	41,108	15,356	9,045	3,884	1,516	635	275	49	7	3	28,204	12,669	6,364	2,612	1,017	388	132	36	4	3
1990	48,088	18,467	6,872	3,885	1,623	589	216	72	12	1	26,374	12,628	5,603	2,685	1,037	367	116	40	8	1
1991	40,304	21,530	8,264	2,905	1,548	580	172	49	14	1	26,191	11,812	5,623	2,320	1,035	339	89	21	6	1
1992	67,653	18,099	9,632	3,570	1,190	527	157	42	10	2	25,994	11,763	5,259	2,404	903	327	96	22	3	1
1993	43,521	30,371	8,116	4,222	1,476	437	159	41	10	1	24,224	11,659	5,255	2,252	952	314	93	24	5	1
1994	38,065	19,428	13,517	3,503	1,781	561	121	39	9	2	22,875	10,837	5,171	2,196	903	340	90	24	5	1
1995	45,985	16,189	8,322	5,736	1,404	709	193	29	9	1	27,410	9,965	4,650	2,091	837	329	111	25	5	1
1996	41,867	19,648	6,675	3,445	2,463	532	263	60	5	2	26,642	12,174	4,053	1,828	805	292	106	36	7	2

TABLE 6. Estimates of average annual F (longline and surface-fishing vessels combined) for bigeye tuna in the eastern Pacific Ocean.

$M = 0.4$

Age	X cohort				Y cohort			
	1971-79	1980-87	1988-93	1994-96	1971-79	1980-87	1988-93	1994-96
0	0.0069	0.0129	0.0123	0.1347	0.0107	0.0041	0.0080	0.0316
1	0.0256	0.0204	0.0136	0.1822	0.0344	0.0293	0.0167	0.0680
2	0.0722	0.0969	0.0612	0.1611	0.0956	0.1149	0.0771	0.1314
3	0.1914	0.1591	0.1830	0.1523	0.1937	0.2386	0.2298	0.2249
4	0.2384	0.2860	0.2567	0.1878	0.2920	0.3468	0.3211	0.2068
5	0.2796	0.3549	0.4374	0.2695	0.2764	0.4641	0.6661	0.3550
6	0.3160	0.4432	0.7821	0.5073	0.2326	0.6584	0.7957	0.4990
7	0.2374	0.5112	0.9510	0.7028	0.1412	0.6142	1.0825	0.6527
8	0.1309	0.3911	1.2708	0.8517	0.0682	0.4967	1.2205	0.7214
9	0.0621	0.2685	1.8411	0.9223	0.0205	0.1493	1.1098	0.6759

$M = 0.6$

Age	X cohort				Y cohort			
	1971-79	1980-87	1988-93	1994-96	1971-79	1980-87	1988-93	1994-96
0	0.0024	0.0048	0.0050	0.0649	0.0041	0.0016	0.0030	0.0134
1	0.0103	0.0088	0.0061	0.0856	0.0155	0.0138	0.0075	0.0375
2	0.0330	0.0505	0.0317	0.0922	0.0479	0.0627	0.0425	0.0716
3	0.0974	0.0922	0.1089	0.0937	0.1072	0.1469	0.1442	0.1339
4	0.1290	0.1853	0.1745	0.1209	0.1720	0.2334	0.2266	0.1380
5	0.1604	0.2554	0.3282	0.1831	0.1795	0.3376	0.5095	0.2453
6	0.1925	0.3392	0.6206	0.3937	0.1695	0.4739	0.6349	0.3738
7	0.1750	0.4052	0.7864	0.5858	0.1327	0.4538	0.9050	0.5214
8	0.1217	0.3564	1.1042	0.7253	0.0739	0.3546	1.0272	0.5816
9	0.0838	0.2435	1.7719	0.8389	0.0308	0.0923	1.0084	0.6330

$M = 0.8$

Age	X cohort				Y cohort			
	1971-79	1980-87	1988-93	1994-96	1971-79	1980-87	1988-93	1994-96
0	0.0008	0.0016	0.0014	0.0209	0.0012	0.0005	0.0010	0.0058
1	0.0046	0.0032	0.0019	0.0294	0.0053	0.0056	0.0032	0.0196
2	0.0149	0.0226	0.0143	0.0287	0.0197	0.0297	0.0212	0.0389
3	0.0537	0.0478	0.0575	0.0368	0.0532	0.0789	0.0830	0.0835
4	0.0741	0.1228	0.1094	0.0682	0.0927	0.1423	0.1487	0.0943
5	0.1100	0.1756	0.2340	0.1063	0.1103	0.2256	0.3681	0.1716
6	0.1511	0.2529	0.4738	0.2867	0.1143	0.3221	0.4865	0.2702
7	0.1472	0.4105	0.6356	0.4750	0.1123	0.3134	0.7357	0.3929
8	0.1201	0.4097	0.9504	0.6050	0.0736	0.2503	0.8687	0.4479
9	0.0910	0.4693	1.4911	0.7319	0.0412	0.0623	0.9011	0.5605

TABLE 7. Average sizes of bigeye tuna at various ages. The ages are expressed as months after recruitment, rather than months after hatching.

Month		Average length (cm)	Average weight (kg)	Age in months
X cohort	Y cohort			
Mes		Talla promedio (cm)	Peso promedio (kg)	Edad en meses
Cohorte X	Cohorte Y			
July	January	32.7	0.91	0.5
October	April	42.4	1.94	3.5
January	July	48.4	2.83	6.5
April	October	54.7	4.05	9.5
July	January	60.3	5.38	12.5
October	April	66.1	7.01	15.5
January	July	73.1	9.38	18.5
April	October	80.4	12.37	21.5
July	January	88.2	16.21	24.5
October	April	96.0	20.66	27.5
January	July	103.6	25.85	30.5
April	October	110.4	31.08	33.5
July	January	117.1	36.83	36.5
October	April	123.0	42.42	39.5
January	July	128.5	48.28	42.5
April	October	133.5	53.87	45.5
July	January	138.1	59.50	48.5
October	April	141.9	64.31	51.5
January	July	145.6	69.30	54.5
April	October	148.7	73.66	57.5
July	January	151.8	78.28	60.5
October	April	154.9	82.86	63.5
January	July	158.0	87.84	66.5
April	October	160.9	92.60	69.5
July	January	163.8	97.61	72.5
October	April	166.5	102.27	75.5
January	July	168.9	106.51	78.5
April	October	171.2	110.87	81.5
July	January	173.5	115.15	84.5
October	April	175.7	119.64	87.5
January	July	178.0	124.04	90.5
April	October	180.3	128.85	93.5
July	January	182.3	133.04	96.5
October	April	184.4	137.54	99.5
January	July	186.3	141.69	102.5
April	October	188.3	146.04	105.5
July	January	192.5	155.81	108.5
October	April	195.0	161.76	111.5
January	July	196.7	165.88	114.5
April	October	198.1	169.24	117.5

TABLE 8. Yields per recruit by cohort, in kilograms, of bigeye tuna in the eastern Pacific Ocean.

Cohort	X cohort									Y cohort								
	Catch			M=0.4		M = 0.6		M = 0.8		Catch			M = 0.4		M = 0.6		M = 0.8	
	Number of fish	Tons	Average weight	No. of recruits	YPR	No. of recruits	YPR	No. of recruits	YPR	Number of fish	Tons	Average weight	No. of recruits	YPR	No. of recruits	YPR	No. of recruits	YPR
Cohorte	Cohorte X									Cohorte Y								
	Captura			M = 0.4		M = 0.6		M = 0.8		Captura			M = 0.4		M = 0.6		M = 0.8	
	No. de peces	Tonela-das	Peso promedio	No. de reclutas	RPR	No. de reclutas	RPR	No. de reclutas	RPR	No. de peces	Tonela-das	Peso promedio	No. of reclutas	RPR	No. of reclutas	RPR	No. of reclutas	RPR
1971	5,344	24,644	46.1	3,568	6.91	11,839	2.08	39,002	0.63	4,060	22,613	55.7	3,622	6.24	12,129	1.86	49,130	0.46
1972	5,922	29,728	50.2	3,798	7.83	14,027	2.12	43,585	0.68	4,752	26,812	56.4	4,043	6.63	14,710	1.82	55,948	0.48
1973	7,449	33,536	45.0	4,147	8.09	14,578	2.30	41,836	0.80	6,644	31,778	47.8	3,825	8.31	12,336	2.58	51,612	0.62
1974	8,351	31,828	38.1	4,371	7.28	12,593	2.53	41,488	0.77	7,103	35,693	50.2	4,082	8.74	12,863	2.77	45,630	0.78
1975	6,745	26,860	39.8	4,447	6.04	14,373	1.87	74,525	0.36	6,967	28,050	40.3	4,389	6.39	12,774	2.20	41,757	0.67
1976	11,951	37,903	31.7	5,595	6.77	15,452	2.45	32,648	1.16	6,198	29,925	48.3	4,001	7.48	13,135	2.28	52,803	0.57
1977	9,696	31,801	32.8	5,014	6.34	15,083	2.11	50,821	0.63	12,236	40,362	33.0	4,978	8.11	13,211	3.06	52,435	0.77
1978	11,444	44,564	38.9	5,325	8.37	14,289	3.12	45,050	0.99	9,220	34,735	37.7	4,268	8.14	12,184	2.85	46,387	0.75
1979	12,408	45,209	36.4	5,484	8.24	14,277	3.17	47,718	0.95	8,740	41,224	47.2	4,709	8.75	13,122	3.14	42,045	0.98
1980	8,644	33,655	38.9	4,131	8.15	11,781	2.86	39,626	0.85	9,703	39,415	40.6	4,632	8.51	12,740	3.09	42,219	0.93
1981	7,843	39,815	50.8	4,516	8.82	12,846	3.10	40,707	0.98	6,055	32,152	53.1	3,681	8.73	10,762	2.99	35,275	0.91
1982	13,398	63,854	47.7	6,957	9.18	18,399	3.47	54,497	1.17	9,578	52,233	54.5	5,782	9.03	16,578	3.15	53,925	0.97
1983	9,151	49,540	54.1	5,790	8.56	17,485	2.83	59,078	0.84	13,142	62,347	47.4	6,966	8.95	19,084	3.27	60,075	1.04
1984	8,467	42,104	49.7	4,858	8.67	14,057	3.00	46,053	0.91	9,859	51,557	52.3	5,803	8.89	16,454	3.13	52,232	0.99
1985	7,202	38,926	54.0	4,475	8.70	13,086	2.97	42,720	0.91	6,110	36,939	60.5	4,260	8.67	13,012	2.84	43,832	0.84
1986	8,194	45,323	55.3	5,092	8.90	14,496	3.13	45,586	0.99	6,952	42,028	60.5	4,733	8.88	14,039	2.99	46,140	0.91
1987	11,033	51,663	46.8	5,830	8.86	15,546	3.32	46,595	1.11	9,232	49,637	53.8	5,549	8.95	15,563	3.19	49,071	1.01
1988	8,046	37,097	46.1	4,336	8.56	11,717	3.17	35,331	1.05	9,366	42,742	45.6	4,991	8.56	13,700	3.12	43,584	0.98

TABLE 9. Catches of bigeye tuna (in numbers of fish), effort (in numbers of hooks), and CPUEs (in fish per 1,000 hooks) in the eastern Pacific Ocean.

Year	Catch		Effort		CPUE[5]
	Japanese longline[1]	Total, all gear[2]	Japanese longline[3]	Total, all gear[4]	
Año	Captura		Esfuerzo		CPUE[5]
	Palangres japonesas[1]	Todas las artes[2]	Palangres japonesas[3]	Todas las artes[4]	
1964	858,715	862,891	86,813,848	87,236,029	9.89
1965	541,211	548,378	71,686,968	72,636,283	7.55
1966	645,201	661,479	63,214,844	64,809,710	10.21
1967	648,021	749,910	66,612,272	77,085,788	9.73
1968	640,559	797,281	72,464,336	90,193,784	8.84
1969	962,080	997,358	92,196,280	95,576,976	10.44
1970	603,576	685,132	83,400,928	94,670,173	7.24
1971	526,836	684,208	66,761,264	86,703,624	7.89
1972	650,240	787,496	78,239,624	94,754,845	8.31
1973	886,464	1,007,761	107,227,256	121,899,419	8.27
1974	678,216	732,683	89,205,088	96,369,079	7.60
1975	792,340	983,043	86,133,904	106,864,891	9.20
1976	974,674	1,510,245	117,300,712	181,755,968	8.31
1977	1,296,738	2,117,128	132,874,944	216,939,161	9.76
1978	1,261,057	2,203,627	140,006,144	244,652,948	9.01
1979	1,250,050	1,680,454	137,768,784	185,203,868	9.07
1980	1,122,300	2,179,214	138,140,800	268,233,410	8.12
1981	981,725	1,647,983	131,275,104	220,366,336	7.48
1982	1,061,288	1,486,288	116,199,848	162,732,867	9.13
1983	1,193,849	1,455,204	127,176,160	155,017,312	9.39
1984	1,027,340	1,440,067	119,635,456	167,698,198	8.59
1985	1,378,671	1,651,324	106,757,808	127,870,778	12.91
1986	1,865,733	2,149,703	160,552,528	184,989,091	11.62
1987	1,619,020	1,859,238	188,392,544	216,344,807	8.59
1988	1,187,317	1,430,648	182,694,224	220,135,926	6.50
1989	1,321,219	1,512,430	170,373,088	195,030,029	7.75
1990	1,604,247	2,065,692	178,419,456	229,739,955	8.99
1991	1,496,669	2,092,985	200,364,704	280,195,757	7.47
1992	1,304,131	1,625,258	191,283,709	238,385,094	6.82
1993*	1,062,018	1,621,116	159,955,430	244,163,762	6.64
1994*	1,069,057	3,772,685	163,976,027	578,668,755	6.52
1995*	863,642	3,967,578	125,145,630	574,919,998	6.90
1996*	800,000	6,466,466	125,000,000	1,010,385,388	6.40

1 from: Table 2, Column 2
2 from: Table 4, Column 2
3 from data supplied by the NRIFSF of Japan
4 (Column 3 x Column 4)/(Column 2)
5 (Column 2 x 1,000)/(Column 4)
* preliminary

TABLE 10. Catches of bigeye tuna (in metric tons), effort (in numbers of hooks), and CPUEs (in tons per 1,000 hooks) in the eastern Pacific Ocean.

Year	Catch		Effort		CPUE[5]
	Japanese longline[1]	Total, all gear[2]	Japanese longline[3]	Total, all gear[4]	
Año	Captura		Esfuerzo		CPUE[5]
	Palangres japonesas[1]	Todas las artes[2]	Palangres japonesas[3]	Todas las artes[4]	
1964	45,359	45,427	86,813,848	86,944,387	0.522
1965	28,578	28,695	71,686,968	71,981,668	0.399
1966	34,110	34,375	63,214,844	63,706,726	0.540
1967	34,200	35,864	66,612,272	69,852,660	0.513
1968	33,838	36,398	72,464,336	77,945,816	0.467
1969	50,801	51,377	92,196,280	93,241,538	0.551
1070	31,843	33,175	83,400,928	86,888,466	0.382
1971	29,176	31,742	66,761,264	72,632,850	0.437
1972	34,703	36,941	78,239,624	83,285,305	0.444
1973	50,954	52,933	107,227,256	111,391,850	0.475
1974	35,321	36,211	89,205,088	91,452,831	0.396
1975	41,194	45,530	86,133,904	95,200,191	0.478
1976	49,523	61,278	117,300,712	145,143,732	0.422
1977	67,404	78,134	132,874,944	154,027,222	0.507
1978	67,277	82,273	140,006,144	171,213,423	0.481
1979	54,965	63,535	137,768,784	159,249,335	0.399
1980	55,610	73,675	138,140,800	183,016,066	0.403
1981	45,169	58,447	131,275,104	169,865,085	0.344
1982	41,337	47,997	116,199,848	134,921,356	0.356
1983	74,114	81,697	127,176,160	140,188,234	0.583
1984	64,106	72,739	119,635,456	135,746,474	0.536
1985	65,804	75,263	106,757,808	122,103,716	0.616
1986	96,589	109,332	160,552,528	181,734,245	0.602
1987	91,604	102,828	188,392,544	211,475,793	0.486
1988	58,725	65,238	182,694,224	202,956,250	0.321
1989	62,824	67,520	170,373,088	183,108,221	0.369
1990	78,223	94,205	178,419,456	214,872,926	0.438
1991	74,833	98,973	200,364,704	264,999,343	0.373
1992	62,259	75,593	191,293,709	232,250,910	0.325
1993*	54,768	70,573	159,955,430	206,115,516	0.342
1994*	52,940	89,743	163,976,027	277,969,410	0.323
1995*	40,013	83,904	125,145,630	262,420,187	0.320
1996*	40,000	98,382	125,000,000	307,443,750	0.320

1 from: Table 1, Column 3
2 from: Table 1, Column 7
3 from: Table 9, Column 4
4 (Column 3 x Column 4)/Column 2
5 (Column 2 x 1,000)/Column 4
* preliminary

TABLE 11. Estimates of the parameters for two fits of data for bigeye tuna in the eastern Pacific Ocean to production models. C = catch, in metric tons; E = effort, in thousands of hooks; U = CPUE, in tons per 1,000 hooks; P = population size, in metric tons.

m	E_{opt}	C_{max}	U_{opt}	U_{1995}	P_{opt}	P_{1995}	$\Sigma(E_i - E_i)^2$
0.8	230,900	66,400	0.288	0.344	620,900	767,200	1.78×10^6
0.8	400,000	92,200	0.231	0.344	441,400	729,900	2.06×10^6

TABLE 12a. Predicted catches of bigeye tuna, in metric tons, during 1993-2006, assuming M = 0.4, with the three patterns of fishing effort described in the text.

Year	Pattern A			Pattern B			Pattern C		
	PS	Longline	Total	PS	Longline	Total	PS	Longline	Total
Año	Pattern A			Pattern B			Pattern C		
	Cerquero	Palangre	Total	Cerquero	Palangre	Total	Cerquero	Palangre	Total
1993	7,667	63,135	70,802	7,667	63,135	70,802	7,667	63,135	70,802
1994	27,190	63,742	90,932	27,190	63,742	90,932	27,190	63,742	90,932
1995	33,200	47,560	80,760	33,200	47,560	80,760	33,200	47,560	80,760
1996	47,680	48,331	96,011	47,680	48,331	96,011	47,680	48,331	96,011
1997	4,847	51,321	56,168	41,308	49,097	90,405	57,272	47,979	105,251
1998	5,023	51,549	56,572	34,585	43,539	78,124	43,141	40,117	83,258
1999	5,452	52,689	58,141	31,539	37,164	68,703	36,186	31,577	67,763
2000	5,798	55,308	61,106	30,608	31,185	61,793	33,719	23,848	57,567
2001	5,874	58,704	64,578	30,109	26,823	56,932	32,798	18,332	51,130
2002	5,924	62,504	68,428	30,032	24,103	54,135	32,589	14,863	47,452
2003	5,939	65,199	71,138	30,017	22,849	52,866	32,537	13,215	45,752
2004	5,940	66,728	72,668	30,017	22,367	52,384	32,536	12,551	45,087
2005	5,940	67,360	73,300	30,017	22,203	52,220	32,536	12,333	44,869
2006	5,940	67,559	73,499	30,017	22,203	52,220	32,536	12,308	44,844

TABLE 12b. Predicted catches of bigeye tuna, in metric tons, during 1993-2006, assuming $M = 0.6$, with the three patterns of fishing effort described in the text.

Year	Pattern A			Pattern B			Pattern C		
	PS	Longline	Total	PS	Longline	Total	PS	Longline	Total
Año	Pattern A			Pattern B			Pattern C		
	Cerquero	Palangre	Total	Cerquero	Palangre	Total	Cerquero	Palangre	Total
1993	7,634	65,507	73,141	7,634	65,507	73,141	7,634	65,507	73,141
1994	27,335	66,248	93,583	27,335	66,248	93,583	27,335	66,248	93,583
1995	33,214	49,589	82,803	33,214	49,589	82,803	33,214	49,589	82,803
1996	47,628	50,096	97,724	47,628	50,096	97,724	47,628	50,096	97,724
1997	5,760	52,874	58,634	51,524	51,394	102,918	73,042	50,619	123,661
1998	6,144	53,177	59,321	49,583	47,495	97,078	66,619	44,814	111,433
1999	6,615	55,718	62,333	49,122	44,139	93,261	63,264	39,233	102,497
2000	6,862	59,965	66,827	49,032	41,796	90,828	62,009	34,745	96,754
2001	6,958	64,340	71,298	49,068	40,365	89,433	61,689	31,641	93,330
2002	6,982	68,525	75,507	49,053	39,887	88,940	61,572	29,947	91,519
2003	6,992	70,844	77,836	49,059	39,718	88,777	61,553	29,164	90,717
2004	6,992	72,014	79,006	49,059	39,693	88,752	61,552	28,860	90,412
2005	6,992	72,522	79,514	49,059	39,733	88,792	61,552	28,791	90,343
2006	6,992	72,585	79,577	49,059	39,733	88,792	61,552	28,784	90,336

TABLE 12c. Predicted catches of bigeye tuna, in metric tons, during 1993-2006, assuming $M = 0.8$, with the three patterns of fishing effort described in the text.

Year	Pattern A			Pattern B			Pattern C		
	PS	Longline	Total	PS	Longline	Total	PS	Longline	Total
Año	Pattern A			Pattern B			Pattern C		
	Cerquero	Palangre	Total	Cerquero	Palangre	Total	Cerquero	Palangre	Total
1993	7,683	69073	76,756	7,683	69,073	76,756	7,683	69,073	76,756
1994	28,453	71,101	99,554	28,453	71,101	99,554	28,453	71,101	99,554
1995	35,816	55,431	91,247	35,816	55,431	91,247	35,816	55,431	91,247
1996	50,825	56,824	107,649	50,825	56,824	107,649	50,825	56,824	107,649
1997	5,839	60,042	65,881	55,813	58,995	114,808	81,712	58,443	140,155
1998	6,150	60,076	66,226	55,816	56,327	112,143	79,465	54,435	133,900
1999	6,190	59,470	65,660	54,535	52,672	107,207	76,373	49,368	125,741
2000	6,303	60,716	67,019	54,677	50,817	105,494	75,979	46,159	122,138
2001	6,315	62,239	68,554	54,528	49,929	104,457	75,586	44,287	119,873
2002	6,322	63,076	69,398	54,512	49,145	103,657	75,516	42,874	118,390
2003	6,323	63,680	70,003	54,507	48,948	103,455	75,496	42,367	117,863
2004	6,323	63,980	70,303	54,507	48,892	103,399	75,496	42,182	117,678
2005	6,323	64,026	70,349	54,507	48,828	103,335	75,496	42,075	117,571
2006	6,323	64,046	70,369	54,507	48,828	103,335	75,496	42,070	117566

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