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WORLD MEETING ON STOCK ASSESSMENT OF BLUEFIN TUNAS: STRENGTHS AND WEAKNESSES

edited by

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WORLD MEETING ON STOCK ASSESSMENT OF BLUEFIN TUNAS: STRENGTHS AND WEAKNESSES

OPENING OF THE MEETING

The Inter-American Tropical Tuna Commission (IATTC) hosted a meeting, sponsored jointly by the IATTC and the Australian Fisheries Service, to discuss and report on the strengths and weaknesses of stock assessment techniques used on bluefin tuna stocks in the Pacific, Indian, and Atlantic Oceans and the Mediterranean Sea. The meeting was held in La Jolla, California, on Mat 25-31, 1990. A list of participants is given in Appendix 1.

Dr. Richard Deriso, Chief Scientist, IATTC Tuna-Billfish Program, assumed the chair and introduced the proposed agenda. The agenda, attached as Appendix 2, was adopted.

The meeting was divided into sessions, with the following chairmen and rapporteurs appointed:

Session	**Chairmen**	**Rapporteur**
Overview of Stocks	William Bayliff (northern Pacific), Douglas Clay (northern Atlantic and Mediterranean), Jacek Majkowski (southern), Richard Deriso	Talbot Murray
Basic Data	Peter Miyake	Robert Kearney
Parameter Estimates	Douglas Clay	Pedro de Barros
Stock Assessments	Geoffrey Kirkwood	Stephen Turner
General Recommendations	Richard Deriso	William Bayliff

A set of Review Documents on each stock and Background Papers listed in Appendix 3 was tabled for consideration.

SESSION 1. OVERVIEW OF STOCKS

Northern bluefin, Pacific Ocean

William Bayliff introduced Review Document 1, highlighting patterns of movement in relation to major fisheries. Spawning occurs between Japan and the Philippines and in the Sea of Japan, with eggs, larvae, and juveniles transported northward from the former area toward Japan by the Kuroshio Current. Fish from 15 to more than 200 cm in length are exploited in the western Pacific by a variety of gears. The greatest numbers of fish are taken by trolling and the greatest weights by purse seining. In the eastern Pacific they are caught almost exclusively by purse seines. Most of these fish are about 65 to 100 cm in length, although a few more than 200 cm long are caught.

The commercial catch data for the eastern Pacific are reasonably complete and accurate. The catches for the sport fishery, which were small prior to 1989, are not included in the analyses which have been performed. No sport fishery data are available after 1988. The catch data for the western and central Pacific are less complete and accurate than those for the eastern Pacific, although Yoshio Ishizuka of the National Research Institute of Far Seas Fisheries (NRIFSF) has recently completed a prorating scheme to estimate the amounts of bluefin in the *meji* catches. The catch estimates by Japanese fisheries in Figure 6 and Table 3 of Review Document 1 include fish caught in the central Pacific, as well as the western Pacific. [All page numbers and numbers of figures and tables in this report correspond to the page, figure, and table numbers of Review Papers 1, 2, and 3 in this volume, rather than the page, figure, and table numbers of the original Review Documents.] The drift gillnet fishery of the central Pacific is a matter of concern, as the estimates of the catches by Japanese vessels may be incomplete, and there are no data on the catches by vessels of other nations.

Tagging studies carried out from 1980 to 1988 indicate that variable proportions of age-1 and -2 northern bluefin migrate from Japan to the eastern Pacific. Catches in the eastern Pacific have been low for the past 10 years, except during 1985 and 1986, and four hypotheses relating to changes in abundance, effort, vulnerability, and availability were discussed. The most plausible hypothesis is a link between variation in oceanographic conditions in the western Pacific and the numbers of fish migrating to the eastern Pacific.

Yield-per-recruit analysis suggests that fisheries in both the western and eastern Pacific would benefit by increasing the age at entry to existing fisheries. Cohort analyses were conducted, but the results are speculative. Some of the uncertainties are believed to result from the assignment of fish to older age classes (3, 4, and >4), and to the estimates of mortality for all age classes.

Northern bluefin, Atlantic Ocean and Mediterranean Sea

Douglas Clay introduced Review Document 2 and Background Paper 8. The review of the status of the stock was based primarily on Background Paper 8.

Catches of bluefin tuna are variable in the Atlantic, depending upon the area and gear used. Provisional 1988 catches were 3,000 metric tons in the western Atlantic, 6,500 metric tons in the eastern Atlantic, and 14,500 metric tons in the Mediterranean Sea. These estimates include assumed unreported catches. In the western Atlantic there were no major commercial fisheries before 1960, and fisheries have been regulated by strict catch limits since 1981. Catches during the regulated period have ranged from 1,500 to 3,000 metric tons in the western Atlantic. In the eastern Atlantic, the period of highest catches (10,000 to 24,000 metric tons) was 1959 to 1967. Since then eastern Atlantic catches have declined and been relatively stable, usually ranging from 4,000 to 7,000 metric tons. Mediterranean catches were generally 5,000 to 8,000 metric tons during the late 1950s and early 1960s, increasing rapidly in the 1970s and 1980s. Catches since 1984 have been 15,000 to 18,000 metric tons.

In the eastern Atlantic the most important fisheries are the French and Spanish baitboat and Spanish trap fisheries. Mediterranean fisheries are very diverse, but purse-seining is the most common fishing method used by several countries. Longline, handline, and purse-seine fisheries are the most important in the western Atlantic.

Stock assessments assume two stocks based on separate spawning grounds. Limited mixing of about 3-4% is acknowledged but not incorporated into current assessments. The spawning ground for the western Atlantic stock is in the Gulf of Mexico, while spawning of the eastern Atlantic-Mediterranean stock takes place in the Mediterranean Sea. These stock assessments assume different growth rates, mortality, and maturation, with western Atlantic fish considered to mature at about 10+ years (>200 cm) and eastern Atlantic-Mediterranean fish at 5+ years (>130 cm). There is some uncertainty in these estimates of age at maturity. Assessments have been based on virtual population analyses (VPAs), using a number of abundance indices for each stock. Abundance indices used vary in quality and hence are weighted (see section on Stock Assessment). Partial recruitment is estimated using separable VPA (Pope and Shepherd, 1982). Fish of ages 13+ are considered fully recruited in the eastern Atlantic and Mediterranean. In the western Atlantic a dome-shaped partial recruitment relationship is used in the assessment (see section on Stock Assessment).

Southern bluefin

Jacek Majkowski and Albert Caton gave an overview of southern bluefin tuna based on Review Document 3 and Background Paper 7. Southern bluefin tuna are distributed in all oceans south of 30°S. There is believed to be a single stock which spawns in the eastern Indian Ocean south of Java from September to March. Juveniles occur off the south coast of Australia, but are also reported from longline catches off South Africa and New Zealand. Southern bluefin are on average slow-growing, maturing at about 140 cm (8+ years) and living to over 20 years.

Southern bluefin are fished as a target species by vessels of Australia, Japan, and New Zealand, with unknown amounts caught in fisheries of Indonesia, Korea, and Taiwan. Adults have been caught by Japanese longliners since 1952 and by the New Zealand handline-troll fishery since 1980. Australian commercial fishing on juveniles began in 1951-1952. Catches by Australia, Japan, and New Zealand have been limited by quotas agreed to by consensus since 1986. These quotas have not been realized in any year except 1989, and catches have continued to decline.

Data available for stock assessment include catch in weight and effort by time-area strata for all fisheries, a limited set of length-frequency data, length and weight data, data from tagging, and some independent survey data. Tag recoveries have been primarily within the Australian 200-mile zone, but also throughout the entire range of the Japanese fishery. Growth relationships have been based primarily on tagging studies, although hard parts can be used for fish younger than 6+ years.

Stock assessments are carried out annually, using VPAs, but in recent years increasing emphasis has been placed on direct fisheries indicators such as catch per unit of effort (CPUE) trends, changes in age composition, and changes in proportions of areas fished. Increased emphasis on direct fisheries indicators result from the uncertainties in the reliability of VPA estimates. Some of the problems with assessments in this species result from the sensitivity of projections to the choice of stock-recruit relationship and exclusion of catches by Indonesia, Korea, New Zealand, Taiwan, and others.

SESSION 2. BASIC DATA

The basic data sets, and in particular catch and effort data, were considered for the three major species or areas in turn. Priority was given to identifying major sources of data, the limitations of each data set, and identification of the problems which need to be overcome to improve data coverage and quality.

Catch and effort

Northern bluefin, Pacific Ocean

Eastern Pacific

Logbook systems are in place for all major tuna fisheries in the northeastern Pacific. Basic catch and effort data for the purse-seine fishery, which is responsible for virtually all bluefin catches, are therefore available. There are, however, problems with identifying effort directed primarily at bluefin and with standardizing effort, which may have become more efficient since the introduction of spotter planes. Therefore the available data, as summarized in Tables 1 and 2 of Review Document 1, is catch from nominal fishing effort in selected areas.

Data on catches by recreational fisherman has been collected by the California Department of Fish and Game (CDFG) up to at least 1988, and will presumably continue in the future. The recreational take is a very small fraction of that from commercial fisheries.

Western Pacific

Fishing for bluefin tuna in the northwestern Pacific is dominated by Japanese activities utilizing a large variety of gears, *viz.* longline, purse-seine, pole and line, troll, gillnet, and trap.

The logbook system presently in place for longliners and purse seiners results in good statistics for these two fisheries. However improvements are needed to generate reliable data from the gillnet fishery. Present data on bluefin catches by gillnetters come from unloading surveys, rather than catch declarations by vessel. Nonetheless it is believed that catches by this gear have declined from the levels of the late 1970s of approximately 1,900 metric tons per annum. Effort has remained relatively constant in recent years, although the area fished has varied. While the actual catches of bluefin by some gillnetters operating in the central Pacific requires validation, there does not appear to be a problem of discards from this fishery, but rather a problem of differentiation by species of the retained total catch.

Total western Pacific bluefin catches reported in Review Document 1 (Table 3) include estimated central Pacific catches.

The Japanese pole-and-line catch of bluefin has remained relatively constant at about 1,000 metric tons per year (Review Document 1, Table 3).

It was noted that Japanese catches of small bluefin declared as *meji*, probably represented 90% by number of the western Pacific catch. These fish are almost exclusively 0 and 1 age groups. Catches are taken by a very large number of small trolling vessels, plus traps of greatly varying sizes. Furthermore, most of these small bluefin are marketed through local outlets with no centralized or coordinated marketing system. Therefore it has not been possible to obtain reliable details on catches and/or landings.

The meeting acknowledged the importance of obtaining accurate data on the catches of these small bluefin, but recognized the problems with trying to improve statistics by traditional means (such as logbooks or market sampling). It was agreed that consideration should be given to initiating some form of subsampling program: telephone surveys of licensed fishermen was one possibility discussed.

In discussions of the reliability of effort data on north Pacific bluefin, it was noted that the logbook systems in use in the eastern and western Pacific gave coverage of the purse-seine, longline, and pole-and-line fisheries to the standard normally accepted for tuna fisheries. However, no estimate of effort at all is available for the catches of very small fish taken in the inshore waters of Japan.

It was noted that there is presently no formal agreement for the centralized compilation of eastern and western Pacific bluefin catches, although the NRIFSF and the IATTC cooperate informally on this issue.

Effort data for the major western Pacific fisheries were not provided because a meaningful index could not be found.

Northern bluefin, Atlantic Ocean and Mediterranean Sea

The history of the development of the data base of the International Commission for the Conservation of Atlantic Tunas (ICCAT) and its use is presented in Review Document 2, Section III. Nominal catches by gear type and by country for the western and eastern Atlantic and the Mediterranean are given in Table 7 of Background Paper 8. Coverage is incomplete and imprecise for the Mediterranean.

The lack of declarations of small age-0 and -1 fish was considered to be a serious problem, particularly for the Mediterranean coast. It was suggested this undeclared catch was of the order of 1 to 5 million fish per annum.

Attention was drawn to the high percentage of fish smaller than the size limit of 6.4 kg which were present in declared catches (Background Paper 8, Table 16), particularly when these figures do not include the undeclared catches of very small fish.

In considering the derivation of CPUE indices it was noted that standardized effort was used in most cases; however, for baitboat fisheries nominal effort was all that was available. Various methods of standardization have been used, with the generalized linear models (GLMs), as discussed in Review Document 2, pages 157-158, being currently most popular.

The use of larval densities, derived by the methods described in Review Document 2, pages 95-97, were discussed in the light of results presented on page 93 of that document. Many limitations of the technique were acknowledged, but in the absence of other reliable indices of abundance from the spawning area, efforts to improve its reliability are continuing.

Recent changes to the Canadian fishery for large fish were discussed. In 1975 the fishery largely shifted to the Gulf of St. Lawrence, but the long-term downward trend in CPUE has continued since that time. In 1980-1981 commercial fisherman began to use the "tended line," which elevated catch rates by individual fisherman by 300%. The decline in standardized CPUE continued through 1988 (Background Paper 8, Figure 42). The present catch rate in the Gulf of St. Lawrence is approximately 0.06 fish per day. There has recently been a further change in the distribution of the Canadian fishery with an effective split between two mid-shore areas, the Virgin Rocks area of the Grand Bank and the southern side of Brown's Bank near the northeast peak of George's Bank.

Southern bluefin

Surface fishery off Australia

The surface fishery off Australia did not become commercial until the early 1950s, from which time it expanded from a troll fishery to a baitboat fishery and finally to a combination pole-and-line and purse-seine fishery by the mid-1970s. In the early days of the fishery catches were measured from cannery throughput, where almost 100% of catches were processed. By 1981 a logbook system was established, and catch figures for all areas of the fishery have been reliably reported (Background Paper 7, Table 1). Recreational catches of southern bluefin are not included in these catch figures, but these are known to be extremely small (less than 20 metric tons per annum).

The changes in the distribution of the surface fishery, and in particular the contraction in area in recent years, are described in Background Paper 7, Figures 6 and 7.

Even though there has been excellent coverage of catches taken in the Australian fisheries, it has been extremely difficult to derive a consistent measure of effort for surface fisheries for southern bluefin. The Australian fishery prior to 1950 was a very small troll fishery; pole-and-line fishing expanded rapidly through the 1950s, with larger vessels progressively entering the fishery. In the 1960s aircraft spotting support began to be provided, and by the mid-1970s purse seiners became prominent. In the 1980s the fishery operated with aircraft spotting of schools, pole-and-line boats holding the schools with live bait while purse seiners circled them. It is therefore believed that CPUE from the surface vessels is meaningless as an index of abundance.

It was also noted that the tremendous changes which have occurred in the marketing of surface-caught southern bluefin have further complicated interpretation of CPUE. For example, prior to 1980 almost all of the

Australian catch went to canneries at a very low unit price, in the 1989-1990 season approximately 90% of the Australian catch went to the Japanese sashimi market, providing incentive for vessels to bypass schools of small fish.

Japanese longline fishery

The Japanese longline fishery for southern bluefin commenced in the early 1950s in the area now known to be the spawning ground for this species. The fishery subsequently expanded throughout all southern oceans, with the exception of the central and eastern Pacific. Accurate catch figures have been available from a logbook program in operation since the early days of the fishery. Coverage of logbook returns is 85 to 90% of the fleet. In recent years there has been a concerted effort to shorten the time lag in the return of logbooks brought about by the length of fishing trips by southern bluefin longliners. Captains now return their logbooks from all port calls, rather than just upon their return to Japan. This should reduce the lag time from 1 1/2 years to approximately 3 months.

Changes in the area of distribution and magnitude of catch are shown in Review Document 3, Figures 14 and 16, respectively.

New Zealand fisheries

The domestic hand-line and troll fishery for southern bluefin has never been large, the highest catch of 305 metric tons being taken in 1982. In 1989 initiation of a joint venture with Japanese longline fishing interests increased total New Zealand catches. The domestic and joint-venture catches have been well documented by a logbook program, and catch summaries are given in Background Paper 10, Table 3.

Fisheries of other nations

Reported catches by longliners from Indonesia, Korea, and Taiwan are given in Background Paper 7, Table 2. It was noted that these declared catches very likely under-represent total catches by countries other than Australia, Japan, and New Zealand, particularly if suspected catches of southern bluefin in recently developed gillnet fisheries are a reality.

In summarizing the status of catch data on all species of bluefin three major areas of concern were noted:

1. There is a serious problem with reporting of small fish, particularly in the Mediterranean and northwestern Pacific.
2. Non- or under-reporting by some fleets, in particular gillnet fleets in the southern Pacific and Indian Oceans, could well be giving rise to significant underestimates of total catches.
3. There is a problem with illegal retention, discarding, and "high-grading" (continuing to fish after reaching the legal limit and, if a fish larger than one or more of those obtained legally is caught, discarding the smallest of these) of bluefin in the western Atlantic.

Standardization of effort

Southern bluefin

A method similar to that of Honma (1974), which is based on catch and effort statistics by statistical area and quarter, has been used to date to provide an overall index for the longline fishery. In 1990 alternative measures, including GLMs, are being investigated, but problems remain with accounting for targeting of alternative tuna species and interactions with fisheries for other species.

As already discussed, there are various problems with using surface CPUE data. Present investigations are concentrating on time series of individual vessel-skipper data.

Sampling of catches

Northern bluefin, Pacific Ocean

Eastern Pacific

From 1952 to 1973 the California Department of Fish and Game (CDFG) collected size composition data on bluefin, with a few years of missing or incomplete data. From 1974 onward the IATTC has been collecting length-frequency information, and is converting all CDFG and IATTC data to a common format.

Very few data have been collected on sex of eastern Pacific bluefin; however, it has been noted that all of the very large fish caught off Los Angeles in 1988 were males in non-spawning condition.

Western Pacific

Data are available from the various Japanese offshore fisheries by gear type, longline, gillnet, purse seine, and pole and line. Unfortunately the sampling system has low priority and is not well coordinated. Longline data come from two primary sources.

1. Sampling at unloading ports. There is no set sampling design, and port samplers operate under standing instructions to measure (length) as many fish as possible. It is estimated that 10 to 20% of unloadings at key ports are measured, and occasionally fish are also weighed.
2. On-board training and research vessels all fish captured are measured, weighed, and sexed, but unfortunately the sample size is small.

Drift gillnet samples are measured only at unloading ports; the sample size measured is always small. Samples from commercial purse seiners are measured on an *ad hoc* basis at Shiogama, the principal port of unloading for such vessels. There is no on-board sampling from pole-and-line vessels and only opportunistic sampling of unloadings. Even then there are serious problems with determining where and when fish were caught.

For all vessel types data quality is better from vessels which fished "locally," as then information on area and time of capture is more reliable.

Research vessel data are available to Japanese scientists, but such data are not routinely published. Even though they represent a very small percentage of total catches, they are extremely valuable.

Northern bluefin, Atlantic Ocean

Size sampling levels for all Atlantic bluefin fisheries are summarized in Review Document 2, Table III.1.3.

There has been very little consistent sampling for sex composition of bluefin catches in the Atlantic. Samples were taken by Japanese research vessels in the 1950s and 1960s and some small numbers of samples have been taken by official observers on vessels of various nationalities.

Sex sampling is further discussed in Review Document 2, Sections II.4 and II.5.

In summary, it was noted that very little information is available on composition of catches by sex throughout the Atlantic, and there are serious inadequacies in size composition sampling in the Mediterranean.

Southern bluefin

In the very early days of the Australian surface fisheries, when almost 100% of the catch went to canneries, every fish arriving at the cannery was measured. This was subsequently modified to 200 to 300 fish each day at each cannery.

Since 1984 200 fish from every unloading in South Australia are measured. Most fish are transshipped at sea, and present licensing agreements require that in such cases every fish be measured. Overall, more than 50% of South Australian catches are measured.

In Western Australia a different sampling regime is in operation, and approximately 10% of the catch is measured.

Joint-venture (Australia-Japan) longliners and Japanese longliners licensed to fish in the Australian Exclusive Economic Zone (EEZ) are required to measure every southern bluefin caught. In addition, observers on longliners operating in the Australian EEZ are a source of additional length, weight, and sex data, and some hard parts.

Japanese longliners operating in other areas have a sampling program similar to that in operation for other Japanese longline fisheries, in that size composition data are compiled by area and quarter from individual weights and lengths taken on board vessels and from other sources of samples.

In the early years of the fishery (up to the mid-1960s) fish were measured at unloading at Yaizu and Tokyo and, because of the short trip lengths, the locations and times of the catches could be accurately determined. From 1970 about 10 fishing vessels also recorded length and weight of all fish as they were caught, and as most vessels tended to move extensively over the total fishing area this gave good coverage even though the sample size was small. From 1980 onward, individual fish weight and date and location of capture data were also collected from 10% of southern bluefin longliners from the fishing masters' private logbooks. In 1988, the Far Seas Fisheries Research Laboratory (now the NRIFSF) distributed new data forms (Review Paper 3, Figure 25) to all southern bluefin longliners. An additional voluntary program of obtaining accurate length data is therefore in place, with the coverage being about 15% in 1988.

In New Zealand length, weight, and sex are separately recorded for all fish taken in the domestic fishery. Weights are recorded for all fish taken by the Japanese longliners operating in the New Zealand EEZ. These programs are summarized in Background Document 10.

Tagging data

Northern bluefin, Pacific Ocean

Eastern Pacific

Tagging, using dart tags, has been carried out irregularly in the north-eastern Pacific since 1953, as detailed in Review Document 1, Table 9. A total of 3,435 fish has been tagged, and 622 recorded as recovered. The IATTC maintains a comprehensive data base of all returns of bluefin tagged in the eastern Pacific.

Western Pacific

Review Document 1, Table 10, lists all relevant release and recovery data for fish tagged in the northwestern Pacific. All fish were measured at release, and many were double-tagged. IATTC and NRIFSF both have comprehensive data bases.

Northern bluefin, Atlantic Ocean

Eastern Atlantic

Full details are given in Review Document 2, Tables II.7.1 and II.8.1-II.8.10. ICCAT maintains a comprehensive data base.

Western Atlantic

In the western Atlantic tagging has been carried out irregularly from purse seine-caught small fish (approximately 7,000 fish were released in the 1970s), small numbers of trap-caught fish were released prior to 1970, and sport-caught large fish continue to be released. Tagging of small fish has decreased in recent years due to the cessation of purse seining of small fish. Comprehensive data bases are maintained by U.S. National Marine Fisheries Service (NMFS) in Miami and ICCAT.

Southern bluefin

Tagging of juvenile southern bluefin began in 1959, with approximately 62,000 being released to the present. All fish have been dart-tagged, and most have been double-tagged. Recoveries have been reported over the full range of distribution of all southern bluefin fisheries.

The Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia maintains a comprehensive data base.

SESSION 3. PARAMETER ESTIMATES

The discussion was opened by the Chairman, Douglas Clay, who suggested that it should be divided in four sections: growth and mortality, length-weight relationships and conversion from length to age, reproduction and maturity, and migration.

Growth and mortality

Northern bluefin, Pacific Ocean

Growth

The results of the most recent studies on growth of northern Pacific bluefin tuna were presented.

The estimates of growth parameters from tag-recapture data show a two-stage growth pattern, with a Gompertz-type curve in earlier ages (fish 15-56 cm), and von Bertalanffy (near linear) growth for older fish (>56 cm), over the size range of available data (<150 cm). The largest fish recorded was about 300 cm.

Analyses of length-frequency data indicate an annual rate of growth virtually identical to the linear phase of growth obtained from the tagging data. The length-frequency data, however, indicate that the growth is more rapid in summer than in winter.

Growth studies from hard parts are currently in progress, but the results to date are not encouraging.

The estimation of t_0 is based mostly on a rough guess of the ages of some of the fish at the time of tagging, considering the dates when spawning is believed to occur.

Natural mortality

There is no dependable estimate of natural mortality rates.

The group was concerned about the validity of the current value adopted for M. The value ($M = 0.4$) currently adopted for this parameter was selected on the basis of VPA runs. It is much higher than equivalent estimates for all other bluefin stocks. It was pointed out that this estimate might be appropriate for younger ages, but it would likely be much lower in older age classes. [Subsequent to the meeting, the analyses were redone, using estimates of 0.2 and 0.3 for M.]

Northern bluefin, Atlantic Ocean

Eastern Atlantic

Growth

Several studies were made on estimation of growth parameters of this stock. Some were based on unvalidated hard-part analysis, while others came from the analysis of size frequencies (Review Document 2, Table IV.2.3).

The growth parameters currently being used for stock assessment purposes are those derived by Farrugio (1981), based on vertebral ring counts. These estimates have been corroborated by later observations of modal progression analysis and other hard-part studies.

José Cort presented Background Paper 5 on aging eastern Atlantic bluefin from spines. From this study it can be deduced that:

1. The hyaline rings are winter rings which are formed between fall and winter (October-March).
2. The opaque areas of active growth start forming in spring, and conclude their formation in the fall (March-October).
3. For younger bluefin (ages 1 to 3), growth in length during summer is from 3 to 4 times that of winter and the growth in weight during summer is 4.5 to 6 times that in winter.
4. The winter hyaline rings can be single (thick or thin) or double.
5. The combination of data from the juvenile bluefin fishery of the Cantabrian Sea (Bay of Biscay) and data from the adult bluefin fishery of the Strait of Gibraltar lead to the estimation of a value of L_∞ = 318.85 cm, corresponding to W_∞ = 615.90 kg.

This paper, and comments on it, indicated that this technique opened promising prospects for aging bluefin tuna, but further investigations will have to be carried out before it can be used for routine work, as the precision of the estimates for older fish was not very clear, and the assumed annual marks have yet to be fully validated.

Evidence was presented for a strong seasonal pattern of growth for younger fish, with fast growth in summer, and virtually no growth during winter. This evidence came both from the hard-part investigations and from the evolution of growth, as measured by mean weight at age, in the French purse-seine fishery. This effect may also appear in older fish, but it was not conclusively demonstrated.

Natural mortality

A value of M = 0.18 is currently adopted by the Standing Committee on Research and Statistics (SCRS) of ICCAT for the eastern "stock."

Western Atlantic

Growth

For the western Atlantic, growth parameter estimates were derived from tagging data collected before the late 1970s. Later information from some studies on modal analysis and other tag-recapture data confirmed these early estimates. Hard-part data are currently being investigated as a possible source of additional information.

Some unvalidated hard-part studies (Caddy *et al.*, 1976) show different growth equations for males and females. It was considered that this possibility should be further investigated.

Natural mortality

A natural mortality rate of 0.1 has been adopted by the SCRS of ICCAT for the western "stock."

Southern bluefin

Growth

For southern bluefin, growth parameters are estimated using mostly tag-recapture data. Age-at-length, length-at-age, and individual growth models are fitted to these data.

Tagging data and length-frequency data, especially for young fish, are used to estimate t_0 for the growth equations currently being used. Some attempts at using hard parts for aging did not give good results, but a new technique, based on microchemical analysis of otolith structure, is being developed, and may lead to progress in this area.

There is evidence from tagging that growth rate of juveniles during the mid-1980s was about 50% higher than during the 1960s.

Seasonal growth models fitted to tag-recapture data also indicate a strong seasonal pattern in growth of younger fish, growing faster in summer than in winter.

Some research was carried out on possible biases on growth estimation due to the effect of the tagging operation. Results indicate that tagging will not affect growth in length, although it can slow down growth in weight for a few weeks after tagging.

No investigations were conducted on possible differences in sex-specific growth rates.

Natural mortality

Several models and different methods have been tried to estimate the coefficient of instantaneous natural mortality, M. Comparisons were made between recruitment estimates from tagging data and VPA results, using several trial *M*s. Intermediate values of *M* ($M = 0.2$) provided the most coherent set of results, and this value was therefore adopted.

General discussion

There is a need for validation of all hard-part aging techniques.

Apart from the western Atlantic, where no investigation has been conducted, all other bluefin stocks showed a seasonal pattern of growth for young fish. It was suggested that this might be a general feature of these species, and that it should be further investigated.

It was also considered that the spine-aging technique should be given more attention, and that studies should be conducted to determine the possibility of using this technique for routine aging of bluefin.

The group also considered that it would be useful to investigate the possibility of sex-specific growth patterns, as this might be a possible explanation for the variability of sex ratio at the larger size classes observed in all bluefin stocks.

Some other considerations were made, drawing the group's attention to the necessity of considering the use to be given to growth equations when deciding which estimation procedure to use (*e.g.* deciding between predictive and functional regressions).

The group discussed the problem of natural mortality estimates. There is more evidence for the value of *M* adopted for southern bluefin than for any of the other stocks.

Length-weight relationships and conversion of length to age

Northern bluefin, Pacific Ocean

Length-weight relationships

Length-weight relationship data for bluefin of a wide range of sizes caught in both the eastern and western Pacific, particularly the former, are available. These are listed in Review Document 1, Table 7.

Conversion of length to age

Conversion of catch at length to catch at age is done by "age-slicing," that is, deterministically separating length compositions into age classes. For the eastern Pacific the break points between age-1 and age-2 fish and between age-2 and older fish for each month were determined from length-frequency data. Those for older fish were determined by extrapolation of the growth relationship determined from the length-frequency data. For the western Pacific the von Bertalanffy curve of Yukinawa and Yabuta (1967) was the basis for assigning ages to the fish.

It was considered that the aging by modal separation for the younger age classes is accurate, but there are no estimates of reliability for aging done by using the von Bertalanffy growth curve.

Northern bluefin, Atlantic Ocean

Eastern Atlantic

Length-weight relationships

Separate length-weight relationships are used for the eastern Atlantic and Mediterranean sub-areas.

French and Spanish scientists have developed catch-at-length tables for their respective fisheries, using two length-weight relationships in each of these sub-areas, one for juveniles and another for older fish.

For raising and substitution purposes, ICCAT uses a single length-weight relationship for each of the sub-areas for the fisheries for which raising is not done by national scientists.

None of these length-weight relationships takes into account strong seasonal variations of condition factors. It was considered, therefore, that seasonal length-weight relationships should be used to try to reduce the errors involved in this process.

Conversion of length to age

Again, the "age-slicing" method of assigning ages to each length class is used. This process is based on the von Bertalanffy growth equation estimated by Farrugio (1981). Monthly break points are constant for every cohort and year.

There was some discussion that the spine-reading method presented by José Cort (Background Paper 5) may be useful for building length-age keys.

Western Atlantic

Length-weight relationships

In the western Atlantic, monthly length-weight and weight-length relationships are used. Other conversion factors are available, if required.

Conversion of length to age

To convert length frequencies to age frequencies the "age-slicing" method is used, based on a von Bertalanffy growth equation derived from mark-recapture data collected through the late 1970s (Parrack and Phares, 1979). Break points (divisions between age classes) are determined from month of the catch, assumed birth month, and a von Bertalanffy growth curve.

The effect of introducing variance in the mean length at age has been investigated, but results are still preliminary.

Southern bluefin

Length-weight relationships

Several length-weight relationships have been used, with separate length-weight relationships for younger (<130 cm) and older (>130 cm) fish. Relationships have been developed to convert from processed weight to length (Review Document 3, Table 3).

In the processed weight-length conversions, no account is taken of seasonal or area changes in the relationship.

Conversion of length to age

An "age-slicing" method has been used to assign ages to each length class, on the basis of regression of age on length derived predominantly from tagging data. The parameter estimates corresponding to these growth curves are shown in the Review Document 3, Table 1.

Neither seasonal changes in growth rates nor changes in growth rates in most recent years were considered in this aging process.

It was considered that it would be desirable to take account of seasonal and annual differences in growth in the conversion procedure.

Concern was expressed regarding the quality of the estimates of age composition currently used (in particular for fish older than age 12).

To the above-mentioned sources of imprecision in converting from length to age, a high degree of inaccuracy may be added by the process of estimating length compositions from processed weight, especially as no seasonal- or area-specific relationships are used.

Jacek Majkowski presented a report on MULTIFAN (Background Paper 3), an alternative method for converting length frequencies to age distributions.

This method provides estimates of growth parameters consistent with tag-based estimates, but several sources of uncertainty and potential biases were pointed out. The main comments were as follows:

1. Growth parameter estimates seem to depend mostly on the first two to four age classes, where modes are quite evident anyway.
2. The method assumes the same growth pattern for all cohorts.
3. The computer implementation, sold as MULTIFAN, is not flexible.

The general conclusion was that this method might represent a good line of research. It may be useful to extend the model (*e.g.* by incorporating tagging information, more data sets, or including a VPA structure).

General discussion

As far as length-weight relationships are concerned, there are quite different approaches taken in each of the stocks. It was considered that a significant improvement on the estimation process would be to develop area-and season-specific length-weight relationships to take into account known and possible changes of condition factors, which are sometimes quite high.

Also, attention might be given to the problem of seasonal growth, as this might affect age compositions estimated from length frequencies.

Reproduction and maturity

Northern bluefin, Pacific Ocean

There are very few studies on reproduction of northern Pacific bluefin tuna. These studies indicate that 50% maturity would include fish 5-6 years old, (60 kg or 150 cm). The group agreed that current estimates of 50% maturity at 5-6 years of age seem reasonable. There have been no extensive studies of fecundity, but some information indicates that, for older females, fecundity would be around 10^7 eggs. There is also some indication that these fish might have multiple spawning.

There is only one known major spawning area, between Japan and the Philippines. In this area spawning probably occurs from late April until late July, peaking in May and June. There are also records of spawning activity in other areas, such as the Sea of Japan (August), and the Pacific side of Japan, south of 40°N.

There are no records of mature fish in the eastern Pacific, although there are few maturity data records. No larvae or age-0 fish have been reported in the eastern Pacific.

Northern bluefin, Atlantic Ocean

Eastern Atlantic

One study on maturity carried out in 1967 points to a size of 50% maturity of about 100-110 cm (3 to 4 years old), with 100% maturity occurring at 130 cm (4 to 5 years of age).

There is an established relationship between size and fecundity which agrees with estimates of fecundity of western Atlantic bluefin, given the size ranges involved.

Spawning areas are located in the Mediterranean Sea, and the spawning season runs from June to July.

Sex ratios calculated for some range of sizes indicate a predominance of males over females in the larger size classes (>200 cm), with a possibly reversed situation in smaller size classes.

Western Atlantic

There is only one known spawning ground, in the Gulf of Mexico, and the spawning season seems to last from April to June, peaking in May, based on studies of gonadosomatic indices and the distribution of larvae.

There is little sign of sexual maturity in fish under 180 cm.

There is only one published study of fecundity. More studies on reproduction are needed.

Most information regarding sex ratios comes from the Canadian and the Gulf of Mexico fisheries. There are indications that fish over 260 cm are mostly males. No systematic study of sex ratio with age has been conducted.

Southern bluefin

Data for spawning and maturity of southern bluefin come from the Japanese fishery and from Japanese and Australian research cruises in the only known spawning area, located off northwestern Australia. There have been no maturation studies in recent years, even though size or age at maturity may have changed since the previous studies. There is still no indication if all, or only some, mature females spawn each year.

Approximate estimates of maturity indicate that 50% maturity would correspond to fish 130 to 140 cm in length. With the current length-age model, this would be equivalent to ages 7+ to 8+.

Fecundity for a 150-cm female was found to be in the order of 4 to 15 x 10^6 eggs. Multiple modes of age-0 fish and egg diameter studies suggest that there may be more than one pulse of spawning during the season. However, recent larval studies suggested peak spawning in January-February.

It was pointed out that information on reproduction is very scarce, and that more studies are needed to elucidate this aspect of southern bluefin biology. It was suggested that specimens for such a study could be available from the southern bluefin by-catch of the bigeye longline fishery made in the southern bluefin spawning grounds.

It was mentioned that immediately after spawning the quality of the fish decreases markedly, and that this corresponds with market category. Therefore, it was suggested that the distribution of market categories by area and time be used to study spawning season and area.

There is some variation of sex ratio with size, but data available do not make it possible to define any clear patterns.

Some semi-quantitative information indicates that adult males probably outnumber adult females, but this could be reversed in juveniles (Review Document 3, Section 6).

General discussion

Several hypotheses were put forward to explain the large size at maturity observed for the western Atlantic bluefin. Sampling errors might be responsible for this observed relatively large size. Another possibility was that there might be a spawning area other than the Gulf of Mexico. It was agreed that this question should be investigated.

The question that sampling fish in the spawning area was possibly a biased way of estimating the size of 50% maturity was also raised, and it was agreed that this problem should also be investigated for all the stocks in general.

Some discussions were held on the necessity of investigating variations of sex ratio with age.

Migration

Northern bluefin, Pacific Ocean

The main feature of the pattern of migration in the northern Pacific is a strong south-north movement along both coasts. There is also a marked west-east migration of the younger fish, and the eastern Pacific relies exclusively on young fish migrating from the western Pacific. The proportion of western Pacific fish which migrates to the eastern Pacific varies greatly from year to year.

This model of migration was developed from tagging data, and from an analysis of distribution and age composition of catch.

Northern bluefin, Atlantic Ocean

Information on movements of both eastern and western Atlantic bluefin tuna were presented. These hypothesized patterns were inferred from mark-recapture studies, but also from distribution of catch data and the study of natural tags.

There was some discussion about transatlantic migrations of bluefin. It was concluded that the only real evidence available is mark-recapture data. Catch data provide circumstantial evidence, and serious doubts were mentioned for the validity of using parasites, used in previous studies, to study migration patterns.

Garth Murphy presented a hypothesis for stock structure of the Atlantic bluefin stock (Background Paper 1). The essence of the hypothesis is that the Gulf of Mexico spawners supply a large, perhaps dominant contribution to the eastern Atlantic recruits, while the Mediterranean supplies all the Mediterranean recruits, and a relatively small number of recruits to the eastern Atlantic and western Atlantic fisheries.

The group considered that the evidence presented in this paper did not warrant rejection of the current null hypothesis of separate eastern and western stocks with minor mixing without further evidence, for example, from new tagging programs.

Another hypothesis for explaining migration was put forward by Douglas Clay, who proposed a learning mechanism among older fish to explain several observed trophic migrations and local fishery collapses. This hypothesis explained the pattern of varying fisheries off Canada, and was also a good fit to similar patterns observed in Australian and New Zealand southern bluefin fisheries.

Southern bluefin

Evidence, both from tag and recapture data (Shingu, 1978: Figure 35) and from the distribution of catches suggests that these fish make extensive migrations in the Southern Ocean. There is only one known spawning area, northwest of Australia, and adults have been caught in waters south of 30°S in almost all longitudes, and northward to the spawning grounds in the eastern Indian Ocean. Tag-recapture data show that juveniles in southern Australian waters migrate eastward, but some migrate in the opposite direction. Fish tagged in each of the three main Australian fisheries migrate to all of the important Japanese longline fishing grounds. Japanese catch and effort data seem to suggest seasonal migratory movements in larger fish. It was believed that these possible migratory movements need to be investigated further. This might be achieved using archival tags or tagging of older fish. Costs would have to be considered, but it was thought that this would be a very important question.

SESSION 4. STOCK ASSESSMENTS

Standardization of effort and catch-effort data

Different approaches for northern (Atlantic) and southern bluefin

Differences in VPA calibration procedures and in the use of assessment results have led to differences in the use and treatment of catch-effort information between scientists working on Atlantic and southern bluefin stocks. Atlantic bluefin VPAs have relied on indices of abundance for estimation of one or more fishing mortality rates (*F*) in the most recent year of the catch at age. As a result, emphasis has been on obtaining indices from a number of sources which cover the most recent years, but which may not necessarily cover all years in the catch at age. Southern bluefin analyses have focused on estimates of terminal *F*s for some ages in the most recent year and for a terminal age in all earlier years. The effort series from the Japanese longline fishery has been used in setting relative *F* levels in the VPAs.

Treatment of catch-effort data

Northern bluefin, Atlantic Ocean

In the Atlantic, GLM analyses have been used to derive several standardized indices of abundance from catch rates. In all cases catches are known to have been composed of only fish of a given age (size) range or they have been restricted to an age range prior to analysis. Review Document 2 describes the approaches to standardization which have been used historically, and briefly describes GLM analyses. The specific uses of standardization in the Atlantic bluefin analyses are more fully reviewed here.

In general, GLM analyses have included standardization for the effects of time within a year (month or season) and area where those effects have been found to have statistically significant influences on catch rates. In addition, some analyses have investigated the effects such as gear type, gear configuration, and water temperature, and indices have been standardized for these effects when they have been found to have significant impacts on catch rates. Examination of the importance of first-order interactions not involving years and extensive examination of residual plots have been performed.

The indices derived with these methodologies have included information from the Japanese longline fishery and from the U.S. rod-and-reel fishery for large (greater than 199 cm or 141 kg) bluefin. Analyses of the effects of gear configuration were performed on Japanese longline catch rates in the U.S. EEZ (Turner, 1987; Davis and Turner, 1988 and 1989). Brown and Turner (1989) considered the effects of small differences in gear type (handline and rod and reel) on catch rates in the U.S. rod-and-reel fishery for large fish.

Not all indices of abundance used in analyses of Atlantic stocks have been standardized using GLMs. In several cases catch-effort data have been restricted to times, areas, or fishery conditions which have been shown to be or are thought to be consistent. The index from the Canadian tended-line fishery has been restricted to a consistent time, area, and fishing method. The Bay of Biscay catch-effort data have been adjusted for changes in gear efficiencies, and careful examination has shown that catch rate patterns are consistent across months. The Spanish trap index has been restricted to one trap which has been fished in a consistent manner. The French purse-seine indices have been derived from a series of years when effort is thought to have been comparable as a result of the use of a single airplane for the bluefin fleet.

The French purse-seine data have been in units of catch per successful day's fishing. No attempts to standardize for search time have been made. The group believed that this index may be a measure of school size, rather than abundance. Despite this concern, this index shows good correlation with other indices of abundance.

Southern bluefin

Scientists working on southern bluefin tuna have relied heavily on Japanese longline catch and effort data in assessing the status of that resource. That the spatial distribution of the effort has shifted over time is reported in Review Document 3, as is the observation that catch rates have shown relatively consistent geographic differences. Standardization for areal differences in the effectiveness of the effort has not yet been attempted. The problem has been handled in some assessments by developing area-specific estimates of terminal *F*, using the information on relative effectiveness of effort in each area, the area-specific effort, and additional information.

As noted in Session 2, under Catch and effort, no reliable abundance index is available from Australian surface fisheries.

The need to develop standardized series of Japanese longline catch-effort data is recognized. GLM analyses are being considered for estimating standardized effort trends. In addition, scientific surveys to index juvenile abundance are being conducted or are planned.

As discussed in the Basic Data session, no meaningful effort data exist for northern Pacific bluefin.

Virtual population analyses of historical catches

VPAs have been performed on stocks from all three regions. The mechanics of the VPAs (manipulation of the catch at age as opposed to calibration) differ slightly among the approaches used in each region. Additionally the procedures for determining the best estimate of historical abundances (calibration) differ substantially among regions. These procedures are briefly compared here, because in some cases they are not fully described in the Review Documents. After those comparisons, information on discussions of the methods and assumptions is summarized.

The mechanics of the VPAs, as used here, refer to the use of backward and/or forward VPA calculations, the methods of estimating terminal *F*s on each year class, and assumptions about the condition of the population in the earliest years. In the Atlantic and Pacific only backward VPA is used, while for the southern bluefin both backward VPA is used on one part of the catch at age (ages 1-12) and forward VPA is used on older ages (Review Document 3). For the Atlantic northern bluefin and the southern bluefin analyses, some estimate of the selectivity pattern in the most recent year is used in deriving estimates of *F* in the most recent year. Selectivities in the most recent year are estimated for all ages for the northern bluefin in the Atlantic. For southern bluefin selectivities in the most recent year are estimated only for ages greater than or equal to the assumed age at maturity. The methods for estimating *F*s on the terminal age in earlier years in the assessment also differ between the Atlantic northern bluefin and southern bluefin analyses. For the Atlantic northern bluefin they are calculated using an assumed relationship between the *F* on that age and the *F*(s) on one or more earlier ages. For the southern bluefin they are derived in the VPA adjustment procedure from nominal Japanese longline catch and effort data. In some VPAs, structural relationships between area-specific catchability coefficients are used in attempt to account for shifts in concentrations of effort between areas over time. Differing assumptions are also made in the southern bluefin assessments as to whether or not the population was in equilibrium prior to exploitation (see Background Papers 14 and 15).

Methods for determining the best estimate of historical abundance differed widely among regions. For the northern Pacific, an assumption of relative stability in fishing mortality rates was used to select the most appropriate estimate. Because of doubts about the quality of basic catch-at-age data, the north Pacific researchers decided not to carry out more sophisticated analyses after this initial examination. In contrast, the Atlantic assessments have involved the simultaneous estimation of the *F* on fully-recruited ages in the most recent year and multiple catchability coefficients using least-squares procedures (Review Document 2). For the southern bluefin calibration is carried out, assuming a level of *F* in some earlier period of years for fully-recruited fish (Review Document 3).

The ages and years included in the assessments from the various regions differed. The North Pacific catch at age covered ages 0 to 4 and included a 5+ group. It included those year classes (1966-1982) which were fully represented in 1966-1986. The Atlantic analyses covered ages 1-19 and 20+ in 1970-1988. The southern bluefin analyses included ages 1-20 in 1952-1988 and involved back-calculations from age 12 for each year class.

Participants agreed that there was great uncertainty about the level of natural mortality rate and that it was prudent to conduct analyses at more than one level of *M* if time permits. It was also concluded that while technically it might be feasible to derive estimates of *M* solely from VPA, the reliability of such estimates would be very low, because of the high degree of correlation of *M* with other parameters in the VPA.

It was noted that it was more difficult to obtain reliable estimates of absolute abundance through time with VPA than to obtain estimates of abundance trends. The assessment methods used for the different regions can be contrasted with respect to these objectives. The north Pacific analysis was simply attempting to provide first approximations of possible abundance trends. The Atlantic analyses focus more on recent abundance levels and attempt to obtain information on abundance trends. The southern bluefin VPAs are oriented toward obtaining the best possible information on present and historical population sizes for use in developing stock recruitment models for projection of future population trajectories. That system incorporates analyses of the sensitivities of VPA and projection results to uncertainties in the natural mortality rates and growth used to develop the catch at age.

The effects of the system for developing the catch at age and bias or variability in the assumed growth equation were considered. It was recognized that, if there is variation in growth, the age-slicing method used in all regions does result in (1) reduced estimates of catch at age of strong year classes and increased estimates for weak year classes, and (2) excessively high estimates of the catch at age of the oldest age. Bias in the growth equation can cause much greater problems. The participants were not aware of a better method of assigning age from lengths.

The use of a plus group was discussed as a mechanism for reducing the biases of the aging algorithm. This could present problems, such as when it could not be assumed that the fish in the plus group were equally vulnerable to fishing. Generally it was believed that a plus group reduces bias in the catch at age. However, use of a plus group increases the reliance on auxiliary data for calibrating the VPA. It was reported that some analyses conducted on other species (including Deriso *et al.*, 1989), indicated that for one species the use of a plus group could be handled with some assumptions.

Projections of future stock sizes for bluefin in the western Atlantic and for southern bluefin have been conducted. The western Atlantic analyses have been restricted to only a few years after the most recent VPA estimates, because of the uncertainty about future conditions in the stock and the fisheries. The southern bluefin projections have been carried through 10-15 years after the most recent information in the catch at age to estimate how the stock will respond to the existing management regime. These southern bluefin projections involve the assumption of a stock-recruitment relationship. Stock-recruitment relationships have not been used in western Atlantic projections and have not been estimated in recent years.

Other studies

Yield-per-recruit analyses are presented for the northern Pacific bluefin, although it was recognized that the estimated yields were probably underestimated because of the truncated age distribution. In the Atlantic yield-per-recruit analyses have not been made for several years; however size regulations in the entire Atlantic and specific to the west Atlantic were enacted in the 1976 and 1982, respectively, to try to increase the yield per recruit. Such analyses have been conducted recently for southern bluefin.

The system of weighting the objective function in the Atlantic assessments was discussed. It was recognized that the existing system essentially creates a single intermediate index from all indices included in the calibration, and it was noted that if the indices used in the 1989 assessment were given equal weight, very similar abundances were estimated, though the variances about the estimates increased. Concern was expressed about the possibility of having indices which indicate substantially different population trends for similar ages. Reportedly this situation has not been encountered, and it was pointed out that for long time series one or both indices would display an unacceptable residual pattern. Careful examination of indices and their relationship to population trends is an essential component of such a calibration system.

An alternative approach of estimating abundances and the uncertainty about them from multiple indices of abundance was discussed. This consists of performing a VPA, using single indices or groups of indices, and then using the different results as an indication of the potential range in possible outcomes. Such a system offers an intriguing approach. It can make many decisions more visible and could simply transfer the difficult decisions to after the calibration rather than within it. Such problems might include decisions on how to treat information derived from highly variable indices, indices with poor correlations with stock size, and indices from the extremes of the age range. Given accurate indices of abundance, it would also reduce the number of estimable parameters, and would probably eliminate the possibility of estimating individual fishing mortality rates in the most recent year.

SESSION 5. GENERAL RECOMMENDATIONS

It was unanimously agreed that a permanent group, the World Bluefin Tuna Working Group on Assessment Methods (WBTWGAM), be established to coordinate research on these species. Its members will examine the work done on all the species and/or stocks of bluefin to determine the best methods for research. This group will not duplicate the activities of ICCAT, the tripartite arrangements for the management of southern bluefin, or any other organizations or arrangements. All persons who attended the meeting of May 25-31, 1990, will be members of the working group.

It was agreed that correspondence to this working group will be directed to Geoffrey Kirkwood, CSIRO (southern bluefin); Peter Miyake, ICCAT (Atlantic northern bluefin); Richard Deriso, IATTC, and Ziro Suzuki, NRIFSF (Pacific northern bluefin).

It was agreed that improvements in assessment methods could lead to improved management advice and, for that reason, it was further agreed that a subsidiary working group be formed to study the conversion of length-composition data to age-composition data and to evaluate the effects of errors in this conversion on the results of virtual population analyses (VPAs). The group agreed that VPA and tuned VPA-like procedures are appropriate only if the ages of the fish in the catch can be estimated reliably. After considerable discussion, it was agreed that the working group will initially select the methods most likely to be employed and review the literature on these methods. It will not concern itself with such details as selection of growth relationships, which are the purview of the organizations which carry out the research on bluefin tunas. Then it will convene, possibly just before or just after the Tuna Conference at Lake Arrowhead, California, in 1991, to discuss what further work should be done. It will report its findings to all members of the WBTWGAM. The members of the subsidiary working group are: Ramón Conser and Richard Deriso (co-conveners), Pedro de Barros, Albert Caton, Douglas Clay, José Cort, William Hearn, Geoffrey Kirkwood, Jacek Majkowski, Russell Reichelt, Gerald Scott, Patrick Tomlinson, Sachiko Tsuji, and Stephen Turner.

It was further agreed that a correspondence working group to study the standardization of catch rates, especially with general linear models, be established. The membership of the correspondence working group will be as follows: Geoffrey Kirkwood (convener), Pedro de Barros, Ramón Conser, Pierre Kleiber, Richard Punsly, Russell Reichelt, and Stephen Turner.

Future meetings of the WBTWGAM were discussed, and a steering committee, consisting of Richard Deriso, Geoffrey Kirkwood, Peter Miyake, Gerald Scott, and Ziro Suzuki, was selected to consider this by correspondence.

Specific recommendations

It was recommended that additional effort be directed toward obtaining statistics for bluefin caught by fleets for which the statistics are incomplete, erroneous, or non-existent. The efforts toward obtaining these data would include contact with government officials and industry representatives, and possible placement of technicians to sample the catches.

It was recommended that additional sampling of young bluefin in the Mediterranean Sea and in Japan be conducted to improve the estimates of the catches of age-0 and -1 bluefin.

It was recommended that further data be collected on sex ratios, maturity, and reproduction of bluefin, and that both the new and existing data be placed on computer files for easy access. It was recognized that future research should go well beyond what has been done in the past, *e.g.* the frequencies of spawning should be determined.

It was recommended that an experimental design for tagging of bluefin in the Atlantic Ocean and Mediterranean Sea be formulated to determine the relative contributions of spawning in the Mediterranean Sea and the Gulf of Mexico to the various fisheries, to examine possible changes in growth rates among years, and to obtain independent estimates of the populations of juvenile fish.

The group recognizes that the work currently being done on bluefin by various organizations is appropriate and of high quality. Accordingly, it should not be construed that research not mentioned in the current recommendations is not endorsed by the members of the WBTWGAM.

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STATUS OF NORTHERN BLUEFIN TUNA IN THE PACIFIC OCEAN

by

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World Meeting on Stock Assessment of
Bluefin Tunas: Strengths and Weaknesses

La Jolla, California, USA
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TABLE OF CONTENTS

1 INTRODUCTION

Parts of this report are similar to parts of a species synopsis prepared by Bayliff (1980). The material in Sections 4.2 and 6 is similar to that in sections entitled **ATTRITION** and **LIFE HISTORY AND STOCK STRUCTURE** in Bayliff *et al.* (1991). Most of the material in Section 7 is similar to that in parts of sections entitled **Bluefin studies** and **NORTHERN BLUEFIN** in Anonymous (1991).

2 GENERAL DESCRIPTION OF THE FISHERIES

2.1 Eastern Pacific Ocean

Sport fishing for northern bluefin tuna began in California in 1898 (Bell, 1970). Prior to World War I, before the advent of the commercial fishery, many large fish were taken, particularly by vessels based at Catalina Island. The largest of these fish weighed 251 pounds (114 kg). More recently the average size of the sport-caught fish has been roughly 25 pounds (11 kg), although large fish are still taken (Dotson and Graves, 1984). Most of the sport-caught fish are taken by fishermen who are directing their efforts primarily toward albacore.

The purse-seine fishery for northern bluefin began in 1918 (Whitehead, 1931), and since then the catches by purse seiners have far exceeded those by any other type of gear. From 1918 until about 1959 or 1960 most of the vessels were relatively small, with capacities less than about 200 short tons (181 metric tons). None of them fished exclusively for bluefin. The smaller ones fished chiefly for sardines, mackerel, and other pelagic fish other than tunas, and the larger ones fished mostly for yellowfin and skipjack. During 1959 and 1960 most of the larger tuna baitboats were converted to purse seiners, and during the ensuing years many new purse seiners were built. During the 1960s, 1970s, and 1980s many of the smaller, older vessels sank or dropped out of the fishery, and the new vessels which replaced them tended to be larger. As a result there are now more larger purse seiners and fewer smaller ones than had been the case during the early 1960s. Bluefin are now taken by vessels of all sizes, but the smaller ones account for a proportionally larger share of the catch. The proportion of the catch made by vessels which fish primarily for pelagic fish other than tunas is less now than it was during the early years of the fishery, as increased exploitation in the southern half of the range of bluefin has caused its center of abundance to shift southward beyond the area where these vessels normally fish. Most of the fish caught by purse seiners weigh less than about 50 pounds (23 kg), but larger ones are sometimes caught, including one weighing 1,009 pounds (458 kg) (Section 4.1).

Most of the information regarding distribution of the catches of tuna purse seiners after 1947 has been obtained from the logbook records of these vessels. The vessel captains or navigators usually record the catch of each set in short tons, the location of each set to the nearest degree and minute of latitude and longitude, the date, and the times each set was initiated and completed. At the end of each trip an abstract of the vessel logbook is prepared. These abstracts are incorporated into the IATTC's computer records, from which summaries of the northern bluefin catch, stratified by any combination of area, time, vessel size class, etc., can be prepared. During the 1961-1989 period the annual logged catches ranged from 69 to 100 percent of the corresponding weighed-out catches.

Northern bluefin are rarely encountered south of Cabo San Lucas, Baja California, or north of Point Conception, California. Within this area a considerable change has taken place during the 20th century (Bell, 1970). Prior to 1930 fishing was conducted only off California. During that year bluefin were discovered off Isla Guadalupe, Baja California, located at about 29°N-118°W, and about 40 percent of the catch in 1930 was made in that area (Whitehead, 1931). From 1930 through 1947 fishing was conducted off both California and Baja California, but in most years the majority of the catch came from off California. From 1948 to the present, however, most of the catch has been made off Baja California (Calkins, 1982: Figure 2; this report: Figure 1). In 1989, for the first time in many years, no catches were made south of 30°N (Figure 1). The average annual catches made off California during the 1960s, 1970s, and 1980s have been considerably less than the average annual catches made in the same area during the 1918-1929 period. It is believed by the compiler of this report that the reason for this is that during more recent years the larger vessels fishing off Baja California have tended to intercept the fish before they reach the waters off California.

The distributions of the catches by months are shown in Figure 3 of Calkins (1982) and Figure 2 of this report. During January through April there are typically only light and sporadic catches. Most of these are made off the coast of Baja California between 24°N and 26°N and in the vicinity of Isla Guadalupe. In May and June the catches increase, and most of them are made between 24°N and 27°N. In July the fishing area spreads to the north and is at its widest extent of the year; most of the catch is made between 25°N and 33°N. In August there are usually only light catches at the southern end of the fishing area, most of the catch being made between 28°N and 33°N. In September most of the catch is made in the same area as in August, but the amount of catch is usually considerably less. In October the catches continue to decline, and most of them are made north of 30°N. In November and December, as in the first months of the year, the catches are light and sporadic. The distribution of the catches was a little more northerly during the 1980s than during the 1960s and 1970s.

Northern bluefin are caught in the vicinity of Isla Guadalupe during all months of the year, but not during every month of every year.

Small amounts of northern bluefin are caught by longline vessels in the eastern Pacific (Anonymous, 1974, 1975, 1976, 1977a, and 1978; Figure 3).

2.2 Western Pacific Ocean

Information on the fisheries which exploit northern bluefin in the western Pacific Ocean is given by Yamanaka (1958 and 1982), Yamanaka and staff (1963), Tatsuki *et al.* (1963), Yukinawa and Yabuta (1967), Shingu *et al.* (1974), Honma and Suzuki (1978), and Bayliff (1980). Bluefin are exploited by various gears in the western Pacific Ocean from Taiwan to Hokkaido. Age-0 fish about 15 to 50 cm in length are caught by trolling during July-October south of Shikoku and south of Shizuoka Prefecture. (In this report fish in their first year of life are referred to as 0-year-olds, age-0 fish, or fish 0 years of age, and so on.) During November-April age-0 fish about 35 to 60 cm

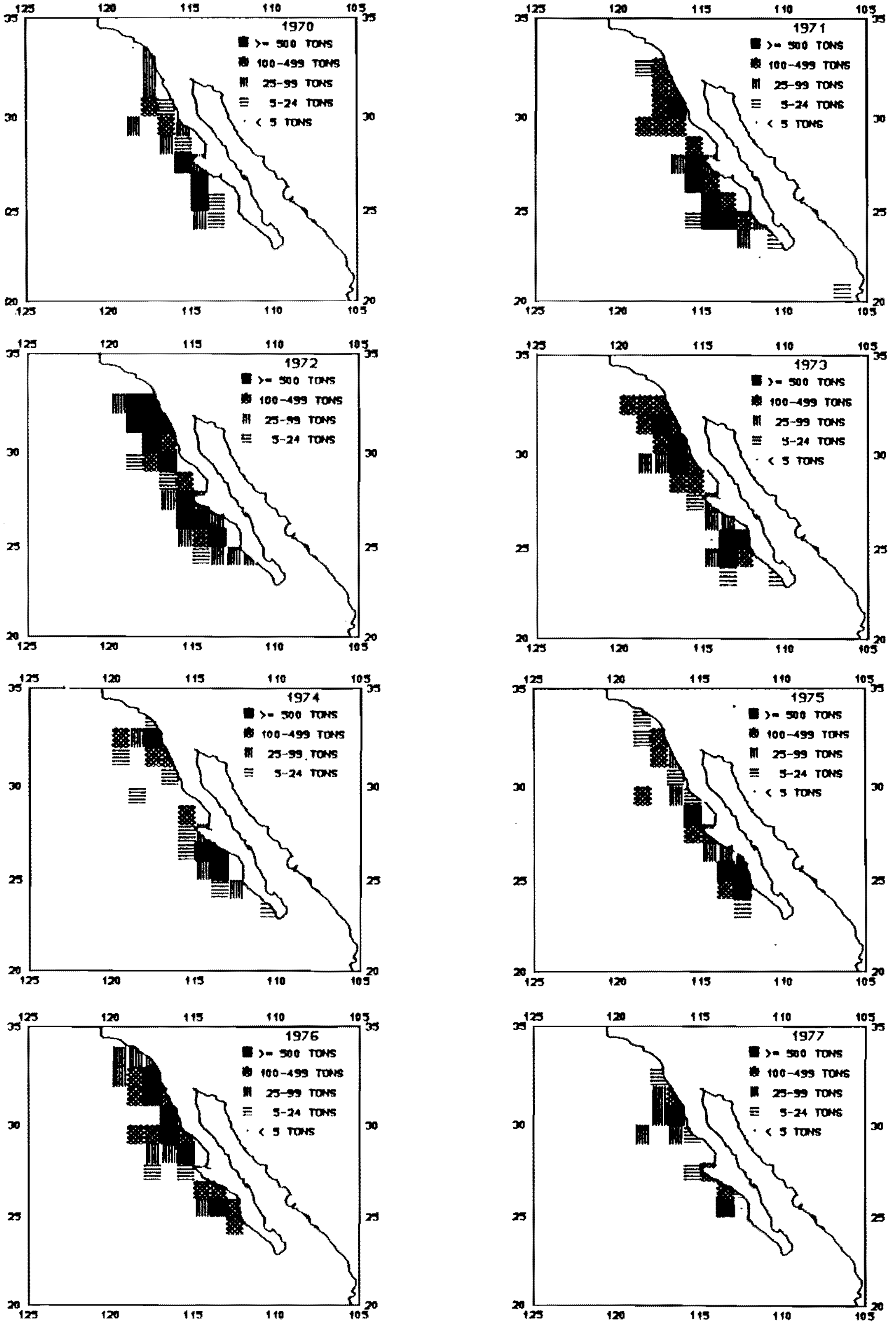

FIGURE 1. Annual distributions of northern bluefin catches in the eastern Pacific Ocean, 1970-1989.

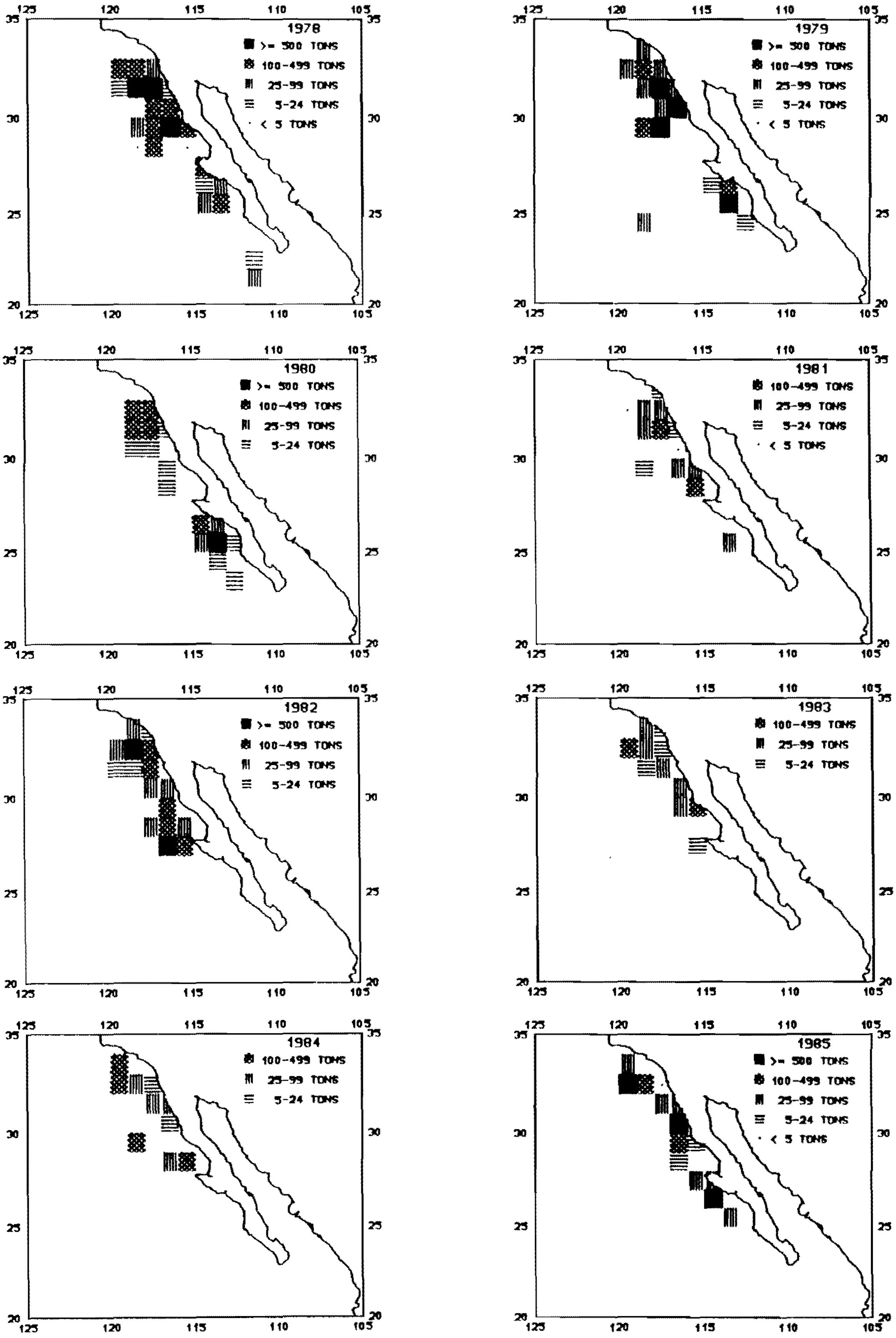

FIGURE 1. (continued)

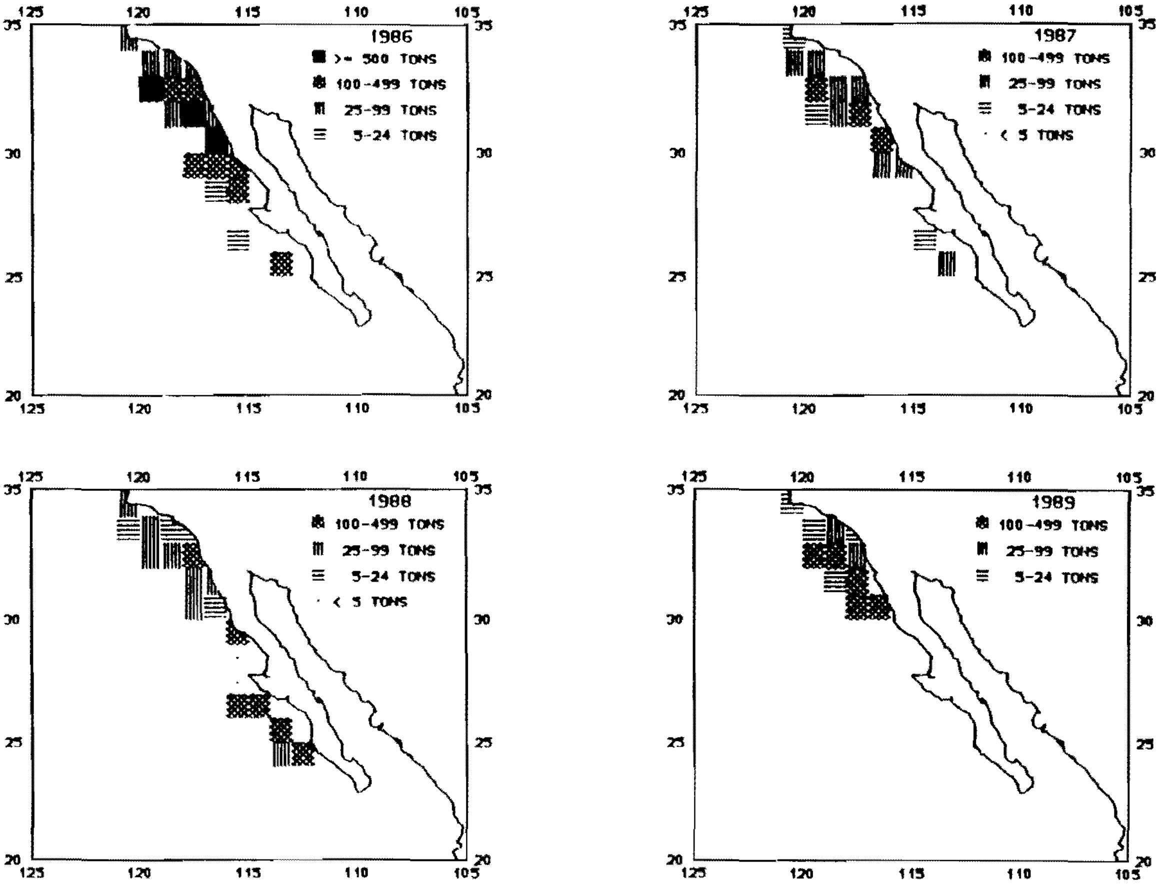

FIGURE 1. (continued)

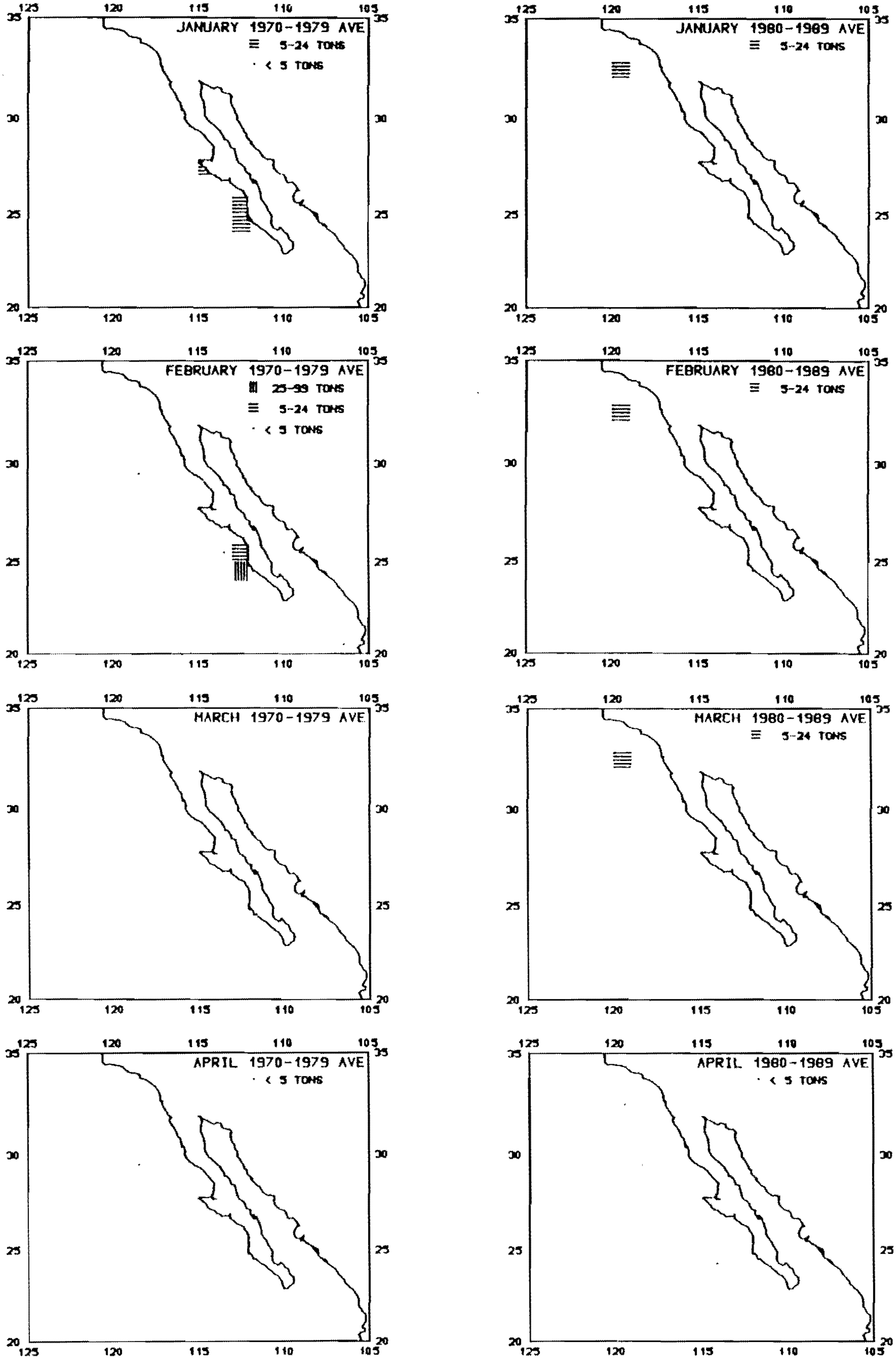

FIGURE 2. Average monthly distributions of northern bluefin catches in the eastern Pacific Ocean, 1970-1979 and 1980-1989.

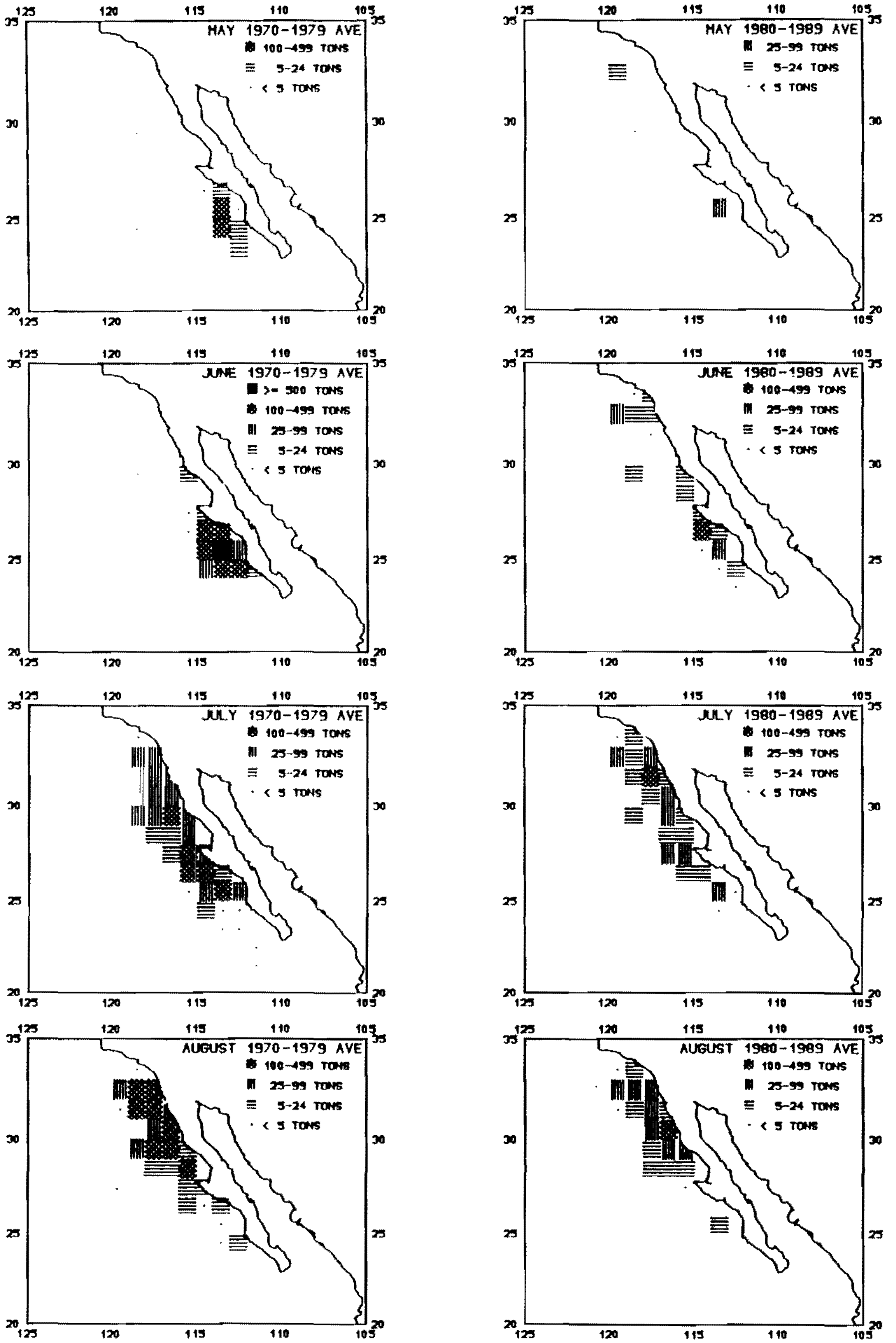

FIGURE 2. (continued)

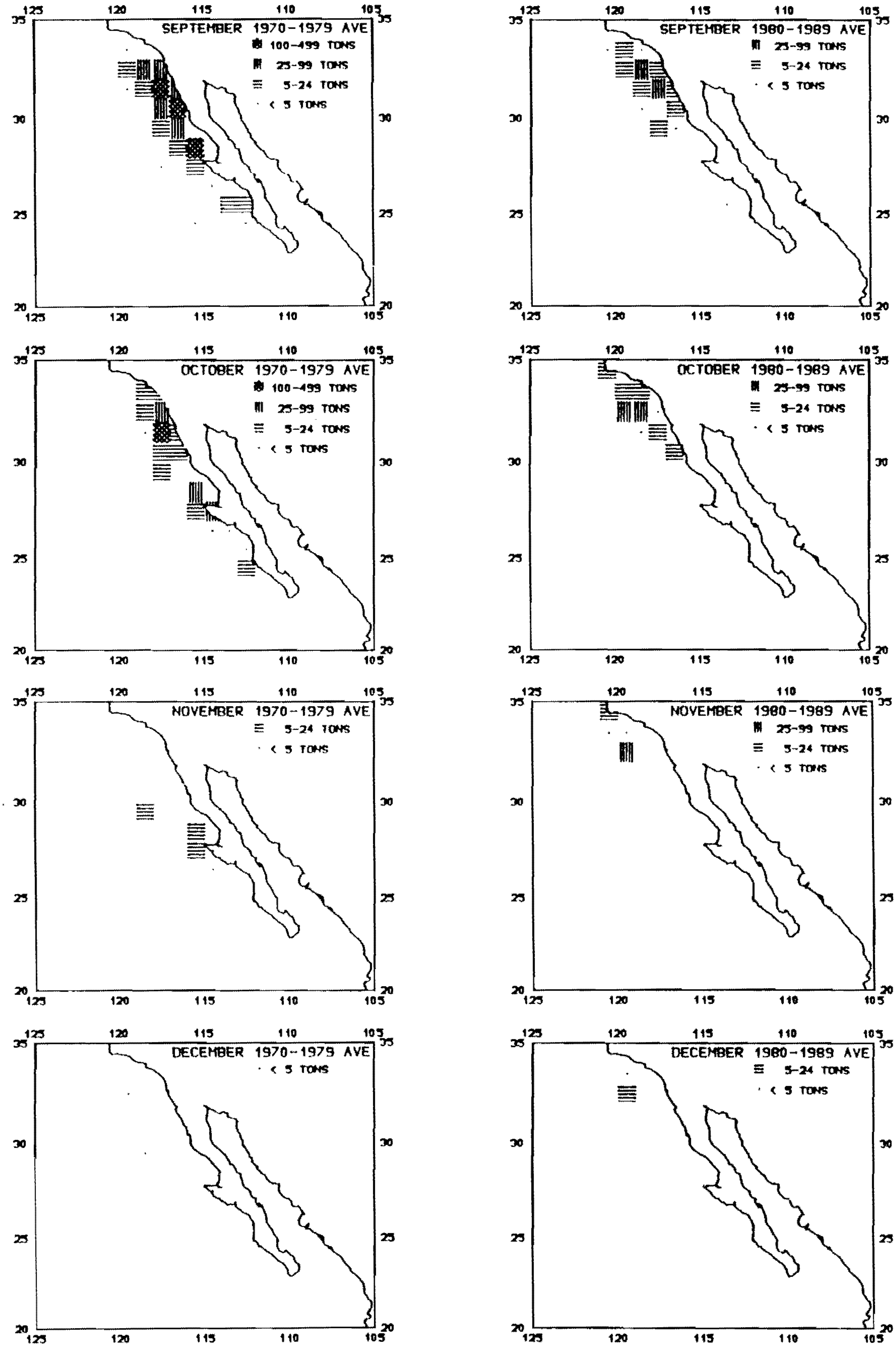

FIGURE 2. (continued)

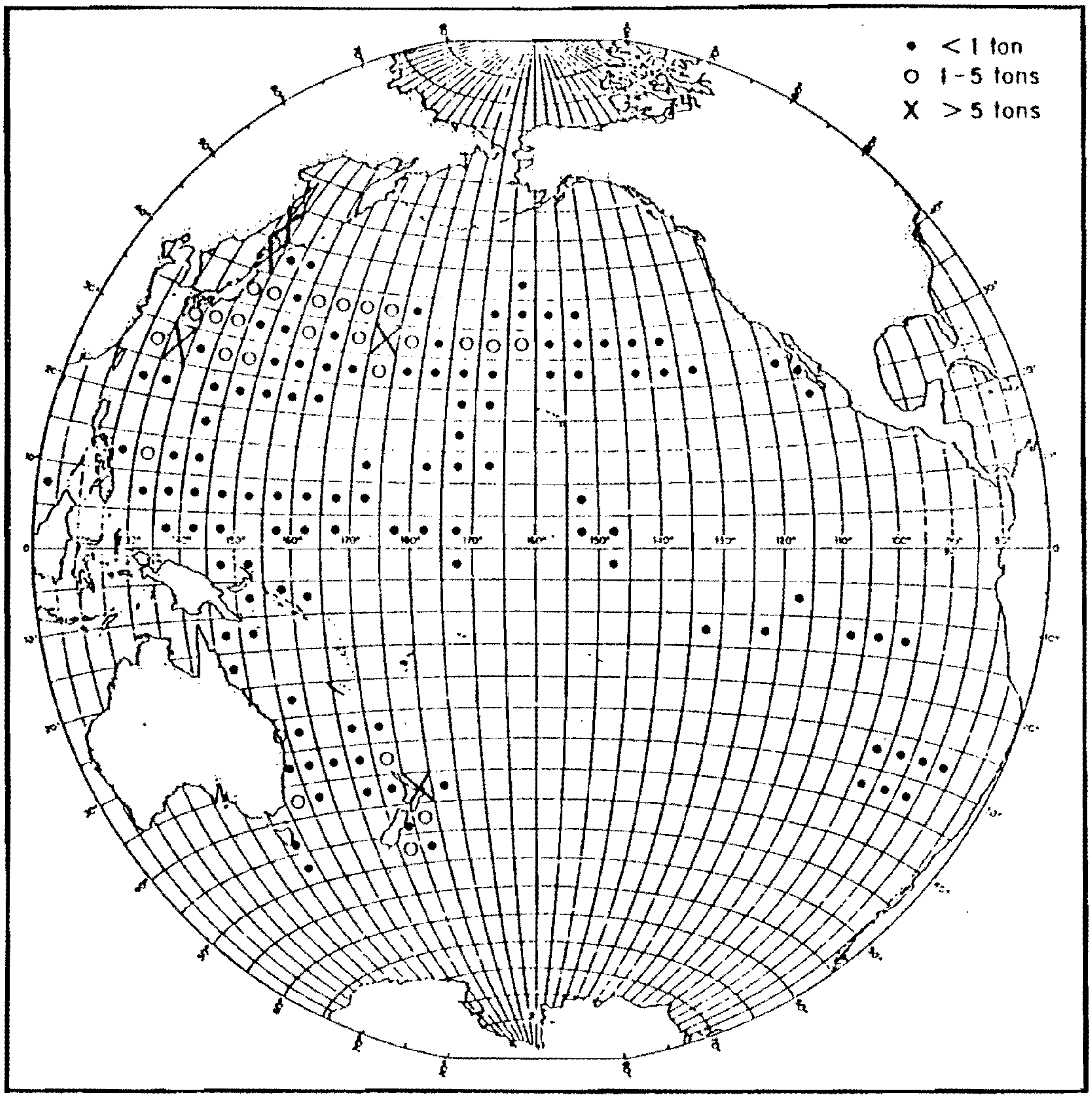

FIGURE 3. Average annual distribution of catches of northern bluefin in the Pacific Ocean by Japanese longliners during 1972-1976 (from Bayliff, 1980).

in length are taken by trolling south and west of Kyushu. Age-1 and older fish are caught by purse-seining, mostly during May-September between about 30°N-42°N and 140°E-152°E. Bluefin of various sizes are also caught nearshore by traps, gillnets, and other gear, especially in the Sea of Japan. Small amounts of bluefin are also caught near the southeastern coast of Japan and offshore by longlining.

2.3 Central Pacific Ocean

Gillnet fisheries for salmon, *Oncorhynchus* spp., flying squid, *Ommastrephes bartrami*, and albacore, *Thunnus alalunga*, exist in the north Pacific Ocean, but nothing has been published about the catches of northern bluefin by these fisheries. The distributions of these fisheries are shown in Figure 4. According to Bell (1963a), in the eastern Pacific bluefin occur mostly in waters with sea-surface temperatures of 17° to 23°C. If their distribution with regard to temperature is the same in the central and western Pacific it would be approximately as shown in Figure 5. Since this distribution coincides with the distributions of the gillnet fisheries, it seems likely that bluefin are taken by gillnets in the central Pacific Ocean. Anonymous (1986a: 55) reported that "a single day's catch [of a squid gillnet] ranged from 871 to 8,256 squid and 5 to 530 tuna." Bayliff *et al*. (1991: Table 6) list data for five tagged bluefin released in the western Pacific and recaptured by gillnet vessels in the central Pacific between 34° and 40°N and 161°E and 161°W.

The Japanese baitboat fishery for albacore extends as far to the east as 175°W (Majors *et al*., 1984: Figure 2). Bayliff *et al*. (1991: Table 6) report that one tagged northern bluefin released in the western Pacific was recaptured by a baitboat at approximately 38°N-167°E.

3 BASIC DATA

3.1 Catch, effort, and catch per unit of fishing effort

3.1.1 Eastern Pacific Ocean

The principal source of detailed information on the purse-seine fishery of the eastern Pacific Ocean is the IATTC's logbook information data. These data are fully computerized for the period of 1959 through 1989.

3.1.1.1 Annual catches

The total annual catches of northern bluefin by commercial and sport vessels in the eastern Pacific Ocean during 1918 through 1989 are shown in Table 1 and Figure 6. The catches prior to 1918 were negligible. The data for 1918 through 1960 include only the catches landed in California, but it is believed that the catches landed elsewhere prior to 1961 were inconsequential. The eastern Pacific subsurface catches for all years are omitted, but these are also believed to be inconsequential.

The catches tended to be greater during the 1960s and 1970s than during the previous period. This is probably due to the fact that during 1959 and 1960 most of the tuna baitboats were converted to purse seiners, and many new purse seiners were built. During the earlier period the catch was made by

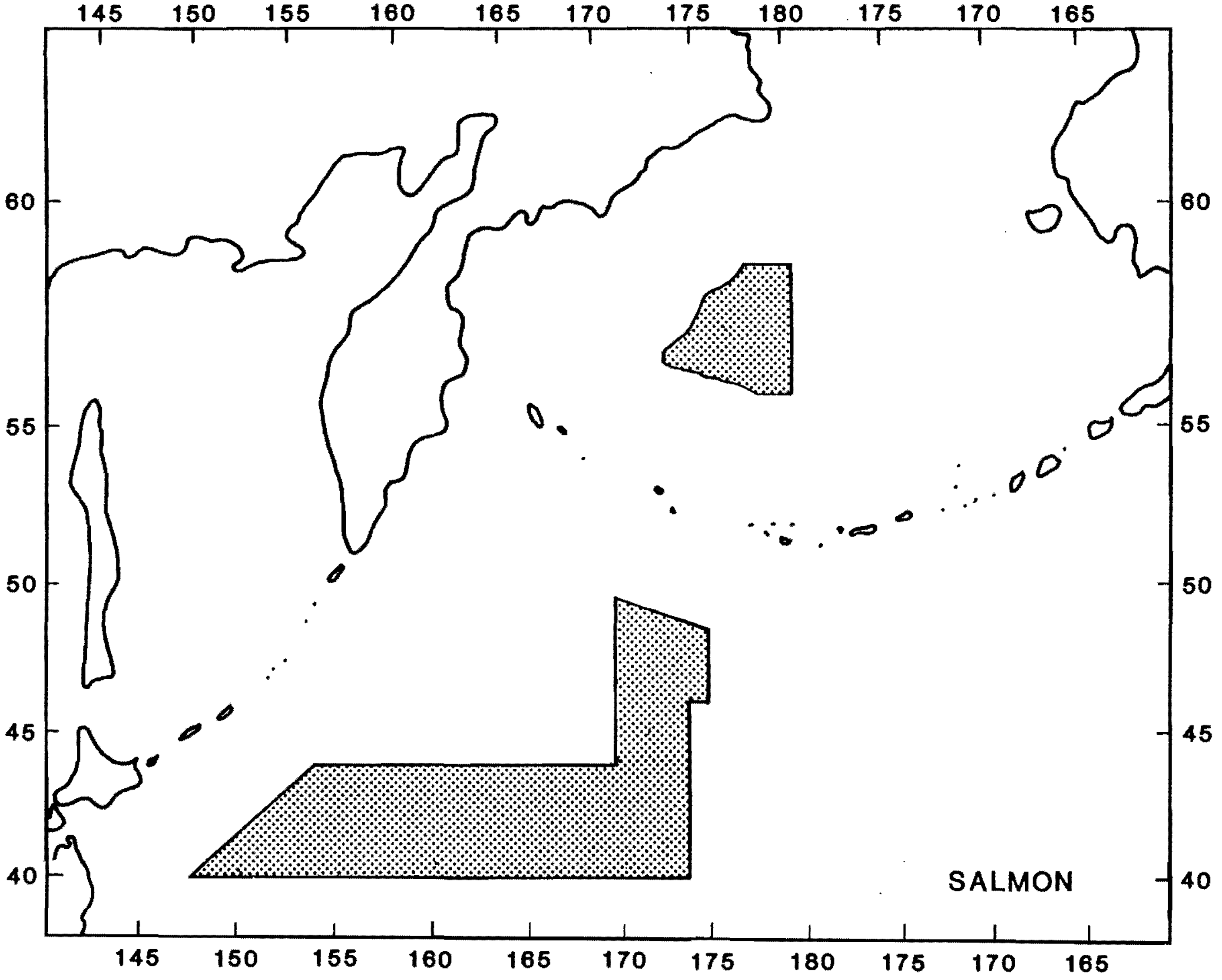

FIGURE 4. Areas in which offshore gillnet fishing by Japanese vessels takes place (after Suzuki, 1990).

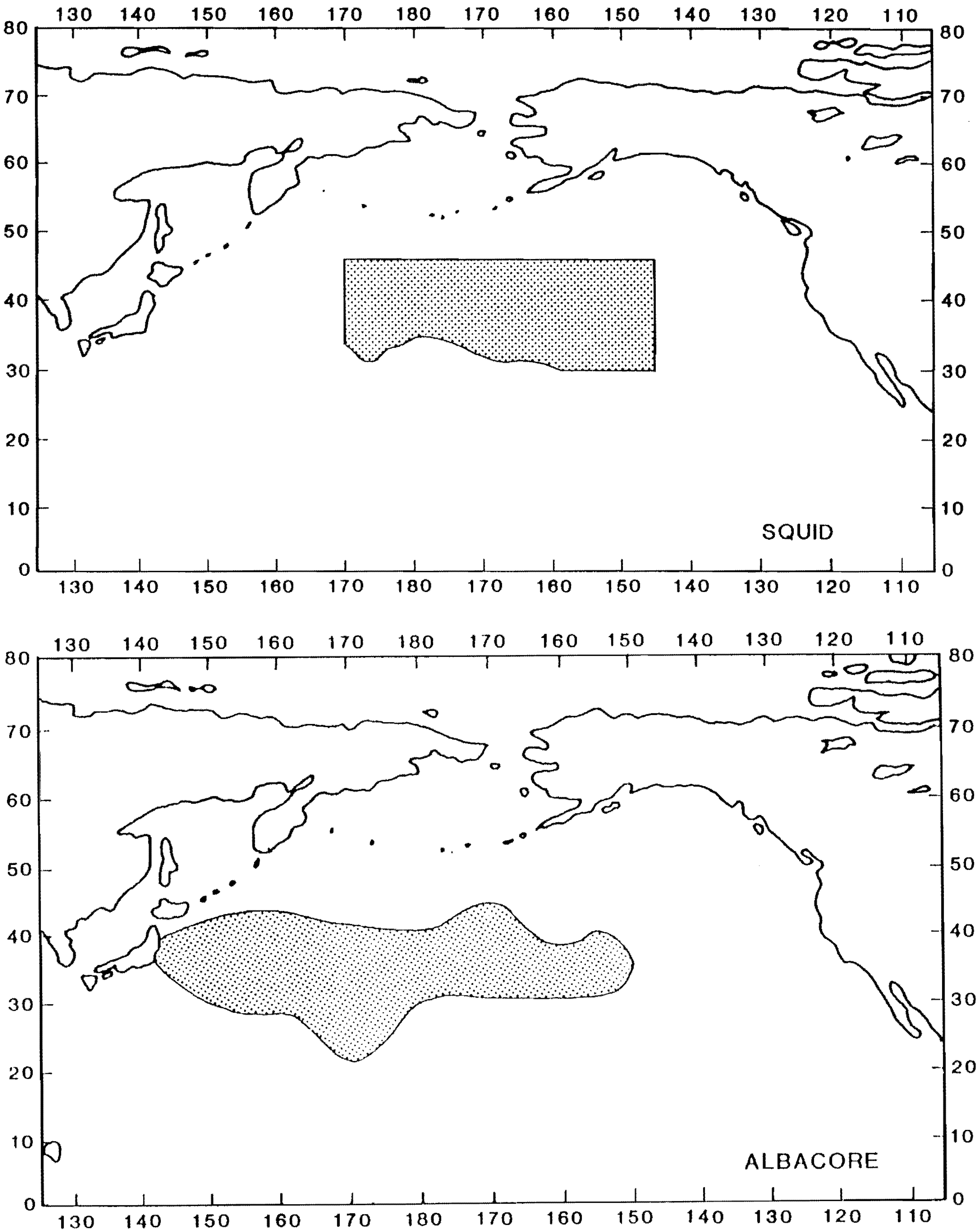

FIGURE 4. (continued)

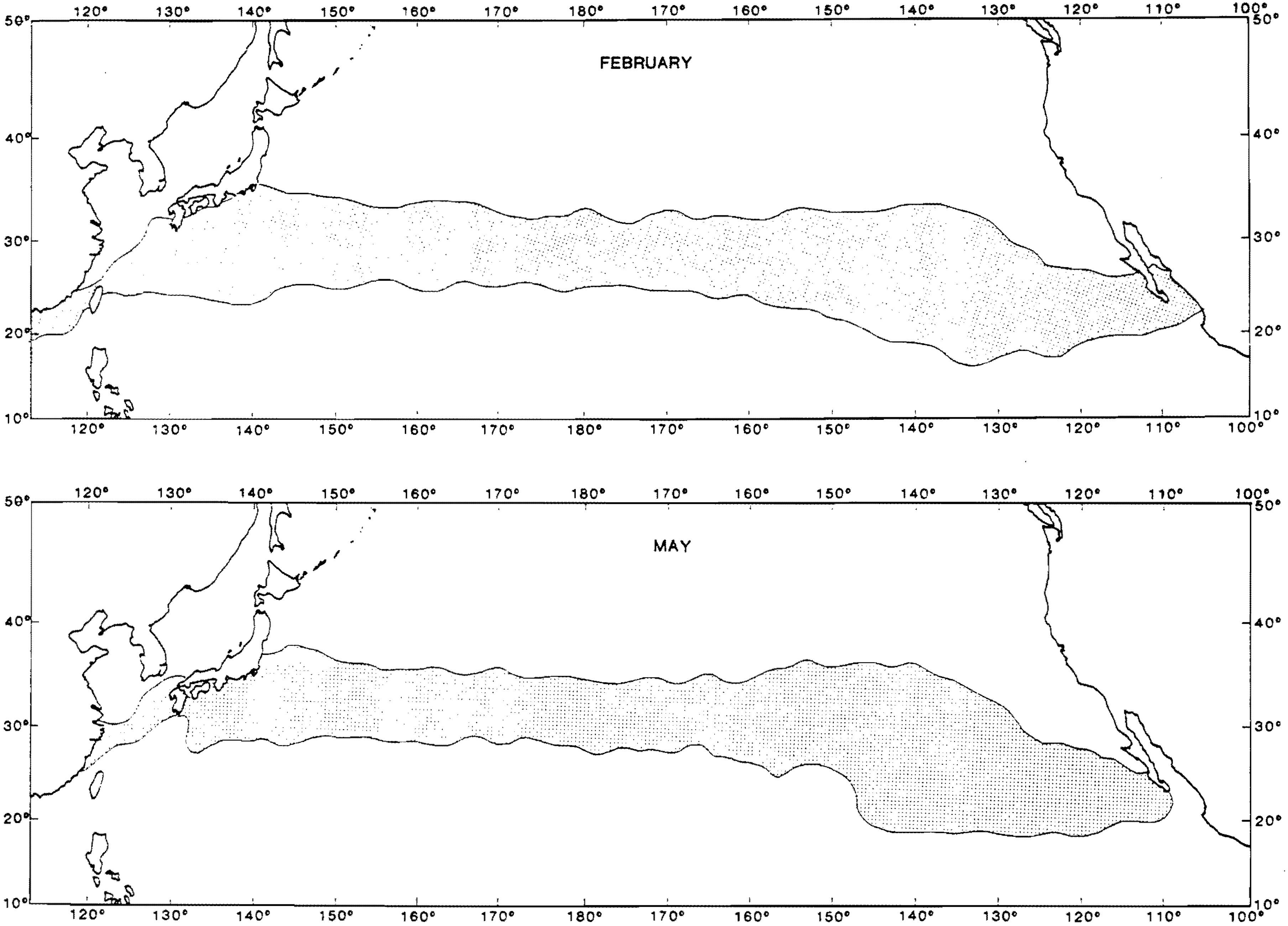

FIGURE 5. Areas of the north Pacific Ocean bounded by the 17° and 23°C surface isotherms (after Robinson, 1976).

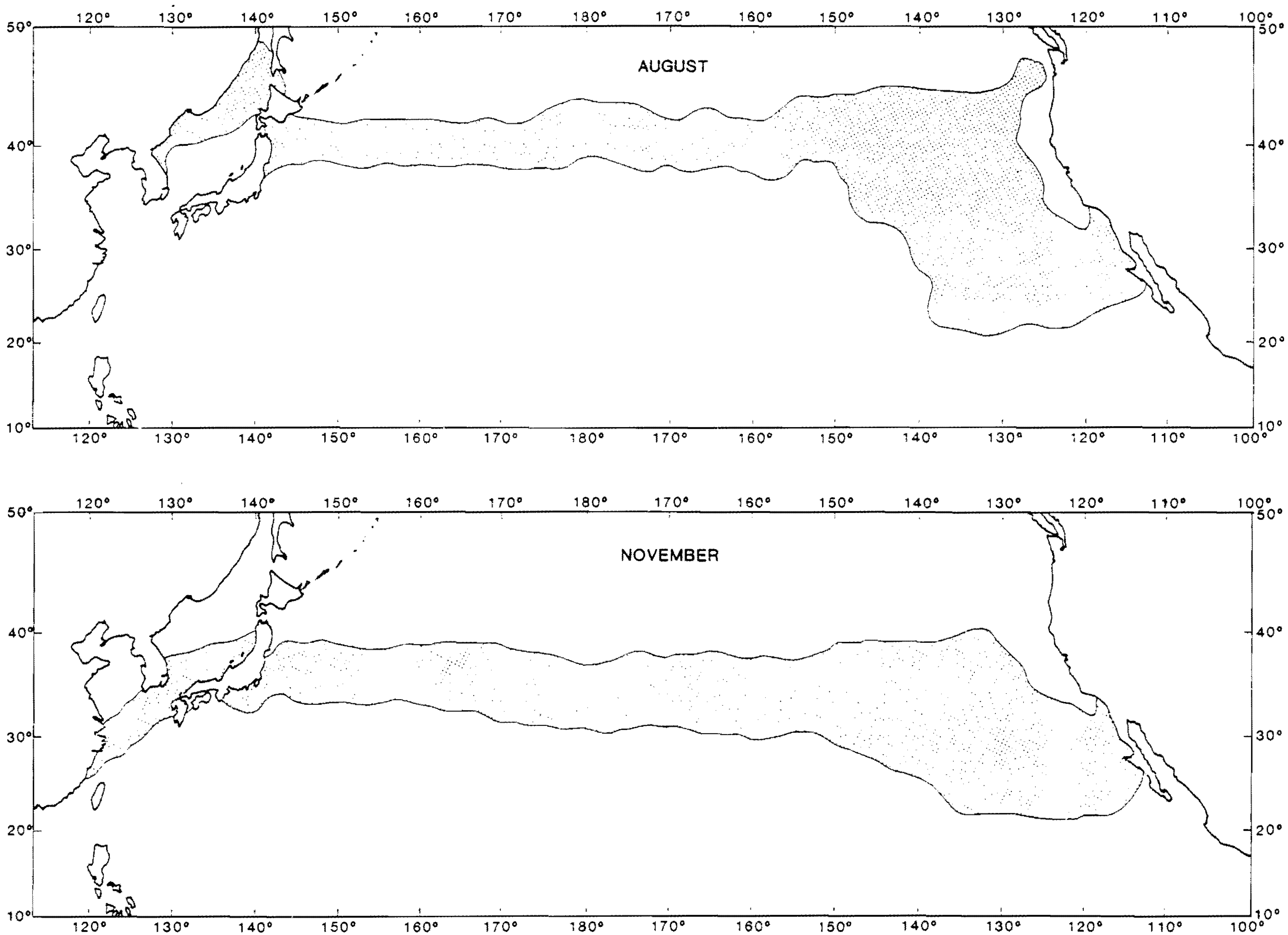

FIGURE 5. (continued)

TABLE 1. Catches of bluefin in the eastern Pacific Ocean in metric tons. The sources of the data are as follows: commercial, 1918-1960, Bell, 1963a; 1961-1989, Anonymous, 1991; sport, 1936-1960, Bell, 1963a; 1961-1970, Bell, 1971; 1967-1976, Oliphant, 1979; 1977-1986, Oliphant *et al.*, 1990; 1987-1988, Malcolm S. Oliphant, personal communication.

Year	Commercial	Sport	Year	Commercial	Sport	Year	Commercial	Sport
1918	2,722		1942	5,826		1966	15,897	23
1919	6,800		1943	4,617		1967	5,889	36
1920	4,776		1944	9,228		1968	5,976	1
1921	894		1945	9,341		1969	6,926	17
1922	1,275		1946	9,993		1970	3,966	21
1923	1,460		1947	9,452	25	1971	8,360	8
1924	1,470		1948	2,961	1	1972	13,348	17
1925	1,725		1949	1,991	22	1973	10,746	61
1926	2,960		1950	1,242	0	1974	5,617	65
1927	2,222		1951	1,752	81	1975	9,583	38
1928	6,215		1952	2,076	2	1976	10,646	23
1929	3,414		1953	4,433	48	1977	5,473	21
1930	9,943		1954	9,537	11	1978	5,396	5
1931	1,603		1955	6,173	93	1979	6,118	12
1932	486		1956	5,727	388	1980	2,938	8
1933	254		1957	9,215	73	1981	1,090	6
1934	8,327		1958	13,934	10	1982	3,150	8
1935	11,418		1959	6,914	15	1983	853	22
1936	8,584	33	1960	5,422	1	1984	882	32
1937	5,758	46	1961	8,136	26	1985	4,054	56
1938	8,041	135	1962	11,268	28	1986	5,084	8
1939	5,369	112	1963	12,271	8	1987	995	21
1940	9,058	78	1964	9,218	8	1988	1,423	4
1941	4,318		1965	6,887	1	1989	1,163	
						1990	1,494	

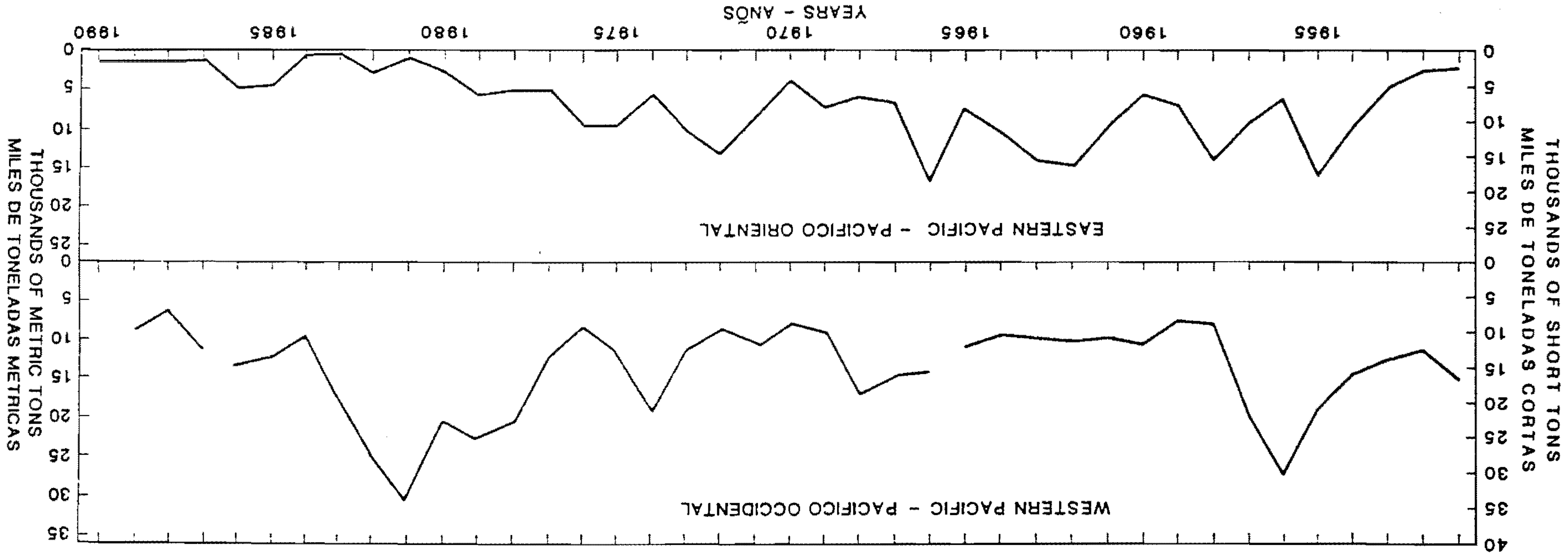

FIGURE 6. Annual catches of northern bluefin in the Pacific Ocean. The data in the top panel are from unpublished files of the National Research Institute of Far Seas Fisheries of Japan. The 1951-1965 and 1987-1989 data include only large fish (greater than about 15 kg or 33 pounds). The 1966-1986 data include both small and large fish. The data for the small fish were estimated from the catches of *meji* (small bluefin, bigeye, and yellowfin) by a proration process based on the catches of large bluefin, bigeye, and yellowfin (Ishizuka, 1989).

smaller purse seiners, most of which fished part time for tunas and part time for other pelagic fish, whereas during the later period most of the catch has been made by larger purse seiners which fish full time for tunas (but not exclusively for northern bluefin, of course).

3.1.1.2 Monthly catches

Data on the monthly logged catches of northern bluefin in the eastern Pacific surface fishery are given in Table 2. The proportions of the annual catches taken in the various months vary considerably from year to year.

3.1.1.3 Effort and catch per unit of effort

Calkins (1982) stated that, since the area where northern bluefin are caught is subjected to intensive searching for tunas and other pelagic fish throughout the year, the "total catch may be the best indicator of bluefin abundance." Nevertheless, he attempted to ascertain the fishing effort directed toward bluefin during 1961-1980. As stated previously, the vessels which catch bluefin also catch considerable quantities of other species of pelagic fish, so it cannot be considered that all their effort is directed toward bluefin. Accordingly, he adopted the following rules: (1) no effort made south of 23°N was considered to be bluefin effort; (2) no effort during the November-April period was considered to be bluefin effort; (3) no effort in 1-degree area-month strata in which no sets were made on bluefin was considered to be bluefin effort. In the area-time strata in which bluefin effort was assumed to occur during the 1961-1980 period the catches of bluefin ranged from 19 to 83 percent of the total catch, with an average of 51 percent (Calkins, 1982: Table 5). These effort data are listed in his Table 6. No attempt was made to standardize these data by vessel size class.

Calkins (1982) calculated the catches per unit of effort (CPUEs) by dividing the catches of northern bluefin in the area-time strata in which bluefin effort was assumed to occur by the effort in those strata. These results are also shown in his Table 6. The total annual catches of bluefin during 1961-1989, plus the logged bluefin effort and the CPUEs for those years, are shown in Figure 7. It can be seen that the catches and CPUEs for 1961 through 1984 are highly correlated. After that the relationship breaks down, high CPUEs occurring in years with low to medium catches. This is due to the fact that in the years with high CPUEs the fish tended to occur in only a few area-time strata, with high CPUEs in them. In 1989, for example, no bluefin were caught south of 30°N (Figure 2), and 70 percent of the catch was made during August.

The relative abundance of many pelagic ocean fishes can also be monitored by aerial surveys. Squire (1983) gives information on northern bluefin recorded during aerial surveys of pelagic fishes carried out over the eastern Pacific Ocean, but the surveys covered only waters off Southern California and Baja California north of 30°N.

TABLE 2. Logged purse-seine catches of bluefin in the eastern Pacific Ocean, in short tons.

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1959	0	111	10	245	8	0	1501	1898	0	0	0	0	3773
1960	108	21	0	0	0	1777	1971	967	208	0	30	0	5082
1961	0	0	0	0	33	1239	1190	4833	1285	152	76	0	8808
1962	25	0	97	34	343	2107	3509	4790	404	0	0	0	11309
1963	53	30	0	121	98	2389	1954	5197	3698	8	17	29	13594
1964	9	0	0	7	20	1621	2335	3917	852	5	6	0	8772
1965	0	7	20	10	3	580	900	2509	1485	973	0	0	6487
1966	0	0	0	0	231	5052	7063	3513	164	0	0	0	16023
1967	12	0	4	0	52	3093	2405	91	245	18	0	0	5920
1968	0	0	0	0	0	813	2252	1485	803	168	0	0	5521
1969	12	0	1	255	557	760	2514	1942	700	0	0	51	6792
1970	13	0	0	33	0	1559	2383	321	59	0	0	0	4368
1971	0	35	0	0	2135	1927	1425	783	1101	880	0	13	8299
1972	0	0	0	0	376	2501	2621	5306	766	1625	0	0	13195
1973	0	10	0	0	18	1923	5283	2528	237	0	0	0	9999
1974	0	0	0	0	0	1317	1565	691	833	67	0	5	4478
1975	0	2	0	0	58	2776	1678	401	1743	628	128	25	7439
1976	192	377	0	2	266	1819	308	3738	3388	343	153	25	10611
1977	0	0	0	0	1525	431	68	2155	715	366	30	40	5330
1978	90	0	0	0	0	648	1571	2315	107	12	0	0	4743
1979	0	0	0	0	1654	394	774	2040	236	123	0	0	5221
1980	0	0	0	0	335	1213	263	552	297	0	0	0	2660
1981	0	0	0	0	5	289	121	296	116	0	0	0	827
1982	0	0	0	0	0	0	939	727	641	368	0	0	2675
1983	95	0	0	0	0	0	277	181	108	41	0	0	702
1984	8	0	0	52	25	89	350	139	135	65	0	0	863
1985	0	88	0	0	30	1710	359	871	143	628	467	85	4381
1986	0	0	107	15	16	338	1717	1720	400	531	239	110	5193
1987	99	3	0	0	0	37	289	272	207	50	10	0	967
1988	0	0	0	0	0	239	930	112	18	66	94	42	1501
1989	8	0	0	0	0	0	7	709	234	39	20	45	1062

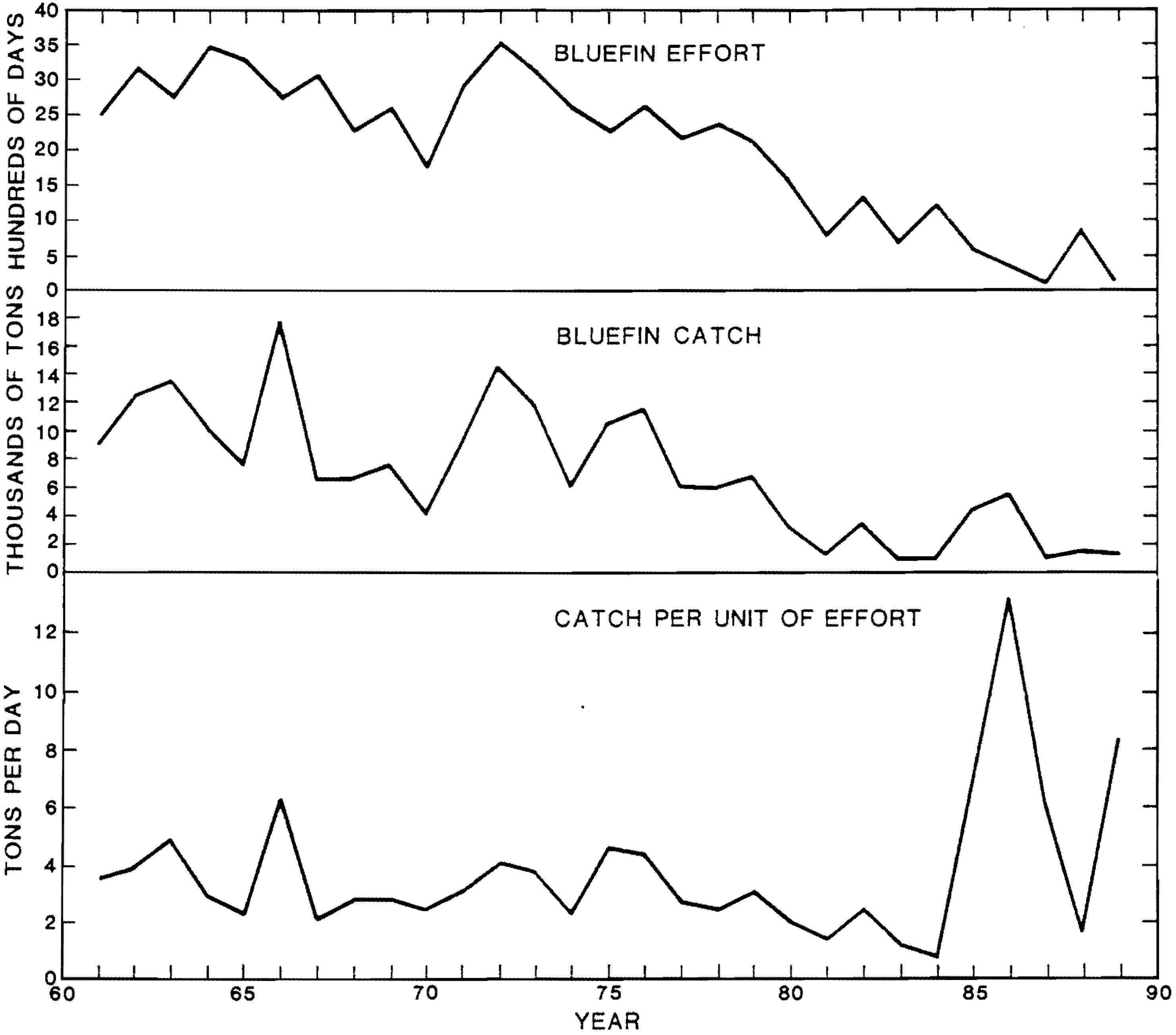

FIGURE 7. Fishing effort, total catch, and catch per day's fishing for northern bluefin in the eastern Pacific Ocean.

3.1.2 Western Pacific Ocean

3.1.2.1 Annual catches

The total annual catches of northern bluefin by Japanese vessels in the Pacific Ocean during 1951 through 1987 are shown in Table 3 and Figure 6. A great majority of these catches was made in the western Pacific. The 1951-1965 data include only large fish (greater than about 15 kg). The 1966-1986 data include both small and large fish. The data for the small fish were estimated from the catches of *meji* (small bluefin, bigeye, and yellowfin) by a proration scheme based on the catches of large bluefin, bigeye, and yellowfin (Ishizuka, 1989).

3.1.2.2 Monthly catches

No information on this subject, other than that given in Section 2.2, is available.

3.1.2.3 Effort and catch per unit of effort

Except for data on the numbers of Japanese purse-seine vessels and traps (Skillman and Shingu, 1980) no information on this subject is available.

3.1.3 Central Pacific Ocean

The catch data in Table 3 and Figure 6 include catches made in the central Pacific. No further information on this subject, other than that given in Section 2.3, is available.

3.2 Length- and weight-frequencies

A list of the length-frequency samples of northern bluefin which have been collected in the eastern Pacific Ocean is given in Table 4. The data for 1923-1925, 1952-1965, and 1970-1971 were obtained from a tape supplied by the California Department of Fish and Game (CDFG). Those for 1966-1969, which were obtained from Schultze and Collins (1977, Tables 6-9), are segregated by age, but not by month. Similar lists for length- and weight-frequency samples which have been taken in the western Pacific Ocean are given in Tables 5 and 6.

3.3 Weight-length relationships

Weight-length relationships which have been calculated for northern bluefin in the Pacific Ocean are listed in Table 7. If the last two samples are disregarded, all of those which include fish greater than 800 mm in length have exponents less than 3, and all those which include only fish less than 800 mm in length have exponents greater than 3.

3.4 Sex ratios

Fragmentary data on the sex ratios of northern bluefin are given in Table 8.

TABLE 3. Catches, in metric tons, of bluefin in the Pacific Ocean by Japanese vessels (after Ishizuka, 1989).

	Small fish								Large fish								Grand total
	Purse seine	Long-line	Bait-boat	Gill-net	Troll	Trap	Other	Total	Purse seine	Long-long	Bait-boat	Gill-net	Troll	Trap	Other	Total	
1966	315	107	0	37	1028	493	23	2004	8517	1311	437	2	392	803	20	11482	13486
1967	1380	104	0	10	1742	1468	193	4897	4742	1193	1011	29	1016	937	67	8995	13892
1968	2705	134	0	3	1341	1810	7	6000	6178	1283	850	2	947	1300	31	10591	16591
1969	202	103	0	13	1261	1237	4	2820	2504	1005	377	5	1285	1015	11	6202	9022
1970	556	62	0	0	1545	684	10	2856	1812	800	378	0	813	1046	10	4859	7715
1971	897	48	0	15	2826	684	12	4482	2665	643	740	1	579	934	2	5564	10046
1972	366	96	0	131	1217	565	9	2383	3445	637	472	3	331	559	1	5448	7831
1973	1032	179	0	160	2928	1251	28	5579	1618	1077	180	115	903	1083	7	4983	10562
1974	927	695	0	165	2439	3955	127	8309	3012	3448	929	70	963	2207	13	10642	18951
1975	1321	241	0	195	1137	1346	28	4267	3505	1219	659	68	307	1138	11	6907	11174
1976	139	115	0	481	860	1185	0	2780	1785	391	565	352	308	2027	0	5428	8208
1977	746	111	0	399	1741	858	12	3868	3751	483	1971	402	469	1475	8	8559	12427
1978	559	139	0	551	3915	1453	40	6657	8526	753	986	1344	752	1308	15	13684	20341
1979	483	313	0	564	2028	2742	35	6164	11854	808	1144	756	672	2084	24	17342	23506
1980	1886	318	0	668	1735	1280	29	5918	9205	838	1279	909	494	1464	42	14231	20149
1981	1089	118	0	970	1757	970	8	4912	21476	619	675	772	363	1233	7	25145	30057
1982	555	143	0	240	834	552	2	2326	17272	756	1710	1337	177	1147	1	22400	24726
1983	1227	84	0	28	1040	427	0	2806	12388	286	320	786	146	546	0	14472	17278
1984	384	77	0	78	1340	1642	25	3546	4021	162	456	430	295	846	2	6212	9758
1985	1522	57	0	228	1332	1318	0	4457	3302	324	1700	332	324	1380	0	7362	11819
1986	1341	21	0	128	808	1911	0	4209	6367	142	1022	141	182	1120	0	8974	13183

TABLE 4. Length samples of bluefin caught in the eastern Pacific Ocean in the files of the IATTC.

Year	Number of samples	Number of fish	Number of months for which fish were sampled	Number of months in which fish were caught	Organization collected by
1923	9	411	3		CDFG
1924	1	21	1		CDFG
1925	5	241	1		CDFG
1952	11	1,140	3		CDFG
1953	12	1,060	6		CDFG
1954	36	3,680	8		CDFG
1955	41	3,751	8		CDFG
1956	59	5,409	6		CDFG
1957	98	5,361	6		CDFG
1958	137	6,620	10		CDFG
1959	130	6,490	5	6	CDFG
1960	65	3,498	5	7	CDFG
1961	107	5,274	6	7	CDFG
1962	98	4,779	7	8	CDFG
1963	117	5,887	9	11	CDFG
1964	97	4,812	7	9	CDFG
1965	111	5,522	7	9	CDFG
1966		1,640		5	CDFG
1967		840		8	CDFG
1968		720		5	CDFG
1969		831		9	CDFG
1970	25	497	5	6	CDFG
1971	34	680	6	8	CDFG
1973	15	750	3	6	IATTC
1974	17	771	4	6	IATTC
1975	22	1,101	5	9	IATTC
1976	67	3,352	8	11	IATTC
1977	32	1,607	8	8	IATTC
1978	30	1,459	3	6	IATTC
1979	25	1,251	5	6	IATTC
1980	30	1,472	5	5	IATTC
1981	15	750	4	5	IATTC
1982	39	2,001	4	4	IATTC
1983	13	650	3	5	IATTC
1984	18	872	6	8	IATTC
1985	58	2,882	8	9	IATTC
1986	59	2,848	7	10	IATTC
1987	16	627	5	8	IATTC
1988	26	1,000	7	7	IATTC
1989	21	966	5	7	IATTC
Total		93,523			

TABLE 5. Numbers of individual length measurements of bluefin caught in the western and central Pacific Ocean in the files of the NRIFSF (after Ishizuka, 1989).

Year	Purse seine	Long-line	Bait-boat	Gill-net	Troll	Trap	Total
1948	0	15	0	0	0	0	15
1949	0	25	0	0	0	0	25
1950	339	34	0	0	0	13	386
1951	496	333	22	0	159	154	1164
1952	0	1122	78	0	88	0	1288
1953	0	2665	800	0	0	0	3465
1954	0	3943	880	0	0	14	4837
1955	87	4144	849	0	0	675	5755
1956	224	2673	597	0	0	2749	6243
1957	0	854	791	0	0	0	1645
1958	0	630	1585	0	0	0	2215
1959	2291	1218	211	0	0	0	3720
1960	0	3341	783	0	0	0	4124
1961	0	628	2712	0	0	0	3340
1962	0	2283	2441	0	0	0	4724
1963	0	1526	1531	0	0	0	3057
1964	0	1745	241	0	0	0	1986
1965	0	919	550	0	0	0	1469
1966	0	56	195	0	0	0	251
1967	77	191	25	0	0	0	293
1968	15	60	400	0	0	0	475
1969	47	1	0	0	0	65	113
1970	1	18	212	0	0	232	463
1971	0	25	0	0	0	0	25
1972	2	10	150	0	0	0	162
1973	0	2	0	0	0	0	2
1974	0	40	150	0	0	0	190
1975	60	24	25	0	1	0	110
1976	0	2	0	0	0	0	2
1977	608	3	1	0	31	21	664
1978	452	19	196	0	6	5	678
1979	2817	2	0	0	100	6	2925
1980	278	1	1	100	1	0	381
1981	751	1	0	0	0	0	752
1982	1471	1	52	0	0	6	1530
1983	143	0	0	0	0	0	143
1984	380	4	2	0	0	0	386
1985	542	0	16	0	0	0	558
1986	780	3	2	0	0	0	785
Total	11861	28561	15498	100	386	3940	60346

TABLE 6. Numbers of individual weight measurements of bluefin caught in the western and central Pacific Ocean in the files of the NRIFSF (after Ishizuka, 1989).

Year	Purse seine	Long-line	Night longline	Bait-boat	Gill-net	Troll	Trap	Hand line	Total
1948	0	0	0	0	0	0	0	0	0
1949	0	9	0	0	0	0	0	0	9
1950	0	0	0	0	0	0	0	0	0
1951	950	3	0	0	0	0	31	0	984
1952	774	298	0	0	0	0	0	0	1072
1953	1635	432	0	0	0	0	0	0	2067
1954	835	56	0	0	0	0	140	0	1031
1955	8574	462	0	0	0	0	1672	0	10708
1956	26842	534	0	0	0	0	7297	0	34673
1957	12194	887	0	0	0	0	2804	0	15885
1958	8405	792	0	22	0	0	1043	0	10262
1959	3657	2433	0	0	0	0	246	0	6336
1960	7214	8244	0	1	0	0	726	0	16185
1961	7313	12658	0	0	0	0	763	0	20734
1962	5598	11224	669	0	0	0	961	0	18452
1963	4899	11406	452	0	0	0	396	0	17153
1964	7547	5201	282	0	0	0	1336	0	14366
1965	6506	1637	183	0	0	0	499	0	8825
1966	658	1778	71	0	0	0	0	0	2507
1967	487	772	136	0	0	0	17	0	1412
1968	188	195	19	0	0	0	2	0	404
1969	2080	215	62	0	0	0	124	0	2481
1970	1471	199	0	0	0	0	375	0	2045
1971	3968	352	0	0	0	0	3373	0	7693
1972	27852	34	0	0	0	0	2489	0	30375
1973	16357	52	0	0	0	0	3054	0	19463
1974	21549	93	0	0	0	0	1213	0	22855
1975	76232	19	0	0	0	0	843	0	77094
1976	20077	190	0	378	0	0	6463	980	28088
1977	58360	958	0	0	0	1749	3499	197	64763
1978	64154	924	0	0	0	43	2353	0	67474
1979	105905	1128	0	0	0	69	1744	0	108846
1980	41751	336	0	0	245	7	2008	0	44347
1981	350933	693	0	0	0	1	1695	43	353365
1982	194331	1967	0	0	0	1	3481	0	199780
1983	158739	827	0	0	0	3	779	0	160348
1984	22328	108	0	0	0	2	216	0	22654
1985	41191	277	0	0	0	0	0	0	41468
1986	35115	139	0	0	0	0	0	0	35254
Total	1346669	67532	1874	401	245	1875	51642	1220	1471458

TABLE 7. Weight-length relationships for northern bluefin in the Pacific Ocean (after Anonymous, 1990). The units of measurement for the eastern Pacific relationships are millimeters and pounds and those for the western Pacific relationships are millimeters and kilograms.

Location	Year	Number of fish	Length range (mm)	Weight-length relationship	Reference
eastern Pacific	1962	295	541-1217	$w = (0.98404 \times 10^{-7}) l^{2.89727}$	Bell, 1964
eastern Pacific	1963	367	558-1784	$w = (0.20334 \times 10^{-6}) l^{2.79012}$	Bell, 1964
eastern Pacific	1963	1530	530-1780	$w = (2.01711 \times 10^{-7}) l^{2\ 79130}$	CDFG, unpublished
eastern Pacific	1964	1428	530-1340	$w = (8.51687 \times 10^{-8}) l^{2.91780}$	CDFG, unpublished
eastern Pacific	1965	1379	530-1680	$w = (1.00053 \times 10^{-7}) l^{2.89878}$	CDFG, unpublished
eastern Pacific	1966	1633	580-1280	$w = (1.92917 \times 10^{-7}) l^{2.79464}$	CDFG, unpublished
eastern Pacific	1967	837	580-1590	$w = (1.40579 \times 10^{-7}) l^{2.84694}$	CDFG, unpublished
eastern Pacific	1968	712	560-1400	$w = (2.78689 \times 10^{-7}) l^{2.74612}$	CDFG, unpublished
eastern Pacific	1969	807	520-1650	$w = (1.10923 \times 10^{-7}) l^{2.88084}$	CDFG, unpublished
eastern Pacific	1970	496	600-1480	$w = (2.70807 \times 10^{-7}) l^{2.74715}$	CDFG, unpublished
eastern Pacific	1971	680	550-1110	$w = (1.08211 \times 10^{-7}) l^{2.84490}$	CDFG, unpublished
eastern Pacific	1974	439	620-1060	$w = (1.10976 \times 10^{-7}) l^{2.88289}$	CDFG, unpublished
eastern Pacific	1988	49	1670-2712	$w = (4.83281 \times 10^{-7}) l^{2.69524}$	IATTC, unpublished
eastern Pacific	1989	101	600-971	$w = (6.99681 \times 10^{-8}) l^{2.95378}$	IATTC, unpublished
southern Kyushu	1980	456	350-658	$w = (1.82335 \times 10^{-9}) l^{3.39759}$	Anonymous, 1981
Sea of Japan	1980	316	438-592	$w = (5.20535 \times 10^{-9}) l^{3.23300}$	Anonymous, 1981
Sea of Japan	1980	232	980-2150	$w = (2.40558 \times 10^{-8}) l^{2.96916}$	Anonymous, 1981
Kochi	1980	308	155-296	$w = (2.87819 \times 10^{-9}) l^{3.33350}$	Anonymous, 1981
Kochi	1981	36	158-226	$w = (4.12648 \times 10^{-10}) l^{3.67388}$	IATTC, unpublished
Kochi	1982	131	177-326	$w = (4.55313 \times 10^{-10}) l^{3.67000}$	IATTC, unpublished
western Pacific			≤ 994	$w = (1.231 \times 10^{-4}) l^{2.5939}$	Ishizuka, 1989
western Pacific			>994	$w = (4.073 \times 10^{-5}) l^{2.8344}$	Ishizuka, 1989

TABLE 8. Data on the sex ratios of bluefin tuna in the Pacific Ocean. The length range for 1988 is the length range for the 987 fish in the catch, rather than for the 45 fish in the sample.

Area	Year	Length range (mm)	Gear	Males	Females	Reference
eastern Pacific	1960	770-892	purse seine	40	35	Bell, 1963a
eastern Pacific	1988	1300-2710	purse seine	45	0	Foreman and Ishizuka, 1990
Lingaen Bay (west. Pacif.)	1938		longline	46	36	Yamanaka and staff, 1963
Formosa (west Pacif.)	1952-1953		longline	28	47	Yamanaka and staff, 1963
Sanriku (west. Pacif.)	1952-1953		longline	29	22	Yamanaka and staff, 1963

3.5 Maturation and spawning

Hirota *et al.* (1976) reported that a male northern bluefin reared in captivity matured at 3 years of age and that a female of the same age appeared to be approaching maturity. The lengths of these fish (male, 1190 mm; female, 1353 mm) were considerably in excess of the average lengths of 3-year-old fish given in Table 11. Nakamura (1943; cited by Hirota *et al.*, 1976) stated that bluefin mature at 3 years of age in nature. Harada (1980), however, stated that spawning of bluefin occurs at about 5 years of age, and that the lengths and weights of these fish are about 150 cm and 60 kg, respectively.

Fish of 270 to 300 kg have about 10 million eggs (Yamanaka and staff, 1963). No information is available on the frequency of spawning.

Spawning occurs between Japan and the Philippines in April, May, and June and off southern Honshu in July (Yamanaka and staff, 1963; Yabe *et al.*, 1966; Nishikawa *et al.*, 1985). Okiyama (1974 and 1979) found larvae in the Sea of Japan, and considered them to have resulted from spawning in that area. In addition, Miller (1979) reported larvae of this species from the Hawaiian Islands. Bruce C. Mundy, U.S. National Marine Fisheries Service, Honolulu, Hawaii (personal communication), however, reports that no bluefin larvae were found in 460 plankton samples collected 1 to 15 nautical miles off Oahu during 1985 and 1986.

3.6 Tagging

Release and return data for tagged northern bluefin are given in Tables 9 and 10. In addition, small tagged bluefin were released off the Japan Sea coast of Hokkaido during 1933 and 1934 (Yamanaka and staff, 1963) and off southeastern Japan in 1965 (Clemens and Flittner, 1969). Two of the fish released in 1965 were recaptured in the eastern Pacific Ocean about 1 year later.

4 ESTIMATION OF PARAMETERS

4.1 Age and growth

The maximum lengths and weights recorded for northern bluefin in the Pacific Ocean, from Foreman and Ishizuka (1990), are as follows:

Location	Date	Length (cm)	Weight (kg)
between 27° and 29°N and 130° and 133°E	April 1986	ca. 300	ca. 555.5
San Nicolas Island (ca. 33°30'N-119°30'W)	December 18, 1988	271	458

The parameters of the von Bertalanffy growth equation for the northern bluefin in the Pacific Ocean have been estimated by various workers from analyses of hard part, length-frequency, and tagging data. These data are summarized in Table 11. The estimates of the average lengths at ages 1-6 are fairly close to one another, but the estimates of L_∞ and K of Anonymous

TABLE 9. Summary of data for tagged bluefin released in the eastern Pacific Ocean. USBCF, CDFG, and MBRF stand for U.S. Bureau of Commercial Fisheries, California Department of Fish and Game, and Mission Bay Research Foundation, respectively.

Organization(s)	Dates of release	Gear at release	Released	Returned East	Returned West	Percent returned
CDFG	Aug. 1953	troll	3	*	*	*
CDFG	Aug.-Sep. 1954	troll	1	*	*	*
CDFG	Sep. 1955	purse seine	50	*	*	*
CDFG	Aug.-Sep. 1956	troll	9	≥1	*	*
IATTC	Jan.-Feb. 1958	purse seine	122	8	1	7.4
USBCF	Jul. 1961	gill net	1	1	0	100.0
USBCF-CDFG	Aug. 1962	purse seine	960	170	5	18.2
USBCF-CDFG	Jul.-Aug. 1963	purse seine	543	83	0	15.3
CDFG-MBRF	Aug. 1963	purse seine	100	32	0	32.0
USBCF-CDFG	Aug. 1964	purse seine	782	172	3	22.4
CDFG-MBRF	Aug. 1964	purse seine	175	28	0	16.0
CDFG-MBRF	Aug.-Sep. 1964	sport	2	0	0	0.0
CDFG-MBRF	Aug. 1965	sport	1	0	0	0.0
CDFG-MBRF	Jun. 1966	purse seine	237	65	0	27.4
CDFG	Jul. 1968	purse seine	35	6	0	17.1
IATTC	Aug. 1979	purse seine	300	39	1	13.3
IATTC	Aug.-Sep. 1980	purse seine	114	7	0	6.1
Total		purse seine	3,418	610	10	18.1
		other	17	≥2	*	*

*no information available

TABLE 10. Releases and recaptures of bluefin tagged off Japan during 1980-1988 (from Bayliff, Ishizuka, and Deriso, 1991). The abbreviations are as follows: W, western Pacific; C, central Pacific (between 160°E and 130°W); E, eastern Pacific; FSFRL, Far Seas Fisheries Research Laboratory.

Release			Recapture																	
Year class	Organization	Number	Year 0			Year 1			Year 2			Year 3			Year 4			Total		
			W	C	E	W	C	E	W	C	E	W	C	E	W	C	E	W	C	E
1979	IATTC	739	-	-	-	157	0	0	33	0	24	9	1	0	3	0	0	202	1	24
1980	IATTC	106	10	0	0	1	0	0	1	0	0	0	0	0	0	0	0	12	0	0
	FSFRL	802	64	0	0	46	0	0	8	0	4	2	0	0	0	0	0	120	0	4
1981	IATTC	3,297	264	0	0	48	2	24	5	0	1	0	0	0	0	0	0	317	2	25
	FSFRL	1,653	127	0	0	67	3	21	17	0	3	2	0	0	0	0	0	213	3	24
1982	IATTC	237	24	0	0	5	0	0	0	0	0	0	0	0	0	0	0	29	0	0
	FSFRL	614	2	0	0	25	0	0	3	0	1	2	0	1	0	0	0	32	0	2
1983	FSFRL	788	8	0	0	111	0	1	9	0	19	1	0	0	0	0	0	129	0	20
1984	FSFRL	1,944	109	0	0	54	0	2	3	0	26	0	0	0	0	0	0	166	0	28
1985	FSFRL	993	1	0	0	84	0	0	10	0	4	1	0	0	-	-	-	96	0	4
1986	FSFRL	863	45	0	0	37	0	0	0	0	1	-	-	-	-	-	-	82	0	1
1987	FSFRL	729	35	0	0	10	0	1	-	-	-	-	-	-	-	-	-	45	0	1
1988	FSFRL	588	14	0	0	-	-	-	-	-	-	-	-	-	-	-	-	14	0	0
Total		13,353	703	0	0	645	5	49	89	0	83	17	1	1	3	0	0	1,457	6	133

TABLE 11. Age and growth data for bluefin in the Pacific Ocean. The lengths are given in centimeters. Schultze and Collins' (1977) estimates are attributed to an unpublished thesis (their Table 1). The sample of Bell (1963b) consisted of 247 fish, of which approximately half had legible scales.

Method	Sample size	Age										L_∞	K (annual)	t_0 (annual)	Reference
		1	2	3	4	5	6	7	8	9	10				
hard parts	21	43	69	94	118	145	168	190	210	230	250				Aikawa and Katô, 1938
length frequencies	4,156	50.0	90.0	125.0	154.0	176.0	198.0	215.0	229.0	241.0		300.0			Yokota et al., 1961
hard parts	about 124	57.10	72.06	90.65	106.95	128.50	142.00								Bell, 1963b
hard parts	97	51.8	78.2	102.0	123.5	142.9	160.3	176.1	190.3	203.1	214.6	320.5	0.1035	-0.7034	Yukinawa and Yabuta, 1967
hard parts	2,743	53.0	80.4	104.8	126.3	145.5	162.4					295.4			Schultze and Collins, 1977
hard parts	232	49.1	71.1	92.4	113.1	133.0	152.2					703.6	0.0343	1.107	Anonymous, 1986b
tagging	84											219	0.211		Anonymous, 1985: 258

(1986b) are considerably greater and less, respectively, than those of the other workers.

Bayliff *et al.* (1991), studied the growth of northern bluefin from tagging experiments. They had 721 fish with data for the dates and lengths at both release and recapture. Because the data included many fish less than 30 cm in length at release and many fish at liberty less than 1 year, and relatively few larger fish or fish at liberty more than 1 year, the data were combined into 84 groups. The times at liberty and lengths at release selected were 1-30, 31-60, 61-90, ... days and 151-200, 201-250, 251-300, ... mm, respectively, and the means of each group were calculated and substituted for individual values. They found that the growth of bluefin in the length range of about 16 to 153 cm is best described by a two-stage model, the growth of the fish less than or equal to 564 mm following the Gompertz model and that of the fish equal to or greater than 564 mm being linear. The relationship between length in millimeters and time in days is expressed by the following equations:

fish less than or equal to 564 mm

$$L_{t2}^{\lambda} = L_{\infty}^{\lambda} + (L_{t1}^{\lambda} - L_{\infty}^{\lambda})e^{-K(t_2 - t_1)}$$

where

L_t = length at time t (t_1 is a time prior to t_2),
λ = 0.001,
L_∞ = 581 mm, and
K = coefficient of growth = 0.01184 per day.

fish equal or greater than 564 mm

$$L_t = 564 + 0.709\Delta t$$

where

Δt = time, in days, elapsed since L_t = 564 mm.

Preliminary studies of growth from length-frequency data, using data for fish in the range of about 60 to 100 cm, indicate that the growth is about 0.7 mm per day, on an annual basis, which corresponds closely to the value of 0.709 estimated for the linear component of growth from tagging data. The length-frequency data, however, indicate that the growth rate is more rapid in the summer and less rapid in the winter.

4.2 Natural mortality

There are no data available for estimating directly the coefficient of natural mortality of northern bluefin in the Pacific Ocean. Pauly (1980) used data on the growth, mortality, and mean environmental temperatures of 175 stocks of fish to calculate the following equation:

$$\ln M = -0.0066 - 0.279\ln L_\infty + 0.6543\ln K + 0.4634\ln T$$

where

M = coefficient of natural mortality,
L_∞ = asymptotic length in von Bertalanffy equation,
K = coefficient of growth in von Bertalanffy equation, and
T = mean environmental temperature.

Values of 223 cm and 0.18 for L_∞ and K, respectively, are given by Bayliff *et al.* (1991: Table 5, line 1). (It should noted, however, that the best fit to the growth data was not a von Bertalanffy curve, but a Gompertz curve for fish between 16 and 56.4 cm and a straight line for fish from 56.4 cm to 153 cm.) Pauly (1980) states that, "the values of L_∞ used [to derive the equation] pertain mostly to total length," so the value of 223 cm for the fork length was converted to 257 cm for the total length by the formula

$$\mathrm{TL} = -17.42 + 1.158\mathrm{FL}$$

where TL = total length and FL = fork length, both in millimeters. Bell (1963a) states that bluefin are found in water with surface temperatures of 17° to 23°C, so 20 was substituted for T. This gives an estimate of 0.276 for M for fish in the range of about 16 to 153 cm. The standard deviation for $\ln M$ is 0.245 (Pauly, 1980), so the 90-percent confidence limits of the estimate are about 0.161 and 0.471.

5 PREDATOR-PREY RELATIONSHIPS

Doi (1960) used data on the catches of northern bluefin and of squid and five species of smaller fishes as indices of their abundance, and then applied Volterra's predator-prey equations to the data to compare the observed and theoretical abundances. The actual and expected results were fairly close for the bluefin-squid model for 1951-1955 and for the bluefin-squid plus smaller fishes model for 1951-1956. Yokota *et al.* (1961) discussed bluefin as a prey species and as a predator species. Kida (1936) said that a "certain connexion seems to exist between the incoming schools of sardine [*Sardinops melanosticta*] ... on one side and the [bluefin] fishery on the other," and, according to Yamanaka and staff (1963), "Nakamura (1949) reported that ... the route of the northward migration of this species coincides with that of the migration of the sardine; ... when sardine suddenly decreased, the fishing of [bluefin] simultaneously declined. Uda (1960) reported that (i) the resources of both this species and of sardine were large from 1933 to 1940, but on and after 1941 decreased simultaneously; (ii) with the decrease in resources, the northern limitation of the area of occurrence for both kinds of fishes shrank southward."

6 LIFE HISTORY AND STOCK STRUCTURE

A model of the life history and stock structure of northern bluefin in the Pacific Ocean has been formulated. This model was first described by Bayliff (1980), but it has been modified considerably since then due to the acquisition of additional data for returns of tagged fish.

Figure 8 is a diagram of the model. The migrations shown by dashed lines are more speculative than those shown by solid lines. The diagram is intended to show the general areas where the migrations are believed to begin and end, but not the precise routes, as space limitations would make this impractical

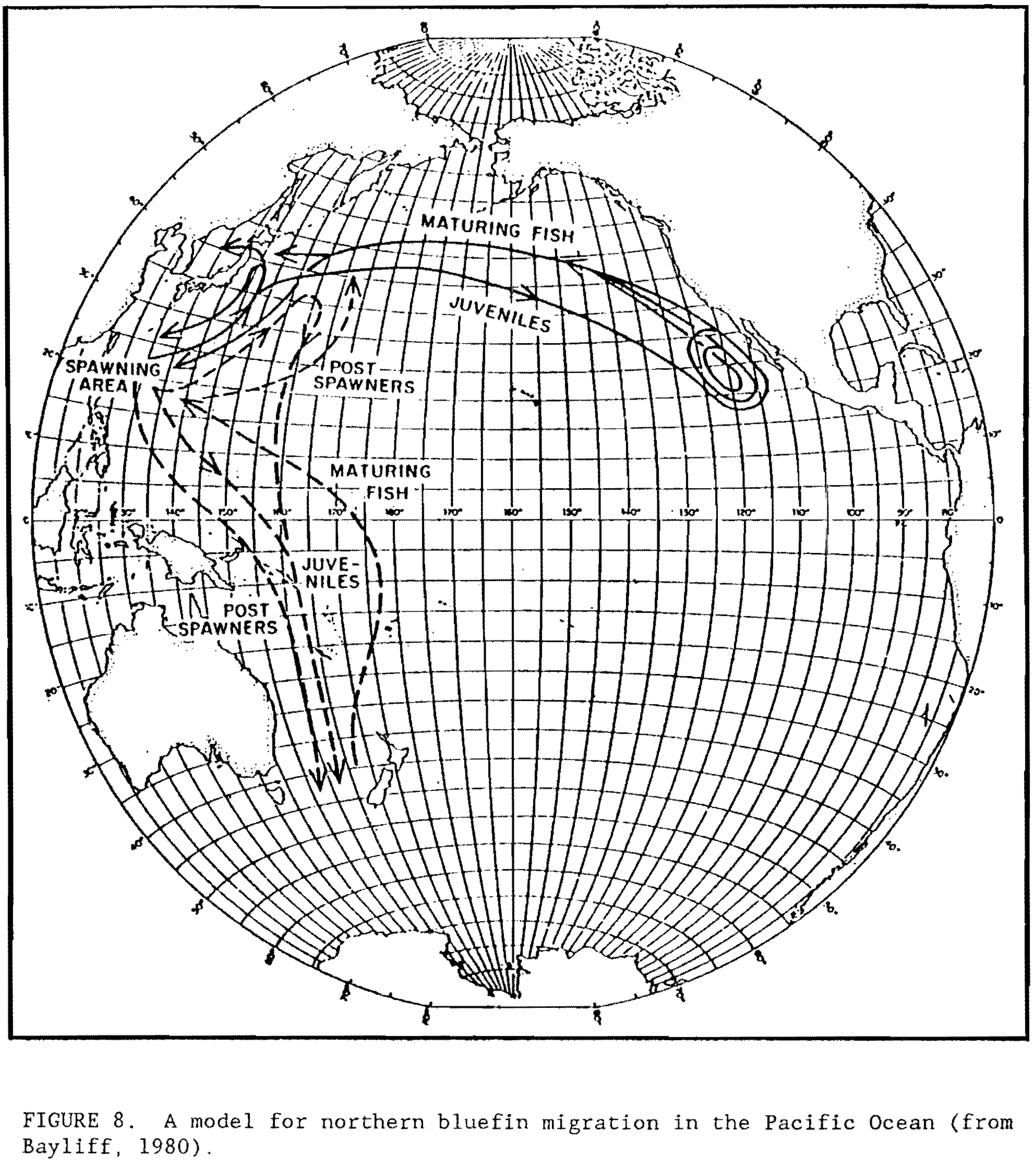

FIGURE 8. A model for northern bluefin migration in the Pacific Ocean (from Bayliff, 1980).

even if the routes were known. For example, it appears that the route of migration of juveniles bound for the eastern Pacific is south of the route of migration of maturing fish bound in the opposite direction, but such is not necessarily the case.

The spawning of northern bluefin occurs between Japan and the Philippines in April, May, and June, off southern Honshu in July, and in the Sea of Japan in August (Yamanaka and staff, 1963; Yabe *et al.*, 1966; Okiyama, 1974 and 1979; Nishikawa *et al.*, 1985). The larvae, postlarvae, and juveniles produced south of Japan are carried northward by the Kuroshio Current toward Japan. Fish of age 0 about 15 to 60 cm in length are caught in the vicinity of Japan during the summer, fall, and winter of their first year of life (Yabe *et al.*, 1966; Yukinawa and Yabuta, 1967). The results of tagging experiments indicate that some of these remain in the western Pacific Ocean and others depart for the eastern Pacific during the fall or winter of their first year of life or the summer, fall, or winter of their second year of life. If the fish are restricted to the temperature range given in Section 2.3 when crossing the ocean, they probably occur mostly in the regions shown in Figure 5. The journey from the western to the eastern Pacific takes as little as 7 months, or perhaps even less. Of 121 such migrants for which dates of recapture were obtained, 23 had been at liberty 215 to 358 days and 98 had been free for 368 to 999 days. It is possible that other fish migrate from the western to the eastern Pacific later in life, but there is no information concerning this because few tagged fish greater than about 1 year of age have been released in the western Pacific.

The fish which migrate from the western to the eastern Pacific form the basis for the fishery in the eastern Pacific, which takes place principally during May through October. In Figure 8 it appears that the fish in the eastern Pacific occur further and further offshore and have an increasingly restricted north-south distribution as they grow older. It was necessary for the sake of clarity to make the diagram this way, but actually such is not necessarily the case. Fish less than about 100 cm in length, which make up the bulk of the eastern Pacific catch, may or may not leave the eastern Pacific Ocean each fall or winter. Northern bluefin of that size are seldom caught in the eastern Pacific during November-April, which might indicate that they have left that region. They probably do not go all the way to the western Pacific, however, as no tagged fish released in the eastern Pacific have been recaptured in the western Pacific after less than 674 days at liberty (Table 12); if most of them migrated to the western Pacific each fall or winter and back to the eastern Pacific each spring some would probably have been recaptured in the western Pacific in the winter or early spring after less than about 100 to 150 days at liberty. Also, the energy costs of making such a long migration are so great that it would probably not be feasible for a fish to make two such migrations each year for several years.

The length of the sojourn in the eastern Pacific appears to be variable. Tagged fish believed to have been 1 year of age at the time of release in the eastern Pacific have been recaptured 2 years later in the western Pacific, but other tagged fish released in the eastern Pacific have been recaptured in the eastern Pacific after as long as 2 years at liberty. Fish of at least 6 or 7 age groups are caught in the eastern Pacific (Bell, 1963b; Schultze and Collins, 1977), so it is possible that some fish stay in that region for at least 5 or 6 years.

TABLE 12. Data on releases and recaptures of tagged bluefin which crossed the Pacific Ocean from east to west (from Bayliff, Ishizuka, and Deriso, 1991).

Tag number	Release			Recapture			Days free	Distance	Gear
	Date	Location	Length	Date	Location	Length			
N1033	Feb. 2, 1958	28°45'N-118°15'W	?	Apr. 23, 1963	29°03'N-139°42'E	1,825	1,907	5,147	longline
A0374	Aug. 15, 1962	29°43'N-117°20'W	?	Jun. 18, 1964	40°44'N-140°00'E	?	674	4,781	trap
A0405	Aug. 15, 1962	29°43'N-117°20'W	?	Aug. 17, 1964	41°39'N-141°09'E	1,150	734	4,708	longline
A0575	Aug. 16, 1962	29°50'N-117°13'W	?	Aug. 29, 1964	41°15'N-140°43'E	?	745	4,737	sport
A0189	Aug. 14, 1962	29°48'N-116°57'W	?	Jun. 23, 1965	34°16'N-136°54'E	1,380	1,045	5,124	trap
A0603	Aug. 21, 1962	33°21'N 119°01'W	?	Aug. 10, 1965	41°43'N-141°03'E	1,200	1,086	4,514	troll
A1950	Aug. 20, 1964	32°41'N 117°55'W	600	Jul. 1, 1966	38°25'N-139°15'E	1,100	681	4,746	trap
A1608	Aug. 13, 1964	30°30'N-116°45'W	850	Jul. 4, 1968	38°49'N-142°28'E	?	1,422	4,734	purse seine
A2123	Aug. 20, 1964	32°41'N-117°55'W	650	Jul. 14, 1968	39°37'N-143°16'E	1,580	1,425	4,549	purse seine
P3134	Aug. 16, 1979	31°19'N-117°50'W	850	Apr. 29, 1982	33°00'N-136°30'E	1,526	988	5,092	purse seine

After a sojourn in the eastern Pacific, which may or may not be interrupted by temporary visits to the central or western Pacific, the survivors return to the western Pacific, where they eventually spawn. If the fish are restricted to the temperature range given in Section 2.3 when crossing the ocean, they probably occur mostly in the regions shown in Figure 5. The return journey from the eastern to the western Pacific may take nearly 2 years, as 674 days is the minimum time recorded between release and recapture of a tagged fish making this migration (Table 12).

Large fish are occasionally caught in the eastern Pacific Ocean, especially in the vicinity of Guadalupe Island, Mexico, and the Channel Islands, off Southern California (Calkins, 1982: Figures 5 and 6; Anonymous, 1987: Figure 22; Anonymous, 1991: Figure 20). The largest of these are probably over 10 years old. These have not necessarily resided in the eastern Pacific Ocean since they were about 1 to 2 years old. They may have arrived for the first time shortly before they were caught, or they may have made more than one round trip across the Pacific. It seems unlikely that all the large fish could spawn in the western Pacific each year, as some have been caught during or shortly before or after the spawning season, *e.g.* July 1978 (Calkins, 1982: Figure 6).

Many of the fish caught by longliners in the mid-Pacific (Figure 3) are presumably *en route* from the eastern to the western Pacific. Upon arriving in the western Pacific they presumably proceed to one or more of the spawning areas to spawn, either immediately or eventually.

Northern bluefin are also caught by longline vessels east of the Philippines, northeast of Papua New Guinea, and southeast of Australia, especially in the vicinity of New Zealand (Figure 3), and by sport gear in the Gulf of Papua (Collette and Smith, 1981). The question arises as to whether these fish come from juveniles which went south from one of the spawning areas, from immature fish which migrated south from Japan after a brief sojourn there, or from older fish which migrated south from the spawning area after spawning. If either the first or second possibility is the case there should be small bluefin south of 20°N. Small numbers of baitboat-caught northern bluefin have been recorded north of Papua New Guinea and in the vicinity of the Solomon and Marshall Islands (Anonymous, 1977b, 1977c, 1977d, 1977e, and 1977f; Figure 9), so it appears that at least some of the northern bluefin caught south of the spawning grounds by longline vessels are the result of movement of juveniles from the spawning area or the result of migration of immature fish south from Japan. However, this does not mean that none of them are the result of movement of adult fish south from the spawning areas after spawning.

Larvae or postlarvae of northern bluefin have not been found in the Australia-New Zealand area, so it does not appear that the fish which were caught there by longlines would have spawned there. Rather, they would have to migrate back to the spawning area or not spawn at all. It seems unlikely that all the large fish found in the southwestern Pacific spawn in the northwestern Pacific each year, as the large bluefin reported by Collette and Smith (1981) off Papua New Guinea was caught in April. Also, the bluefin reported by de Buen (1958) in the southeastern Pacific were caught in April and May, during the spawning season.

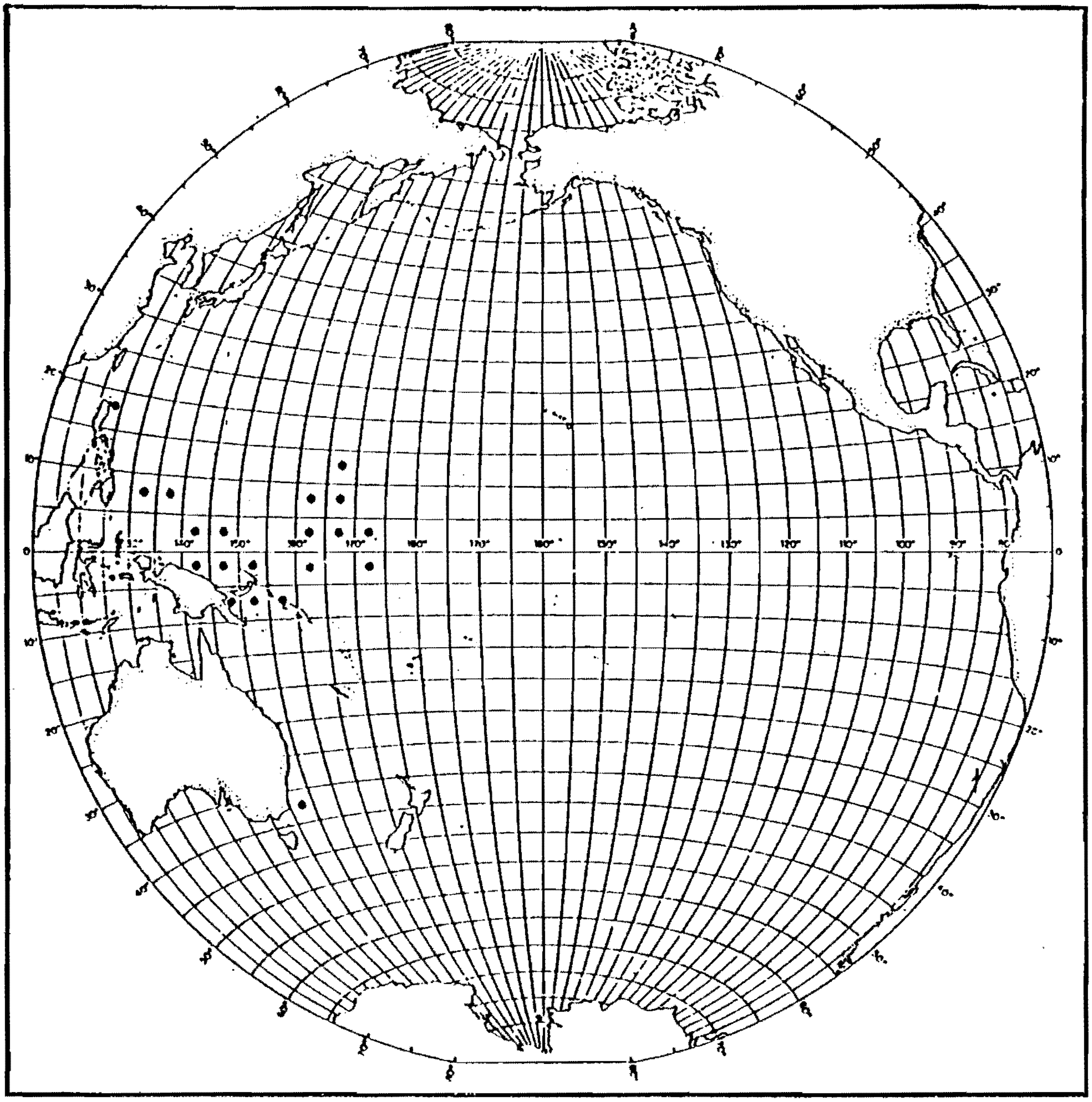

FIGURE 9. Five-degree areas south of 20°N in the Pacific Ocean in which northern bluefin were caught by surface gear during 1982-1976 (from Bayliff and Calkins, 1979).

After spawning the fish probably disperse from the spawning area to other areas of the western Pacific. Some may even migrate to the eastern Pacific, as large fish are found there (see above). The following year, if they have not travelled too far, they presumably return to the spawning areas to spawn again.

7 STOCK ASSESSMENT

7.1 Yield-per-recruit relationships

A yield-per-recruit analysis has been performed for northern bluefin, using the data in Table 13 and Figure 10. The annual coefficient of natural mortality was set at 0.2 and 0.3, and the annual coefficients of fishing mortality were set at 1.0 for the periods of substantial catches, 0.0 for the periods of zero or very low catches, and 0.5 for the periods of transition. The data in Figure 10 are based upon what are believed to be three of the most common scenarios for individual fish: remaining throughout life in the western Pacific Ocean (Option 0); beginning a west-east migration during the first year of life and then beginning an east-west migration during the third year of life (Option 1); and beginning a west-east migration during the second year of life and then beginning an east-west migration during the third year of life (Option 2). Graphs showing the yields per recruit possible with different ages of entry into the fishery, and with three multipliers of the vector of fishing effort, are shown in Figure 11. Because the values of the natural and fishing mortality, especially the latter, are little more than guesses, the results of these analyses should not be taken literally. Nevertheless, it appears that increasing the age at entry into the fishery to about 2 1/2 years (about 90-100 cm) would maximize the overall yields of fish which migrate to the eastern Pacific Ocean, and increasing the age at entry to about 4 years (about 130-140 cm) would maximize the yields of fish which remain in the western Pacific.

7.2 Cohort analysis

The fish in the catches of the eastern Pacific Ocean have been assigned to ages (1, 2. and older then 2) on the basis of length frequencies. The growth estimated from these data has been extrapolated to assign the older fish to ages 3, 4, and older than 4 (Table 14) for use in a cohort analysis. Data on the age composition of northern bluefin caught in the western Pacific are shown in Table 15. In these tables all fish caught during the calendar year in which they were hatched are referred to as age-0 fish, all fish caught during the calendar year after that in which they were hatched are referred to as age-1 fish, and so on.

Cohort analyses were run, using the data in Tables 14 and 15 and the methods described by Abramson and Tomlinson (1972). The annual instantaneous rate of natural mortality, *M*, was set at 0.2 and 0.3 and the annual instantaneous rate of fishing mortality, *F*, for the last cohort (>4) of the 1966 year class was set at 0.1. The results are shown in Table 16. It can be seen that the catches in the western Pacific usually exceed those in the eastern Pacific for all ages except the 2-year olds. The 1969 year class, which was about average (Table 16, second column), produced very poor catches of age-2 fish in the western Pacific and excellent catches of age-2 fish in the eastern Pacific. The 1972 year class, which was a little below average

TABLE 13. Growth and weight-length data used for estimation of yields per recruit of northern bluefin.

Age in years	Equation	Units of measurement	Source
Growth			
0.125-0.917	$L_{t2}^{\lambda} = L_{\infty}^{\lambda} + (L_{t1}^{\lambda} - L_{\infty}^{\lambda})e^{-K(t_2 - t_1)}$	millimeters, days	this report, Section 5.1
0.917-4.500	$L_t = 564 + 0.709\Delta t$	millimeters, days	this report, Section 5.1
5.500-13.500	$L_t = 1482 + 105.9\Delta t$	millimeters, years	linear interpolation
14.500	$L_t = 320.5(1 - e^{-0.1035(t + 0.7034)})$	centimeters, years	this report, Table 11
Weight-length			
0.125-1.042	$w = (1.82335 \times 10^{-9})l^{3.39759}$	millimeters, kilograms	this report, Table 7
1.042-14.500	$w = (2.01711 \times 10^{-7})l^{2.79130}$	millimeters, pounds	this report, Table 7

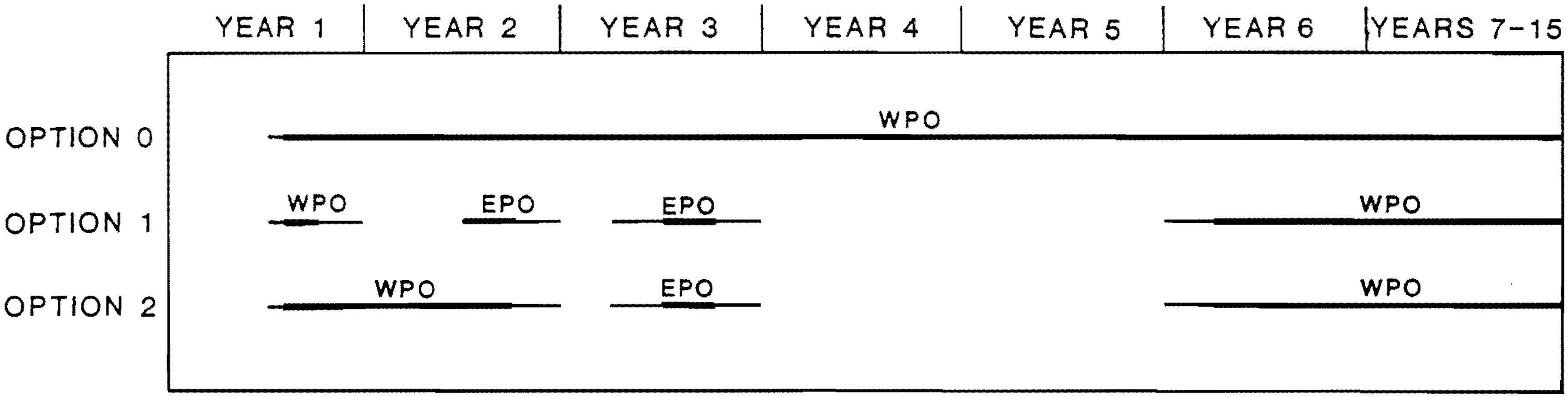

FIGURE 10. Fishing mortality rates used for estimation of yield-per-recruit curves for northern bluefin. WPO and EPO stand for western Pacific Ocean and eastern Pacific Ocean, respectively. The heavy and light segments of the lines indicate annual instantaneous fishing mortality rates of 1.0 and 0.5, respectively, and the blank areas between segments of the lines indicate no fishing. The options are described in the text.

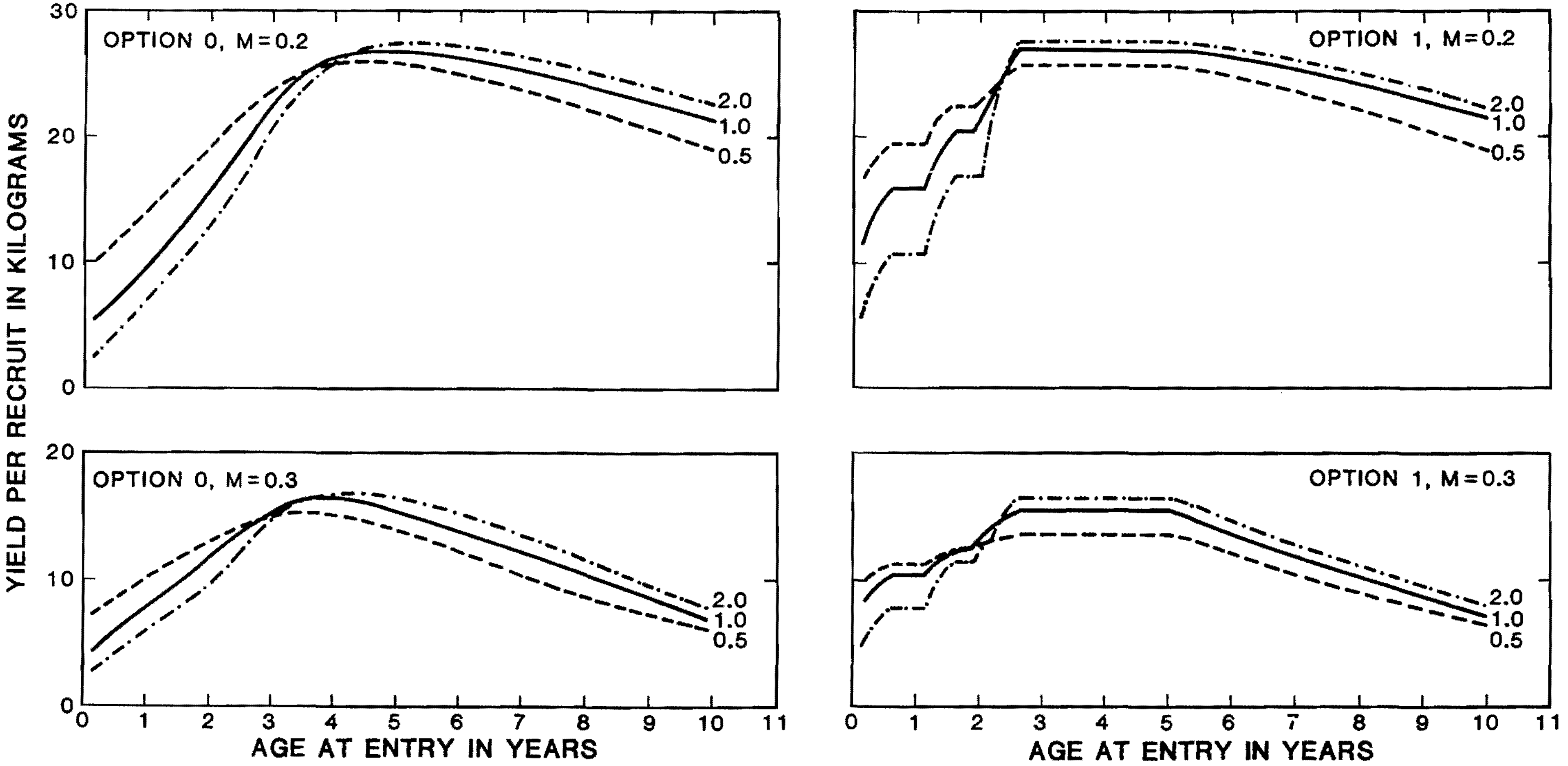

FIGURE 11. Yield-per-recruit curves for northern bluefin, based on the data in Table 13 and Figure 10. The three values, 0.5, 1.0, and 2.0, represent multipliers of the vectors of fishing mortality shown in Figure 10. The horizontal portions of the curves are caused by lack of fishing effort during those periods.

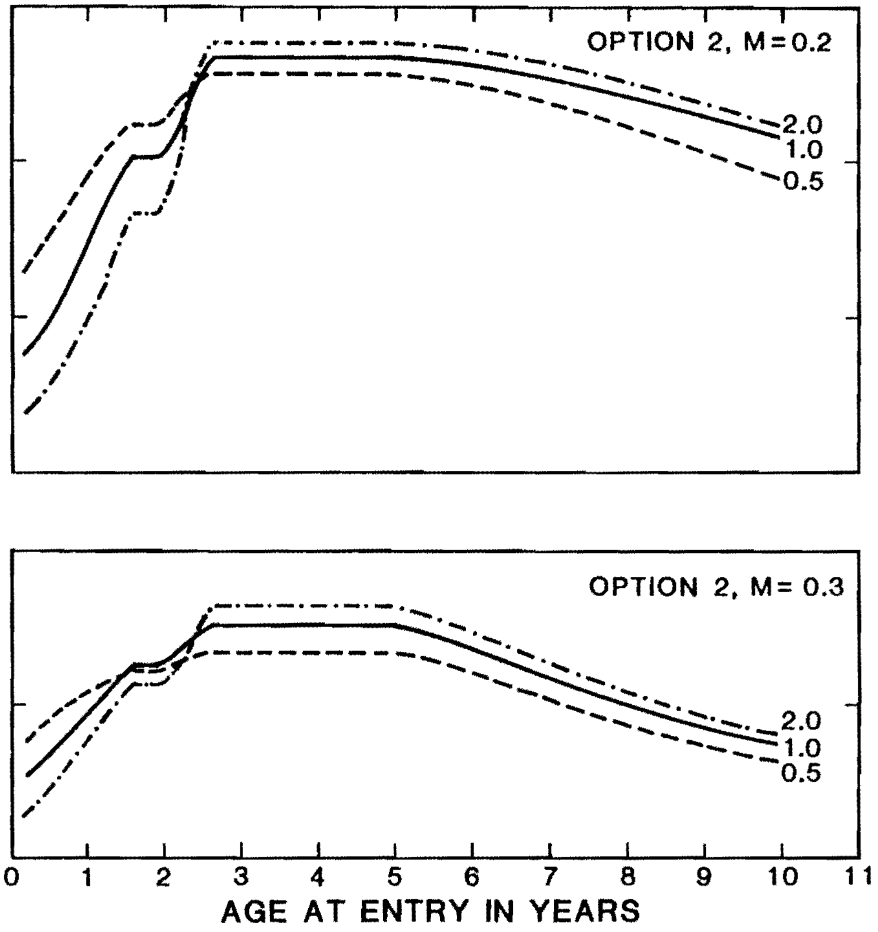

FIGURE 11. (continued)

TABLE 14. Estimated numbers of bluefin, in thousands, caught in the eastern Pacific Ocean.

	Year caught											
Age	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
1	17	24	577	990	501	982	333	622	97	416	290	13
2	121	47	298	450	529	202	288	715	308	155	311	256
3	65	23	10	16	51	38	16	35	34	5	32	29
4	2	63	<1	2	10	5	5	0	1	0	1	<1
>4	<1	3	0	1	7	0	2	0	<1	0	1	<1

	Year caught											
Age	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
1	366	-	810	163	439	483	50	473	161	118	6	281
2	556	-	458	407	529	173	211	94	457	225	60	88
3	4	-	0	<1	18	131	21	10	0	1	12	2
4	0	-	0	0	3	29	23	10	0	0	0	3
>4	0	-	0	0	0	3	13	8	0	0	0	<1

	Year caught					
Age	1983	1984	1985	1986	1987	1988
1	28	35	117	40	16	27
2	69	42	272	369	62	47
3	1	<1	0	<1	<1	1
4	1	1	0	<1	2	<1
>4	1	<1	0	<1	<1	1

TABLE 15. Estimated numbers of bluefin, in thousands, caught in the western Pacific Ocean (after Ishizuka, 1989).

	Year caught											
Age	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
0	1270	3607	2300	2970	1938	3316	498	4875	3953	1277	1784	2542
1	266	461	964	371	378	443	682	124	1403	676	222	698
2	91	3	1	78	48	2	15	20	28	46	96	61
3	62	5	52	13	23	14	18	4	12	115	61	44
4	30	8	17	1	17	24	18	16	3	29	26	95
5	25	22	41	5	5	3	34	15	11	10	8	10
6	63	7	28	19	16	7	7	19	27	10	6	14
7	1	22	22	9	13	15	6	8	30	9	2	2
8	2	21	7	2	1	11	4	5	13	6	4	1
9	4	4	4	1	<1	2	1	2	7	2	4	1
10	3	2	3	1	<1	1	<1	1	5	1	1	1
11	1	1	2	1	<1	<1	<1	1	2	<1	<1	<1
12	<1	<1	1	1	<1	<1	<1	<1	<1	<1	<1	<1
13	<1	<1	<1	<1	<1	<1	0	<1	<1	<1	<1	<1
14	<1	<1	0	0	0	0	<1	<1	<1	<1	0	<1
15	0	<1	0	0	0	<1	0	<1	0	0	0	<1
16	0	<1	0	0	0	0	0	<1	0	0	<1	0

	Year caught								
Age	1978	1979	1980	1981	1982	1983	1984	1985	1986
0	5091	2088	2810	1975	665	1362	2417	2046	1470
1	478	1452	611	605	785	213	421	757	760
2	151	98	119	180	200	139	44	49	61
3	14	38	76	584	64	54	21	86	123
4	10	28	7	84	99	56	15	75	30
5	87	15	11	32	73	71	15	4	24
6	20	72	3	26	22	43	4	3	3
7	31	61	27	5	19	13	4	2	2
8	5	4	51	10	11	4	5	2	3
9	2	1	7	15	10	3	3	2	4
10	2	1	3	2	13	2	3	2	4
11	1	1	2	1	3	2	4	2	4
12	1	<1	1	<1	1	1	1	1	2
13	<1	<1	<1	<1	<1	<1	<1	<1	1
14	<1	<1	<1	<1	<1	<1	<1	<1	<1
15	<1	<1	<1	0	<1	<1	<1	<1	<1
16	<1	<1	<1	0	<1	0	<1	0	<1

TABLE 16a. Results of the cohort analysis described in the text, with an annual coefficient of natural mortality of 0.2. IPS, WPO, EPO, F, and Mort. stand for initial population size, catch in **western** Pacific Ocean, catch in eastern Pacific Ocean, annual coefficient of fishing mortality, and natural mortality, respectively. All the values except those for F are thousands of fish.

Year class	Age 0					Age 1				
	IPS	WPO	EPO	F	Mort.	IPS	WPO	EPO	F	Mort.
1966	2755	1270	0	0.70	363	1122	461	97	0.78	143
1967	6892	3607	0	0.84	856	2429	964	416	0.96	288
1968	4220	2300	0	0.90	512	1408	371	290	0.72	185
1969	4956	2970	0	1.05	566	1420	378	13	0.36	217
1970	3655	1938	0	0.86	450	1267	443	366	1.17	138
1971	5989	3316	0	0.92	721	1952	682	292	0.78	249
1972	3499	498	0	0.17	585	2416	124	810	0.55	340
1973	10916	4875	0	0.67	1458	4583	1403	163	0.47	668
1974	6595	3953	0	1.05	753	1889	676	439	1.02	218
1975	3094	1277	0	0.60	426	1391	222	483	0.80	176
1976	3472	1784	0	0.82	435	1253	698	50	1.04	143
1977	5743	2542	0	0.66	771	2430	478	473	0.56	341
1978	9912	5091	0	0.82	1243	3578	1452	161	0.68	476
1979	3978	2088	0	0.85	493	1397	611	118	0.84	174
1980	4518	2810	0	1.12	502	1206	605	6	0.80	152
1981	4603	1975	0	0.63	625	2003	785	281	0.87	247
1982	1662	665	0	0.57	231	766	213	28	0.42	114
Average	5086	2527	0	0.78	646	1912	622	264	0.75	251

Year class	Age 2					Age 3					Age 4				
	IPS	WPO	EPO	F	Mort.	IPS	WPO	EPO	F	Mort.	IPS	WPO	EPO	F	Mort.
1966	421	1	155	0.52	60	205	13	32	0.28	33	127	17	<1	0.16	21
1967	761	78	311	0.81	96	276	23	29	0.23	44	180	24	0	0.16	31
1968	562	48	256	0.89	68	190	14	4	0.11	33	139	18	6	0.21	23
1969	812	2	556	1.36	83	171	18	24	0.31	27	102	16	0	0.18	17
1970	320	15	269	2.81	20	16	4	0	0.33	3	9	3	0	0.44	1
1971	729	20	458	1.23	77	174	12	<1	0.08	30	132	29	3	0.31	21
1972	1142	28	407	0.54	162	545	115	18	0.31	85	327	26	29	0.20	54
1973	2349	46	529	0.31	367	1407	61	131	0.16	236	979	95	23	0.14	166
1974	556	96	173	0.75	72	215	44	21	0.40	32	118	10	10	0.21	20
1975	510	61	211	0.87	62	176	14	10	0.16	30	122	28	0	0.29	19
1976	362	151	94	1.32	37	80	38	0	0.74	11	31	7	0	0.28	5
1977	1138	98	457	0.76	146	437	76	1	0.22	72	288	84	0	0.38	43
1978	1489	119	225	0.29	235	910	584	12	1.23	97	217	99	3	0.72	28
1979	494	180	60	0.75	64	190	64	2	0.48	27	97	56	1	1.02	11
1980	443	200	88	1.21	47	108	54	<1	0.79	14	40	15	1	0.57	6
1981	690	139	69	0.40	104	378	21	3	0.07	66	288	75	0	0.34	44
1982	411	44	42	0.26	66	259	86	<1	0.45	38	135	30	<1	0.28	22
Average	776	78	256	0.89	104	337	73	17	0.37	52	196	37	4	0.35	31

TABLE 16b. Results of the cohort analysis described in the text, with an annual coefficient of natural mortality of 0.3.

Year class	Age 0					Age 1				
	IPS	WPO	EPO	F	Mort.	IPS	WPO	EPO	F	Mort.
1966	3473	1270	0	0.54	705	1498	461	97	0.55	302
1967	8139	3607	0	0.70	1543	2989	964	416	0.74	556
1968	5032	2300	0	0.73	941	1791	371	290	0.55	363
1969	5751	2970	0	0.88	1013	1768	378	13	0.29	400
1970	4055	1938	0	0.78	743	1374	443	366	1.09	223
1971	6942	3316	0	0.78	1272	2354	682	292	0.64	458
1972	4951	498	0	0.12	1211	3242	124	810	0.40	700
1973	14527	4875	0	0.48	3020	6632	1403	163	0.32	1485
1974	7465	3953	0	0.91	1296	2216	676	439	0.85	396
1975	3712	1277	0	0.50	767	1668	222	483	0.66	322
1976	3912	1784	0	0.73	732	1396	698	50	0.93	241
1977	6916	2542	0	0.54	1401	2973	478	473	0.46	626
1978	11500	5091	0	0.70	2179	4230	1452	161	0.57	847
1979	4563	2088	0	0.73	853	1622	611	118	0.72	306
1980	5035	2810	0	1.00	847	1378	605	6	0.70	261
1981	5758	1975	0	0.50	1188	2592	785	281	0.63	506
1982	2192	665	0	0.43	467	1060	213	28	0.30	239
Average	6113	2527	0	0.65	1187	2399	622	264	0.61	484

Year class	Age 2					Age 3					Age 4				
	IPS	WPO	EPO	F	Mort.	IPS	WPO	EPO	F	Mort.	IPS	WPO	EPO	F	Mort.
1966	638	1	155	0.33	142	340	13	32	0.17	82	213	17	<1	0.10	53
1967	1053	78	311	0.55	213	451	23	29	0.14	109	290	24	0	0.10	72
1968	767	48	256	0.60	151	312	14	4	0.07	79	215	18	6	0.14	52
1969	977	2	556	1.03	162	257	18	24	0.21	60	155	16	0	0.13	38
1970	342	15	269	2.41	35	23	4	0	0.23	6	13	3	0	0.30	3
1971	922	20	458	0.88	162	282	12	<1	0.05	71	199	29	3	0.21	47
1972	1608	28	407	0.37	351	822	115	18	0.21	193	496	26	29	0.13	121
1973	3581	46	529	0.20	844	2162	61	131	0.11	533	1437	95	23	0.10	355
1974	705	96	173	0.57	141	295	44	21	0.29	67	163	10	10	0.15	39
1975	641	61	211	0.66	124	245	14	10	0.12	60	161	28	0	0.22	37
1976	407	151	94	1.13	65	97	38	0	0.59	19	40	7	0	0.23	9
1977	1396	98	457	0.60	276	565	76	1	0.17	135	353	84	0	0.32	79
1978	1770	119	225	0.25	408	1018	584	12	1.08	165	257	99	3	0.60	51
1979	587	180	60	0.63	114	233	64	2	0.39	51	116	56	1	0.81	21
1980	506	200	88	1.03	84	134	54	<1	0.62	26	54	15	1	0.42	92
1981	579	139	69	0.27	233	579	21	3	0.05	147	408	75	0	0.24	95
1982	356	44	42	0.19	138	356	86	<1	0.32	79	191	30	<1	0.20	45
Average	990	78	256	0.69	214	481	73	17	0.28	111	280	37	4	0.26	71

produced very poor catches of age-0 and -1 fish in the western Pacific and excellent catches of age-1 and -2 fish in the eastern Pacific. The 1981 year class, which was about average, produced above-average catches of age-1 and -2 fish in the western Pacific and very poor catches of age-2 fish in the eastern Pacific.

The cohort analysis is highly speculative. The errors in assigning the fish to ages 0, 1, 2, and >2 are probably minimal, but those in assigning them to older groups (Tables 14 and 15) are probably much greater, at least for fish caught in the eastern Pacific. Values of 0.2 and 0.3 were selected for M because they bracket the estimate of 0.287 calculated in Section 4.2. Actually, M probably varies among age groups.

There has been a decline in the catches of northern bluefin in the eastern Pacific in recent years. This decline could be due to (1) a decrease in the overall abundance of fish greater than about 60 cm in length caused by heavy exploitation of age-0 fish off Japan, (2) reduced fishing effort in the eastern Pacific, (3) a decrease in vulnerability to capture of the fish which have migrated to the eastern Pacific, and/or (4) a decrease in the availability of bluefin in the eastern Pacific (*i.e.* a decrease in the proportion of the population which has migrated to the eastern Pacific or a shorter average sojourn in the eastern Pacific of the fish which have made that migration).

In regard to Point 1 above, data for the age composition of the catch of northern bluefin during 1966-1986 by Japanese vessels (Table 15) indicate that there has not been a decline in the catches of fish older than age-0 nor an increase in the proportion of age-0 to older fish, which seems to rule out the first possibility.

Proceeding now to Point 2, the numbers of smaller purse seiners, which previous to the late 1970s had been responsible for most of the northern bluefin catches in the eastern Pacific, declined during the late 1970s and the 1980s. The catch and effort data should be examined in such a way that it can be determined to what extent the decline in the catches is due to declines in effort by vessels of various sizes. Accordingly, for the area north of 23°N and the May-October periods for 1975 through 1987, tabulations were made of (a) the tons of bluefin caught, (b) the numbers of purse-seine sets, (c) the proportions of those sets which caught bluefin, (d) the tons of bluefin caught per successful bluefin set, and (e) the percentages of bluefin caught off Mexico and the United States. Virtually all of the bluefin catches are made north of 23°N, and the great majority are made during the May-October period. The 1975-1987 period includes years of normal and below-normal catches. Some results obtained from manipulation of these data are shown in Figure 12. The greatest decline has been for catch (except for Class-2 and -3 vessels). The numbers of sets have declined by about 50 percent for Class-3, -4, and -5 vessels, while the average catches per successful bluefin set have remained about the same. The proportions of the sets which caught bluefin were greater in 1985 and 1986 than in the other years with average to greater-than-average bluefin catches, 1975-1980 and 1982. The proportions of the catches taken off Mexico and the United States remained about the same for each vessel size class during the period under consideration. From these data it appears that

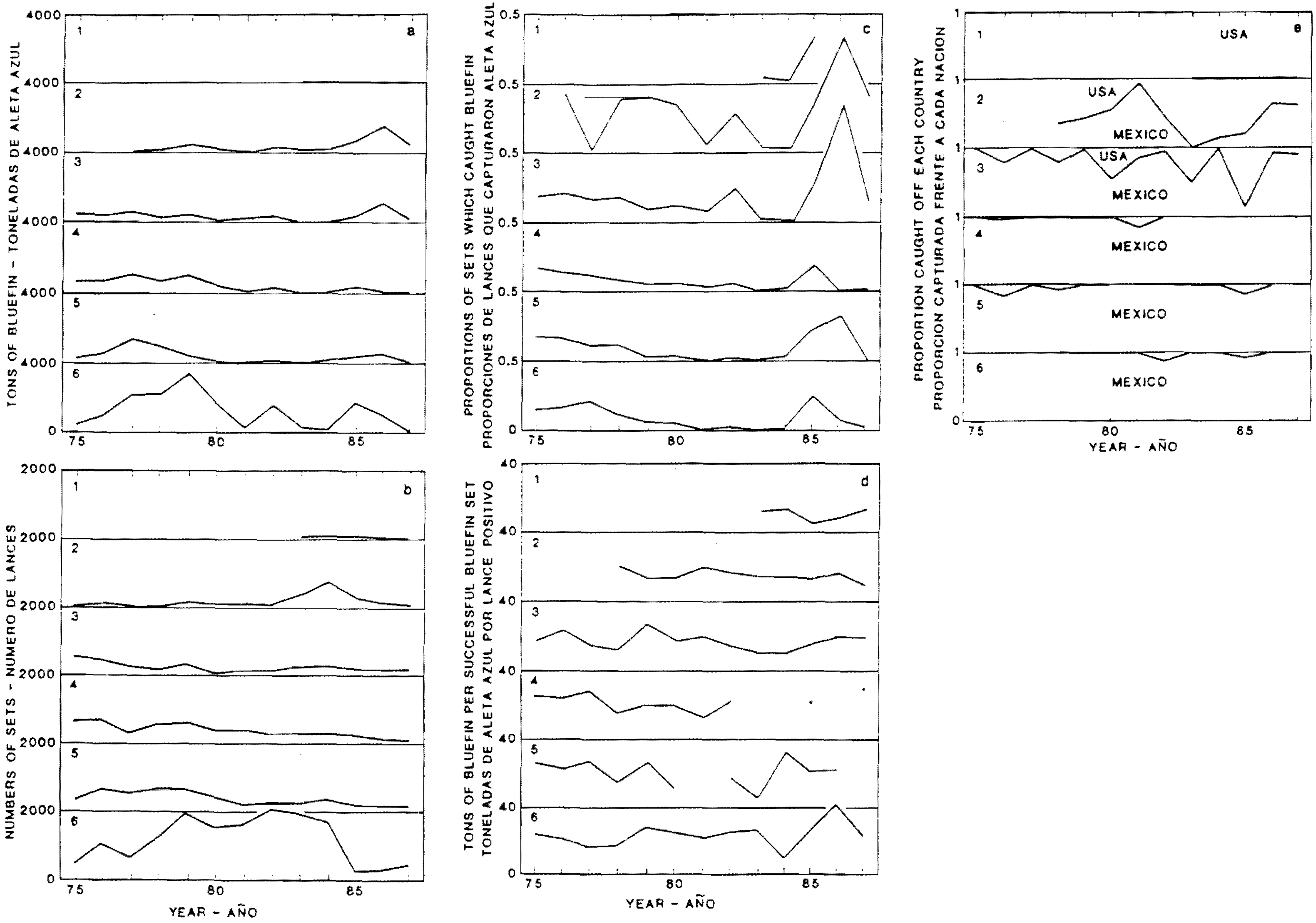

FIGURE 12. Trends in (a) tons of northern bluefin caught in bluefin area-time strata, (b) numbers of purse-seine sets in those strata, (c) proportions of those sets which caught bluefin, (d) tons of bluefin caught per successful bluefin set, and (e) percentages of bluefin caught off Mexico and the United States. The numbers in the upper left corners of the panels indicate the vessel size classes (from Anonymous, 1989).

most of the decrease in catches of bluefin is due to lesser availability or lesser vulnerability to capture of this species and/or declining effort. Information of tagging and age composition, discussed below, indicate that lesser availability is an important factor in the reduced catches in the eastern Pacific.

In regard to Point 3, there is no obvious reason to suggest that the vulnerability to capture of the fish in the eastern Pacific has been declining, so this possibility has been discounted until evidence to the contrary is produced.

The tagging data of Bayliff *et al.* (1991) provide some useful information in regard to Point 4. It can be seen in Table 10 that only the 1981 year class contributed significant numbers of returns to the eastern Pacific fishery during Year 1. It can also be seen that for Year 2 nearly half the returns for the 1979 year class and more than half of those for the 1983 and 1984 year classes were from fish caught in the eastern Pacific. This information suggests that the proportion of age-1 fish which migrated to the eastern Pacific was greatest for the 1981 year class and that the proportions of age-2 fish which migrated to the eastern Pacific were greatest for the 1983 and 1984 year classes, intermediate for the 1979 year class, and least for the 1980, 1981, 1982, and 1985 year classes.

A large proportion of the catch of northern bluefin in the eastern Pacific in 1982 consisted of age-1 fish (Table 14). This is consistent with the evidence from tagging (Table 10) that a large proportion of the fish of the 1981 year class appeared in the eastern Pacific as age-1 fish in 1982. The catch of bluefin in the eastern Pacific was poor in 1983, however, perhaps because the fish of the 1981 year class experienced heavy mortalities in the eastern Pacific in 1982 or mostly began their return trip to the western Pacific before the start of the 1983 season.

The greatest catches of northern bluefin in the eastern Pacific in recent years were those of 1985 and 1986 (Figure 6), and the catches in those years consisted mostly of age-2 fish (Table 14), *i.e.* 1983-year-class fish in 1985 and 1984-year-class fish in 1986. This is consistent with the evidence from tagging (Table 10) that large proportions of the fish of the 1983 and 1984 year classes appeared in the eastern Pacific as age-2 fish in 1985 and 1986.

If it were certain that the fish which were tagged in the western Pacific were selected randomly it would be concluded that greater proportions of age-2 fish of the 1983 and 1984 year classes migrated to the eastern Pacific, and that this resulted in greater catches of northern bluefin in the eastern Pacific in 1985 and 1985. It is possible, however, that there are separate non-migrant and migrant subpopulations, and that greater proportions of the migrant subpopulation were selected for tagging during the first year of life of the 1979, 1981, 1983, and 1984 year classes. Thus the relatively high proportion of eastern Pacific returns for the 1979 year class, even though the catch in the eastern Pacific in 1981 was poor, might be the result of heavy concentration of tagging effort on a relatively small subpopulation of migrants. This possibility can be evaluated by examining the data in Table 17 for both age-1 and age-2 fish. For the age-1 fish it appears that the proportions of migrants were high for the 1981 year class and low for the other year classes, regardless of the areas or months of release of the fish.

TABLE 17. Data for tagged fish released in the western Pacific and recaptured during Year 1 (upper panel) and Year 2 (lower panel) in the western (W) and eastern (E) Pacific (from Bayliff, Ishizuka, and Deriso, 1991).

Year classes	Areas released	Month of release																									
		7		8		9		10		11		12		1		2		3		4		5		6		Total	
		W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E
1979-1980	Kochi	2	1	18	0																					20	1
1982-1987	Shizuoka	1	0	2	0	7	0	3	0																	13	0
	Nagasaki									20	0	108	1	61	1	20	0									209	2
	Kagoshima											9	1	45	0	65	0	67	0	8	0	3	0			197	1
	Hokkaido							2	0															6	0	8	0
	Total	3	1	20	0	7	0	5	0	20	0	117	2	106	1	85	0	67	0	8	0	3	0	6	0	447	4
1981	Kochi	1	0	40	24	7	0																			48	24
	Shizuoka			4	8	2	0																			6	8
	Nagasaki									19	6	38	7													57	13
	Hokkaido									4	0															4	0
	Total	1	0	44	32	9	0			23	6	38	7													115	45
1979	Kagoshima													10	10			17	12	6	2					33	24
1980-1982	Kochi			6	1																					6	1
1985	Shizuoka			2	1																					2	1
	Shimane									1	1															1	1
	Nagasaki									10	2	13	5	2	0											25	7
	Kagoshima															6	3									6	3
	Toyama Bay									1	0															1	0
	Hokkaido							3	0																	3	0
	Total			8	2			3	0	12	3	13	5	2	0	6	3									44	13
1983-1984	Shimane									8	2															8	2
	Nagasaki											1	16	2	15											3	31
	Kagoshima											1	11													1	11
	Hokkaido																							0	1	0	1
	Total									8	2	2	27	2	15									0	1	12	45

For the age-2 fish it can be seen that fish of the 1980-1982 and 1985 year classes released during December and January tended to be non-migrants and those of the 1983 and 1984 year classes released during December and January tended to be migrants. Fish of all year classes released during August-November tended to be non-migrants, but there are only 10 returns of these from the 1983 and 1984 year classes, and all of these fish were released at Shimane in the Sea of Japan, so these fish would seem to be less likely than any others, because of the physical barriers, to migrate to the eastern Pacific. These data do not offer much support for the subpopulation hypothesis. They indicate that for the age-1 fish the tendency to migrate to the eastern Pacific was strong for the 1981 year class and much weaker for all the others, and that for the age-2 fish the tendency to migrate was strongest for the fish of the 1983 and 1984 year classes, intermediate for those of the 1979 year class, and weakest for those of the 1980-1982 and 1985 year classes.

The age composition data in Table 18 provide some further information pertinent to Point 4. Correlation coefficients were calculated for 10 pairs of data (Table 19, upper panel), using the data in Table 18. Three of these were significant at the 5-percent level. The numbers of age-2 fish in the eastern and western Pacific are negatively correlated (Test 6), indicating that poor catches in the eastern Pacific could be due at least partly to greater-than-normal proportions of the total population failing to migrate from the western to the eastern Pacific Ocean. The catches of age-1 and -2 fish in the eastern Pacific are positively correlated (Test 7), indicating that the catch of age-2 fish in the eastern Pacific can be predicted, albeit poorly, from the catch of age-1 fish in the eastern Pacific one year previously. The catches of age-0 and -1 fish in the western Pacific are highly correlated (Test 8), indicating that the catch of age-1 fish in the western Pacific can be predicted from the catch of age-0 fish in the western Pacific one year previously.

The coefficient of correlation for the catches of age-0 fish in the western Pacific and the catches of age-2 fish in the eastern Pacific two years later is 0.386 (Table 19, Test 2). Although this relationship is not significant at the 5-percent level, it may indicate that the catch of age-2 fish in the eastern Pacific is related to recruitment two years previously, assuming that the catch of age-0 fish in the western Pacific is a valid index of recruitment. Since the catch of age-2 fish in the eastern Pacific appears to be related to the recruitment two years previously (Test 2) and the catch of age-2 fish in the western Pacific in the same year (Test 6), a multiple correlation of these three variables was run (Test 11). The resulting coefficient of correlation was highly significant, indicating that 55.6 percent ($0.746^2 \times 100$) of the variation of the catches of age-2 fish in the eastern Pacific is explained by (1) recruitment in the western Pacific and (2) the portion of fish which migrate from the western to the eastern Pacific. Since the catches of age-2 fish make up the majority of the catch by weight in the eastern Pacific in most years, those two factors appear to have major influences on the total catches in the eastern Pacific.

In general, the results of the analysis of the catch-at-age data tend to support the tentative conclusion from the studies of the tagging data that variations in the proportions of western Pacific fish which migrate to the eastern Pacific are at least partly responsible for variations in catches in the eastern Pacific.

TABLE 18. Estimated numbers of bluefin, in thousands, caught in the western and eastern Pacific Oceans. The data are taken from Tables 14 and 15, but arranged by year class instead of by year.

	Western Pacific Ocean			Eastern Pacific Ocean	
Year class	Age 0	Age 1	Age 2	Age 1	Age 2
1958	-	-	-	17	47
1959	-	-	-	24	298
1960	-	-	-	577	450
1961	-	-	-	990	529
1962	-	-	-	501	202
1963	-	-	-	982	288
1964	-	-	91	333	715
1965	-	266	3	622	308
1966	1270	461	1	97	155
1967	3607	964	78	416	311
1968	2300	371	48	290	256
1969	2970	378	2	13	556
1970	1938	443	15	366	-
1971	3316	682	20	-	458
1972	498	124	28	810	407
1973	4875	1403	46	163	529
1974	3953	676	96	439	173
1975	1277	222	61	483	211
1976	1784	698	151	50	94
1977	2542	478	98	473	457
1978	5091	1452	119	161	225
1979	2088	611	180	118	60
1980	2810	605	200	6	88
1981	1975	785	139	281	69
1982	665	213	44	28	42
1983	1362	421	49	35	272
1984	2417	757	61	117	369
1985	2046	760	-	40	62
1986	1470	-	-	16	47

TABLE 19. Correlations for various combinations of catches of bluefin (from Anonymous, 1990). WPO and EPO stand for western and eastern Pacific Ocean, respectively.

Correlation	Degrees of freedom	*r*
1. WPO, age 0, *versus* EPO, age 1	18	-0.069
2. WPO, age 0, *versus* EPO, age 2	18	0.386
3. WPO, age 1, *versus* EPO, age 1	18	-0.306
4. WPO, age 1, *versus* EPO, age 2	18	0.078
5. WPO, age 2, *versus* EPO, age 1	18	-0.278
6. WPO, age 2, *versus* EPO, age 2	18	-0.463*
7. EPO, age 1, *versus* EPO, age 2	25	0.418*
8. WPO, age 0, *versus* WPO, age 1	18	0.843**
9. WPO, age 0, *versus* WPO, age 2	17	0.174
10. WPO, age 1, *versus* WPO, age 2	18	0.344
11. EPO, age 2, *versus* WPO, age 0, and WPO, age 2	15	0.746**

Length-frequency data (Calkins, 1982: Figure 5; Anonymous, 1987: Figure 22; Anonymous, 1991: Figure 20) for the eastern Pacific provide information on the length of the average sojourn in that area. The proportions of smaller and larger fish in the eastern Pacific catches were about the same during the poor years, 1980-1984 and 1987-1988, as during other years, which indicates that the average sojourn in the eastern Pacific has not decreased.

8 ACKNOWLEDGEMENTS

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ATLANTIC BLUEFIN TUNA (Thunnus thynnus thynnus (L.)): A REVIEW

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Atlantic Bluefin Tuna

I. Introduction

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Tuna of world

Tuna belong to the family Scombridae, one of the most prized sport and commercial marine fish in the world. Although by no means the most important commercial group, tuna do support fisheries with significant landings in excess of two million tonnes per annum. Skipjack and yellowfin comprise about 75% of these landings, bigeye and albacore about 20%, and northern bluefin averages less than 40,000 tonnes (<2%). Tuna are highly migratory often passing through several jurisdictions during each annual cycle. Bluefin tuna exhibit some of the longest migrations and have more restricted spawning grounds than many of the tropical tunas. This mobility coupled with their high economic value make their conservation and management a priority for all involved countries - it also makes finding a concensus difficult.

Atlantic bluefin

The Atlantic bluefin tuna Thunnus thynnus thynnus, L. inhabits the north Atlantic Ocean, the northern bluefin tuna Thunnus thynnus orientalis, L. inhabits the Pacific Ocean. In the north Atlantic the assessment is conducted under the premise of two stocks, despite the 'limited' mixing that is known to occur. The western Atlantic stock which spawns in the Gulf of Mexico has been considered in a serious state of depletion for almost 20 years. The eastern stock which spawns in the Mediterranean Sea is also in a depleted state - the degree of depletion is still the subject of active discussion.

Management of the western stock takes the form of catch restrictions, minimum size limits, and closed areas. Although only voluntarily enforced through national agencies, the management regulations passed by the International Commission for the Conservation of Atlantic Tunas (ICCAT) do appear to be enforced. The management of the eastern bluefin stock has only a minimum size regulation passed by ICCAT and even this appears to have been effectively ignored by many national agencies, particularly in the Mediterranean.

Assessment process

Bluefin tuna issues have always had a high profile in ICCAT and until recently it was the only species upon which an analytical (age structured) assessment was conducted. The scientific monitoring quotas recommended by the Commission since 1982 have been above the $F_{0.1}$ management target, however they are considered necessary to collect the data required to permit annual stock updates. Stock assessments in recent years have taken the form of marathon sessions of the bluefin working group of the Standing Committee on Research and Statistics (SCRS) of ICCAT. These sessions have taken place the week before and during the plenary sessions of the SCRS. This results in little time for the SCRS as a whole to study and comment upon the analysis. The inexactness of the assessment process itself and the bluefin data in particular leads to the task filling whatever time might be allocated to it. The purpose of this review of the biology and the assessment methodology of the Atlantic bluefin tuna is to provide an opportunity for scientists to exchange views (outside the ICCAT forum) on the assessment process in particular and provide the background information to assist in and encourage the preparation of enhanced national data sets. This, it is hoped, will lead to more accurate and timely stock assessments.

Summary of the 1989 ICCAT assessment

The assessments of the two Atlantic bluefin tuna stocks that were conducted in November 1989 were the sixth in a series of analytical assessments (Sequential Population Analysis (SPA)) conducted by the SCRS Bluefin Working Group during the annual ICCAT meetings. These assessments based on 1988 data attempted to define the 1990 fishery. Although there have been several improvements in the data handling and software used during recent years the overall analysis techniques and results have been relatively consistent.

The Atlantic bluefin is a single species that is assessed as two separate stocks (Figure III.1.2). This is done, despite a known inter-mixing of at least 3 to 4 %. The bluefin stock in the east Atlantic and Mediterranean Sea supports a larger fishery than that of the west Atlantic. The former has minimum size limits as the only management recommendation while the latter stock has minimum size limits, quotas, area closures, and limited entry constraining it.

The major fisheries in the east Atlantic in 1988 were baitboats (Spain: 2,200 t, France: 480 t), trap (Spain: 2,400 t) and longline (Japan: 800 t). These totalled with other gear/nation categories resulted in a fishery of 6,500 t. The Mediterranean Sea, the area providing the greatest landings (15,000 t) in 1988, has many non-ICCAT member nations that are active participants in the bluefin fishery. The major fisheries are purse seine (France: 5,750 t, Italy: 2,300 t, Yugoslavia: 1,500 t, Turkey: 900 t), trap (Italy: 300 t, Spain: 200 t), and longline (Japan: 250 t). The Mediterranean is considered to have a significant amount of non-reporting of catch and has poor often unrepresentative sampling. A particular problem exists with the age 0 and 1 year old fish. In the past 5 years the 0 age fish have comprised 20 to 75 % of the fishing mortality of the eastern stock of Atlantic bluefin (ICCAT, 1990).

The west Atlantic bluefin fisheries are managed more closely than those of the east. The major fisheries in 1988 were the purse seine (USA: 380 t), recreational (USA: 430 t), longline (Japan: 1,100 t, USA: 160 t, Canada: 105 t) and handline (USA: 320 t, Canada: 280 t). Other nation/gear categories bring the total landings to nearly 3,000 tonnes. The total allowable catch (TAC) has been limited to 2,660 tonnes since 1983.

The prime aspect of any SPA style assessment is the calibration of the stock estimates (population) with calculated abundance indices. This calibration allows decisions to be made as to what is the most appropriate stock estimate. Ten indices of abundance were available for study of the eastern stock and 10 indices for the western stock. Further investigation of these indices resulted in 6 being considered acceptable for assessment of the eastern stock and 5 for the western stock.

The eastern stock of Atlantic bluefin appears to be supporting a large fishery (>20,000 t), over 90 % of the catch by numbers being composed of fish of age 1 or less (ICCAT, 1990). The stock is not (according to the admittedly limited 1989 assessment) showing any clear signs of stress (Figure I.1). The western stock, on the other hand has been protected by various management measures but over the past 5 years, except for an apparent stability in the numbers of younger fish, does not appear to be recovering as rapidly as expected (Figure I.2).

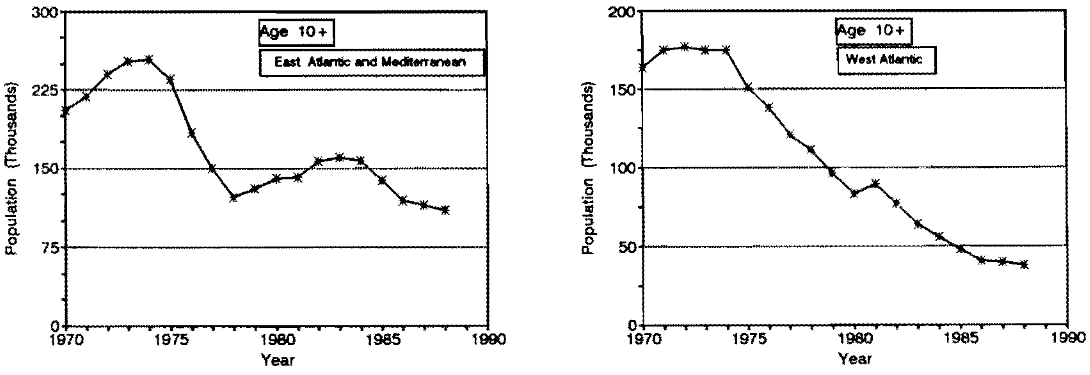

Figure I.1.and 2. Population estimates (numbers) of bluefin tuna from the eastern and western stocks.

II. Biology of Atlantic bluefin tuna

1. Early Life History - WESTERN ATLANTIC

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The bluefin tuna of the western Atlantic is an oviparous fish of high fecundity. The mean relative fecundity has been estimated at 128.5 eggs per gram of female body weight per year (Richards, Potthoff and Houde 1981), but this value may be inaccurate because it is unknown whether or not they spawn in batches over the spawning season. The fecundity estimates assume a single spawning per season and thus could be low estimates. The eggs are shed into the sea and are fertilized externally although actual spawning has never been observed. Eggs have been described from the eastern Atlantic stock and are presumed to be identical to western Atlantic stocks (Richards 1989). Identifying eggs from plankton samples has not been done in the western Atlantic because the eggs are similar to the eggs spawned by several other species at that time in the Gulf of Mexico and environs. The eggs are about 1 mm in diameter, with a clear shell, homogenous yolk, one oil globule, and the embryo has melanophores scattered over it. There are probably other diagnostic pigments which would be lost during preservation thus making identification from preserved samples extremely difficult. The report by Rivas (1954) of spawning in the Straits of Florida (Figure II.1.1) was an error based on assumed bluefin eggs and larvae. Their larvae do occur in the Florida Straits, but Rivas' larval specimens were gempylids and the eggs were not saved. Larval bluefin are the easiest to identify within the genus and have been described by Richards and Potthoff (1974); Richards et al. (1989); and Richards (1989). Earlier descriptions are referenced in Richards and Klawe (1972). The larvae are the only Thunnus sp. which have dorsal as well as ventral tail pigment. To verify identification of larvae greater than 5 mm SL it is necessary to clear and stain them to verify the vertebral count of 18 + 21 and presence of the first closed hemal arch on the tenth vertebrae. Identification of all Thunnus sp. larvae to species is very difficult in the western Atlantic because of variability of characters found in T. atlanticus.

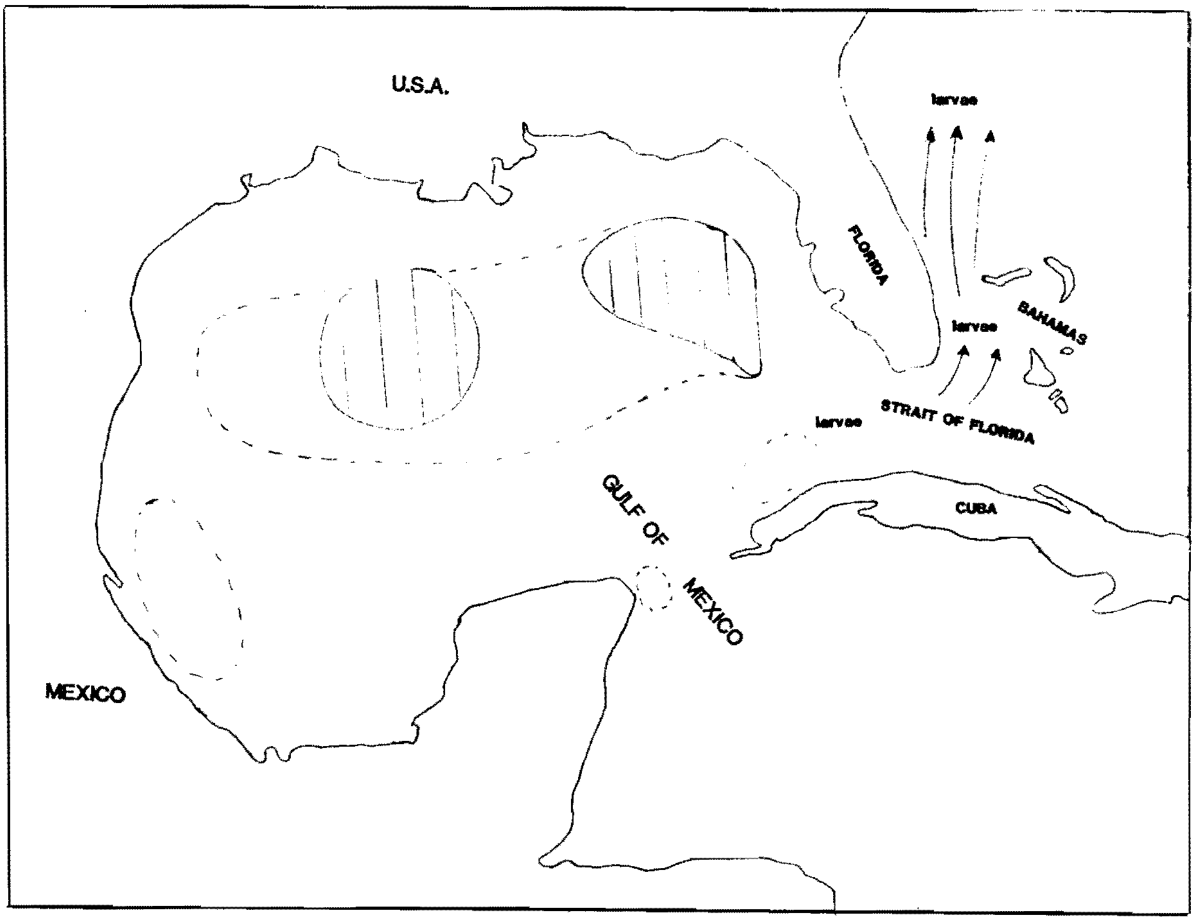
The history of spawning verification for bluefin in the western Atlantic has been detailed by Richards (1976). In short Rivas (1954) made the first report which was followed by Klawe (1960) who assumed that his larvae were bluefin because of the report by Rivas. Gorbunova and Salabarria (1967) reported bluefin around Cuba and in the Gulf of Mexico, but over a longer time span than is now accepted. Potthoff and Richards (1970) reported on juveniles in the Dry Tortugas area in June and July. The first accounts of widespread spawning in the Gulf of Mexico based on correctly identified larvae were by Juarez (1972, 1974, 1975, 1976) and Montolio and Juarez (1977). These accounts also quantified the abundance and demonstrated that the Gulf was the major spawning ground for bluefin in the western Atlantic. Richards (1976) reported on extensive larval occurrence in the Straits of Florida; Clark et al. (1969) and Berrien et al. (1977) have reported on bluefin larvae occurring off the Carolinas; and Richards (1977) reported the occurrence of bluefin larvae in the western Gulf of Mexico. Since the late 1970's, ichthyoplankton surveys have been conducted in the Gulf of Mexico to provide information on relative spawning stock sizes. The results have been documented in a series of reports (Houde et al. 1979, Richards and Potthoff 1980, Richards et al. 1981, Richards et al. 1984, Kelley et al. 1986, McGowan and Richards 1986, 1987) and summarized by Sherman et al. (1983) and Richards (1987). Bluefin tuna larvae have been collected in the Gulf of Mexico and Straits of Florida between April 15th and June 19th. Most of the larvae are found in the Gulf with concentrations centered along the 1,000 fathom curve in the northern Gulf with some sporadic abundances off Texas. In the Straits of Florida they are most abundant along the western edge of the Florida Current which implies a Gulf origin. Few larvae have been caught off the southeastern states. The Gulf larvae survey results have shown a decline in larval population and thus probable spawning stock size. This data series (index) correlates with fishery dependent indices and has been used with these indices in VPA calibration.

Atlantic Bluefin Tuna

To better understand the dynamics of the early life history of bluefin larvae ageing studies have been done by Brothers et al. (1983). They showed rapid larval growth of about one mm of length per day over the first several days of larval life before transformation to juveniles at about 15 mm. Recently, an ecological study by McGowan and Richards (1990) has shown that the occurrence of larvae off the Carolinas may be due more to current advection from the Gulf of Mexico and southern Florida Straits than to any significant spawning in the area (Figure II.1.1). As part of ichthyoplankton surveys in 1987, 1988, and 1989 additional collecting has been carried out in the vicinity of the Loop Current in the Gulf of Mexico to study the relation of bluefin larvae abundance in relation to oceanic fronts. Richards et al. (1989) in the preliminary analysis of some of these data show a strong relationship between fronts formed between the Loop Current and shelf water and abundance of bluefin larvae. This relationship could be due to concentrating mechanisms of currents acting on the larvae or to adults preferring to spawn in these areas.

(see also Sections II.3 and IV.7)

Figure II.1.1 The distribution of Atlantic bluefin larvae in the Gulf of Mexico and adjacent waters. (Figure prepared by the editor after Richards (1976), Richards and Potthoff (1980) and Richards (personal communication)). The crosshatched areas indicate a high density of bluefin larvae, the areas enclosed in the broken lines indicate presence of larvae. The word 'larvae' indictes locations observed by various authors, the arrows indicte possible advection currents. Although the map implies large areas with no bluefin larvae, this is more an indication of restricted surveying.



2. Larval Biology - EASTERN ATLANTIC & MEDITERRANEAN SEA

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Yabe et al. (1966) described bluefin larvae and found no differences between Atlantic bluefin (T. t. thynnus) and northern Pacific bluefin tuna (T. t. orientalis) larvae.

Studies and ichthyoplankton surveys have been conducted on bluefin larvae from the spawning area of the eastern Atlantic bluefin stock, the Mediterranean Sea (Scaccini 1961, Duclerc et al 1973, Piccinetti 1973, Piccinetti-Manfrin 1973, Dicenta 1975, Dicenta and Piccinetti 1977 and 1979). The area of the highest concentration of larvae is found in the central part of the western basin of the Mediterranean (Figure II.2.1).

In the eastern part of the Atlantic Ocean, bluefin larvae have not been found, although exploratory surveys for larvae have been carried out (Rodriguez-Roda 1975) and some small-sized bluefin tunas were caught in the autumn (Furnestin and Dardignac 1962; Aloncle 1964). No recent oceanographic surveys have been carried out in the east Atlantic to study distribution and mortality of larvae, nor to study new or suspected spawning areas.

Dicenta (1975) distinguished three important stages in growth of larvae: larvae up to 6 mm, from 6-10 mm and > 10 mm. (Figure II.2.2). The most significant differences between these stages of larval development concern pigmentation, the appearance of melanophores and the development of spines and vertebrae.

The larval phase is the time which transpires from the hatching of the egg until the fingerling acquires adult characteristics (>12 mm length). It can last from one and a half to two months (Dicenta, pers. com.). Larval mortality is an important factor in estimating the spawning stock by direct evaluation. These mortality estimates have been hypothetical due to the lack of more realistic data. Dicenta and Piccinetti (1978) assume three levels of larval survival which vary between 1 and 100 per thousand.

Richards et al (1981) estimated larval mortality (based on studies by Dahlberg) at 59.2 per thousand for the west Atlantic.

3. Larvae abundance index - WESTERN ATLANTIC

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In 1977, soon after the first reports of extensive catches of bluefin larvae in the Gulf of Mexico, systematic ichthyoplankton surveys of the Gulf were begun (Richards and Potthoff, 1980). These surveys were conducted during the spawning season, which was considered to be April 15 to June 15 (Richards 1976). In 1977, 1978,

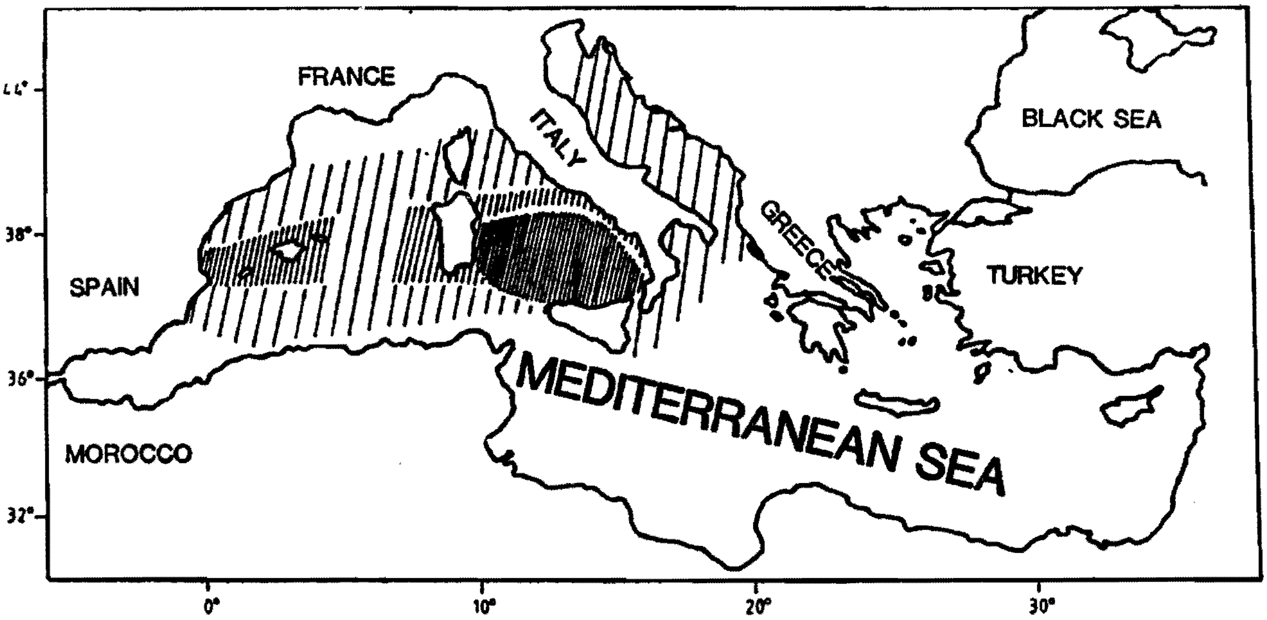

Figure II.2.1. Distribution and abundance of the bluefin spawning areas in the Mediterranean Sea, based on larval catches in 1970 and 1971.

(Working Doc. coll. Biol. Peche Aquac. thons Mediterr., Sete, 1978).

The darker shaded areas indicate higher larval concentration.

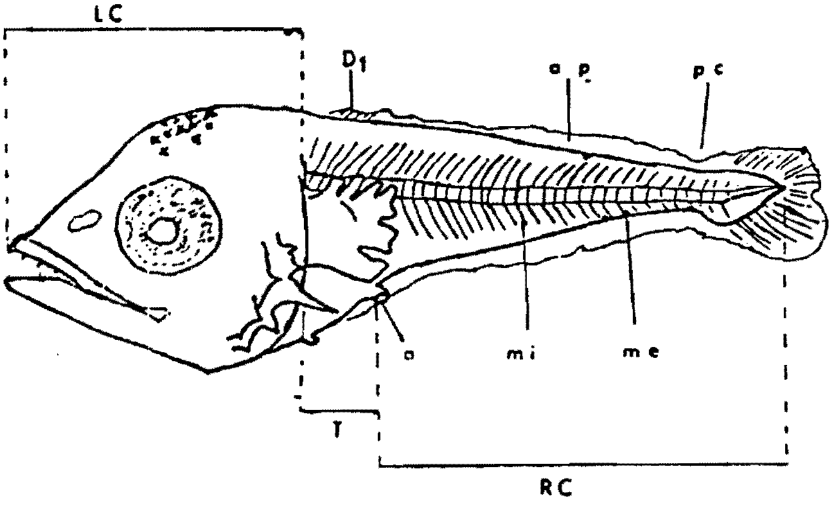

Figure II.2.2. Characteristic aspect of a tuna larva which measures 5.5 mm in total length (according to Dicenta, 1975).

LC: Total length of head

T : Trunk

RC: Caudal area

D1: Outline of the first dorsal fin

ap: primary fin

a : Anal opening

mi: myomeres

me: Melanophores

PC: Caudal appendage

and 1981 the surveys sampled waters throughout much of the Gulf of Mexico while between 1982 and 1984 and between 1986 and 1989 the surveys have generally covered only the U.S. EEZ.

These ichthyoplankton surveys employed both bongo and neuston nets. Generally bongo and neuston samples were taken at 60 km intervals, and additional neuston samples were taken along the cruise track every 30 km (Richards and Potthoff 1980, McGowan and Richards 1986). Bongo sampling consisted of double oblique tows to a maximum of 200 m depth, using paired 61 cm bongo nets with ship speed of about 1.5 knots and a 45^o wire angle. The mesh size of the sorted bongo net was 0.505 mm in 1977 to 1981 and 0.303 mm since 1982; ichthyoplankton scientists believe that such a change would have little effect on catches (Richards, pers. comm.). Neuston sampling consisted of 10 minute tows with a net having a 1 m by 2 m opening, it was towed such that it sampled the upper 0.5 m of the water column. From 1977 to 1988 all samples were preserved in formalin. In 1989 at all stations for each type of net fished, one sample was preserved in formalin and another in ethanol, permitting the otoliths of the larvae preserved in ethanol to be examined for age.

Sampling has generally been conducted in late April through May. In 1989 neuston samples were taken in late June in the eastern Gulf of Mexico, weather and vessel constraints interfered with conducting a full survey with both bongo and neuston nets. During 1990 two complete surveys in June are planned.

Average catches per 10 m^2 were generally higher (4.4 to 10.8) between 1977 and 1983 and lower (1.2-4.0) between 1984 and 1988 (Anon. 1990). Efforts to derive an index of spawning stock abundance from these data have incorporated adjustments for annual size differences of the larval catch and natural mortality.

A review of the survey and the associated index of spawning stock abundance was conducted in 1989 at the request of the SCRS of ICCAT (Richards 1989). Recommendations on improving the survey were made, including sampling during the latter part of the spawning period and collecting samples for determining age and possibly annual mortality rates of the larvae.

(see also Sections II.1 and IV.7)

4. Reproduction - WESTERN ATLANTIC

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There is only a limited amount of information on reproductive aspects of bluefin tuna in the western Atlantic. Size at first maturity, size specific fecundity and sex ratio are not well known but are all basic input parameters for some stock assessment processes. The work by Baglin (1982) appears to be the most extensive among the relevant papers.

The terminology used to describe the different size groups of Atlantic bluefin tuna follows the proposal by Rivas (1979), i.e., zero age fish (less than 50 cm - 3 kg), small fish (50 to 129 cm - 3 to 44 kg), medium fish (130 to 180 cm - 45 to 130 kg) and giant fish (larger than 180 cm - 130 kg).

Sexuality

The Atlantic bluefin tuna is heterosexual.

Atlantic Bluefin Tuna

Sex composition (large fish only)

For giant fish taken in Canadian waters, the sex ratio (number of females / number of males and females) decreases steadily for fish above 240 cm (approximately 70% females), about 50% for 260 cm fish and less than 20% for fish over 280 cm (Maguire and Hurlbut 1984). This observed sex ratio agrees with that of the giants caught by Japanese longliners in the Gulf of Mexico (Nagai 1985). Only limited information is available for fish smaller than 240 cm.

Maturity

No mature (ripe) fish were found among the small and medium sized females (95 to 169 cm) from the Middle Atlantic Bight between June and August (Baglin 1982). *This is the post-spawning season of west Atlantic bluefin* (Ed. note). If this observation were to be generalized, the size at first maturity for bluefin tuna in the western Atlantic is much larger than that in the eastern Atlantic and the Mediterranean Sea (Rodriguez-Roda 1967) (see Section II.5 Reproduction - East Atlantic). Baglin noted that GSI (gonadosomatic index) for medium sized fish in the western Atlantic tended to be less than for similar sized fish in the eastern Atlantic.

(Ed. note) *The current accepted age of 100 % (knife edge) maturity for the west Atlantic is 10 years of age (200 cm) and 5 years of age (130 cm) in the east Atlantic (ICCAT 1990). Baglin (1982) states that "age 6 would probably be the earliest age at which a majority of females could possibly reach maturity". His sample of 12 fish were collected in June, toward the end of the spawning in the west Atlantic, and he states "a majority of vitellogenic oocytes in these age 6 fish were being absorbed and most likely would not have been spawned during [that year]". This indicates that an age of 10 years old may be too high for an age of total maturity. Rodriguez-Roda (1967) had only a very small sample upon which to base his conclusions. He had a single immature female in the length interval 75 to 80 cm, his next size interval was 115 to 120 cm in which all the fish were mature. From these data subsequent workers have accepted that 100 % of females are probably mature at 4 to 5 years of age (120 to 140 cm) in the east Atlantic. It is more than likely that the small sample size and poor seasonal representation of the samples has resulted in both studies being inadequate and the results insufficient to discern any difference in age of maturity.*

Spawning grounds and spawning seasons

Major spawning areas of western Atlantic bluefin are located in the Gulf of Mexico and the Florida Straits (Figure II.1.1). This is according to ichthyoplankton surveys (Richards 1976, Montolio and Juarez 1977) and ovary examinations (Baglin 1976, 1982). In the Gulf of Mexico where the giants (spawners) predominate, it appears that intensive spawning occurs in the central part, mostly north of 25°N (Montolio and Juarez 1977) from April to June with a peak in May (Baglin 1982). Richards (1976) noted that other than the Gulf of Mexico and the Florida Straits there seems no significant spawning areas of this species in the western Atlantic. However, studies on maturation of medium sized fish in the Middle Atlantic Bight should be re-investigated as the sample size reported by Baglin (1982) was small, especially for fish bigger than 150 cm which are capable of spawning in the Mediterranean Sea (Rodriguez-Roda 1967).

Fecundity

There is limited evidence for sexual maturation in the small and medium fish (<180 cm - 9 years old) sampled from the Middle Atlantic Bight in the summer (Baglin 1982). The average number of eggs > 0.33 mm in diameter was estimated at 60.3 million, and of > 0.47 mm at 34.2 million for giant fish (205 to 269 cm - 156 to 324 kg round weight) sampled from the Gulf of Mexico and Florida Straits (Baglin 1982). However, although he did specifically consider the possibility of multiple spawning of these fish, his calculations of the number of eggs are based on those estimated to be in the ovary at the time of sampling (batch fecundity).

No relationship was found for fecundity as a function of length or weight for the range of size mentioned above (Baglin 1982). He felt this was due to the small size range of ripe fish and the high natural variablity associated with any estimate of fecundity. Baglin and Rivas (1977) estimated age (size) specific fecundity to increase with increasing age. Baglin (1982) indicated that western Atlantic giant tuna were considerably more fecund than their eastern counterparts. The comparison of spawning potential estimated from ichthyoplankton surveys conducted in the Gulf of Mexico and the western Mediterranean Sea indicated the overall potential spawning stock biomass for the western Atlantic stock was higher than that in the western Mediterranean portion of the eastern Atlantic stock (Dicenta and Piccinetti 1980).

Spawning frequency

Although no estimates of the spawning frequency have been made, Baglin (1982) inferred the western Atlantic specimens are multiple spawners.

(see also Section II.5)

5. Reproduction - EASTERN ATLANTIC & MEDITERRANEAN

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Area, season and age at first maturity

Bluefin tuna reproduction has been the subject of numerous studies cited in diverse summaries (Yamanaka 1963, Tiews 1963, and Bayliff 1980). For the east Atlantic stock, various authors have recorded the initial sexual maturity in the third year (Tiews, 1963).

There are two major spawning areas in the Atlantic Ocean, one on the west side, in the Gulf of Mexico, where spawning takes place from early May until mid-June (Rivas 1954, Richards 1977), and another on the east side, in the Mediterranean, where spawning takes place between June and August. The entire western Mediterranean and the Adriatic Sea can be considered as bluefin spawning areas, however the areas of major larval concentration are found between southern Italy (north of Sicily) and Sardinia and around the Belearic Islands of Spain (Piccinetti and Piccinetti-Manfrin 1970, Dicenta and Piccinetti 1978, 1980) (Figure II.2.1).

There is no reason to dismiss the possibility of spawning areas in the eastern part of the Mediterranean, as there are fisheries for spawning bluefin in the Aegean and Marmara Seas (Akyuz and Artuz 1957).

The eastern Atlantic (Ibero-Moroccan Bay) has been considered at times as a possible spawning area for adult fish under 100 kg. Sara (1963) believed that these fish did not enter the Mediterranean to spawn.

Based on a limited study by Rodriguez-Roda (1967) of 50 east Atlantic bluefin tuna, enroute to the spawning grounds, the size of maturity for the eastern Atlantic bluefin stock has been established. Recent work (see Ed. note Section II.4) has accepted the estimates of 50 % maturity to be between 97 and 110 cm for females and 105 and 120 cm for males, i.e. between 3-4 years of age. The age of 100% maturity is considered to be 4 to 5 years old (130 to 140 cm).

(Ed. note) *It should be borne in mind that the fish from which these conclusions were drawn are not a random sample of the population of eastern Atlantic bluefin. They came from the south Atlantic coast of Spain from fish enroute to the spawning grounds. Early workers on sexual maturity of bluefin in the east and west Atlantic often had only limited samples upon which to work. These authors were forced to speculate upon possible explanations for their results - often they expressed reservations which have, over the years, been dropped from our 'current' thinking.*

Absolute fecundity

Rodriguez-Roda (1967) studied fecundity (ova > 0.33 mm diameter) of bluefin in the east Atlantic between 1956 and 1963 and found the following relationship:

$$F = 2.29245 * L^{3.01256}$$

where F = fecundity (ova > 0.33 mm diameter)
L = fork length in cm

the absolute fecundity at size is as follows:

LENGTH (cm)	WEIGHT (kg)	FECUNDITY (x 10^3) (mean of observations)
130	37	5,354
150	57	8,240
170	84	12,013
190	117	16,795
210	157	22,705
230	207	29,864

The weight was calculated using the Rodriguez-Roda (1964) length/weight relationship for "entry" bluefin, i.e. before spawning (see Table IV.2.1).

Although the range of sizes studied by Rodriguez-Roda was between 130 and 230 cm, it is predicted from his regression that bluefin over 250 cm (up to 300 cm), could produce more than 45 million eggs.

Sex ratio

This aspect of bluefin tuna spawning in the east Atlantic was studied by Rodriguez-Roda (1964), Azevedo and Gomes (1985), Rey and Alot (1987), and Rey et al. (1987). For the west Atlantic, studies on sexual proportions were carried out by Maguire and Hurlbut (1984) and Nagai (1985). For the Pacific Ocean, Nakamura (1938) and Yamanaka (1963) presented some data on this subject.

These studies show that, in general, there is a predominance of females in almost all the cases cited, except for the Nakamura (1938) sample. There is more detailed information available in the studies on the Atlantic, which show that for large fish, after a certain size, there is a predominance of males over females.

Rey et al. (1987) referred to studies by Rodriguez-Roda (1964) and to sampling from the traps off southern Spain, in 1984 and 1985, and noted that in all cases the proportion of females is over 50%, and for one year (1956) the difference was even greater.

In analyzing the proportion of males and females by size group for bluefin tuna seasonally sampled in the traps off southern Spain in 1987, the following results were obtained:

		OBSERVED		EXPECTED 1:1			
Intervals	Sample	Females	Males	Females	Males	X^2	P*
130-204	244	166	78	122	122	31.74	<0.005
205-224	424	295	129	212	212	64.99	<0.005
225-274	465	197	268	232.5	232.5	10.84	<0.005
275-300	8	1	7	4	4	4.50	<0.005

* Probability for X^2 observed.

In this case, the X^2 test shows that after a certain size (225 cm, 225 to 274 cm interval), the number of male bluefin is significantly higher than the number of females. This corroborates the results of a growth study by Caddy et al. (1976), which showed greater growth in adult male fish. The size of west Atlantic bluefin at which predominance changes (males over females) is between 242 cm (Maguire and Hurlbut 1984) and 262 cm (Nagai 1985).

A study of the Bay of Biscay fishery (Cort, 1976) provides preliminary results regarding the sex ratio of 43 small spawning bluefin, between 100-165 cm (3 to 6 year-olds) in this area. The data show nearly equal proportions of the sexes: 53.5% males and 46.5% females.

(see also Section II.4)

6. Tagging Methodology - WESTERN ATLANTIC : An Historical Review

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(This section is condensed from:
McFarlane,G.A., R.S.Wydoski and E.D.Prince (1990) A historical review of the development of external tags and marks. Amer. Fish. Soc. Symposium 7:xxx-xxx.)

An excellent example of tag development to meet specific needs is found in the tagging history of marine pelagic fish, particularly tuna (Wilson 1953). The first attempt was made by Sella in 1911 (Rousefell and Kask 1945) using a piece of copper chain around the caudal peduncle. A number of methods were tried following Sella's initial attempt, all of which were unsuccessful. These attempts ranged from the use of hooks (Sella 1924), leather and bronze straps (Frade and Dentinho 1935), celluloid discs (Westman and Neville 1942; Scagel 1949; Partlo 1951), and Petersen discs and plastic strips (Powell et al. 1952; Schaefers 1952). It became apparent to these biologists that a new tag should be developed for pelagic species. Using an experimental water tunnel similar to that of Alverson and Chenowith (1951), Wilson (1953) developed the "spaghetti" loop tag. The low resistance of this tag in flowing water led to the first successful tagging experiments on yellowfin and albacore tuna. The "spaghetti" tag has subsequently been used on many fish species.

Although the "spaghetti" tag was successful for tagging smaller tuna, Mather (1963) found that a satisfactory tag was lacking for larger fish that could not be taken aboard the boat. In 1954, he designed the first dart tag which resembled a "miniature harpoon" and could be applied to the fish while it was still in the water. Since the tag did not require removal of the fish from the water and subjecting it to handling, this tag was quickly adopted for individually marking many large marine pelagic species. The harpoon-like dart of this tag was made of stainless steel and was driven into the musculature of the fish at an angle that would allow the streamer to lie alongside the fish as it swam.

Yamashita and Waldron (1958) modified this tag by using a nylon barb and reported significantly higher returns for skipjack. Subsequent studies using both stainless steel and nylon darts have reported either comparable results (Mather 1963; Baglin et al. 1980) or significantly higher returns with the stainless steel dart (Squire and Nielson 1983).

It should be noted that in experiments comparing efficiency of stainless steel and nylon dart tags, the very tough skin of the test animals (istiophorids) used by Squire and Nielson (1983) could have contributed to the higher return rates of stainless steel darts. While some authors attributed higher return rates to the "in water" application technique used in these experiments, the effect the test animal may have had on these results is supported by other studies using only soft-skinned scombrids, which indicated no significant difference in shedding rates of the two types of heads (Baglin et al. 1980). Therefore, ease of penetration using dart tags is an important consideration when planning a tagging program. For example, the Cooperative Shark Tagging Program coordinated by the U.S. National Marine Fisheries Service (NMFS) Narragansett Laboratory along the U.S. east coast, sharpens the stainless steel heads to improve penetration of the very tough skin of sharks, prior to issuing them to cooperators (J. Casey, personal communication).

Baglin et al. (1980) concluded from their double tagging experiment with bluefin tuna that shedding rates between the stainless steel and plastic dart were not significantly different, but that shedding rates varied over time. In addition, they felt that the tag shedding rates encountered with both tags were unacceptably high and recommended further development. In response to this need, a more reliable plastic head was made at the Southeast Fisheries Center of NMFS in 1982 by miniaturizing the large plastic head (17 mm diameter) previously used to tag giant bluefin tuna (more than 300 lb) in the Atlantic. These new heads (10 mm diameter) were designed as intermuscular tags, with two large barbs and were injection moulded from hydrostatic nylon for use on school-size bluefin tuna (less than 100 lb). The intent was to develop a tag that would encourage the adhesion of tissue to the nylon anchor and thus reduce the long-term component of tag shedding. The heads for both these tags were attached to the information portion of the tag by putting the monofilament section through a hole along the side of the head and then burning the monofilament to form a small bubble. Unfortunately, this form of attachment was not totally satisfactory because burnt monofilament crystallized with age and shedding of tags remained high. An experiment to test these new tags was canceled when the seine fishery for bluefin tuna along the U.S. east coast, where large numbers of fish could be double-tagged easily, was greatly reduced because of ICCAT landing quotas in 1982.

At about the same time, reports from the Cooperative Gamefish Tagging Program at the South East Fisheries Center indicated that numerous recaptured tuna and billfish were appearing with only the monofilament portion of the tag - the yellow vinyl section containing identification numbers and the return address was missing. This led to the discovery that the brass crimp used to attach the vinyl sleeve corroded over time. This known source of shedding was corrected in 1981 by doubling over the monofilament and using shrink tubing to secure the end.

The next step in development of a better dart tag occurred when tagging king mackerel in the Atlantic became popular with recreational anglers. The nylon head developed for school-size bluefin tuna was again miniaturized (6.5 mm diameter) for tagging smaller scombrids. The use of nylon heads was preferred because the skin of scombrids was easily penetrated. In addition, the anchor portion was also modified by eliminating the side hole for the monofilament attachment. Instead, a hole was drilled in the base portion of the anchor and liquid phenol was used to bond the nylon head to the monofilament section. This approach seemed to represent a distinct improvement over burning monofilament or using glue to attach nylon heads to the vinyl portion of dart tags. For example, Bayliff and Holland (1986) reported instances where gluing nylon heads to vinyl tubing caused shedding problems. However, liquid phenol is a known carcinogen and its long term adhesive qualities are unknown.

Experiments to evaluate the 6.5 mm dart tags on king mackerel were delayed and, in the interim, these tags were tried on red drum in the Gulf of Mexico. After developing a procedure that allowed insertion of the nylon darts under the heavy cycloid scales of red drum, several thousand fish were tagged and released, and a portion of these fish were held in experimental holding ponds for observation. Preliminary analysis indicated that muscle tissue does encapsulate the entire area, as well as adhere to the nylon head. Tags encapsulated in this manner were almost impossible to take out by hand and needed to be cut out of the fish with a knife. However, further evaluation is necessary before definitive conclusions can be made concerning long- and short-term shedding rates.

The most recent development of dart tags is currently being conducted in Australia (M. Hall, Hallprint Ltd., August 18, 1987, personal communication) where very sharp stainless steel applicators are being used to insert nylon heads with four strong barbs. This approach takes advantage of the best characteristics of both materials to reduce shedding rates -- i.e., ease and consistency of penetration using stainless steel applicators and adherence of tissue to nylon head. Results of these studies are not yet available. Further experiments in tag development, using this approach on billfish are presently being conducted by the Billfish Foundation and the Southeast Fisheries Center. One of several improvements includes a mechanical attachment of the nylon anchor to the vinyl streamer using shrink tubing along the entire length of the tag. This provides a very strong mechanical attachment and also protects the written portion of the vinyl streamer against wear and abrasion - several researchers have reported tag returns where numbers were missing or hard to read. A double tagging experiment using this tag and the stainless steel tag is being planned starting in 1990.

Most large tagging studies now use either nylon or stainless steel darts, depending on the intended target species. Although some studies reported lower returns using dart tags than spaghetti tags, there is no doubt that the development and use of this tag on larger marine pelagic species has provided considerable information on the movement of these animals, which would have been unobtainable using other conventional tags.

7. Tagging Applications - WESTERN ATLANTIC

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Bluefin have been marked and released by rod and reel fishermen in the west Atlantic since 1954 and these activities continue today ([illegible]). Originally, these releases were of mostly large fish, but in later years, such releases have been predominantly small fish. During the 1960's, 1970's, and early 1980's large numbers of small fish were released from purse seine catches. Purse seine release experiments were carried out to estimate mortality and growth rates. Those of 1980 and 1981 were specifically intended to estimate fishing mortality. Rod and reel releases were opportunistic activities intended to obtain information on movements.

The recovery data has proved valuable. Recaptures of large fish released in the Bahamas in the 1960's documented transatlantic migration and minimum migration speeds of adults. Recaptures of small fish tagged from purse seines documented transatlantic migrations of juvenile bluefin. The current understanding of migratory patterns (Brunenmeister 1980, Mather 1980) rest almost entirely on these data and the ICCAT regulatory regime, based on separate east and west Atlantic stocks is founded on that understanding.

Tagging data have proved valuable for growth studies. The current estimates of west Atlantic bluefin growth used in stock assessments since 1978 (Parrack and Phares 1978) is based entirely on these data. Fish released by both rod and reel and purse seine fishermen during 1966 to 1977 were used to estimate parameters for the logistic, von Bertalanffy, and Richards growth models.

Although an active rod and reel fishery existed, a program to collect the catch statistics did not exist before 1974. Rod and reel catch estimates before 1974 are based on the mark-recapture data and the commercial catch. The ratio of rod and reel to commercial fishery returns was multiplied by the commercial catch to estimate the rod and reel catch each year, 1960 to 1973 (Parks 1976, Parrack et al. 1978).

Several attempts have been made to use mark-recapture data from the purse seine releases to estimate abundances and mortality rates (Lenarz et al. 1973, Baglin et al. 1980, Parrack 1980). These attempts have not contributed to an understanding of bluefin population dynamics in a direct way because of an inability to define mixing rates and, in particular, to demonstrate that marked fish are mixing randomly within the population (Turner 1980).

Table II.7.1. Western Atlantic bluefin tuna tagging activities.

Abbreviations:
NMFS: National Marine Fisheries Service, USA   PS: Purse Seine   [illegible]

YEAR	RELEASE LOCATION	CAPTURE GEAR	NO. RELEASED	SIZE OF FISH	SOURCES
1954	USA, Cape Hatteras to Cape Cod	RR	10[illegible]	<146 cm	[illegible] et al. (1977)
	Bahamas		2	>120 kg	NMFS, unpubl. data

Table II.7.1. con't Western Atlantic bluefin tuna tagging activities.

YEAR	RELEASE LOCATION	CAPTURE GEAR	NO. RELEASED	SIZE OF FISH	SOURCES
1955	USA, Cape Hatteras to Cape Cod	RR	215	small	Aloncle et al (1977)
	Bahamas	RR	14	>120 kg	Aloncle et al (1977)
1956	Bahamas and Gulf of Mexico	RR/LL	40 + 1	>120 kg	NMFS, unpub. data
	USA, Cape Hatteras to Cape Cod	RR	58	>145 cm	Baglin et al (1978) NMFS, unpub, data.
1957	USA, Cape Hatteras to Cape Cod	RR	34	small	Aloncle et al (1977)
	USA, Cape Hatteras to Cape Cod	LL	5	>144 cm	Anonymous (1957), and NMFS, unpubl. data
1958	USA, Cape Hatteras to Cape Cod	RR	38	small	Aloncle et al (1977)
1959	USA, Cape Hatteras to Cape Cod	RR	25	small	Aloncle et al (1977)
	Bahamas	RR	25	>120 kg	Aloncle et al (1977)
	USA, Northeast coast, oceanic waters	LL	97	medium	Anonomous (1958, 1960) and NMFS, unpubl. data
1960	USA, Cape Hatteras to Cape Cod	RR	15	<145 cm	Aloncle et al (1977)
	USA, Cape Hatteras to Cape Cod, oceanic waters	LL	205	80-194 cm	NMFS, unpubl. data
	Bahamas	RR	13	>120 kg	Aloncle et al (1977) and NMFS, unpubl. data
1961	USA, Northeast coast, oceanic waters	?	27	small	NMFS, unpubl. data
	Bahamas	RR/PS	25 + 9	>120 kg	Aloncle et al (1977) and NMFS, unpubl. data
1962	USA, Cape Hatteras to Cape Cod	RR/LL/PS	52 + 25	small	Aloncle et al (1977) and NMFS, unpubl. data
	Bahamas	RR	45	>120 kg	Aloncle et al (1977)
	Newfoundland	RR	6	>120 kg	Aloncle et al (1977)
1963	USA, Cape Hatteras to Cape Cod	RR	29	small	Aloncle et al (1977)
	Bahamas	RR	147	>120 kg	Aloncle et al (1977)
	Newfoundland	RR	3	>120 kg	Aloncle et al (1977)
	Northwest Atlantic oceanic waters & Azores vicinity	LL	44 + 1	medium & large	NMFS, unpubl. data
	Nova Scotia	Trap	18	large	Beckett (1970) and Hurley et al (1979)

Table II.7.1. con't Western Atlantic bluefin tuna tagging activities.

YEAR	RELEASE LOCATION	CAPTURE GEAR	NO. RELEASED	SIZE OF FISH	SOURCES
1964	USA, south of Rhode Island	PS	17	school	Beckett (1970) and Hurley et al (1979)
	USA, Cape Hatteras to Cape Cod	PS/RR	455 + 10	small	Aloncle et al (1977)
	Bahamas	RR	41	>120 kg	Aloncle et al (1977)
	USA northeast, oceanic waters	LL	24	>144 cm	NMFS, unpubl. data
	Newfoundland	RR	41	>120 kg	Aloncle et al (1977)
	Nova Scotia	Trap	6	large	Beckett (1970) and Hurley et al (1979)
1965	USA, Cape Hatteras to Cape Cod	PS/RR	1629 + 43	small	Aloncle et al (1977)
	USA, off Delaware and New Jersey	PS	236	school	Beckett (1970) and Hurley et al (1979)
	Bahamas	RR	55	>120 kg	Aloncle et al (1977)
	Newfoundland	RR	47	>120 kg	Aloncle et al (1977)
	Northwest Atlantic, oceanic waters	LL	36	medium	Beckett (1970) and NMFS, unpubl. data
	Nova Scotia	Trap	60	large	Beckett (1970) and Hurley et al (1979)
1966	USA, Cape Hatteras to Cape Cod	PS/RR	3772 +187	small	Aloncle et al (1977) and NMFS, unpubl. data
	Bermuda	LL	5	medium	NMFS, unpubl. data
	Bahamas	RR	105	>120 kg	Aloncle et al (1977)
	USA, New England	RR	2	>122 kg	Aloncle et al (1977)
	Nova Scotia	Trap/HP	69 + 2	giant	Beckett (1970) and Hurley et al (1979)
	Northwest Atlantic, oceanic	LL	3	large	Beckett (1970) and Hurley et al (1979)
	Newfoundland	RR	49	>120 kg	Aloncle et al (1977)
	USA, Cape Hatteras to Cape Cod	LL	59	medium & large	NMFS, unpubl. data
1967	USA, Cape Hatteras to Cape Cod	PS/RR	614 + 14	small	Aloncle et al (1977) and NMFS, unpubl. data
	Bahamas	RR	82	>120 kg	Aloncle et al (1977)
	Newfoundland	RR	6	>120 kg	Aloncle et al (1977)
	Nova Scotia	Trap	193	large	Beckett (1970) and Hurley et al (1979)
	Northwest Atlantic, oceanic	LL	3/0	giant	Beckett (1970) and Hurley et al (1

Table II.7.1. con't Western Atlantic bluefin tuna tagging activities.

YEAR	RELEASE LOCATION	CAPTURE GEAR	NO. RELEASED	SIZE OF FISH	SOURCES
1968	USA, Cape Cod to Cape Hatteras	PS/RR	219 + 41	small	Aloncle et al (1977)
	Bahamas	RR	57	>120 kg	Aloncle et al (1977)
	USA, New England	RR	6	>122 kg	Aloncle et al (1977)
	Newfoundland	RR	193	>120 kg	Aloncle et al (1977)
	Newfoundland	RR	24	large	Beckett (1970) and Hurley et al (1979)
	Northwest Atlantic, oceanic	LL	2	large	Beckett (1970) and Hurley et al (1979)
1969	USA, Cape Hatteras to Cape Cod	PS/RR	92 + 244	small	Aloncle et al (1977) and NMFS, unpubl. data
	Bahamas	RR	50	large	Baglin et al (1978)
	USA, New England	RR	1	>122 kg	Baglin et al (1978)
	Newfoundland	RR	166	>120 kg	Aloncle et al (1977)
	Newfoundland	RR	29	large	Beckett (1970) and Hurley et al (1979)
	Nova Scotia	Trap	15	large	Beckett (1970) and Hurley et al (1979)
1970	USA, Cape Hatteras to Cape Cod	PS/RR	32 + 426	small	Aloncle et al (1977)
	Bahamas	RR	182	large	Baglin et al (1978)
	USA, New England	RR	4	>122 kg	Aloncle et al (1977)
	Newfoundland	RR	79	>120 kg	Aloncle et al (1977)
	Newfoundland	RR	17	large	Hurley et al (1979)
	Nova Scotia	Trap	3	large	Hurley et al (1979)
1971	USA, Cape Hatteras to Cape Cod	PS/jig/RR	311 + 31	small	Aloncle et al (1977)
	USA, northwest coast	PS	271 + 72	49 to 111 cm	Hurley et al (1979) and Aloncle et al (1974)
	Bahamas	RR	49	large	Baglin et al (1978)
	USA, New England	RR	10	>122 kg	Aloncle et al (1977)
	Newfoundland	RR	32	>120 kg	Aloncle et al (1977)
	Newfoundland	RR	55	large	Hurley et al (1979)
	Nova Scotia	Trap	45	large	Hurley et al (1979)
1972	USA, Cape Hatteras to Cape Cod	PS/RR	127 + 66	small	Aloncle et al (1977) and NMFS, unpubl. data
	Bahama Islands	RR	32	>120 kg	Baglin et al (1978)
	USA, New England	RR	17	>122 kg	Baglin et al (1978)
	Newfoundland	RR	38	>120 kg	Aloncle et al (1977)
	Newfoundland	RR	70	large	Hurley et al (1979)
	Nova Scotia	Trap	12	large	Hurley et al (1979)

Table II.7.1. con't Western Atlantic bluefin tuna tagging activities.

YEAR	RELEASE LOCATION	CAPTURE GEAR	NO. RELEASED	SIZE OF FISH	SOURCES
1973	USA, Cape Hatteras to Cape Cod	PS/RR	351	small	Baglin et al (1978) and USA unpubl. data
	USA, northeastern coast	PS	156	small	Hurley et al (1979)
	Bahama Islands	RR	47	>120 kg	Baglin et al (1978)
	USA, New England	RR/PS	15	>122 kg	Aloncle et al (1977)
	Gulf of St. Lawrence	RR	16		Hurley et al (1979)
1974	USA, Cape Hatteras to Cape Cod	PS/RR	1713	small	Baglin et al (1978) and USA unpubl. data
	Bahama Islands	RR	31	large	Baglin et al (1978)
	USA, New England	RR/PS	9	large	Baglin et al (1978)
	Gulf of St. Lawrence	RR	41	large	Hurley et al (1979)
	Nova Scotia	Trap	8	large	Hurley et al (1979)
1975	USA, Cape Hatteras to Cape Cod	PS/PR	309	small	Baglin et al (1978) and USA unpubl. data
	Bahama Islands	RR	18	large	Baglin et al (1978)
	USA, New England	RR	19	large	Baglin et al (1978)
	Gulf of St. Lawrence	RR	20	large	Hurley et al (1979)
	Nova Scotia	Trap	148	large	Hurley et al (1979)
1976	USA, Cape Hatteras to Cape Cod	PS/RR	2379	small	Baglin et al (1978) and NMFS, unpubl. data
	Bahama Islands	RR	5	large	Baglin et al (1978)
	USA, New England	RR	34	large	Hurley et al (1978)
	Gulf of St. Lawrence	RR	17	large	Hurley et al (1979)
	Nova Scotia	Trap	11	large	Hurley et al (1979)
1977	USA, Cape Hatteras to Cape Cod	PS/RR	1900	small	Baglin et al (1978) and NMFS, upubl. data
	Bahama Islands	RR	11	large	Baglin et al (1978)
1977	USA, New England	RR/HP	190	large	Tyler et al (1979)
	Nova Scotia	RR	1		Hurley et al (1979)
	Gulf of St. Lawrence	RR	10	large	Hurley et al (1979)
1978	USA, Cape Hatteras to Cape Cod	PS/RR	1362	small	NMFS, unpubl. data
	Bahama Islands	RR	2	large	Tyler et al (1979)
	USA, New England	RR	20	large	Tyler et al (1979)
	Newfoundland	RR	1	large	Hurley et al (1970)
	Nova Scotia	Trap	5	large	Hurley et al (1979)

Table II.7.1. con't Western Atlantic bluefin tuna tagging activities.

YEAR	RELEASE LOCATION	CAPTURE GEAR	NO. RELEASED	SIZE OF FISH	SOURCES
1979	USA, New England	PS	931	medium & large	NMFS, unpubl. data
	North American coast	RR	174	small & medium	NMFS, unpubl. data
1980	USA Mid-Atlantic Bight	PS	3036	small	NMFS, unpubl. data
	North American coast	RR	121	small & medium	NMFS, unpubl. data
1981	USA, Mid-Atlantic Bight	PS	1790	small	NMFS, unpubl. data
	Mid-Atlantic Bight	RR	182	small	NMFS, unpubl. data
	Florida	RR	2	large	NMFS, unpubl. data
	Bahamas	RR	5	large	NMFS, unpubl. dat
1982	USA, Mid-Atlantic Bight		198	small/med./large	NMFS, unpubl. data
	New England		13	large	NMFS, unpubl. data
	Gulf of Mexico	LL	2	large	NMFS, unpubl. data
1983	USA, Mid-Atlantic Bight		130	small & medium	NMFS, unpubl. data
	New England		17	large	NMFS, unpubl. data
	Gulf of Mexico		1	large	NMFS, unpubl. data
	Bahamas	RR	1	large	NMFS, unpubl. data
1984	North Atlantic coast	RR	85	small & medium	NMFS, unpubl. data
	Bahamas	RR	1	large	NMFS, unpubl. data
1985	North American coast	RR	115	small & medium	NMFS, unpubl. data
	USA, Gulf of Mexico		9	large	NMFS, unpubl. data
	Bahamas		2	large	NMFS, unpubl. data
1986	North American coast	RR	34	small	NMFS, unpubl. data
		LL	1	large	
	Bahamas	RR	16	medium	NMFS, unpubl. data
1987	North American coast	RR	45	small	NMFS, unpubl. data

8. Tagging Interpretation - EASTERN ATLANTIC AND MEDITERRANEAN SEA

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In this chapter two tagging methods have been considered:

i) artificial tags, the application of some type of tag to bluefin caught by different fishing methods, and
ii) natural tags or parasites, this method was used for the study of transatlantic migration rates for young bluefin.

The distance and direction of movement since tagging of each recovered fish are shown in preliminary maps. At each recovery site the number of days since tagging is indicated. The lines are continuous for presumed direct movements (within the same year) and broken when they refer to the distance moved during more than

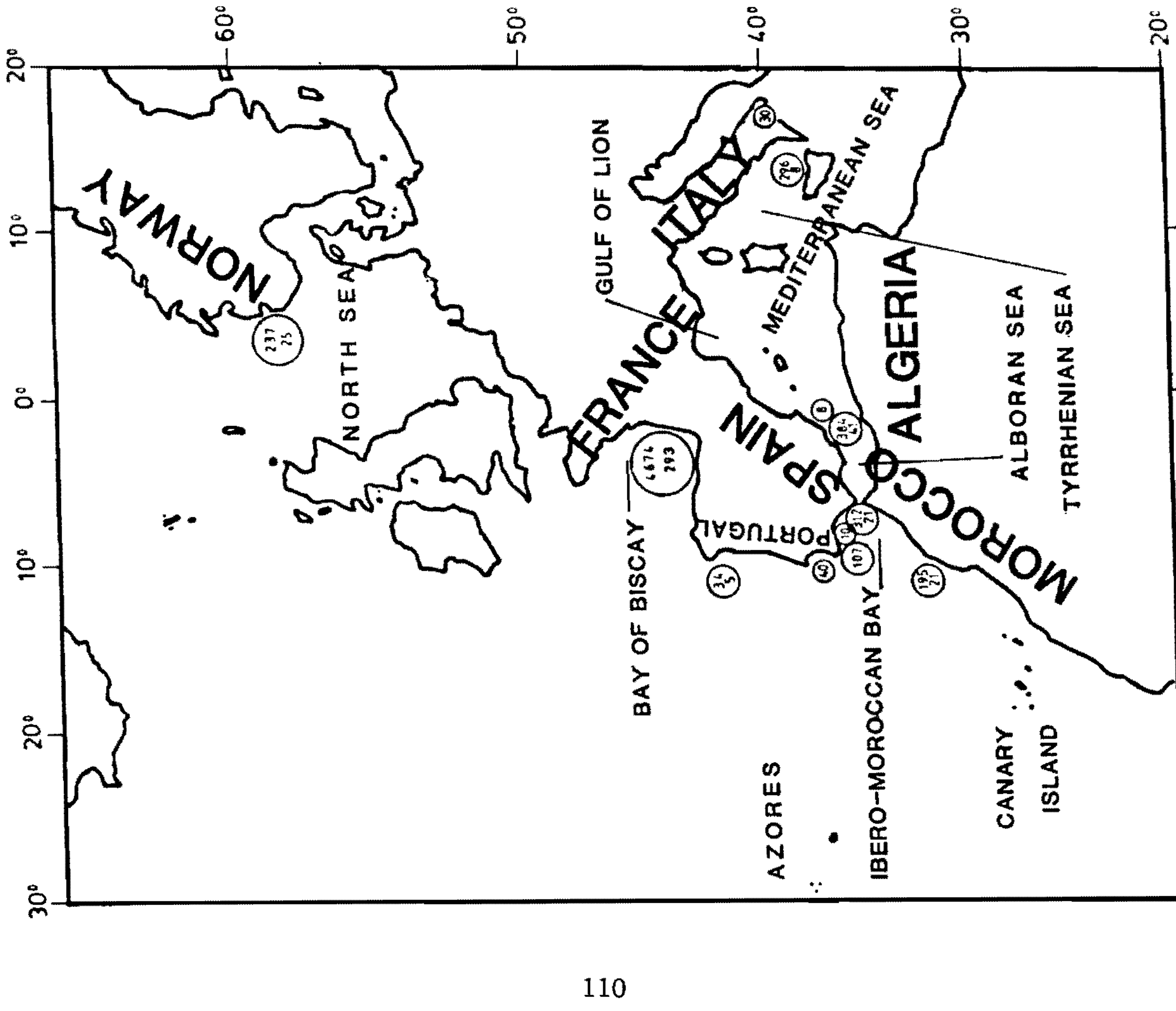


Figure II.8.1. Areas where bluefin tuna were tagged. (Upper number indicates the number of fish tagged; lower number indicates recoveries.)

one year. All the east Atlantic and Mediterranean locations where bluefin tagging took place are shown on Figure II.8.1. The total number of fish tagged and recovered are indicated.

For each tagging experiment , the tables indicate movement using the 'data rose' concept. This is provided to indicate the direction of movement according to the protocols proposed by Fink and Bayliff (cited by Bard et al, 1983). This technique does not take into account intervening land masses, it consists of grouping the movements by sectors of the compass. The sectors are labelled 1 to 8, each one covering 45^0, the 'rose' is arranged in a diagram whose center coincides with the tagging site (Figure II.8.2).

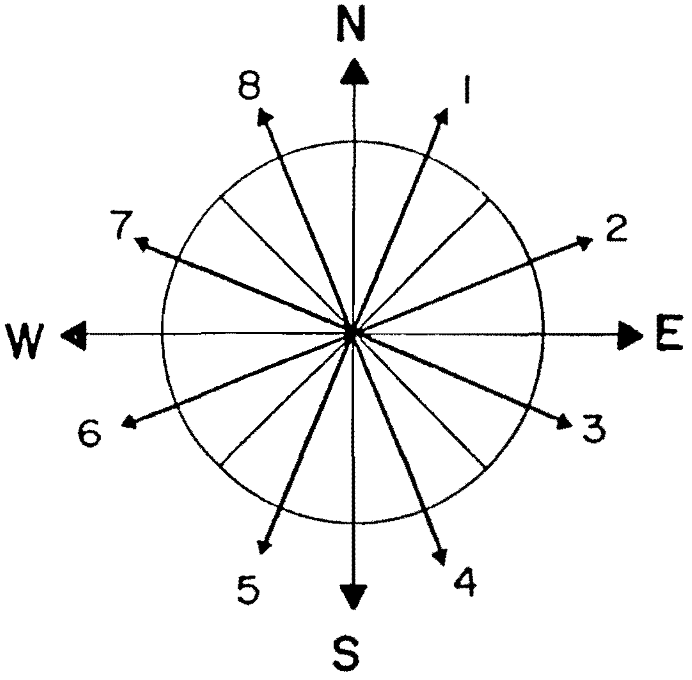


Figure II.8.2. Directional rose used to indicate the direction of movement (ignoring intervening land masses) of tagged fish. This concept is used in subsequent tables of this section.

Artificial tags

We have completed a review and compilation of recent data of bluefin tagging in the east Atlantic and Mediterranean Sea covering the period from 1911 to the present. In the earliest experiments, copper disks fastened to a ring were inserted in the caudal penduncle of the bluefin (Sella 1929). At that time Sella tagged 30 bluefin tuna caught in traps located in the Bay of Tarento, southern Italy, 10 bluefin tagged off Apuglia and 20 off Gallipoli. There were no recoveries of these tagged bluefin (cited by Heldt 1927).

Between 1931 and 1935 Frade and Dentinho used "phosphorous copper" pieces and tagged 107 bluefin in the "Senhora de Livramento" trap (Algarve, Portugal). Of these releases it seems that 3 bluefin were recovered, but the details about them are unknown (cited by Rodriguez-Roda 1980).

After the metal disks the 'Lea' hydrostatic tag was used for many years. Since the 1970's, the tags most commonly used have been the dart type (FT-2), which consist of a yellow plastic (PVC) tube measuring 2.5 mm in diameter, and 12 to 15 cm in length.

Table II.8.1 gives an overall summary of the results of the tagging experiments, including the percentages of the recoveries for each year of the tagging program, as well as the average total value (6.5%).

Table II.8.1. Tagging programs for the Atlantic bluefin tuna in the east Atlantic and Mediterranean Sea.

		Recoveries				
Tagging Country (Year)	Number of tuna tagged	Total (%)	Atlantic to Mediterranean	Mediterranean to Atlantic	Trans-Atlantic	
Italy (1911-1912)	30	-	-	-	-	Heldt, 1927
Portugal (1931-1935)	107	-	-	-	-	Rodriguez-Roda, 1980
Norway (1957-1962)	237	25 (10.5)	-	-	-	Hamre, 1963, 1964
Spain (Atl.) (1960-1967)	312	21 (6.7)	6	-	-	Rodriguez-Roda, 1969, 1980
Portugal (1960)	50	-	-	-	-	Vilela, 1960
Italy (1963-1968)	296	6 (2.0)	-	-	-	Arena & Li Greci, 1970
France-Portugal (1967-1972)	34	5 (14.7)	-	-	2	Aloncle, 1973; Mather and Mason, 1973
CIESM * (1972)	8	-	-	-	-	Cendrero, pers. com.
Morocco (Atl.) (1972-1978)	195	21 (10.8)	-	-	-	Lamboeuf, 1975 Brethes, 1978, 1979b Brethes and Mason, 1979
Spain (Atl.) (1976-1989)	4674	293 (6.3)	6	-	13	this document
Spain (Medit.) (1977-1984)	384	41 (10.7)	-	3	-	Rey and Cort, 1978, 1986 Rey, pers. com.
TOTAL	6327	412 (6.5)	12	3	15	

* International Commission for the Exploration of the Mediterranean Sea

Norwegian tagging program

From 1957 until 1962 tagging programs were conducted off the southeastern coast of Norway (Hamre 1963, 1964). Twenty-five of the 237 released fish were recovered. These were giant bluefin (> 150 cm) that were tagged from the purse seine fishery using 'Lea' hydrostatic tags.

The 25 recoveries reported from this program are shown in Table II.8.2 and Figure II.8.3. Information for three of these recoveries was obtained from Farrugio (1980b). Five fish were recovered from the traps in the Bay of Cadiz, four in the year following tagging, and one 2 years after release. The remainder of the recoveries came from the Norwegian fisheries.

These recoveries show the movement of adult spawning bluefin in a north to south direction, whereas the return movement (south to north) has not yet been verified.

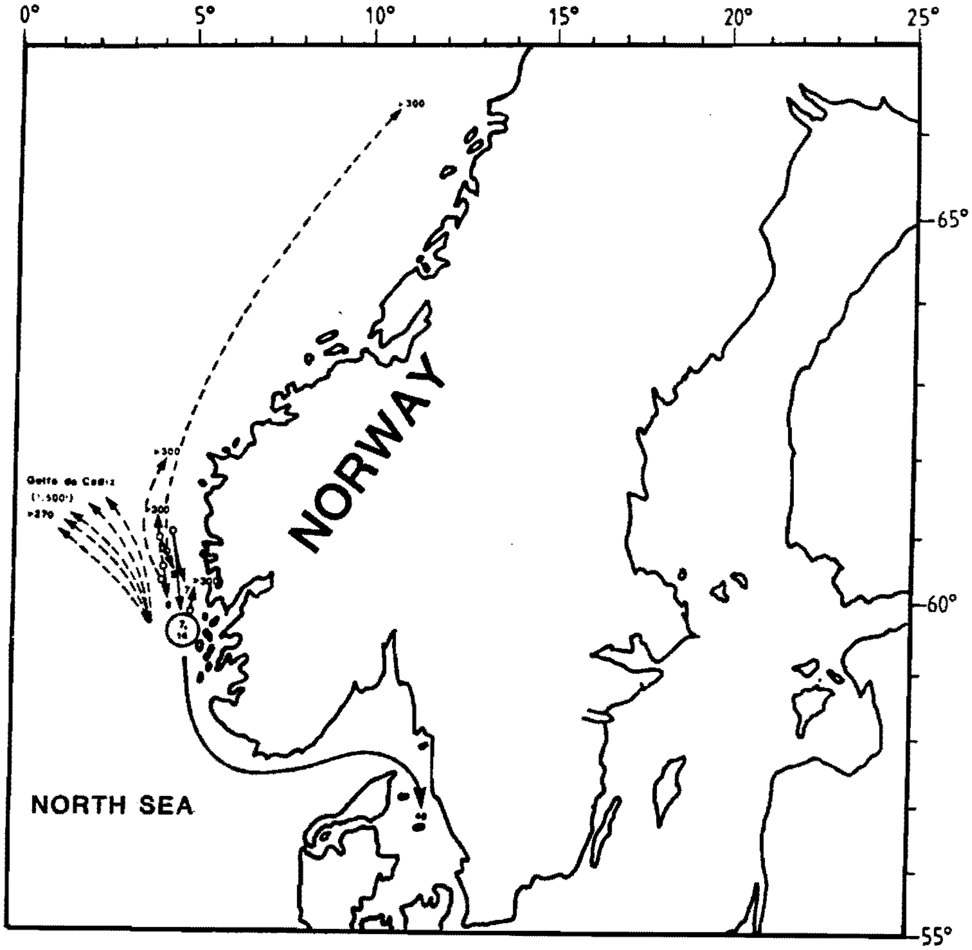


Figure II.8.3. Tagging/Recovery of bluefin spawners in Norway. (Number indicates the days free)

Table II.8.2. Norweigian tagging program for bluefin spawners (>150 cm). Adapted from Hare (1964).

Tagging		Recovery				
Date	Location	Date	Location	Country[+] (Sector)	Dist.[*]	Days
15/09/58	5935N/0504E	20/06/59	3609N/0553W	E(5)	1474	278
15/09/58	5932N/0504E	20/08/59	5955N/0500E	N(8)	23	339
17/09/58	5938N/0502E	19/06/59	3609N/0553W	E(5)	1474	275
17/09/58	5938N/0502E	04/07/59	3609N/0553W	E(5)	1477	291
10/08/59	6055N/0425E	17/08/59	6015N/0445E	N(4)	41	7
10/08/59	6055N/0425E	17/08/59	6000N/0445E	N(4)	56	7
12/08/59	6030N/0440E	17/08/59	6030N/0440E	N(-)	-	5
12/08/59	6030N/0440E	18/08/59	6005N/0450E	N(4)	26	6
21/08/59	5930N/0505E	06/10/59	5650N/1140E	D(3)	266	46
21/08/59	5940N/0455E	20/05/60	3609N/0553W	E(5)	1474	272
01/09/59	5955N/0455E	01/08/60	6152N/0435E	N(8)	117	334
08/09/59	5944N/0451E	19/10/60	6102N/0420E	N(8)	80	406
08/08/60	6047N/0415E	17/08/60	6039N/0420E	N(4)	8	9
08/09/59	5944N/0500E	05/08/61	6043N/0435E	N(8)	60	696
08/08/60	6044N/0429E	31/07/61	6051N/0435E	N(1)	8	357
08/08/60	6044N/0429E	28/08/61	6018N/0449E	N(4)	28	385
09/08/60	6030N/0442E	03/08/61	6615N/1030E	N(1)	380	359
25/08/60	6024N/0450E	18/08/61	6103N/0425E	N(8)	41	358
16/08/61	6044N/0440E	30/08/61	5941N/0500E	N(4)	64	14
21/08/61	6044N/0438E	28/08/61	6008N/0458E	N(4)	37	7
28/08/61	6015N/0450E	06/10/61	6050N/0440E	N(8)	35	39
03/09/59	6015N/0450E	30/09/61	6040N/0440E	N(8)	26	757
25/08/60	6035N/0450E	02/08/62	3609N/0553W	E(5)	1528	707
21/08/61	6045N/0435E	02/08/62	6100N/0430E	N(8)	15	346
23/08/61	6045N/0435E	25/08/62	6135N/0435E	N(1)	50	367

[+] N = Norway
E = Spain
D = Denmark

[*] = Distance in nautical miles (1 n. mile = 1,852 m)

Note: - The number in ( ) after the country where the fish was recovered indicates the directional sector between the tagging and recovery positions.
(-) = Recovery in the tagging area

Tagging in Spanish and Portuguese traps

In the summer of 1960, 10 bluefin (measuring 160-180 cm) were tagged from the Tavira trap in the Bay of Cadiz off southern Portugal. Later, in November of the same year, 40 small (60-65 cm) bluefin were tagged near the coast of Sesimbra, Portugal (at 16-18' from Cape Espichel). None of the 50 tagged bluefin was recovered (Vilela, 1960).

Atlantic Bluefin Tuna

Between 1960 and 1967 bluefin tagging experiments took place in the Sancti-Petri and Barbate traps, off southern Spain in the Bay of Cadiz (Rodriguez-Roda 1969, 1980). In six tagging cruises, 312 giant bluefin (> 150 cm) were tagged, of which 21 were recovered. Hydrostatic tags were used according to the Norwegian method, but with some variations (Rodriguez-Roda 1964).

Of the 21 recoveries reported from these tagging experiments, 15 came from the Atlantic fisheries (eastern side) and six fromthe Mediterranean Sea. We know that two of these latter fish were recovered in Tripoli (Libya), but no other details on them are available. The remainder of the recoveries have been divided into two groups according to whether the bluefin were tagged in an "entry" phase (migration to the spawning areas in the Mediterranean) or in an "exit" phase (migration to the feeding areas outside the Mediterranean). The data on the above are given in Table II.8.3 and in Figure II.8.4, respectively.

This tagging program shows spawning bluefin enter the Mediterranean Sea from the east Atlantic.

Table II.8.3. Tagging program for bluefin spawners (>150 cm) in Spain. Adapted from Rodriguez-Roda (1969; 1980).

Tagging		Recovery				
Date	Location	Date	Location	Country+ (Sector)	Dist.#	Days
23/05/60	3625N/0615W	24/05/60	3708N/0740W	P(7)	81	1
24/05/60	3609N/0553W	27/07/60	3608N/0520W	E(3)*	27	63
28/05/60	" "	29/05/60	3609N/0553W	E(-)	-	1
28/05/60	" "	21/08/60	4330N/0353W	F(1)*	451	84
27/07/60	" "	08/06/61	3512N/0610W	M(5)	59	315
27/07/60	" "	25/05/61	3700N/0755W	P(7)	111	302
27/07/60	" "	29/05/62	3512N/0610W	M(5)	59	671
27/07/60	" "	07/08/60	3710N/0720W	E(7)	93	11
27/07/60	" "	10/06/62	3512N/0610W	M(5)	59	682
13/06/61	" "	02/07/61	3554N/0517W	E(3)*	33	19
12/07/61	" "	21/05/62	3625N/0615W	E(7)	24	313
14/07/61	" "	18/07/61	3708N/0740W	P(7)	104	4
14/07/61	" "	19/07/61	3710N/0720W	E(7)	93	5
14/07/61	" "	23/07/61	3609N/0553W	E(-)	-	9
22/05/62	" "	24/05/62	3708N/0740W	P(7)	104	2
07/08/62	" "	18/08/62	3708N/0740W	P(7)	104	11
07/08/62	" "	11/12/62	3120N/0950W	M(5)	350	125
14/07/65	" "	20/07/65	3708N/0740W	P(7)	104	6
02/08/67	" "	25/08/67	3730N/0100W	E(2)*	259	23

+P = Portugal
E = Spain
F = France
M = Morocco

\# = Distance in nautical miles (1 n. mile = 1,852 m)

Note: - The number in ( ) after the country where the fish was recovered indicates the directional sector between the tagging and recovery positions.
(-) = Recovery in the tagging area
* = Recovery in the Mediterranean Sea

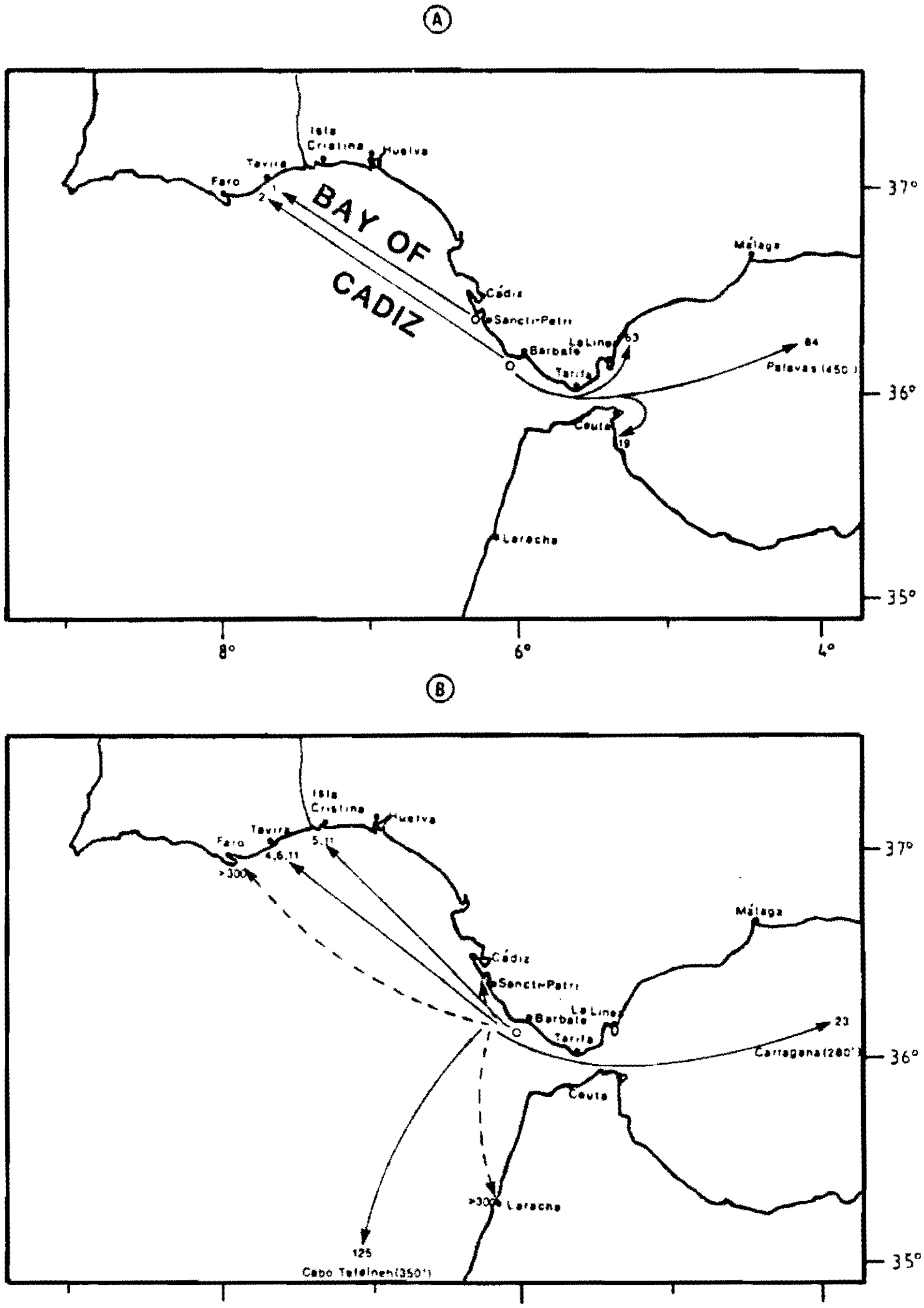


Figure II.8.4. Tagging/Recovery of bluefin spawners in the Bay of Cadiz.

(A) - Tagged in "entry" phase.
(B) - Tagged in "exit" phase.
(Number indicates days free)

Italian tagging programs

A tagging program conducted in the Tyrrhenian Sea (North of Sicily) tagged 296 bluefin between 1963 to 1968 (Figure II.8.5). All of these, except 8, were immature fish. The young bluefin were tagged from the troll fishery and the adult bluefin were tagged from Sicilian traps.

Five of the young bluefin were recovered close to the release sites - Cape Milazzo and Eolinas Islands (Arena and Li Greci 1970) (Table II.8.4). This indicates that the Tyrrhenian and Ionian Seas are possibly areas of juvenile bluefin tuna concentration throughout the year.

Table II.8.4. Tagging program for bluefin spawners (>150 cm) in Italy. Adapted from Arena and Li Greci (1970).

Tagging		Recovery				
Date	Location	Date	Location	Country^{+} (Sector)	Dist.*	Days
31/05/68	3806N/1300E	17/10/69	4000N/0010E	E(7)	609	503

The adult bluefin, age between 4 and 6 (28 to 60 kg) were tagged during the spawning period in the Punta Raisi trap (Palermo). One was recovered in the area around Benicasim (Spain, Mediterranean) in the autumn of the following year (17 months after release). This recovery is an indication of the dispersion of spawning bluefin and their movement between fisheries within the Mediterranean (Table II.8.5 and Figure II.8.5).

Table II.8.5. Tagging program for bluefin tuna (age class 0) in Italy. Adapted from Arena and Li Greci (1970).

Tagging		Recovery				
Date	Location	Date	Location	Country^{+} (Sector)	Dist.*	Days
09-11/63	3819N/1510E	-/05/65	3850N/1515E	IT(1)	31	>550
10/10/67	" "	24/10/67	3806N/1500E	IT(5)	73	14
10/10/67	" "	23/10/67	3812N/1455E	IT(5)	68	13
10/10/67	" "	17/10/67	3848N/1555E	IT(3)	47	7
15/10/67	3840N/1448E	20/12/67	3748N/1545E	IT(4)	69	65

$^{+}$E = Spain
IT= Italy
- = Date unknown

* = Distance in nautical miles (1 n. mile = 1,852 m)

Note: - The number in ( ) after the country where the fish was recovered indicates the directional sector between the tagging and recovery positions.

There was no indication from these studies of an interaction of juvenile bluefin from this area with the Atlantic fisheries. Therefore, it was deduced that the spawning area of the Tyrrhenian Sea produces a recruit destined initially for the Mediterranean.

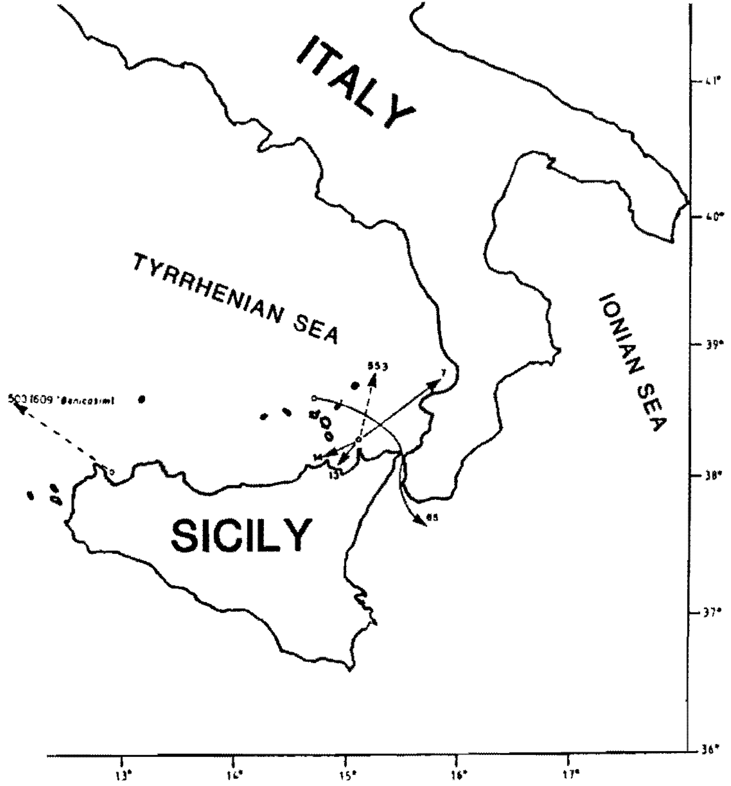


Figure II.8.5. Tagging/Recovery of juvenile bluefin tuna in the south of Italy. (Number indicates days free)

Tagging programs of France and Portugal

Studies by Aloncle (1973) and Mather and Mason (1973) describe the results of tagging experiments carried out between 1968 and 1972. The fishing area off the Atlantic coast of Portugal and Spain, from Cape San Vicente to Finisterre and the Cantabrian Sea. Thirty-four juvenile bluefin tunas were tagged by troll. Of these 5 were recovered, however, the exact recovery sites for two of these are unknown. Aloncle (1973) assumed that they were recovered in the Bay of Biscay. Specific data are given in Table II.8.6.

Table II.8.6. Joint French/Portuguese tagging program for age class 1 bluefin tuna in the eastern Atlantic. Adapted from Aloncle (1973); Mather III and Mason, Jr. (1973).

Tagging		Recovery				
Date	Location	Date	Location	Country+ (Sector)	Dist.*	Days
23/09/68	4013N/0931W	13/10/68	4000N/0900W	P(3)	27	20
28/09/69	4400N/0735W	20/10/69	?	-	-	22
26/09/69	4400N/0505W	20/07/70	4000N/7300W	EEUU(6)	3038	298
23/09/68	4414N/0930W	08/08/70	4028N/7038W	EEUU(6)	2735	684
04/06/72	3715N/1014W	27/08/72	?	-	-	83

+P = Portugal
EEUU = U.S.A.
-/? = Recovery location unknown

* = Distance in nautical miles (1 n. mile = 1,852 m)

Note: - The number in ( ) after the country where the fish was recovered indicates the directional sector between the tagging and recovery positions.

From this tagging program, the first 2 transatlantic recoveries of juvenile bluefin tuna in an east to west direction were recorded (Figure II.8.6).

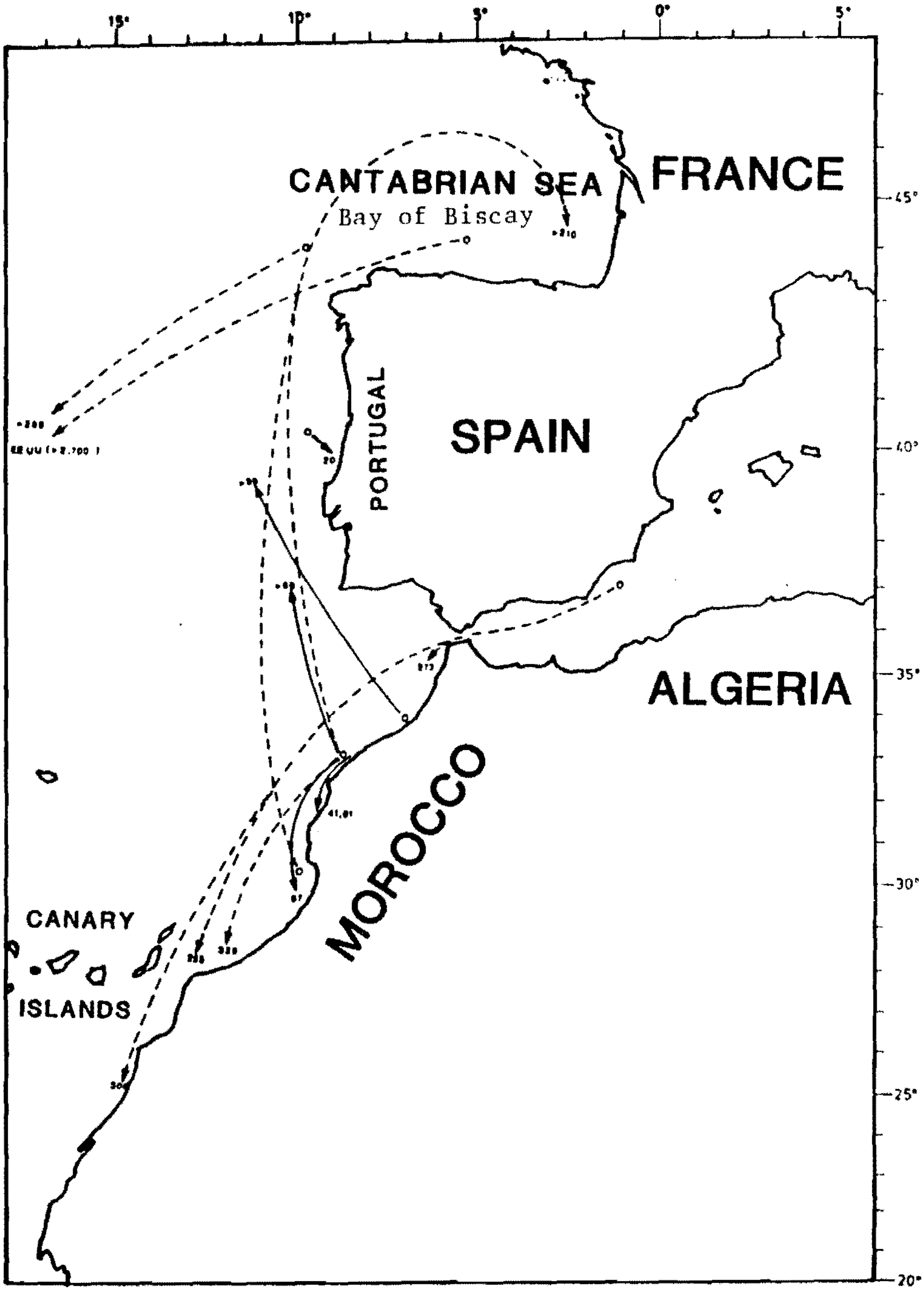


Figure II.8.6. Tagging/Recovery of juvenile bluefin tuna in Morocco (Atlantic area), Cantabrian Sea, Portugal and Spain (Mediterranean area). (Number indicates days free)

International tagging program

An international tagging cruise took place from November 1-15, 1971, in the western Mediterranean, off the coasts of Aguilas and Garrucha (Spain). Eight 'age 0' individuals were tagged by troll; none were recovered (Cendrero, pers. com.; see Table II.8.1).

Moroccan tagging program

During tagging cruises conducted between 1972 and 1978, 195 bluefin (age 1) were tagged off Morocco. The fishing areas were located off the Atlantic coast of Larache, from Casablanca to Cape Blanco, and Agadir. All the bluefin were caught by troll (Lamboeuf 1975; Brethes 1978, 1979; Brethes and Mason 1979).

Twenty-one bluefin were recovered; of these, five were recovered one year after release in the Bay of Biscay, 2 were recovered 3 and 4 months after release close to the coast of Portugal and the remainder were recovered off the Moroccan coast. These recoveries are shown in Table II.8.7 and Figure II.8.6. In this figure, three juvenile bluefin recoveries which pertain to the Spanish tagging program in the Mediterranean are included.

In the majority of cases it is difficult to ascertain the precise data regarding the tagging and recovery dates and the exact locations of release and recovery.

Table II.8.7. Tagging programs for age class 1 bluefin tuna in Morocco. Adapted from Lamboeuf (1975); Brethes and Mason, Jr. (1979); and Brethes (1978; 1979).

Tagging		Recovery				
Date	Location	Date	Location	Country+ (Sector)	Dist.*	Days
-/08/72	33N/8W	-/09/72	33N/8W	M(-)	-	N.D.
-/08/72	33N/8W	-/06/73	44N/2W	E(1)	718	>270
-/08/72	33N/8W	-/08/73	44N/2W	E(1)	718	>330
-/08/72	33N/8W	-/08/72	33N/8W	M(-)	-	N.D.
-/08/72	33N/8W	-/06/73	44N/2W	E(1)	718	>270
-/08/72	33N/8W	-/09/72	33N/8W	M(-)	-	N.D.
-/11/72	30N/9W	-/12/72	31N/10W	M(8)	79	N.D.
-/11/72	30N/9W	-/12/72	31N/10W	M(8)	79	N.D.
-/11/72	30N/9W	-/07/73	43N/2W	E(1)	850	>210
-/06/73	34N/6W	-/10/73	39N/11W	P(8)	385	> 90
-/08/73	33N/7W	-/11/73	37N/10W	P(8)	282	> 60
06/07/77	33N/8W	30/08/78	44N/2W	E(1)	718	420
07/07/77	33N/8W	?	33N/8W	M(-)	-	N.D.
08/07/77	33N/8W	25/07/77	?	M(-)	-	17
08/07/77	33N/8W	18/08/77	32N/9W	M(5)	79	41
11/07/77	33N/8W	10/09/77	32N/9W	M(5)	79	61
12/07/77	33N/8W	28/05/78	28N/12W	M(5)	364	320
15/07/77	33N/8W	24/07/77	33N/8W	M(-)	-	9
15/07/77	33N/7W	-/09/77	33N/7W	M(-)	-	>45
15/07/77	33N/7W	10/10/77	30N/9W	M(5)	207	87
-/07/78	34N/8W	23/07/78	34N/8W	M(-)	-	N.D.

+M = Morocco
E = Spain
P = Portugal

* = Distance in nautical miles (1 n. mile = 1,852 m)

Note: - The number in ( ) after the country where the fish was recovered indicates the directional sector between the tagging and recovery positions.
(-) = Recovery in the tagging area

Spanish tagging in the Cantabrian Sea (1976-1989)

In 1976, Spain initiated a bluefin tagging program in the Cantabrian Sea and the Bay of Biscay which is still (1989) in progress. Using baitboats, 4674 bluefin tunas (ages 1-7) have been tagged. Of these, age-classes 1-3 (fish measuring from 50-119 cm) represent 98.1% of the tagged sample (2769 age 1 fish, 1531 age 2 fish, and 287 age 3 fish).

As of December, 1989 293 tags have been recovered (Table II.8.8), including 13 transatlantic migrations (recovered from U.S. western Atlantic fisheries). Six tagged fish were recovered in the Mediterranean and five were recovered in the east Atlantic far from the Bay of Biscay. The remainder were recovered close to the release site (Cort 1986, 1987; Cort and Cardenas 1978; Cort and Rey 1979, 1981, 1983, 1984; Cort et al 1980; Rey and Cort 1982, 1985).

Table II.8.8. Spanish tagging program for Atlantic bluefin tuna in the Cantabrian Sea (Bay of Biscay) from 1976 to 1989.

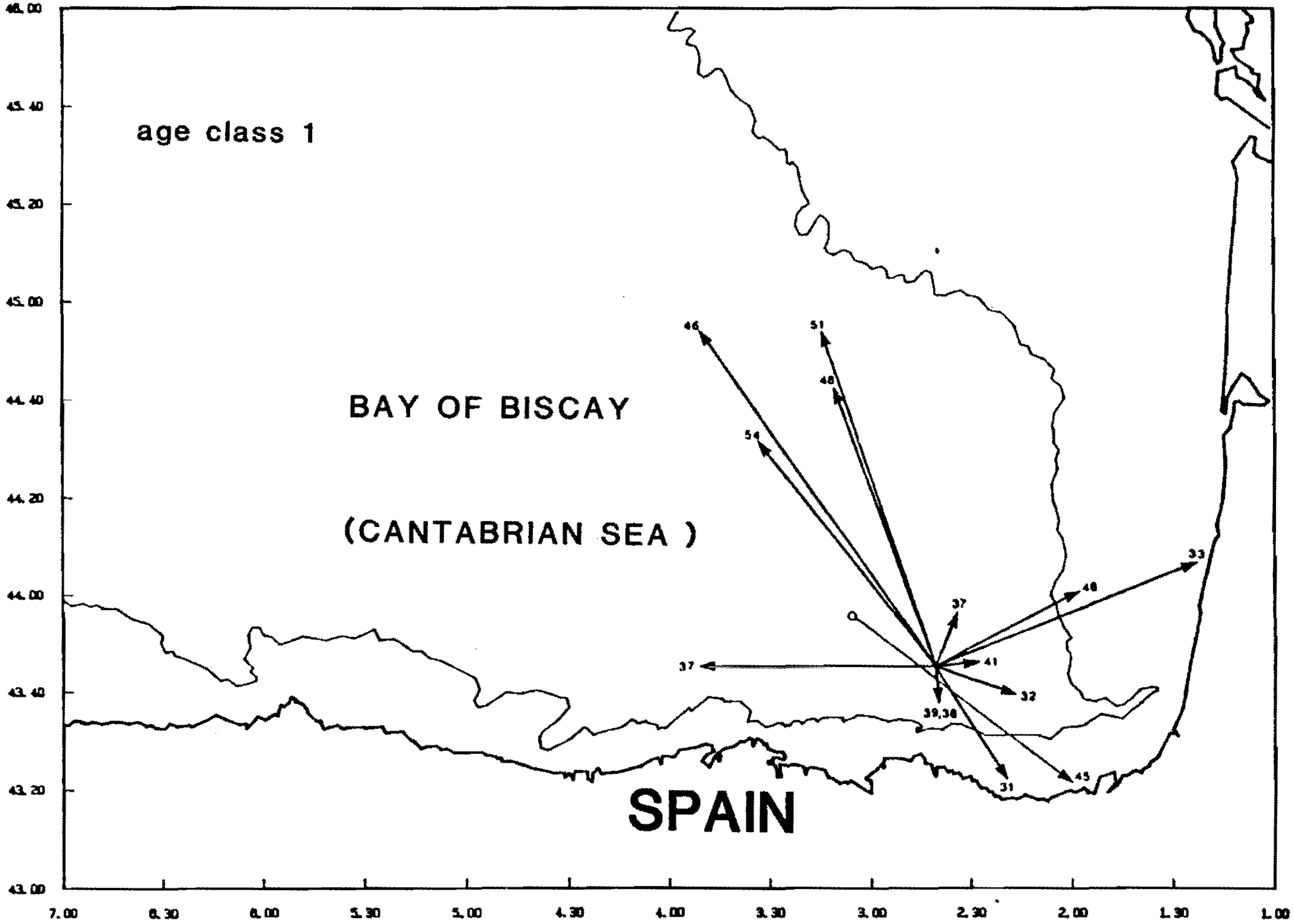
		<-----RECOVERIES----->									
		in the Cantabrian Sea					outside the Cantabrian Sea				
		years at liberty									
Year	N	* 0	1	2	3	4	Trans-Atlantic	Medit.	East Atlantic	No Data	TOTAL
1976	3	0	0	0	0	0	0	0	0	0	0
1977	10	0	0	0	0	0	0	0	0	0	0
1978	170	29	2	4	1	0	1	0	0	5	42
1979	101	1	10	0	0	0	2	0	0	1	14
1980	302	15	2	2	0	0	3	0	2	8	32
1981	293	3	5	0	1	0	0	2	0	2	13
1982	395	5	6	4	2	0	1	2	2	1	23
1983	370	2	1	1	0	0	0	1	0	1	6
1984	513	8	7	1	0	1	0	1	1	6	25
1985	407	12	2	0	2	0	1	0	0	4	21
1986	838	37	8	4	0	0	4	0	0	11	64
1988	1150	26	17	-	-	-	1	0	0	7	51
1989	122	2	-	-	-	-	-	-	-	-	2
Total	4674	140	60	16	6	1	13	6	5	47	293
Percent		47.8	20.5	5.5	2.	0.3	4.4	2.	1.7	15.7	

* Recovered in the same year as tagging

Some recoveries (15.7% - generally local) lack reliable data for use in any type of study.

Figure II.8.7 gives an example of the dispersion of juvenile bluefin tuna in the Cantabrian Sea 1-2 months after release. Figures II.8.8 to II.8.11 show the other recoveries, i.e., transatlantic migrations, Mediterranean Sea migrations, and towards areas far from the tagging area in the Atlantic. Figure II.8.12 indicates the possible migratory route followed by bluefin in transatlantic migration. Table II.8.9 gives precise data on the transatlantic recoveries and the long-range recoveries figured above.

Figure II.8.7. TAGGING/RECOVERY OF BLUEFIN TUNA IN THE CANTABRIAN SEA



Bluefin tuna recovered between 1-3 months from the date of tagging (number indicates days free).

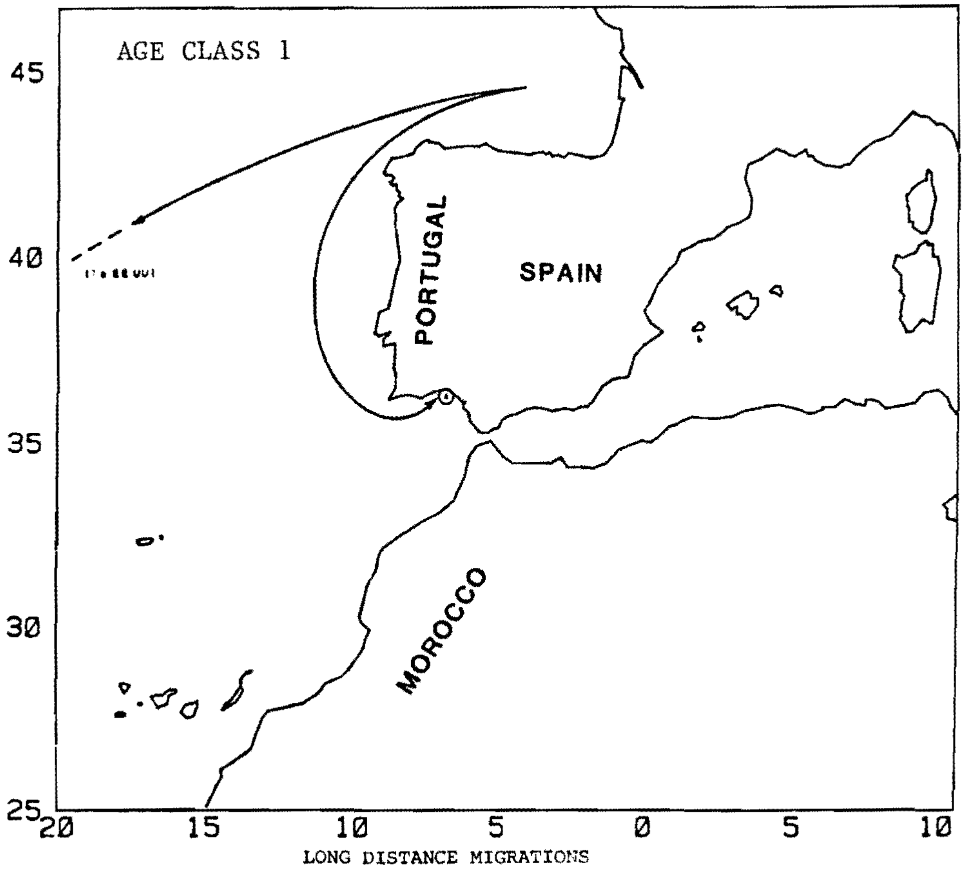


Figure II.8.8.
Age class 1 bluefin tuna. (Number indicates years at liberty)

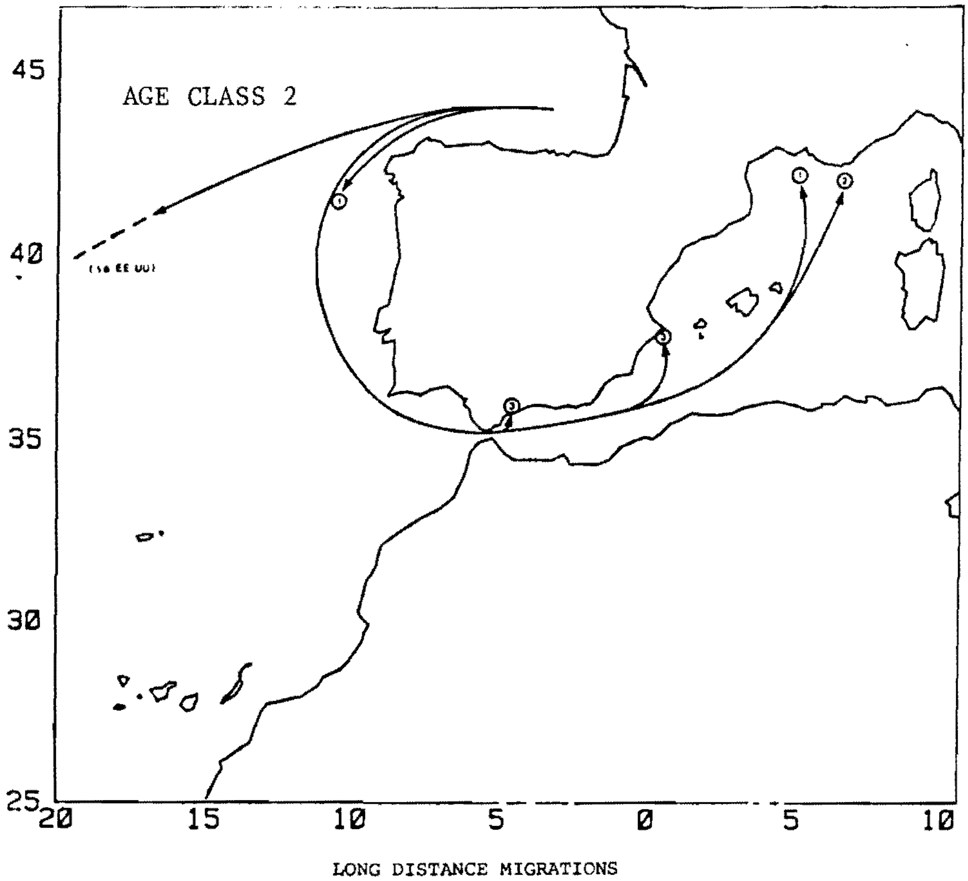


Figure II.8.9.
Age class 2 bluefin tuna (Number indicates years at liberty).

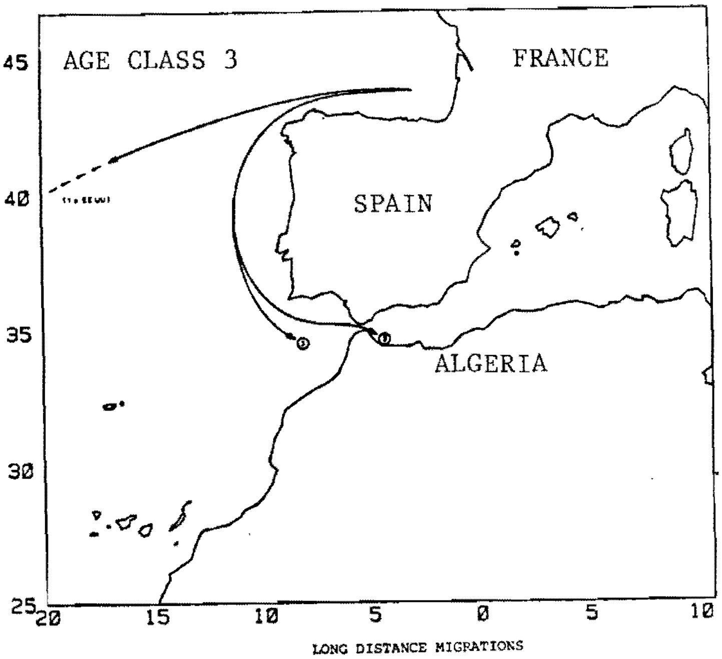


Figure II.8.10. Age class 3 bluefin tuna (Number indicates years at liberty).

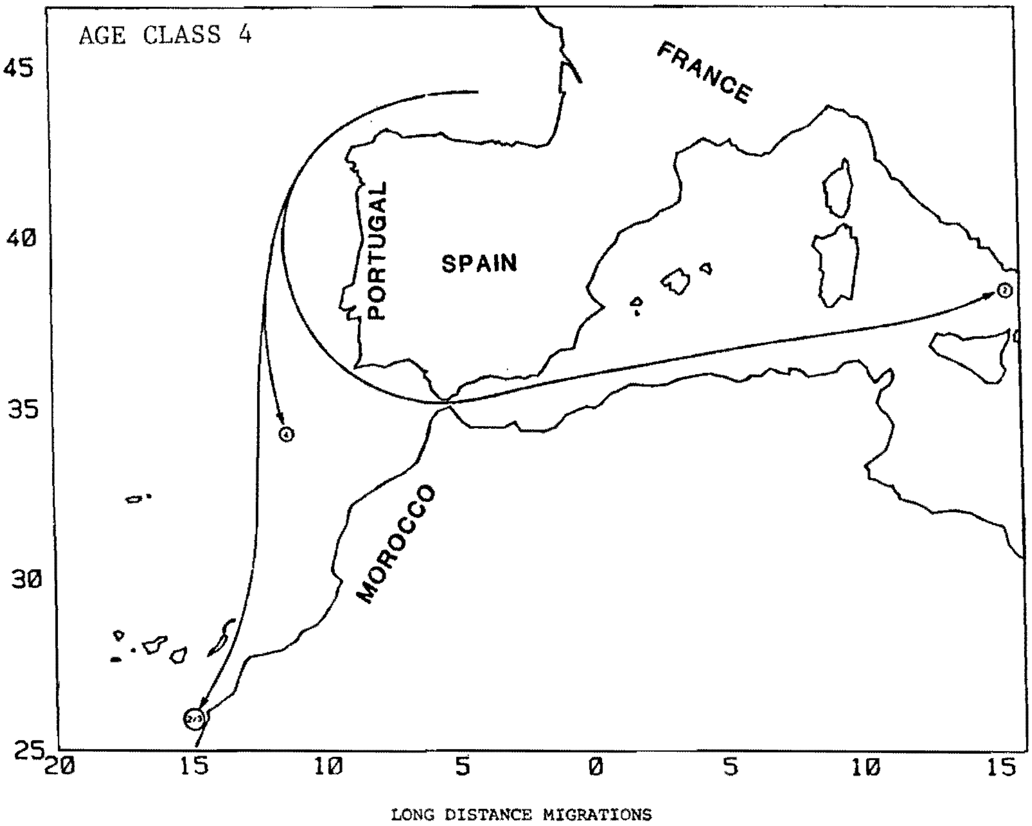


Figure II.8.11. Age class 4 bluefin tuna (recovered in the Atlantic) and age class 5 bluefin tuna (recovered in the Mediterranean). (Number indicates years, or fraction of year, at liberty)

Table II.8.9. Spanish tagging program in the Cantabrian Sea (Bay of Biscay).

TransAtlantic Migrations

	T A G G I N G				R E C O V E R Y						
Tag No.	Date	Latitude	Longitude	Fork Length	Date	Latitude	Longitude	Fork Length	Weight	Fishery*	Country
R 7336	13-09-79	44.20	2.40	103.0	25-08-80	43.00	69.00	114.0	27.0	Sport ?	U.S.A.
R 9706	17-08-80	43.40	3.15	60.0	13-08-82	40.36	72.03	112.0	0.0	PS	U.S.A.
R 9757	17-08-80	43.40	3.15	84.0	05-09-81	39.40	72.40	93.0	13.6	PS	U.S.A.
S 2469	04-08-80	43.55	3.03	80.0	10-08-81	39.40	72.40	99.0	0.0	PS	U.S.A.
S 5898	13-08-82	44.30	2.25	60.0	07-09-83	41.30	72.30	94.0	17.7	Sport	U.S.A.
EM 7218	05-10-86	43.57	2.27	67.0	03-09-87	40.04	73.40	105.0	18.5	Sport	U.S.A.
AT 3869	30-09-86	43.43	2.55	64.0	25-06-88	38.50	73.58	114.0	32.4	Sport	U.S.A.
AT 3547	09-08-85	43.30	1.48	80.0	25-08-88	45.00	66.00	0.0	0.0	Sport	U.S.A.
EM 7486	07-10-86	43.55	2.31	64.0	13-08-88	39.20	73.45	113.0	27.0	Sport	U.S.A.
EM 7172	05-10-86	43.57	2.27	66.0	15-08-89	39.44	73.20	130.0	0.0	Sport	U.S.A.
EM 8479	03-08-88	44.18	2.24	60.0	15-10-89	38.00	75.00	90.0	0.0	Sport	U.S.A.
R 3874	20-08-78	43.50	2.35	78.0	02-01-80	42.18	60.45	0.0	11.5	LL	Japan
R 7388	13-09-79	44.20	2.40	85.0	15-12-85	41.02	51.01	209.0	150.0	LL	Japan

Mediterranean Sea Migrations

Tag No.	Date	Latitude	Longitude	Fork Length	Date	Latitude	Longitude	Fork Length	Weight	Fishery*	Country
S 5543	23-08-81	43.26	2.26	78.0	29-09-82	42.47	6.34	93.0	15.0	PS	France
S 5598	23-08-81	43.26	2.25	82.0	06-10-83	42.20	4.00	127.0	0.0	PS	France
PE 385	25-08-82	43.40	2.30	104.0	28-07-85	35.30	5.30	0.0	0.0	Trap	Spain
S 5942	14-08-82	44.20	2.10	78.0	24-07-85	36.20	5.30	143.0	57.0	Trap	Spain
KA 6043	27-08-83	44.00	2.33	87.0	12-09-86	37.35	0.40	146.0	53.1	LL	Spain
KA 9845	30-08-84	43.44	2.13	142.0	15-06-86	40.00	14.30	160.0	0.0	PS	Italy

Migrations Far From The Cantabrian Sea

Tag No.	Date	Latitude	Longitude	Fork Length	Date	Latitude	Longitude	Fork Length	Weight	Fishery*	Country
R 8657	15-08-80	43.38	2.47	115.0	03-05-83	34.30	9.30	150.0	0.0	Gill net	Spain
S 2227	10-08-80	43.50	2.56	120.0	15-04-81	26.00	15.00	0.0	0.0	Bait boat	Spain
PE 313	16-08-82	44.20	2.30	120.0	22-04-86	35.10	12.11	180.0	113.0	LL	Japan
S 5775	13-08-82	44.30	2.25	60.0	12-09-86	36.50	7.40	139.0	49.5	Gill net	Portugal
KA 9760	29-08-84	43.50	2.10	82.0	13-06-85	42.00	12.00	84.0	13.1	?	Spain

* PS - purse seine LL - Long line

Tagging program off the Spanish Mediterranean coast

Since 1977 tagging cruises for juvenile bluefin tuna have been conducted (age 0) in the Spanish Mediterranean (Rey and Cort 1978; 1986). During these cruises, 384 bluefin were tagged, most of them (333) were tagged by baitboat in 1983 off the coast of Garrucha (Almeria); the majority of the remainder were tagged off Malaga from the troll fishery, with a few releases (13) from the "Aguas de Ceuta" trap, off Ceuta (Rey and Cort 1981).

The total number of fish recovered to date (1989) is 41. Of these, 37 were recovered within the same year near the tagging site (between 1' and 12'). One recovery was made one year later near the tagging site. The remaining three were recovered in the Atlantic Ocean, a year later. The data on these recoveries are shown in Table II.8.10 (Rey pers. com. and ICCAT information) and in Figure II.8.6.

Table II.8.10. Tagging program for age class 0 bluefin tuna in the Spanish Mediterranean Sea (Rey, pers. comm.; ICCAT, Madrid)

Tagging		Recovery				
Date	Location	Date	Location	Country+ (Sector)	Dist.*	Days
23/11/83	3708N/0148W	27/11/83	3708N/0148W	E(-)	-	4
23/11/83	" "	12/12/83	3700N/0149W	E(5)	8	19
23/11/83	" "	01/12/83	" "	E(5)	8	8
23/11/83	" "	05/08/84	2810N/1300W	M(6)	782	255
23/11/83	" "	28/11/83	3708N/0148W	E(-)	-	5
23/11/83	" "	15/12/83	" "	E(-)	-	22
23/11/83	" "	28/11/83	3659N/0152W	E(5)	10	5
24/11/83	" "	12/12/83	3700N/0152W	E(5)	9	18
24/11/83	" "	12/12/83	" "	E(5)	9	18
24/11/83	" "	27/11/83	3657N/0148W	E(5)	11	3
24/11/83	" "	30/11/83	3657N/0152W	E(5)	12	6
24/11/83	" "	30/11/83	3708N/0148W	E(-)	-	6
24/11/83	" "	12/12/83	3700N/0152W	E(5)	9	18
24/11/83	" "	12/12/83	" "	E(5)	9	18
24/11/83	" "	12/12/83	" "	E(5)	9	18
24/11/83	" "	25/11/83	3708N/0148W	E(-)	-	1
24/11/83	" "	15/12/83	3708N/0147W	E(3)	1	21
24/11/83	" "	25/11/83	3708N/0148W	E(-)	-	1
25/11/83	3710N/0149W	12/12/83	3700N/0152W	E(5)	10	17
25/11/83	3709N/0148W	27/07/84	3705N/0148W	E(5)	4	245
25/11/83	" "	12/12/83	3700N/0152W	E(5)	10	17
25/11/83	" "	12/12/83	" "	E(5)	10	17
25/11/83	" "	12/12/83	" "	E(5)	10	17
25/11/83	" "	12/12/83	" "	E(5)	10	17
25/11/83	" "	12/12/83	" "	E(5)	10	17
25/11/83	" "	12/12/83	" "	E(5)	10	17
25/11/83	" "	29/09/84	2530N/1517W	M(5)	985	308
25/11/83	" "	27/11/83	3709N/0148W	E(-)	-	2
25/11/83	" "	12/12/83	3700N/0152W	E(5)	10	17
25/11/83	" "	12/12/83	" "	E(5)	10	17
25/11/83	" "	12/12/83	" "	E(5)	10	17
25/11/83	" "	28/11/83	" "	E(5)	10	3
25/11/83	" "	12/12/83	" "	E(5)	10	17
25/11/83	" "	15/12/83	3708N/0147W	E(4)	1	20
25/11/83	" "	12/12/83	3700N/0152W	E(5)	10	17
25/11/83	" "	28/11/83	3709N/0148W	E(-)	-	3
25/11/83	" "	12/12/83	" "	E(-)	-	17
28/11/83	3708N/0148W	12/12/83	3707N/0149W	E(5)	1	14
28/11/83	" "	28/08/84	3536N/0643W	M(6)	256	273
29/11/83	3710N/0149W	12/12/83	3700N/0152W	E(5)	10	13
30/11/83	3707N/0149W	01/12/83	3707N/0149W	E(-)	-	1

+M = Morocco
E = Spain

* = Distance in nautical miles (1 n. mile = 1,852 m)

Note: - The number in ( ) after the country where the fish was recovered indicates the directional sector between the tagging and recovery positions.
(-) = Recovery in the tagging area

Atlantic Bluefin Tuna

These 3 recoveries should be considered separately. They represent the first confirmed movement of bluefin tuna (age 0), born in the Mediterranean, crossing through the Strait of Gibraltar to the Atlantic. These three fish were recovered off the African coast (Rey pers. com.).

Natural tags

Walters (1980) described two species of parasites which could indicate transatlantic migrations of bluefin tuna.

These species are: the copepod in the branchial cavity (Elytrophora brachyptera) common to the east Atlantic, and the platyhelminth worm in the nasal cavity (Nasicola klawey), common to the west Atlantic area.

In the Walters study (1980) results are given which indicate migration rates for age-classes 1-3. Later, Cort and Rey (1983) continued these studies and found different results:

% infection with Nasicola klawey in the east Atlantic:

1978-1979	14.6	(Walters 1980)
1980-1982	2.5	(Cort and Rey 1983)

% infection with Elytrophora brachyptera in the west Atlantic:

1977-1979	27.4	(Walters 1980)
1981	8.8	(Cort and Rey 1983)

McKenzie (1983) criticized the use of external parasites, such as the copepod E. brachyptera, for the study of bluefin tuna migrations. However, he defended the application of the N. klawey for this species.

(Ed. note) *Fonteneau (pers comm, May 1990, CRO, Dakar, Senegal) indicated that N. klawey is found off Morocco and in the Gulf of Guinea. Further work is obviously required to determine if this parasite is naturally endemic to the west Atlantic and if so, what is the infestation rate in the west Atlantic.*

Figure II.8.12. Supposed route followed by bluefin tuna which make the east to west transatlantic migration.

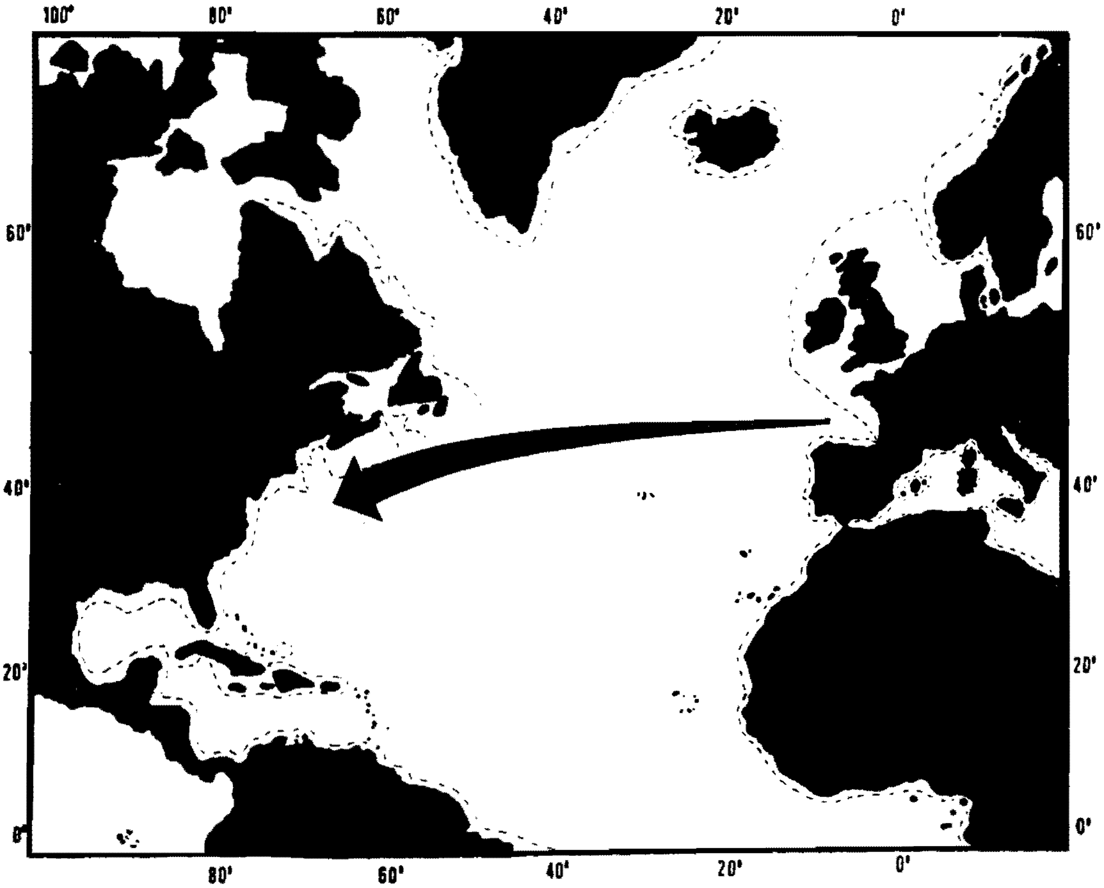


Figure II.8.12. Supposed route followed by bluefin tunas which made transatlantic migration.

9. Migration - WESTERN ATLANTIC

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Migration of Atlantic bluefin tuna has been studied using a variety of methods. Spacial-temporal changes in various fisheries and tagging experiments form a major source of our knowledge (Mather et al. 1974). In addition, studies to determine the degree of mixing between the western and eastern Atlantic stocks of bluefin have been conducted by morphometric analyses, electrophoretic studies, parasite investigation and more recently microconstituent analysis (Brunenmeister 1980, Calaprice 1986).

The terminology for different size groupings of this species follows the proposal by Rivas (1979). Rivas (1978) noted that there is a correlation of the size groups with temperature and distance moved. This information can be used to construct a working hypothesis on the migration of Atlantic bluefin.

Zero age fish

Fish spawned in the Gulf of Mexico and adjacent waters in mid-May appear to migrate northward along the coastal areas reaching Cape Cod in mid summer. As the water temperature declines in the autumn, the zero age fish migrate south from mid-October and overwinter in the Middle Atlantic Bight where the water temperature is warmer than 16°C (Rivas 1978). However, the wintering areas for the zero age fish are not well known.

Small fish

Small fish show similar seasonal north-south migrations to the zero age fish. However, they appear to migrate further north in the summer and remain in the higher latitudes in the winter than the zero age fish (Rivas 1978). In some years, limited numbers of small fish migrate to the east Atlantic (Bay of Biscay) (Mather 1980) and possibly to the Mediterranean Sea (ICCAT 1987). (Ed. note) *Thermo regulation is thought to be more efficient in larger fish, thus smaller fish tend to remain in warmer waters. Larger fish tend to be in deeper cooler water in the tropics.*

Medium fish

Migration of medium sized fish is less understood than the other size groups. (Ed. note) *This lack of knowledge is the result of the history of the fishery. There have been fisheries for juveniles (purse seine) and giants (sport) for many years, however, due to marketing restrictions (mercury), the fisheries along the coast of North America have actively avoided medium sized fish.* However, their migration appears to be wider ranging than that of the smaller fish. In fact, the Japanese longline fishery operating in the oceanic part of the north Atlantic, catch medium sized fish over almost the entire range of the fishing grounds (Suzuki and Hisada 1983). Medium size fish also show similar north south seasonal movements to the other size groups, but extending farther eastwards to offshore areas in the winter (Mather 1980).

Giant fish

The giants show the most extensive migration among all the size groups. Summer to autumn feeding ranges extend as far north as the waters of Newfoundland and in winter from Bermuda to tropical areas south of the equator (Mather 1980). Seasonal migration from the spawning grounds in the Gulf of Mexico and adjacent areas to the feeding areas off New England and Canada is well known. Some giants have continued to migrate in a northeastern direction to the east Atlantic, off Norway. The migration toward the spawning grounds from the wintering areas is not well documented.

Transatlantic migration

Transatlantic migration from the western Atlantic to the eastern Atlantic has been reported from the tagging experiments (Mather 1980, Cort and Rey 1985). Most of the transoceanic recoveries are of small fish and giants, this is apparently due to less medium sized fish being available for tagging. Overall transatlantic recovery rates (number of transatlantic recoveries/ total number of recoveries within the western Atlantic), as of 1988, was 3.2%. This is fairly close to that for eastern stock (pers. comm., P. Miyaki, ICCAT Secretariat, Madrid). Miyabe and Suzuki (1989) compared these rates to that of two tagging sites of the Pacific bluefin (6.5 %) which is considered to be composed of a single stock. Since the overall rates between the Atlantic and Pacific are in the same order of scale, they inferred the Atlantic bluefin mixed much more extensively between western and eastern sides than previously believed. More tagging studies and detailed analyses of the accumulated data should be attempted to elucidate various aspects of the transatlantic migration such as timing of crossing the ocean, size of the tagged and recovered fish and yearly changes in the recovery rates. (Ed. note) *Miyaki (pers. comm., ICCAT, Madrid, May 1990) reported a fish tagged along the USA east coast was recently recovered in the Mediterranean Sea as a medium sized fish.*

The microconstituent analysis (Calaprice 1986) indicates movements among the sampled fish of 0% west to east and 5% east to west of the small fish and movements of 3% west to east to 13% east to west of the giants. He noted more influx of fish from the eastern to the western Atlantic than from the western to the eastern Atlantic. However, additional studies appear necessary to verify the hypothesis that the microconstituents of vertebrae are retained over long periods of time.

There was one recovery from the area near Recife, Brazil of a giant fish tagged near the Bahama's.

(see also Sections II.7 and II.8)

10. Migration - EASTERN ATLANTIC & MEDITERRANEAN

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Bluefin tuna migrations are due, among other reasons, to biological, ecological and physiological demands of the species. We distinguish different types of migrations: spawning, feeding, and those affected by environmental changes.

Atlantic Bluefin Tuna

General conditions affecting bluefin migration

Numerous authors have studied the physiology of bluefin tuna, Sharp and Dizon (1978) summarized the earlier data. Bluefin tuna can be considered one of the most highly developed of the tuna species. Bluefin body temperature varies between 24^{0} and 35^{0}C. Their highly developed thermal exchangers allow the bluefin to maintain these temperatures over a wide range of distribution in water ranging from 6^{0} to 30^{0}C. Older individuals are more likely to encounter these extreme conditions. For this reason, the highest catches are taken in water temperatures between 15^{0} to 22^{0}C (Rivas 1977).

This species avoids water with a high salt level (over 40 ppt). On the other hand, bluefin may occur in low salinity water (between 18 and 20 ppt), such as the Black Sea where this species is caught during certain periods of the year.

Spawning and feeding migrations must be considered when conducting a stock assessment. In the east Atlantic stock, there are massive spawning migrations of bluefin tuna (> 5 years old - 130 cm). These fish come from the east Atlantic and the Mediterranean Sea. In both cases, bluefin concentrate in the summer spawning areas of the Mediterranean Sea.

Lozano Cabo (1958) using echo-sounders observed that in the area around the Strait of Gibraltar the hydrological conditions influence the number of individuals which pass through the Strait towards the spawning areas.

After spawning, bluefin tuna schools quickly disperse in search of feeding areas. Some of these areas are located outside the Mediterranean Sea, as a result some bluefin pass through the Strait of Gibraltar after spawning.

Juvenile bluefin concentrate in large schools (often >5000) of similar size fish and follow an annual migration. They do not move as widely as larger sized fish as they are more sensitive to environmental factors. As noted in the chapter on tagging (Section II.8), these migrations can involve great distances, such as to the Bay of Biscay or the Gulf of Lion.

This discussion on migration refers mainly to the eastern Atlantic; however, as stated earlier both giants and young bluefin tuna cross the Atlantic Ocean. From results obtained from transatlantic tag recoveries (4.4%) mentioned in Tables II.8.8 and II.8.9 and from the results of the study of the composition of microconstituents of vertebrae sections (Calaprice 1986), the migration rate across the Atlantic for juvenile bluefin tuna is in the order of 5%.

Migration between fisheries

Spawning bluefin

The recoveries of tagged bluefin tuna provided information on the interdependence of the Atlantic and Mediterranean fisheries. We can, therefore, conclude the following:

> there is a movement of fish between the fisheries of northern Europe and the traps in the Bay of Cadiz, where bluefin released in Norway have been recovered in later years,
>
> the bluefin tagged in the areas around the Strait of Gibraltar (Atlantic side) during the "entry" phase (before spawning) may return to the Atlantic, after spawning, or form part of a Mediterranean stock,
>
> bluefin tagged in the "exit" phase (after spawning) show a greater tendency to disperse in the direction of the Atlantic, and

recoveries of bluefin released in the Mediterranean Sea show movement to other fisheries within the Mediterranean.

Juvenile bluefin tuna

In this analysis two areas of recruitment in the Mediterranean are considered: one in the Tyrrhenian Sea, where no movement to the Atlantic fisheries has been observed, and another off the southern coast of Spain, where movement to the Atlantic has been observed.

The following is an outline of the proposed migration pattern of juvenile bluefin tuna that move to the east Atlantic:

recruitment in the western Mediterranean, off the coast of Spain,

migration through the Strait of Gibraltar,

wintering and summer concentration along the Moroccan coast and in the Canary Islands - Sahara area, and

summer dispersion of juvenile bluefin shows two trends, one southwards to the Canary Islands - Sahara area, and the other northwards, as far as the Bay of Biscay.

Bay of Biscay

From a time/area analysis of the tag recoveries, the following is deduced:

juvenile bluefin tuna return to the Bay of Biscay, at least until they reach 5 years of age (130 cm),

dispersion within the Bay of Biscay is wide, and distances travelled are relatively small; in principal these increase as the fishing season progresses towards autumn,

mixing of the fish occurs between the Bay of Biscay fishery and the following fisheries:

- summer fishery for juvenile bluefin in the northwestern Mediterranean (Gulf of Lion); and
- summer fishery for juvenile bluefin in the east Atlantic and west Atlantic (U.S. fishery).

in the period of maturation from the juvenile to the adult stage, mixing occurs between the Bay of Biscay fishery and the following fisheries:

- winter fishery in the Canary Islands - Sahara area,
- fishery for spawning bluefin in the area around the Strait of Gibraltar, both -entering and exiting the Mediterranean, and
- fishery for spawning bluefin in the Tyrrhenian Sea, western Mediterranean (Balearic Islands area) and Gulf of Lion.

(see also Sections II.7 and II.8)

III. Data Management

1. ICCAT Data Base

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ICCAT data base for tunas and tuna-like species

Since ICCAT was established in 1969, one of its primary objectives has been to create and maintain a good data base for all tuna and tuna-like species. The Commission's Standing Committee on Research and Statistics (SCRS) established the following criteria for the collection of data:

i) annual nominal catches by species, gears, nationality of fishing vessels, and defined statistical areas,

ii) catch and effort statistics by 1^{O} latitude x 1^{O} longitude rectangle (or 5^{O} x 5^{O} rectangle for longline fisheries only), month, species, gear and flag,

iii) length frequencies by species, areas (smallest by 1^{O} x 1^{O} and largest by ICCAT sampling areas), month (or quarter for long line fisheries), gear and flag (the sampling areas for bluefin tuna are shown in Figure III.1.1; the length of bluefin tuna should be expressed in fork length and the length intervals should be 1 cm for all sizes, although they can be 2 cm for large fish),

iv) catch at length for selected species, including bluefin tuna, by specified areas (for bluefin: east Atlantic, west Atlantic and Mediterranean), and month or quarter, and

v) tagging release and recovery data, with detailed information on releases and recoveries.

The national offices are responsible for submitting their data to the Commission and ICCAT's Sub-Committee on Statistics is responsible for monitoring the collection of this data. The Secretariat manages all the data received, including checking for errors in the data and for completeness of the data. When the data are incomplete or are not available, the Secretariat staff often contacts the problem area to try to aid in solving the difficulties in the sampling system or organization.

All the data are kept as ASCII computer files in documented ICCAT formats. These data are available for all member country users, unless the data are of a confidential nature. The data are analysed and reports produced with various computer software written in FORTRAN by ICCAT staff and member country scientists.

Unfortunately, due to limited staff and an overload of work, the tagging data file is an exception to the above. These data are incomplete and are kept in various formats and stored as received from individuals and countries (see later section).

Catch, effort and length frequency data

History of the ICCAT data base

In the late 1970's, there were indications of a reduction in the bluefin stocks, particularly in the west Atlantic. The Commission decided to conduct an intensive research program on Atlantic bluefin tuna in order to gather all the data available. The initial meeting held for this purpose took place in Santander, Spain in September, 1979 (Coll. Vol. Sci. Pap. XI, ICCAT, 1980).

Atlantic Bluefin Tuna

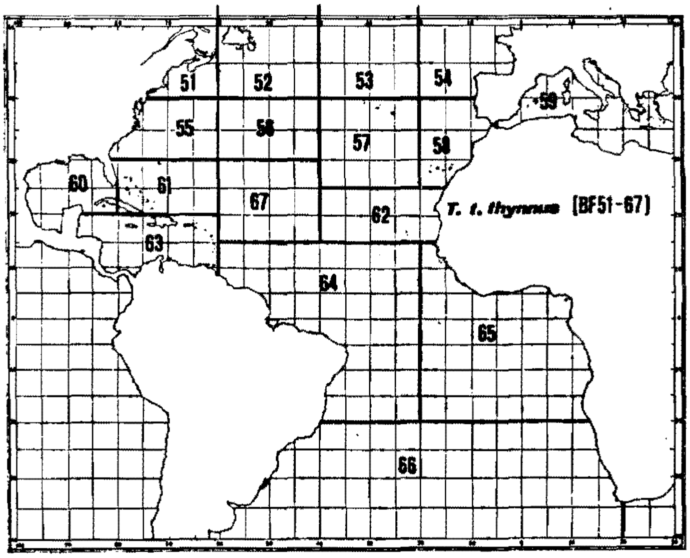


Figure III.1.1. ICCAT sampling areas for bluefin tuna.

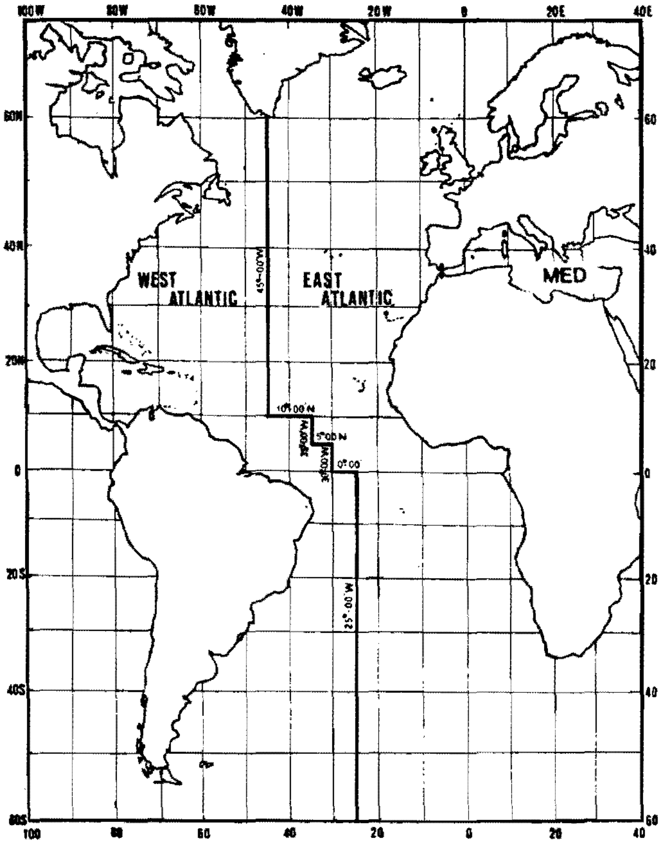


Figure III.1.2. Catch-at-length base area.

Atlantic Bluefin Tuna

At this meeting, it was confirmed that a Virtual Population Analysis (VPA) model would be used to analyse the data and that the first requirement was to create catch-at-length tables for the bluefin stocks in the entire Atlantic. With this in mind, all the bluefin fisheries in the Atlantic and the Mediterranean were identified and data availability for those fisheries was studied. It was found that the catch and effort as well as length frequency data available at that time were inadequate for this purpose. Consequently, the Secretariat became responsible for gathering all the catch and effort statistics, while Dr. M. Parrack (U.S.A.) was in charge of compiling all the length frequency data available.

After several years work more basic data on catch, catch and effort and length frequency became available and the Commission held a data preparatory meeting in Trapani (Sicily) in May, 1983. At this meeting, basic agreements were reached on the methodology to make the best estimates of the annual number of bluefin tuna caught at length in each of the fisheries in the Atlantic and Mediterranean (Coll. Vol. Sci. Pap. XIX, ICCAT, 1984).

Based on the criteria established at the Trapani meeting, the Secretariat started creating the catch-at-length database. As available samples were incomplete, this involved substitution of length frequency data for fisheries with no sampling and the raising of sample length frequency data to total catches. For many fisheries, the fishing seasons were assumed. For catch and effort data, it was agreed that the basic data would be kept in the original form (as detailed as possible), and that scientists would standardize the data to obtain abundance indices as required.

In September, 1983, a Workshop was held at Tsukuba and Shimizu, Japan, to finalize and agree upon the catch-at-length data base as well as to discuss the application of stock assessment computer software to the data base (ICCAT, SCRS, Coll. Vol. Sci. Pap. XIX, 1984). Thus, the catch-at-length data base was completed for the years 1960 through 1981, for the east Atlantic, west Atlantic and the Mediterranean Sea. All the substitutions and raising procedures used in this work are attached to the report of this Workshop.

Annual updating of the data base

Since 1983, the basic nominal catch, catch and effort and length frequency data, and the catch-at-length data base have been updated each year with the most recent years data. Whenever the historic catch data are changed or new size data become available, all affected data are updated.

In principle, each national office is responsible for updating these data. However, for catch at length, this has generally been carried out only by Canada, France (Mediterranean only), Japan, Portugal (except mainland), Spain and the U.S.A. The Secretariat has to update the catch-at-length data base for all the other fisheries, as well as format and merge all the data. ·

The nominal total catches are reported in the Commission's "Statistical Bulletin"; basic catch and effort as well as basic size data are summarized and catalogued in the ICCAT "Data Record" series. The updating procedures applied by the Secretariat for catch at length have been reported in the following papers:

SCRS/84/26	Coll. Vol. Sci. Pap. XXII,	ICCAT, 1985
SCRS/85/20	Coll. Vol. Sci. Pap. XXIV,	ICCAT, 1986
SCRS/86/10	Coll. Vol. Sci. Pap. XXXVI,	ICCAT, 1987
SCRS/87/19	Coll. Vol. Sci. Pap. XXVIII,	ICCAT, 1988
SCRS/88/64	Coll. Vol. Sci. Pap. XXX(2),	ICCAT, 1989
SCRS/89/ 8	Coll. Vol. Sci. Pap. XXXII(2),	ICCAT, 1990

Current status of the data base

The nominal catch data were completely updated (up to and including 1988) in March, 1990. The preliminary 1989 data are scheduled to be compiled by September, 1990.

Atlantic Bluefin Tuna

The compilation of the detailed catch and effort data is behind that of the nominal catch data by up to one year. This is particularly true for the Japanese longline data which are delayed as the logbook records cannot be assembled until the end of the vessels' fishing trip which may last as long as 14 months.

The individual size data are not available for all fisheries, and in some cases not for those for which catch at length data are available. For example, France (Mediterranean) submits catch-at-length data, but not actual size frequencies. The data are generally about one half year behind the nominal catch data.

Catch-at-length are complete up to 1988. However, much of the data used for the 1988 assessment (Oct/Nov 1989) were preliminary and will be updated as the final statistics become available. The formats in which these data are kept are given in Table III.1.1. For the catch-at-length data, only three areas have been adopted (Figure III.1.2). In the data base, all the frequencies are kept by 1 cm intervals. If the data are received in intervals larger than one centimeter, they are equally distributed into single centimeter intervals. The records are kept by gear and by month for the west Atlantic and by month or quarter for the east Atlantic and Mediterranean Sea. However, they are merged and summed up for use by the analytical programs.

Tagging data base for Atlantic bluefin tuna

It was the Commission's intention to put all the tagging records into one format and one file. However, this has never been realized, due to the following:

i) the release information for fish which have never been recovered has not been well documented and was not always submitted to the Commission by the agencies which conducted the tagging (information on past releases were often lost or difficult to find),

ii) there are many errors in the tag recovery files which already exist, these are due to misreporting, double reporting, and mis-entries, (generally a lack of verification of the data), and

iii) the Secretariat has not been able to work on the historical data, due to time constraints. (Before the Secretariat obtained the present in-house Micro-VAX the data were kept as a file on a time-sharing computer system. This old file has not been reformatted or reorganized, due to a lack of time.)

At present, release and recovery information for those tags already recovered has been kept in computer files since 1979. This has been possible only because ICCAT has been holding annual tagging lotteries for recovered tags. The files are, however, in various formats and use two distinct coding systems. The outline of the tagging files and a summary of the results are reported in Miyake (1990).

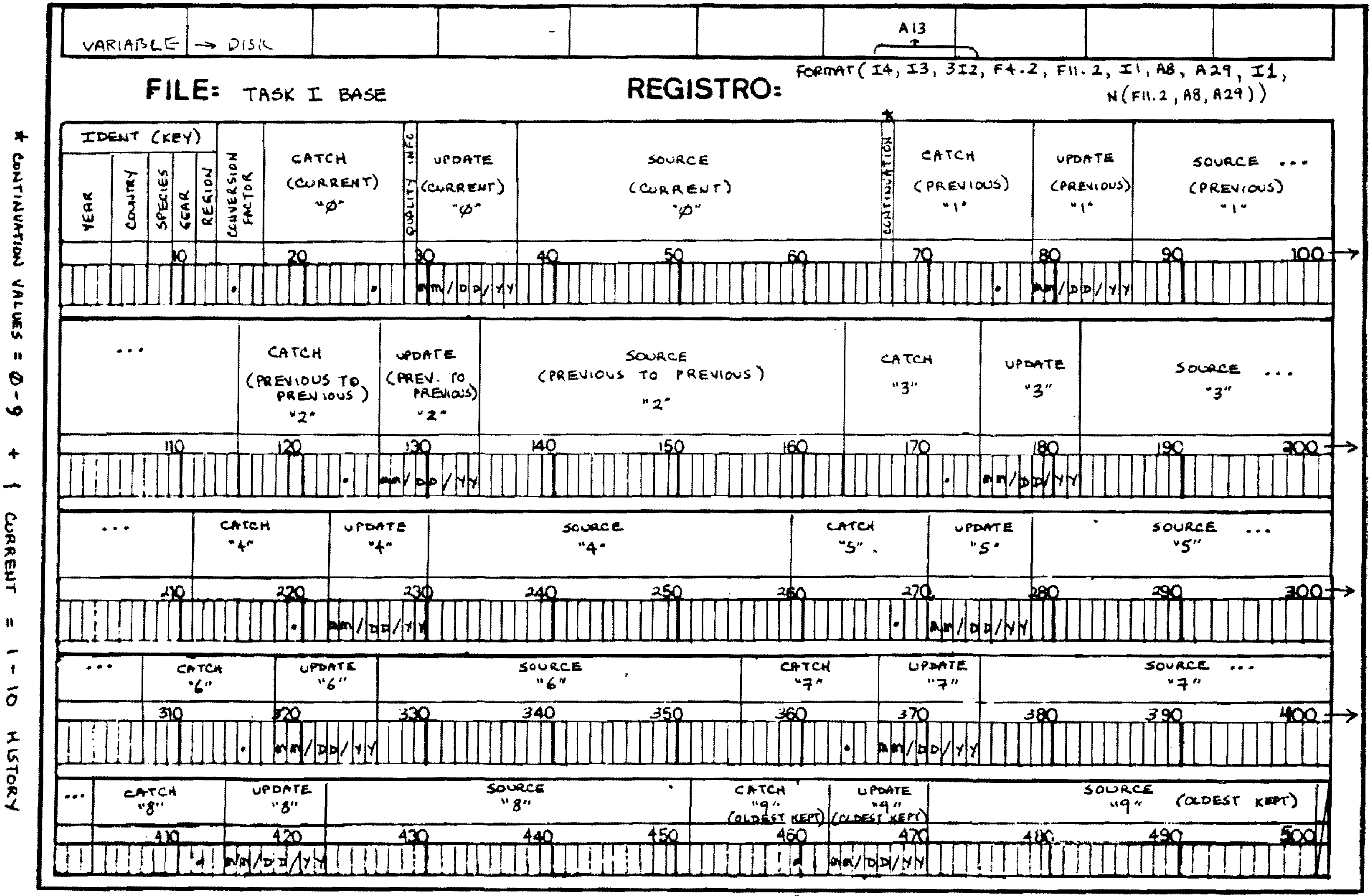
Brief evaluation of the data base

These data bases have many deficiencies which have been pointed out by ICCAT scientists at each meeting. An evaluation of the inadequacy of the data base would be time consuming and complicated.

In this report, the catch-at-length data base has been examined for the level of data substitution and raising, for 1984 through 1988. The data base for the years prior to 1984 was documented in Coll. Vol. Sci. Pap. XIX, ICCAT, 1984. Although data from the east Atlantic and Mediterranean Sea are combined and used in a single stock assessment, there are considerable differences in the quality of data between these two areas. Therefore, they are processed separately until the final analysis.

All the Atlantic bluefin fisheries, their catches and the associated size samples are itemized in Table III.1.2. From this table it is possible to identify if these fisheries were raised by length frequency samples from the same fishery of the same year or other size substituted length frequency data. It also provides the number of

Table III.1.1a Format for nominal annual catch file.



minimum + continuation max (catch + update + source)

BYTES/REC : minimum 67 , maximum 499 = 67 + 9 (11 + 8 + 29)

Table III.1.1b.Format to store detailed catch and effort data in a file.

FILE= C/E ASCII VARIABLE

REGISTRO= max. of 15 catches (must check for zero catches, which is possible)

FILE TYPE *	RECORD TYPE *	YEAR	COUNTRY	GEAR	TIME STRATA	KIND SQUARE	QUADRANT	LATITUDE	LONGITUDE	(PCCT)	KIND CATCH	KIND EFFECT	DATE	EFFORT	COVERAGE RATE %	# CATCHES	SPECIES	CATCH	SPECIES	CATCH	SPECIES	CATCH	SPECIES	CATCH	SPECIES
													DD-MM-YY												
		1	2	3	4	5	6	7	8	9	10	11													

CATCH	SPECIES	CATCH	SPECIES	CATCH	SPECIES	CATCH	SPECIES	CATCH	SPECIES	CATCH	SPECIES	CATCH	SPECIES	CATCH	SPECIES	CATCH

	SPECIES	CATCH	SPECIES	CATCH

max rec size = 229 bytes

FORMAT(2I1, I2, I3, 2(3I2, I1), I2, A8, F10.1, F6.2, I2, N(I2, F10.1))

* FILE TYPE ⇒ 0 WITHOUT INFO
1 BASIC (DATA RECORD)
2 WORKING GROUP

RECORD TYPE ⇒ 0 WITHOUT CHECK
1 DATA WRONG
2 DATA OK

3 CONFIDENTIAL, 4 Reference, 5 special, 6 extra, 7 Puerto Rico Tr., 8 Adjusted Basic

Table III.1.1c. Format for storing size frequency data in a file.

FILE= SIZE ASCII **REGISTRO=** on TAPE format (for disk: detail(s) follow header to make one record)

HEADER

FILE TYPE ★	I	1
RECORD TYPE ★	I	2
YEAR	I	3
COUNTRY	I	4
GEAR	I	5
PORT	I	6
SPECIES	I	7
SEX ★	I	8
KIND FREQ.	I	9
ICCAT AREA	I	10
KIND SQUARE	I	11
QUADRANT	I	12
LATITUDE	I	13
LONGITUDE	I	14
DAY	I	15
TIME STRATA	I	16
# SAMPLES ★★	I	17
# FISH SAMPLED ★★	I	18
WEIGHT SAMPLE (KGS) ★★	I	19
# FISH CATCH ★★	I	20
WEIGHT CATCH (KGS) ★★	I	21
BEGIN (cm)	I	22
INTERVAL (mm)	I	23
IMI	I	24
IMA	I	25
COVERAGE	R	.
RAISING FACTOR	R	.
MEAN LENGTH (cm)	R	.

10 20 30 40 50 60 70 80 90 100 →

MEAN WEIGHT (KGS)	R	.
DATE	A	DD-MM-YY
REPORTED CATCH (MT or # FISH)	I	
KIND INTERVAL ★	I	

110 120 130 40 50 60 70 80 90 100

FORMAT
(2I1, I2, I3, 2(3I2, I1), 4I2, I5, I6, 3I9, 4I3, F6.2, F10.5, 2F5.1, A8, I10, I1, 6X)

DETAIL(S)

F(IMI)	F(IMI + 1)	F(IMI + 2)	... F(IMA)
R	R	R	
.	.	.	

TAPE FORMAT (13 F 10.1)

#details = (IMA - IMI + 13) / 13

last detail is zero-filled if necessary

10 20 30 40 50 60 70 80 90 100 → 130

★ File Type
0 Without info
1 Basic (Data Record)
2 Working Group
3 Confidential
4 Reference
5 Special Basic
6 Extra
7 Puerto Rico trans.
8 Adjusted Basic

Record Type
0 Without Check
1 Data Wrong
2 Data OK

Sex
0 Unknown
2 Male
3 Female
9 Immature

Kind of Interval
0 No info
1 Lower limit (trunc.)
2 Midpoint
3 Upper limit

10 20 30 40 50 60 70 80 90 100

★★ for File Type '2' or catch-by-size data, meanings differ: # samples ⇒ sample # fish (actually measured), # fish sampled ⇒ # fish original record, weight sample (kgs) ⇒ weight original record (kgs), # fish catch ⇒ # fish after raising for c-by-s, weight catch (kgs) ⇒ estimated weight (kgs) after raising for c-by-s from equations

Table III.1.2. Level of the substitutions made on the catch-at-size base.

YEAR	COUNTRY	GEAR	CATCH	# FISH	SOURCE
EAST ATLANTIC					
1984	CAP VERT	BBF	1		1
1984	ESPANA	BB	2		1
1984	ESPANA	PS	41		1
1984	ESPANA	LLHB	7	66	2
1984	ESPANA	GILL	2		1
1984	ESPANA	BB	2364		2
1984	ESPANA	SURF	117		1
1984	ESPANA	TRAP	2271	1398	2
1984	FRANCE	TROL	36		1
1984	FRANCE	BB	566		1
1984	JAPAN	LLHB	1514	899	2
1984	MAROC	PS	127		1
1984	MAROC	SURF	44		1
1984	NORWAY	PS	243		3
1984	PANAMA	LLFB	17		1
1984	PORTUGAL	SURF	16		1
1984	PORTUGAL	BB	1		1
1984	PORTUGAL	BB	14		1
1984	PORTUGAL	PS	3	7	3
RAISE FROM SAMPLE			6402	2370	
SUBSTITUTED			984		
TOTAL			7386		
1985	ESPANA	BB	133	47	2
1985	ESPANA	BB	1850		2
1985	ESPANA	TRAP	1630		2
1985	ESPANA	TROL	1		1
1985	ESPANA	LLHB	16		1
1985	FRANCE	BB	380		1
1985	FRANCE	TROL	110		1
1985	JAPAN	LLHB	420	691	2
1985	KOREA	LLFB	77		1
1985	MAROC	PS	86		1
1985	PANAMA	LLFB	22		1
1985	PORTUGAL	SURF	25		2
1985	PORTUGAL	HAND	1	3	2
1985	PORTUGAL	BB	3	27	2
RAISED BY SAMPLE			4062	768	
SUBSTITUTED			692		
TOTAL			4754		
1986	DENMARK	UNCL	1		1
1986	ESPANA	BB	78	12	2
1986	ESPANA	BB	1875		2
1986	ESPANA	TRAP	891	1006	2
1986	ESPANA	PS	12	856	2
1986	ESPANA	LLHB	20		1
1986	FRANCE	BB	272		1
1986	FRANCE	TROL	76		1
1986	JAPAN	LLHB	710	939	2
1986	MAROC	PS	122		1
1986	NORWAY	PS	31	70	3
1986	PANAMA	LLFB	11		1
1986	PORTUGAL	SURF	41		2
1986	PORTUGAL	HAND	1	12	2
1986	PORTUGAL	BB	28	221	2
1986	PORTUGAL	PS	123	37	2
RAISED BY SAMPLE			3790	3153	
SUBSTITUTED			502		
TOTAL			4292		
1987	ESPANA	BB	25	12	2
1987	ESPANA	BB	1512	2412	2
1987	ESPANA	TRAP	939		2
1987	FRANCE	BB	533		1
1987	JAPAN	LLHB	900	1741	2
1987	MAROC	TRAP	460		1
1987	PANAMA	LLFB	4		1
1987	PORTUGAL	SURF	102		1
1987	PORTUGAL	HAND	3	10	2
1987	PORTUGAL	BB	58		2
RAISED BY SAMPLE			3437	4175	
SUBSTITUTED			1099		
TOTAL			4536		
1988	ESPANA	BB	92	12	2
1988	ESPANA	BB	2082	5609	2
1988	ESPANA	TRAP	2389	275	2
1988	MAROC	SURF	202		1
1988	MAROC	TRAP	131		1
1988	POLAND	UNCL	2		1
1988	PORTUGAL	SURF	16		2
1988	PORTUGAL	HAND	1	30	2
1988	PORTUGAL	BB	29	6	2
RAISED BY SAMPLE			4609	5932	
SUBSTITUTED			335		
TOTAL			4944		
YEAR	COUNTRY	GEAR	CATCH	# FISH	SOURCE
MEDITERRANEAN					
1984	ALGERIE	UNCL	254		1
1984	ESPANA	GILL	3		1
1984	ESPANA	HAND	145	495	2
1984	ESPANA	BB	1699	834	2
1984	ESPANA	UNCL	101	592	2
1984	ESPANA	SURF	26	1173	2
1984	ESPANA	TRAP	621		2
1984	ESPANA	PS	79		1

Table III.1.2. con't

YEAR	COUNTRY	GEAR	CATCH	# FISH	SOURCE
1984	ESPANA	LLHB	69		2
1984	FRANCE	PSM	3570		2
1984	FRANCE	SPOR	30		1
1984	GREECE	UNCL	500		1
1984	ITALY	PSFS	993		1
1984	ITALY	PSFB	2476	3550	2
1984	ITALY	GILL	100		1
1984	ITALY	HAND	10		1
1984	ITALY	UNCL	1250		1
1984	ITALY	SPOR	10		1
1984	ITALY	TRAP	327		1
1984	ITALY	PS	1913		1
1984	ITALY	LLHB	41		1
1984	JAPAN	LLHB	1036	763	2
1984	LIBYA	UNCL	300		1
1984	MALTA	UNCL	21		1
1984	MAROC	SURF	4		1
1984	TUNISIE	TRAP	80		1
1984	TURKEY	UNCL	869		1
1984	YUGOSLAV	PS	825		1
RAISED FROM SAMPLE			9743	7407	
SUBSTITUTED			7609		
TOTAL			17352		
1985	ALGERIE	UNCL	260		1
1985	ESPANA	GILL	2		1
1985	ESPANA	HAND	267		2
1985	ESPANA	BB	278		2
1985	ESPANA	UNCL	22		1
1985	ESPANA	SURF	415		2
1985	ESPANA	TRAP	302		2
1985	ESPANA	PS	56		2
1985	ESPANA	LLHB	129		2
1985	FRANCE	PSM	5400		2
1985	FRANCE	SPOR	30		1
1985	GREECE	UNCL	500		1
1985	ITALY	PSFS	2329		1
1985	ITALY	PSFB	1453	2458	2
1985	ITALY	GILL	100		1
1985	ITALY	HAND	10		1
1985	ITALY	UNCL	2100		1
1985	ITALY	SPOR	50		1
1985	ITALY	TRAP	295		1
1985	ITALY	PS	740		1
1985	ITALY	LLHB	62		1
1985	JAPAN	LLHB	873	2568	2
1985	LIBYA	UNCL	300		1
1985	MALTA	UNCL	21		1
1985	MAROC	SURF	12		1
1985	TUNISIE	TRAP	80		1
1985	TURKEY	PS	2230		1
1985	YUGOSLAV	PS	1010		1
RAISED BY SAMPLE			9173	5026	
SUBSTITUTED			10153		
TOTAL			19326		
1986	ALGERIE	UNCL	566		1
1986	ESPANA	HAND	29	126	2
1986	ESPANA	SURF	220		2
1986	ESPANA	TRAP	168		1
1986	ESPANA	PS	22		1
1986	ESPANA	LLHB	117	1453	2
1986	FRANCE	PSM	3460		2
1986	FRANCE	SPOR	30		1
1986	GREECE	UNCL	125		1
1986	ITALY	PSFS	2207		1
1986	ITALY	PSFB	1082	1513	2
1986	ITALY	GILL	45		1
1986	ITALY	UNCL	2338		1
1986	ITALY	SPOR	50		1
1986	ITALY	TRAP	293		1
1986	ITALY	PS	1500		1
1986	ITALY	LLHB	1		1
1986	JAPAN	LLHB	421	761	2
1986	LIBYA	UNCL	300		1
1986	MALTA	UNCL	41		1
1986	MAROC	SURF	18		1
1986	TUNISIE	TRAP	84		1
1986	TURKEY	PS	1524		1
1986	YUGOSLAV	PS	757		1
RAISED BY SAMPLE			5329	3853	
SUBSTITUTED			10069		
TOTAL			15398		
1987	ALGERIE	UNCL	420		1
1987	ESPANA	HAND	177	411	2
1987	ESPANA	SURF	404		2
1987	ESPANA	TRAP	219	332	2
1987	ESPANA	LLHB	116	398	2
1987	FRANCE	PSM	4300		2
1987	FRANCE	SPOR	30		1
1987	GREECE	UNCL	100		1
1987	ITALY	PSFS	522		1
1987	ITALY	PSFB	557	851	2
1987	ITALY	UNCL	1495		1
1987	ITALY	SPOR	53		1
1987	ITALY	TRAP	310		1
1987	ITALY	PS	1500		1
1987	ITALY	LLHB	65		1
1987	JAPAN	LLHB	280	*	2
1987	LIBYA	UNCL	300		1

Table III.1.2. con't

YEAR	COUNTRY	GEAR	CATCH	# FISH	SOURCE
1987	MALTA	UNCL	36		1
1987	TUNISIE	TRAP	83		1
1987	TURKEY	PS	910		1
1987	YUGOSLAV	PS	641		1
RAISED BY SAMPLE			6053	1992	
SUBSTITUTED			6465		
TOTAL			12518		
1988	ALGERIE	UNCL	677		1
1988	ESPANA	TRAP	201	333	2
1988	ESPANA	LLHB	136	761	2
1988	ESPANA	HAND	553	1458	2
1988	ESPANA	SURF	225		1
1988	FRANCE	PSM	5750		2
1988	FRANCE	SPORT	30		1
1988	GREECE	UNCL	100		1
1988	ITALY	PSFS	395		1
1988	ITALY	PSFB	334	395	2
1988	ITALY	UNCL	1452		1
1988	ITALY	SPOR	51		1
1988	ITALY	TRAP	301		1
1988	ITALY	PS	1500		1
1988	ITALY	LLHB	63		1
1988	JAPAN	LL	250		1
1988	LIBYA	UNCL	300		1
1988	MALTA	UNCL	25		1
1988	MAROC	SURF	44		1
1988	MAROC	TRAP	96		1
1988	TUNISIE	TRAP	83		1
1988	TURKEY	PS	910	86	2
1988	YUGOSLAV	PS	1512		1
RAISED BY SAMPLE			7884	3033	
SUBSTITUTED			7104		
TOTAL			14988		

YEAR	COUNTRY	GEAR	CATCH	# FISH	SOURCE
WEST ATLANTIC					
1984	CANADA	R R	1		1
1984	CANADA	HAND	260	1346	2
1984	CANADA	TRAP	3		2
1984	CHI.TAIW	LLFB	3	29	3
1984	DOMIN.R.	SURF	207		1
1984	JAPAN	LLHB	696	796	2
1984	URUGUAY	LLHB	9		1
1984	USA	R R	400	3246	2
1984	USA	HAND	275	824	2
1984	USA	HARP	115	265	2
1984	USA	UNCL	2		2
1984	USA	PS	401	852	2
1984	USA	LL	127	159	2
RAISED FROM SAMPLE			2282	7522	
SUBSTITUTED			217		
TOTAL			2499		
1985	ARGENTIN	UNCL	6		1
1985	BRAS.JPN	LLFB	1		1
1985	CANADA	R R	1		2
1985	CANADA	HAND	121		2
1985	CANADA	TRAP	20		2
1985	CHI.TAIW	LLFB	3		1
1985	DOMIN.R.	SURF	81		1
1985	JAPAN	LLHB	1092	2088	2
1985	URUGUAY	LLHB	10		1
1985	USA	R R	465	2089	2
1985	USA	HAND	284	932	2
1985	USA	HARP	166	506	2
1985	USA	PS	377	1498	2
1985	USA	LL	132	243	2
RAISED FROM SAMPLE			2658	7356	
SUBSTITUTED			98		
TOTAL			2756		
1986	CAN.JPN.	LL	32	1112	2
1986	CANADA	HAND	39		2
1986	CANADA	R R	2		2
1986	CHI.TAIW	LLFB	3		1
1986	DOMIN.R.	SURF	109		1
1986	JAPAN	LLHB	584	2711	2
1986	URUGUAY	LLHB	6		1
1986	USA	R R	326	903	2
1986	USA	HAND	190	621	2
1986	USA	HARP	127	470	2
1986	USA	PS	360	1589	2
1986	USA	LL	139	341	2
RAISED FROM SAMPLE			1799	7747	
SUBSTITUTED			118		
TOTAL			1917		
1987	ARGENTIN	UNCL	2		1
1987	BRAS.JPN	LLFB	2		1
1987	CAN.JPN.	LL	33		2
1987	CANADA	R R	1		2
1987	CANADA	HAND	32	461	2
1987	CANADA	TRAP	17		2
1987	DOMIN.R.	SURF	199		1
1987	JAPAN	LLHB	960	2644	2
1987	URUGUAY	LLHB	4		1
1987	USA	R R	538	809	2
1987	USA	HAND	186	516	2

Table III.1.2. con't

YEAR	COUNTRY	GEAR	CATCH	# FISH	SOURCE
1987	USA	HARP	122	409	2
1987	USA	PS	367	1527	2
1987	USA	LL	30	33	2
1987	USA	LL	109	679	2
RAISED FROM SAMPLE			**2395**	**6542**	
SUBSTITUTED			**207**		
TOTAL			**2602**		
1988	CANADA	R R	7	7	2
1988	CANADA	HAND	268	1841	2
1988	CANADA	TRAP	14	43	2
1988	CANADA	LLHB	104	1526	3
1988	DOMIN.R.	SURF	199		1
1988	JAPAN	LLHB	1100		2
1988	ST.LUCIA	HAND	3		1
1988	URUGUAY	LLHB	2		1
1988	USA	R R	432	1137	2
1988	USA	HAND	159	508	2
1988	USA	HARP	151	474	2
1988	USA	UNCL	6		2
1988	USA	PS	383	1557	2
1988	USA	LL	15		1
1988	USA	LL	143		1
RAISED FROM SAMPLE			**2624**	**6093**	
SUBSTITUTED			**362**		
TOTAL			**2986**		

DATA SOURCE:

1 = SIZE DATA WERE SUBSTITUTED
2 = DATA ARE RAISED USING SAMPLES FROM THE SAME FISHERY
3 = 100% SAMPLE

* SAMPLE SIZE CAN NOT BE SEPARATED FOR MEDITERRANEAN AND EAST ATLANTIC AND THEREFORE INLCLUDED IN THE EAST ATL.

fish measured when the data are available. For each year, the catches which were matched with real samples and those substituted by other samples are summarized. For many fisheries, the number of fish measured is unknown, as only catch-at-length data were sent to the Secretariat with no information on the original samples. The data are summarized by three major regions and by year (Table III.1.3). Information on the sampling rate is incomplete. However, this table gives a general idea on the level of sampling and data substitution.

In 1989, the SCRS recommended setting up a protocol by which information on the sampling level could be easily retrieved and assessed. Accordingly, a new file format has been developed for use in substitutions and raising, this will also serve for checking sample sizes and substitution levels. This new format is attached as Table III.1.4.

Table III.1.3. Summary of sampling and substitution levels of Atlantic bluefin tuna used by the ICCAT secretariat.

YEAR	AREA	TOTAL CATCH	SAMPLED CATCH		# FISH MEASURED*	SUBSTITUTED	# FISH PER tonne CATCH
		tonnes	tonnes	%		tonnes	
1984	EAST	7386	6402	86.7%	2370	984	0.32
	MED	17352	9743	56.1%	7407	7609	0.43
	WEST	2499	2282	91.3%	7522	217	3.01
1985	EAST	4754	4062	85.4%	768	692	0.16
	MED	19326	9173	47.5%	5026	10153	0.26
	WEST	5414	2658	49.1%	7356	2756	1.36
1986	EAST	4292	3790	88.3%	3153	502	0.73
	MED	15398	5329	34.6%	3853	10069	0.25
	WEST	1917	1799	93.8%	7747	118	4.04
1987	EAST	4536	3437	75.8%	4175	1099	0.92
	MED	12518	6053	48.4%	1992	6465	0.16
	WEST	2602	2395	92.0%	6542	207	2.51
1988	EAST	4944	4609	93.2%	5932	335	1.20
	MED	14988	7884	52.6%	3033	7104	0.20
	WEST	2986	2624	93.2%	6093	362	2.04

* The number of fish measured can be very underestimated, as information for some countries is not always available.

Table III.1.4.
Format to be used for substitution and raising.

(separate for each species)
SUBSTITUTION AND RAISING PARAMETER FILE

Format:
(I2, I3, 3I2, I10, I1, F10.5, I2, I1, 2I2, I3, 3I2, I7, I5, A20)

ICCAT

	CATCH BY SIZE								SUBSTITUTION OR SAMPLE SIZE										REMARKS
	IDENT					REPORTED CATCH		RAISING FACTOR	SUBSTITUTION								SAMPLE		
									AREA										
	AREA	COUNTRY	GEAR	YEAR	TIME	KGS (0) or #FISH (1)	TYPE		ICCAT	QUAD.	LAT.	LONG.	COUNTRY	GEAR	YEAR	TIME	WEIGHT KGS (Actually weighed)	#FISH (Actually measured)	
	1	5			10	15 20		25 30		35			40		45		50 55	60	65 70 75
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Atlantic Bluefin Tuna

2. Conversion of Length to Age

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Catch at length is converted to catch at age considering the following:

the month associated with the catch,
the growth curve for the bluefin stock, and
the birth date of the bluefin stock.

The month associated with the catch at size is the month when the size sample was collected. For each age and time period (month for the east Atlantic and year-month for the west Atlantic), lower and upper limits of length at age are established using a growth equation and birth date. Age is assigned by determining the age and time specific length range within which the size observation occurs. This method has been described as "age slicing" by Conser (MS1990).

Monthly length boundaries are established by first estimating the upper limit for each age at the middle of the month. The upper limit is set to the size predicted from the growth curve at an age half a year older. After the upper limit is estimated, the lower limit for the next older age is set equal to it. For age 0 the lower limit is set to 0 cm, and for the oldest age the upper limit is set to a very large size.

East Atlantic and Mediterranean Sea

In 1984 the SCRS conducted its first analytical assessment of the east Atlantic and Mediterranean catches (ICCAT 1986). Various size-age relationships were examined, and the equation derived by Farrugio (1980) with an L_{inf} of 351.13 cm (see section IV.2.b) was selected for developing the monthly limits of length at age. These limits are considered to be half way between the modes of the adjacent age groups. Due to lack of additional data, the same equation has been used for all years. This limitation makes the assumption that the monthly length range is constant over time for this stock.

West Atlantic

A modification of the von Bertalanffy growth equation derived by Parrack and Phares (1979) from mark-recapture data has been used to assign age from length since the SCRS conducted its first analytical assessment in 1984. Nichols (1985) showed that use of different values of t_0 with the Parrack and Phares growth equation provided a useful way to account for variation among year classes in the modal sizes at young ages. This modification was adopted by the 1984 Bluefin Working Group (ICCAT 1985) for establishing limits of length at age and has been used ever since. Because t_0 differs between year classes, limits of length at age are established for each year and month. This allows for differences in growth by cohort based on estimating a different birth date (t_0) for each cohort. The estimated t_0's for the 1958-1984 year classes were presented in the SCRS working group report from the meeting in Miami in 1985 (ICCAT 1986). Year class specific t_0's have not been estimated for more recent year classes, so the original estimate by Parrack and Phares has been used. (From 1982 to date, detailed data on the sizes of small fish in the catch have not been available (from purse seine catches) for these year/month calculations and the t_0 has, of necessity, been fixed.)

IV. Stock Assessment

1. Biological parameters - WESTERN ATLANTIC

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a. Length-weight relationship

The initial Atlantic bluefin stock assessment employed a single length-weight function for the west Atlantic (Sakagawa and Coan 1974). A later analysis (Parrack 1980) based on a larger accumulation of data (3545 observations collected during 1974-1977) indicated appreciable seasonal variation in these relations (Table IV.1.1), therefore, biostatistic conversions used by ICCAT for west Atlantic data employ monthly conversions (Parrack 1981).

Table IV.1.1. Length weight regression coefficients used in recent ICCAT SCRS assessments of the west Atlantic bluefin (Parrack, 1981).

Month(s)	**Formula**
January - March	$W = 0.00002861 \times L^{2.9290}$
April - May	$W = 0.00006043 \times L^{2.7794}$
June	$W = 0.00004044 \times L^{2.8370}$
July	$W = 0.00003733 \times L^{2.8683}$
August	$W = 0.00002227 \times L^{2.9704}$
September	$W = 0.00001520 \times L^{3.0531}$
October - November	$W = 0.00000387 \times L^{3.3172}$
December	$W = 0.00002861 \times L^{2.9290}$

Several conversions are required to transform diverse size measures of west Atlantic bluefin into straight fork length. Although these conversions are available, the method and data used to derive many of them are unknown and all are based on data collected before the late 1970's.

b. Growth

Hardpart samples from bluefin caught in the west Atlantic were first used to study growth (Mather and Schuck 1960) and the first stock assessments were based on growth equations estimated from those data (Sakagawa and Coan 1974). Several studies followed the initial efforts (Caddy and Butler 1976, Butler et al. 1977, Tyler et al. 1979, Hurley et al. 1981, Farber and Lee 1981), however, evidence that major circuli are formed just once annually does not exist and the results of the various studies and methods used were different.

Mark and recapture data were also used to derive growth rates. The data available for the original analysis (Parrack and Phares 1979) contained few growth measures of large fish, however, those results were corroborated by later analysis of more extensive data (Farber and Lee 1981), thus these tagging derived estimates are currently used in west Atlantic stock assessments. It should be noted that the growth data available for analysis were collected before the late 1970's, when common least squares procedures were used to obtain growth parameter estimates rather than maximum likelihood procedures, and that variance-covariance estimates were not obtained.

c. Natural Mortality

One of the first estimates of the instantaneous rate of natural mortality (i.e. that rate of change in population numbers due to all factors except recorded catches) was based on the estimated M/k ratio for eastern Pacific yellowfin tuna and a k estimated from west Atlantic hardpart data (Sakagawa and Coan 1974). (Ed. note) *Recently Wild (1980) presented new (different) estimates of 'k' for the eastern Pacific yellowfin tuna.* This estimated rate, 0.1 to 0.2 on an annual basis, has not been challenged since and has been noted to be consistent with the results of tagging studies (Parks 1976). These two levels have been assumed in all subsequent stock assessments although Parrack (1981) did assume age specific rates (0.14 for ages 1 to 5 and 0.18 for older fish). This rate has been assumed time invariant in all assessments.

(Ed. note) *The natural mortality assumed for assessment purposes for the bluefin of the west Atlantic is currently 0.1 and for the east Atlantic and Mediterranean Sea 0.18.*

(Ed. note) *Immediately prior to the final editing of this document the 1990 SCRS of ICCAT decided there was insuffient evidence to support different values of M for these two stocks. Thus they agreed to use the mid-range (M = 0.14) for both stocks until evidence becomes available to indicate otherwise.*

2. Biological parameters - EASTERN ATLANTIC & MEDITERRANEAN

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a. Length weight relationship

Farrugio (1981) provided a review of different relationships between length and weight of bluefin tuna. These were generally annual equations for different areas. In some cases (Rodriguez-Roda 1964), this relationship is expressed according to the different time periods of their migratory cycle ("entry" into the Mediterranean and "exit" from the Mediterranean after spawning). It was not possible to separate any of the data sets by sex. Table IV.2.1 adapted from Farrugio (1981), shows the values of the different equations relating length and weight. The equations used in the ICCAT assessment process follow (Table IV.2.2). Some countries convert their data before it is submitted to ICCAT and use size and/or area specific equations.

Table IV.2.1. Length weight relationships for eastern Atlantic bluefin tuna (<u>Thunnus thynnus thynnus</u>) (after Farrugio, 1981) all measurements are fork length unless otherwise stated.

Author	Sample size	Length range	* a	* b	Comments
Sella (1929)					
	1500	64-254	1.86×10^{-5}	2.97	Flank (curved) length
Vilela (1960)					
	203		1.90×10^{-5}	3.00	1958
	387		1.70×10^{-5}	3.00	1959
	580		1.80×10^{-5}	3.00	1958-59
Rodriguez-Roda (1964)					
	467	25-279.5	1.90×10^{-5}	3.00	"entry" 1956-59
	326	130-249.5	5.30×10^{-5}	2.80	"exit" 1956-59
	188	95-219.5	3.10×10^{-5}	2.90	"entry" 1956
	175	25-279.5	1.70×10^{-5}	3.00	"entry" 1958
	92	110-244.5	7.70×10^{-5}	2.70	"entry" 1959
	152	150-239.5	2.00×10^{-4}	2.60	"entry" 1961
Le Gall (1954) & Scaccini (1965)					
	60-250		6.20×10^{-6}	3.19	Flank (curved) length
Bard <u>et al</u> (1978)					
			2.50×10^{-5}	2.90	September - February
Farrugio (1977)					
	574	24-112	2.03×10^{-5}	2.9679	Immature
	100	114-247	1.60×10^{-5}	3.0324	Adults

* - regression coefficients from equation in the form of: $Wt = a \times FL^{b}$

Table IV.2.2. Length weight regression coefficients used in recent ICCAT SCRS assessments of the east Atlantic bluefin.

Size Range	Month(s)	Formula
East Atlantic and Mediterranean Sea		
≤ 100 cm	January - December	$W = 0.00004389 \times L^{2.81516}$
East Atlantic		
> 100	January - May	$W = 0.00001900 \times L^{3.0000}$
> 100	June - December	$W = 0.00005300 \times L^{2.8000}$
Mediterranean Sea		
	January - December	$W = 0.00001961 \times L^{3.0092}$

b. Growth

The study of the annual deposition of rings in hard parts (vertebrae, otoliths, spines and scales) due to cyclical variations in the fishes ecology provide the marks from which age can be determined. Other methods used to estimate age are analysis of successive size frequencies and the modal analysis of individual length frequencies (Farrugio 1981). Studies have also been carried out on changes in the weight of individual fish over time

(Liorzou, 1987). Direct methods of age measurement, such as aquaculture (Harada 1978) and tag/recovery (Parrack and Phares 1979; Cort and Rey 1985) have also been used to study age and growth of this species.

There are some summaries of these studies, Bayliff (1980) reviews these carried out in the Pacific; Cort (1978) and Farrugio (1979), those for the Atlantic and Mediterranean. Later, other authors give new data on the growth of Atlantic bluefin tuna (Table IV.2.3).

The only studies carried out on differential growth between sexes (Caddy, et al. 1976) were on west Atlantic bluefin. These studies show more growth in males than in females.

Table IV.2.3. Length at age relation for bluefin tuna in the east Atlantic and Mediterranean.

REGION	Italy and Libia	Mediterr. France	Mediterr. France	Norway	Portugal	Portugal	Atlantic Spain	Atlantic Spain	Atlantic Spain	Mediterr. Italy	Mediterr. Tunisia	Mediter France
METHOD	vert.	modal analysis	modal analysis	vert.	vert.	vert.	vert.	spine	spine	modal analysis		vert.
LENGTH TYPE	FL(?)	FL(?)	FL(?)	FL	FL	FL	FL	FL	FL	FL	FL	FL
SAMPLE	1500	344	571	?	?	43	153	221	191	1648	?	96
AGE												
1	64	64-66	-	-	-	-	55	64	63	57	42	54
2	81	-	85	-	-	-	79	84	83	77	69	77
3	97	94-96	101	-	-	-	116	100	102	97	93	98
4	118	108-110	118	-	-	-	130	120	120	115	113	117
5	136	-	-	135	-	120	147	136	136	128	127	135
6	153	-	-	153	150	136	165	151	152	145	139	152
7	169	-	-	161	170	146	178	166	166	165	151	167
8	182	-	-	180	180	164	193	177	180	176	157	181
9	195	-	-	198	195	187	206	194	193	187	164	194
10	206	-	-	207	220	196	220	203	204	198	183	207
11	216	-	-	221	-	218	232	215	216	216	-	218
12	227	-	-	228	230	233	244	232	226	228	-	228
13	239	-	-	239	-	233	255	240	236	239	-	237
14	254	-	-	-	-	-	-	247	245	250	-	246
15	-	-	-	-	-	-	-	255	253	260	-	-
16	-	-	-	-	-	-	-	261	261	270	-	-
17	-	-	-	-	-	-	-	266	268	-	-	-
18	-	-	-	-	-	-	-	272	275	-	-	-
19	-	-	-	-	-	-	-	276	282	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-
AUTHOR	1	2	3	4	5	6	7	8	9	10	11	12

Author references:

1. Sella (1929)
2. Buser-Lahaye and Doumenge (1964)
3. Doumenge and Lahaye (1958)
4. Hamre (1958)
5. Vilella and Pinto (1958)
6. Vilella (1960)
7. Rodriguez Roda (1964)
8. Compean Jimenez (1980)
9. Compean Jimenez and Bard (1983)
10. Arena et al (1980)
11. Hattour (1984)
12. Farugio (1981)

To express the growth of bluefin tuna, a length (or weight) at age key or a von Bertalanffy model are used. A summary of the studies on the application of bluefin growth to the von Bertalanffy model is given in Figure IV.2.1 (Farrugio 1981). Recent SCRS assessment meetings for the east Atlantic bluefin stock, the Farrugio (1980a, 1981) von Bertalanaffy growth curve was used. The parameters of this curve are as follows:

$$L_{\infty} = 351.132;\ k = 0.080;\ t_0 = -1.087$$

c. **Natural mortality**

The only study made on this parameter for east Atlantic bluefin tuna was carried out by Rodriguez-Roda (1977), based on a sample of 8111 bluefin tuna (age 11 to 14), caught by the Barbate (Spain) trap fishery between 1963 and 1975. A curve of the natural logarithm of the catch at age was obtained, from which Z was extracted as the slope of the linear regression of the right side of the curve.

Later, using an M/k relationship developed for eastern Pacific yellowfin (see Ed. note section IV.1.c), M was obtained from a value of k calculated for east Atlantic bluefin. The calculated value of M used in eastern Atlantic bluefin stock assessment is M = 0.18.

Bluefin natural mortality has been considered constant for all age groups and all years in the stock assessments.

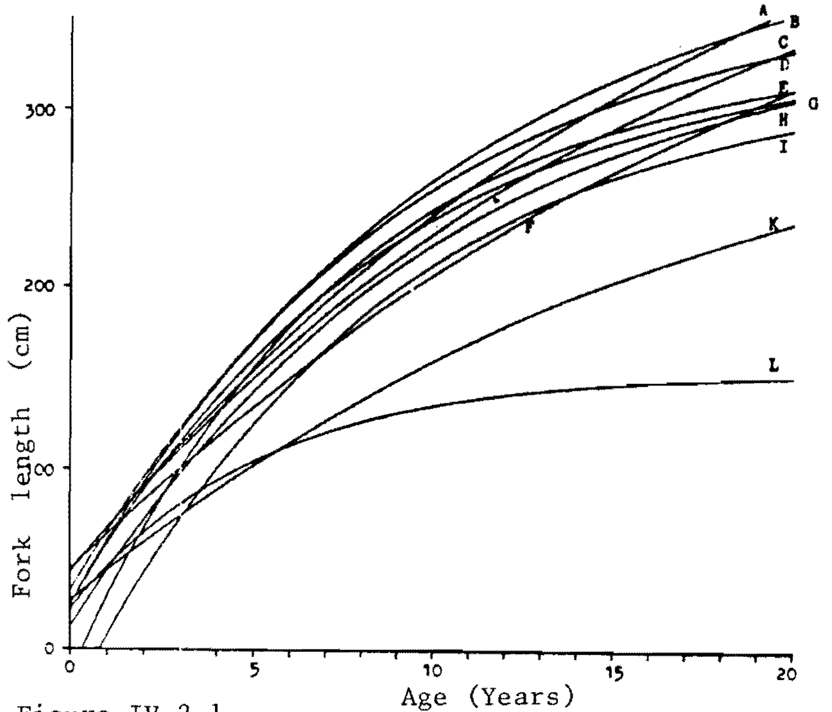

Figure IV.2.1.
Lineal growth curves (von Bertalanffy model) of age 0 to 20 bluefin of the Atlantic Ocean (Farrugio, 1981).

A: Coan, 1975
B: Rodríguez-Roda, 1964
C: Le Gall, 1954; Scaccini, 1956
D: Berry & Lee, 1977 (maximum)
E: Butler, et al, 1976 (males)
F: Sella, 1929
G: Hunt, 1977
H: Berry & Lee, 1977
I: Butler et al, 1976 (females)
K: Mather III & Schuck, 1960
L: Westman & Gilbert, 1941

3. Partial recruitment - WESTERN ATLANTIC

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The partial recruitment (PR) at age i refers to the proportion of age i fish that have been recruited fully to the fishery. A reliable estimate of the partial recruitment vector (or as it is often called the exploitation pattern) of bluefin tuna is vital for VPA as well as for other aspects of stock assessment, e.g. yield-per-recruit analysis and future catch projections. However, given the multi-component, multi-gear nature of the bluefin tuna fishery, PR is difficult to estimate, and can only be estimated empirically from the fisheries data.

Two methods, which estimate partial recruitment from the catch-at-age data, have been used for Atlantic bluefin in recent years:

(1) Separable VPA - SVPA (Pope and Shepherd 1982)
(2) Historical averaging method - HISTAVG (Conser 1987)

Both methods assume that partial recruitment has been constant over a time period, or at least varying about some stationary mean. Conser (1987) examined both methods and concluded that:

(a) partial recruitment estimates from the two methods will be similar
(b) both methods will estimate the same age at full recruitment
(c) diagnostics from both methods will lead to the same conclusion regarding the validity of the constant partial recruitment assumption
(d) partial recruitment estimates from both methods are relatively insensitive to the choice of initial estimates for their respective iterative procedures
(e) SVPA has better defined statistical properties and has the flexibility to handle a dome-shaped partial recruitment pattern
(f) HISTAVG has intuitive appeal and may be less sensitive to outliers in the catch-at-age data

For the purpose of tuning the Atlantic bluefin VPA, the SVPA method has generally been used to estimate the partial recruitment in the terminal year. The flexibility due to (e), above, has made it the practical choice for these assessments. However, it is likely that the use of more flexible tuning methods (e.g. the ADAPTive framework) will allow direct estimation of most of the partial recruitment vector in the future.

4. Partial recruitment - EASTERN ATLANTIC & MEDITERRANEAN

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Fishing mortality (F) vectors at age taken from summarized population tables of east Atlantic and Mediterranean bluefin were presented by Bard et al. (1978). He produced these for the periods 1960 to 1965 and 1972 to 1975 (Figure IV.4.1). The results show that fishing mortality is notably higher on large individuals and on age 1 juveniles.

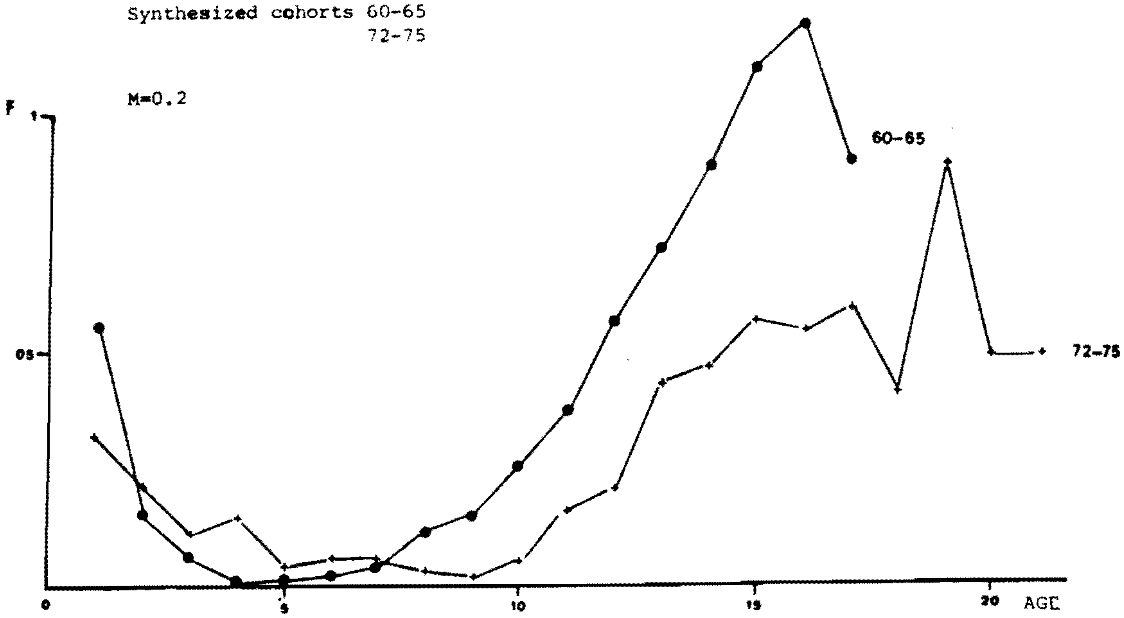

Figure IV.4.1.
Fishing mortality by age classes (from Bard, et al, 1978).

Parrack (1980) presented two starting F vectors for the combined Atlantic bluefin fisheries. Later, Farrugio (1981) calculated a fishing mortality vector for the east Atlantic bluefin fisheries based on a group of analyses on the 1958 to 1969 cohorts. Through a simulation study using different starting F's, the convergence was considered stable after age 9. The values obtained by Farrugio (1981) are lower than those obtained by Parrack (1980) for ages 1 to 3. They are higher for ages 4 to 6, and similar for ages 7 to 9. The fact that different values of F were obtained indicates differences in the exploitation rate of the two fisheries.

In 1985, at the Bluefin Working Group meeting held in Miami, USA, the partial recruitment was calculated by averaging the yearly fishing mortality vectors over a specific time period (historical averaging). This vector of average values obtained was used in a subsequent run of the VPA model. The process is carried out iteratively until the difference between two consecutive steps was lower than 0.01.

At that time, two vectors were retained. One for ages 0 to 18 (1978 to 1982), unweighted (fully recruited at age 3); and another for ages 0 to 18 (1970 to 1982), weighted to the catches (fully recruited at age 18). These vectors were used to study two extreme estimates of the partial recruitment that might be applicable to the final analysis.

Liorzou and Cort (1989) used catch series for age groups 1 to 18 (excluding group 0) for 1983 to 1985.

During the 1989 SCRS meeting the partial recruitment of east Atlantic and Mediterranean bluefin tuna was estimated, using the separable VPA (SVPA) technique with years 1982 to 1986 and ages 1 to 18 as the stable period for these fisheries. The resulting vector shows the same trend as earlier estimates (Figure IV.4.2).

Based on these analyses, it can be surmised that over the past 5 years the exploitation pattern has changed little; i.e., the recent fishery is directed primarily at adult (trap and longline) and young fish (purse seine and baitboat fisheries). This scheme shows, therefore, that there is a less exploited phase in the intermediate age fish (5 to 9).

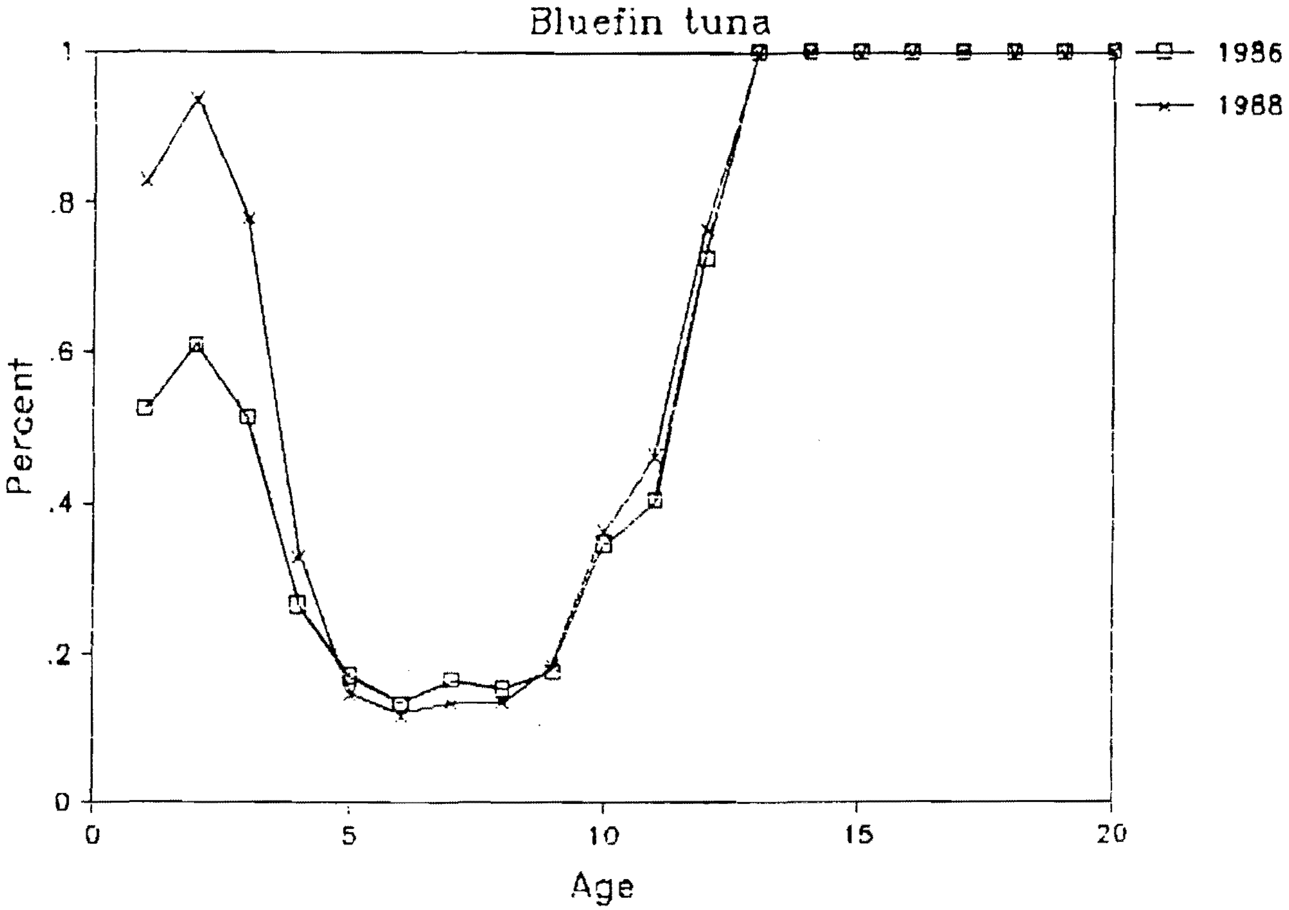

Figure IV.4.2. Partial recruitment of bluefin tuna in the East Atlantic and Mediterranean as calculated for the 1988 and 1989 SCRS assessments

5. Yield per Recruit - WESTERN ATLANTIC

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Some of the first stock assessment analyses were constant parameter equilibrium yield modelling attempts. The results of these studies were presented as research documents at various ICCAT SCRS meetings. These initial yield per recruit studies were based on biological parameter estimates presented by Rodriguez-Roda (1971) and by Sakagawa and Coan (1974). Later analyses employed updated parameter estimates (Parrack and Phares 1979, Parrack et al. 1979, Parrack 1980, Parrack 1981).

The first of these assessments (Shingu et al. 1975) estimated the critical age to be about ten years. The study found that the maximum yield per recruit occurred at a yearly instantaneous fishing mortality rate (F_{max}) of about 0.4 if the annual instantaneous rate of "natural" losses (M) was 0.1 or at an F_{max} of about 1.0 if M was 0.2. Parks (1976) used the Ricker yield per recruit model to estimate the effects of various size regulations on the small, medium, and large fish fisheries. Yield per recruit was calculated for each fishery under various minimum size restrictions on the other two.

Shingu and Hisada (1976, 1977) considered the relation of yield per recruit and relative stock biomass and concluded that production maximized at a stock biomass of about one third (25 to 50%) of the unfished level with an F of about 0.15 to 0.20 or at yields of about 16,500 to 19,500 tonnes Atlantic wide. They also studied the relation between F and relative yields for small versus large fish and concluded that maximum production would occur with a predominantly large fish fishery. Parks (1977) also concluded that the yield could be improved dramatically (53 to 86%) by increasing the minimum size.

Later studies (Parrack et al. 1979) corroborated this conclusion by comparing the yield per recruit in the west Atlantic that occurred before the juvenile purse seine fishery with that during the peak of such catches. It was concluded that a 30% decrease had occurred and that only an increase in minimum harvest size would increase yields. The study notes that critical size was about 186 cm and that the optimal minimum size seemed to be about 146 cm if M was 0.2 or about 225 cm if M was 0.1. Nichols (1981) estimated that the realized yield per recruit for cohorts before the juvenile fishery began was about 12 to 15 kgs. He also found that yield per recruit was higher in the early 1960's before the origin of the juvenile fisheries and that if escapement could be guaranteed until age five, yield per recruit would be increased from 50 to 90%.

These past studies present two consistent conclusions. First, critical size (about 180 to 200 cm) is rather old (9 or 10 years old). Bluefin biologists working closely with the fishery in the early 1970's came to believe that fish were recruited into the Gulf of Mexico spawning stock at about this size. Although special samples were not taken to support this hypothesis, catch size frequencies do provide strong support. Second, these yield per recruit studies have consistently concluded that yields will not be maximized if small fish fishing mortality exists. All results indicate that the minimum harvest size that maximizes yield is between 150 to 200 cm, and that the existence of juvenile fisheries in the Atlantic decreased yields of Atlantic bluefin. This conclusion resulted in the current regulation for the west Atlantic that created a minimum harvest size of 120 cm. Only 10 to 15 % of the catch-by-weight is allowed below this size.

Modification of the relative yield and biomass computations as employed by Shingu and Hisada (1976) to assess Atlantic bluefin may offer an alternative assessment method. Since such methods are free from the assumptions required to prepare the data for and to carry out a cohort analysis, agreement between various independent stock assessment studies seem more likely.

6. Yield per recruit - EASTERN ATLANTIC & MEDITERRANEAN

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Before 1985 (ICCAT 1986), yield per recruit estimates for Atlantic bluefin combined the entire Atlantic population (Nichols 1981, Parks 1976, 1977). It was at the Miami Working Group that the yield per recruit curve for the east Atlantic and Mediterranean for age 1+ was calculated. It used two partial recruitment vectors and weight at age calculated from the Farrugio growth equation (Farrugio 1980a) for the eastern Atlantic.

The results indicate F_{max} at 0.25 and $F_{0.1}$ between 0.16 and 0.17. The average yield per recruit of age 1 fish is 14 to 15 kg. If this estimate is multiplied by the average geometric recruitment for age 1 fish for the years 1970-1980, an equilibrium catch of 17,400-19,600 t is obtained. The equilibrium catch at $F_{0.1}$ is between 16,600-18,500 t (Table IV.1.1).

7. Abundance indices - WESTERN ATLANTIC

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* This co-authored section was produced independently and 'fused' by the editor - who apologizes for any errors and roughness.

Standardized catch rates

(Ed. note) *Most bluefin tuna fisheries are part of a multispecies harvest, single species (bluefin) catches are not possible in such fisheries. The different species (fishery components) tend to have 'preferred' habitats, ie. in the Japanese longline fishery for 3 to 5 year olds (< 140 to 150 cm) deeper sets tend to catch more bigeye and shallower sets more bluefin.*

Nominal catch rates of such multispecies fisheries have been used for many years to develop indices of abundance. Simple averaging procedures are often inadequate because there are:

> differences in catch rates caused by such variables as time, area, environmental conditions and fishing gear, and
>
> annual differences in the distribution of effort across such strata.

Several approaches have been used by SCRS scientists to develop standardized indices which account for some of those effects.

The largest single component (tonnage) of the west Atlantic bluefin fishery is the Japanese longline. This gear component has received the most attention regarding the development of catch rate indices. In the case of the longline fishery, CPUE is usually expressed as the number of fish caught per number of hooks used (usually per 100 or 1000 hooks). It is known that bluefin change their distribution according to the stage of development (both annual and life time). The multi-species longline fishery is able to alter target species, thus the fishing area depends upon its tactics. Accordingly, in order to make CPUE comparable, three kinds of standardization techniques have been adopted for this species.

The first is a very simple method that selects area and time strata in which substantial catch occurred (Shingu and Hisada 1979) and uses the nominal CPUE from that area as an index. To determine whether or not fishing effort was directed at bluefin, Parrack (1982) suggested that minimum catch of at least 45% (in number) of bluefin for a 5 degree square-month strata.

The second technique is called the Honma method (Honma 1974); it has been used for albacore and tropical tuna longline fisheries and for bluefin analyses during the 1970's and early 1980's. The Honma method assumes a constant distribution of the stock and constant catchability. It also assumes that the fishery covers the range of the species. In this method the average density of the stock is used to calculate relative intensity (r_{ij}) of fishing effort. The relative average density is derived from a weighted average of time and area specific densities, and is expressed relative to the total average density. Shingu and Hisada (1977) calculated the average density for the area north of 20^{O}N for 1970-1974, Suzuki (1983) and Conser (1985) obtained it for total Atlantic using the data for 1971-1980 and 1965-1980, respectively.

Anon. (1984) attempted to develop standardized indices using data for each area, year and month. During this analysis they noted a potential bias in the results based on the exponential parameter k from the negative binomial distributions fit to single set catch rate data from the Japanese longline fishery in the Gulf of Mexico. Matsumoto *et al*. (1986) conducted further analysis of the parameter k and found it varied by month with no significant year effect. The results seem to be inconclusive and this approach has not been used since.

In recent years SCRS scientists have used general linear model (GLM) analyses to develop standardized indices. It has become an accepted method for the estimation of abundance indices following the general methodology outlined by Robson (1966) and Gavaris (1980). A multiplicative model was adopted rather than an additive model as it better reflects the general characteristics of CPUE. The general linear model can be written as follows:

$$y = X.B + e$$

where y is the observation, X is a design matrix, B is a parameter matrix, and e is an error term. As GLM is a statistical procedure, it can estimate the reliability of the parameters and can incorporate any factor in the model that may affect CPUE. Generally, the main effects are year, season (month or quarter), area and an interaction term between season and area. When more detailed observer data were available, the number of hooks between floats (gear configuration) and/or oceanographic condition have been investigated (Turner 1987, Davis and Turner 1988, 1989 and Davis 1989).

Conser (1985) compared the Honma and GLM approaches, concluding that the GLM was less subjective and provided the possibility for statistical testing and estimation of confidence intervals because of its formal statistical basis. He further noted that the ease with which effects other than year, month and area could be incorporated into GLM analyses made that approach more flexible. Conser considered that the Honma method to have some practical advantages when dealing with large, unbalanced data sets. Suzuki (1986) compared both CPUE series estimated by Honma method and GLM. He found that both series were similar in their trend. Conser noted that both methods assume constancy across years in distribution, in space, and in time, unless year interactions are incorporated in GLM analyses. To date SCRS scientists have not incorporated year interactions in their GLM analyses.

SCRS scientists have gradually refined the methods of data preparation and GLM analyses. In the last several years size frequencies from the Japanese longline data bases have been used to establish nominal catch rates by age group or single age (Turner 1987 and Miyabe and Suzuki 1989). Through examination of residuals from the full model and at each level of all main effects (Turner 1987, Miyabe 1989), SCRS scientists have been able to examine the results with respect to normality assumptions. For instance, pronounced differences in the distributions of residuals of different gear configurations led to the restriction of the analyses to those fishing sets which were thought to be directed at bluefin and elimination of those sets thought to be directed at other species (Turner 1987).

In recent years SCRS scientists have used GLM analyses to develop standardized indices from three data sets:

> Japanese longline data summarized by month and 5^{0} square,
>
> single set data recorded by observers on Japanese longline vessels fishing in the U.S. EEZ, and
>
> summarized data from the rod and reel and handline fishery for large bluefin off the northeast U.S.

The use of summarized data in GLM analyses presents difficulties in interpreting the estimates of variance and confidence intervals and in using that information in subsequent assessment analyses.

Analyses have been performed on both the detailed and the summarized data from the Japanese longline fishery, because of their different characteristics. The summarized data cover a longer time period and a broader area, but the summarization may obscure trends in catch rates and prohibit investigation of the effects of many variables on catch rates. The single set data provides the opportunity to examine additional factors which might influence catch rates, but sampling error especially in determining size (age) composition may affect the results. Annual values of the standardized indices from analyses of the two data bases generally have been similar, eg. Miyabe (1989) and Davis (1989), and both show considerable year to year fluctuation which is probably greater than the annual changes in stock abundance.

The rod and reel fishery for large bluefin ($>$ 141 kg) in the northeast U.S. has very low catch rates with 80 to 95% unsuccessful trips. Analyses have therefore been performed on summarized data, showing significant year, month and area effects and relatively stable catch rates in recent years, eg. Brown and Turner (1990).

In all GLM analyses by SCRS scientists since 1984, multiplicative models have been assumed, and catch rates of zero (no bluefin caught) have been retained. In most analyses the coefficient of variation (R^2) has been between 0.3 and 0.6 which indicates that a large portion of the variation in catch rates is not explained by the model. The estimated CPUE series from the recent analyses (Miyabe 1989, Davis 1989) show considerable annual fluctuations which appear to exaggerate the real change in stock abundance.

Larval Index

An index of Gulf of Mexico spawning stock abundance for the 1985 meeting of the bluefin working group (ICCAT 1986). McGowan and Richards (1986) presented results for surveys from 1977 to 1983 and estimates of abundance of larvae and spawning stock from those surveys. Using estimates of larval abundance, average

age and information on natural mortality, the working group developed an index. The larval abundance estimates were calculated from the effective fishing area (ICCAT 1987) and estimates of spawning season duration (McGowan and Richards 1986). Values of this index have ranged from 3.9 to 10.8 between 1977 and 1983 and 0.9 to 2.7 between 1984 and 1989 (Anon. 1990).

In 1989 a review of this index and the underlying survey was undertaken at the recommendation of the SCRS (Richards 1989). The review panel concluded that sampling intensity and most aspects of the survey design appeared to be adequate and that the small numbers of larvae caught were reasonable and were not a reason to doubt the results. They stated that the index is probably imprecise, because of variation in many factors which would affect the actual larval abundance and catch rates. The review panel advised that sampling in the latter part of the spawning period was needed and information was needed to estimate the mortality rate of the larvae. Modifications to the sampling have been made to address these recommendations.

(see also Sections II.3 and IV.7)

8. Abundance indices - EASTERN ATLANTIC & MEDITERRANEAN

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Indices of abundance can measure a specific component of recruitment to the stock or some portion of the exploitable stock. For these indices to be comparable over time, there should be no changes in the technology used nor variations in catchability of the fishery. There are two types of abundance indices which have been utilized in bluefin assessments. Some of these were obtained by direct methods, such as egg and larval surveys. Others are based on catch and fishing effort, they are known as fishery relatedindices. The former indices provide a fishery independent index of abundance of the spawning stock, whereas the latter can refer to distinct age groups, such an index can be more precise if the fishery targets specific age groups. It is convenient to have a number of indices which cover the range of ages within the fishery.

As with other pelagic species, these indices for bluefin have inherent problems due to the random nature of the fish/fishery interaction and to market problems. Both of these may result in shifts in the size of fish caught. These indices are very important as they are used to calibrate the assessment of the stock (VPA).

Numerous authors have published CPUE series for the bluefin fisheries of the east Atlantic and Mediterranean, mainly on the longline and trap fisheries for spawning fish and on baitboat and purse seine fisheries for young fish. Various series of these indices have been used to calibrate VPA for the bluefin stock in the east Atlantic in 1988 and 1989. The 1989 assessment used three series of indices for fish of ages 5+, and seven series of indices for age 2 and 3 fish (ICCAT 1990). However, several of these were rejected for the following reasons:

> age 1 CPUE (France PSM and Spain BB): they showed greater than expected variation and this age-class has no or limited data for several fisheries, and
>
> age 2 and 3 CPUE (France PSM, before 1982): spotter planes were used after 1982 to assist fishermen in locating bluefin schools.

The major part of these series have been updated during the meetings, based on data from preceding years.

During the last meeting, SCRS used several of these indices. These were combined in the calibration of the VPA by weighting by the inverse of their contribution to the variance (when considered without weighting) in estimating the stock size.

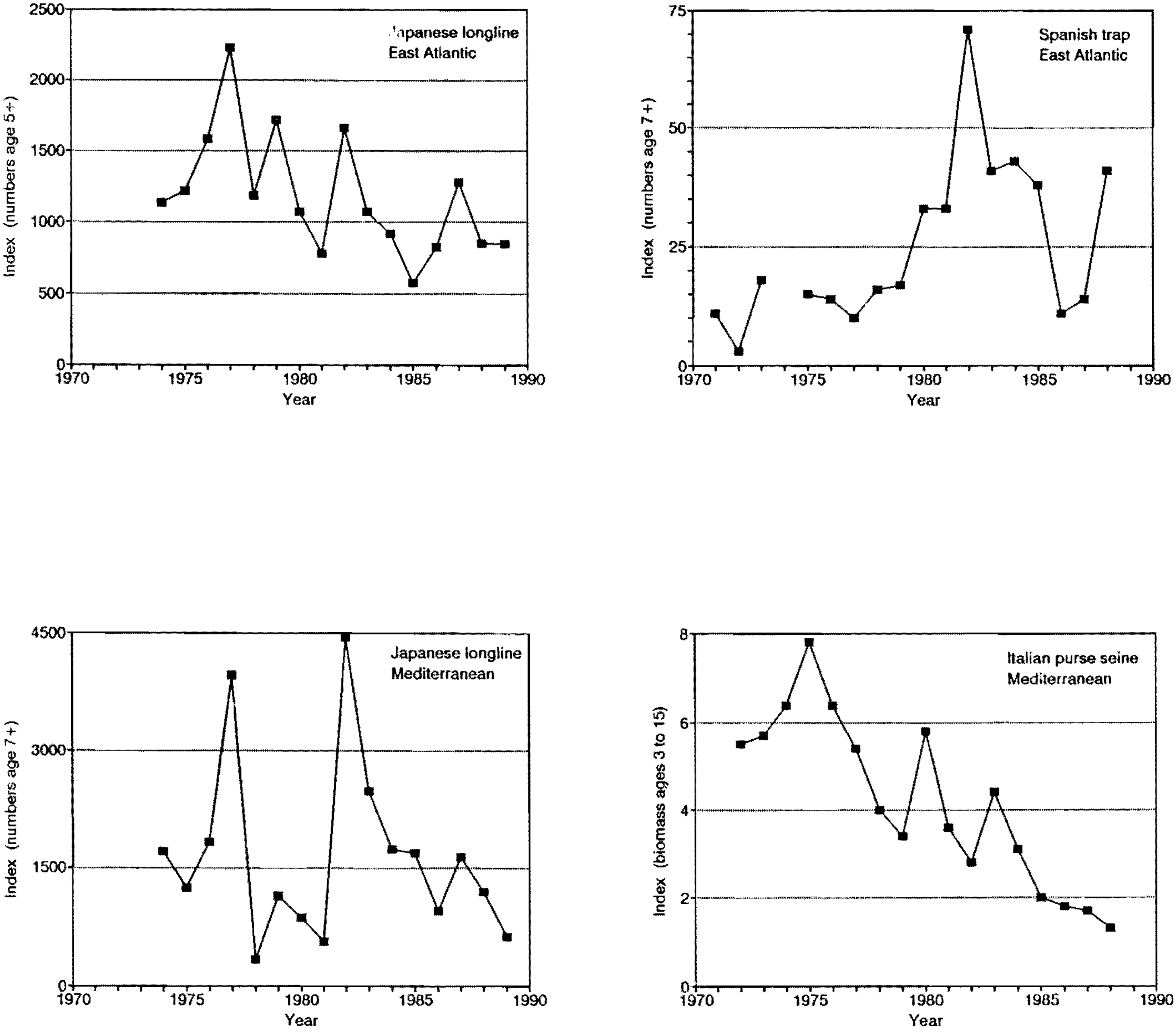

Figure IV.8.1 (Ed. note) Four abundance indices investigated for the eastern stock by the 1990 SCRS. These indices all represent adult fish.

9. VPA: Methodology - WESTERN ATLANTIC

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Virtual population analysis (VPA) has been the mainstay of bluefin tuna assessments since the mid-1970's. Caddy (1975) appears to be the first published paper to employ VPA on bluefin, although references to an unpublished study of Lenarz (MS1974) are found in the literature. While most other tunas were assessed using surplus production models during the 1970's, production models were not considered appropriate for Atlantic bluefin. Many different fisheries and gears exploited bluefin tuna (e.g. longline, purse seine, traps, rod and reel, etc.). The fishing mortality rates imparted by each fishery were highly age-specific. The level of effort and availability of the fish to the various fisheries varied from year to year. These factors caused appreciable changes in the partial recruitment vector over time, a violation of one of the fundamental assumptions of surplus production models.

The standard VPA method of Gulland (1965) was used initially. However, it soon became apparent that given the long-lived nature of bluefin and the relatively low exploitation rates on many ages (inferred from tagging), VPA back-calculations would not converge quickly. This gave rise to interest in methods for estimating objectively the fishing mortality rates in the terminal year (i.e. VPA tuning or calibration).

Parks (1976) tuned VPA backcalculated F's to F's derived independently from tagging experiments. Although not generally recognized, Parks was the first to tune a VPA to auxiliary data using a least squares objective function. As databases improved and additional auxiliary information became available (e.g. effort data), VPA tuning became an integral part of bluefin tuna assessments. This work on VPA tuning methods was often innovative and in the forefront of this important area of fisheries research.

Parrack (1981) was the first to attempt to tune a bluefin VPA using fishing effort data. However, in a departure from Parks' least squares objective function, Parrack used maximum correlation as the optimization criteria. Specifically, he searched for the optimal full F in the terminal year that maximized correlation between effective effort (of the Japanese longline fleet) and partial backcalculated F's from the VPA. Powers et al. (1983) refined the Parrack (1981) procedure. In particular, they established acceptance/rejection criteria for the estimated F's and used graphical methods to examine the age-specific fitted relationships and residuals.

Parrack (1985) suggested the use of Parks (1976) least squares approach, but re-wrote the objective function to tune VPA back- calculated stock sizes to indices of abundance (generally CPUE indices). He also emphasized analysis of residuals to judge the usefulness of the various indices.

Conser (1989) suggested the use of more integrated approaches for tuning the bluefin VPA; specifically the CAFSAC (Canadian Atlantic Fisheries Scientific Advisory Committee) method ADAPT (Gavaris 1988; Conser and Powers 1990). ADAPT is a generalization of the Parrack (1985) approach (CAL). The ADAPT objective function and the least squares approach are quite similar to those of CAL. However, the optimization (Marquardt) algorithm is more general, allowing for the independent estimation of several age-specific F's in the terminal year and their variances (only the full F can be estimated with CAL). Generally, ADAPT is also more flexible, e.g. allowing a log objective function, the use of a plus group, etc. The ICCAT SCRS employed ADAPT for tuning the bluefin VPA during its 1989 session.

The VPA tuning procedures that have been developed for Atlantic bluefin tuna differ from the Doubleday-Deriso catch-at-age models (Doubleday 1976; Deriso et al. 1985; Kimura 1989), developed over a similar period, in several ways. The two most important with respect to the bluefin assessments are:

- none of the bluefin tuning methods have assumed separability, and
- the bluefin tuning methods have been conservative in the parameters estimated.

These practical factors have been particularly important in dealing with the multi-component bluefin fisheries and the high degree of variability in the assessment database.

Future research on tuning methods for bluefin needs to examine:

- weighting methods used for handling indices of abundance of varying quality and reliability,
- means of dealing with indices associated with converged VPA stock sizes; particularly when the correspondence is poor, and
- procedures for incorporating all components of variance into the variance estimates of N and F.

10. VPA: Methodology - EASTERN ATLANTIC & MEDITERRANEAN

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The initial assessments of bluefin tuna for the entire Atlantic were carried out by Caddy (1975), who analyzed the stock of this species by cohort analysis (an approximation to the VPA method). Later, Parks (1976, 1977) and Shingu and Hisada (1976) made other analyses on the combined stock.

Studies on Atlantic bluefin stock structure indicate the existence of two distinct stocks, an eastern and a western, although there is some mixing in both directions. The main arguments which support this theory are:

- difference in the biometry,
- distinct spawning areas,
- differential growth rates, and
- limited mixing of tagged fish between both sides of the ocean.

The first stock assessment of bluefin tuna differentiating between the eastern and western stocks was conducted by Parrack (1980). He evaluated the combined stock as well as the western stock. From the difference between both, he estimated the status of the eastern stock. Later, Farrugio (1981) carried out an assessment on east Atlantic bluefin tuna stock. The most notable differences found between these two studies concern the estimate of the input F vectors in the analysis.

Since 1985 a new methodology has been introduced which consists of calibrating the VPA using abundance indices of different segments of the fishery. Since that time, bluefin stock assessments have been carried out by SCRS working groups prior to and duringthe SCRS meeting.

The general stages of the most recent assessments were as follows:

- analysis of the indices of abundance and a decision on their subsequent utilization in VPA calibrations,
- determination of the partial recruitment vector (exploitation scheme) using SVPA, and
- calibration of the VPA itself using all the indices which were not discarded.

The main problems which are inherent in this type of analysis are:

- the catch table shows significant deficiencies, especially as concerns young fish,
- for the Mediterranean area, many countries report overall catch statistics, and do not specify the corresponding size frequency (resulting in often doubtful data substitutions),
- the selection of input parameters in the analysis (growth, M and terminal F), and
- the analyses have been carried out using only indices of young fish, the selection of abundance indices should include the full range of ages, if they did the results obtained on the stock structure as it concerns adult fish might change.

Results of the assessment - Direct methods

Dicenta and Piccinetti (1978, 1980) carried out assessments on the spawning biomass of the eastern stock of Atlantic bluefin tuna based on 200 larvae collected during two oceanographic cruises. The methodology used is based on the relation described in a paper by Sette and Alsthrom (1948). According to this study, the mortality factor between eggs and larvae (M) is the main source of error in this type of assessment. According to this evaluation, the spawning biomass was estimated, in the years studied, between 66,700 and 6,670,000 t.

Based on the results of an assessment by Farrugio (by cohort analysis), the lower limit of the assessment carried out by Dicenta and Piccinetti would be more likely.

Results of the assessment - Indirect methods

Farrugio (1981) compared the results of various evaluations on the east stock (Figure IV.10.1). The comparison of the number of individuals of age 1-12 for 1970-1979 indicated more fish in Farrugio's analysis than that of Parrack (1980). The latter study indicated the stock has decreased since 1973 and amounted to 900,000 individuals in 1978; this is unlikely, since at least 600,000 fish were caught. However, in Farrugio's assessment, we observe different trends from those of Parrack's assessment.This evaluation shows that recruitment was very high in 1974. Farrugio (1981) noted the fishing mortality on ages 1-12 ceased its the increasing trend which began in 1975, and since 1977 the values obtained are similar to those of 10 years before.

The ICCAT stock assessment conducted in Miami (ICCAT 1986) indicates how the size of the stock and the fishing mortality rate for ages groups 1-4, 5-9 and 10+ differ according to different (previously mentioned) exploitation schemes. It also shows the high recruitment in 1974, cited earlier by Farrugio (1981) and that since 1982 the highest recruitment of the entire series have been observed. The number of spawning individuals obtained in this assessment shows an increasing trend.

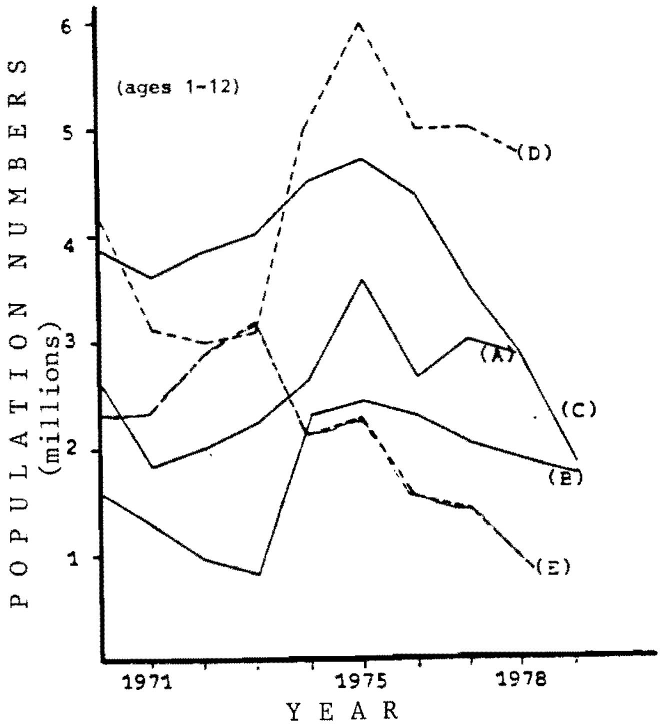

Figure IV.10.1 Comparison of the results of bluefin stock assessments by cohort analysis, according to the one-stock hypothesis for the entire Atlantic and Mediterranean (Parrack, 1980), and by two separate stocks (Farrugio, 1981).

(A): East Atlantic + Mediterranean = East stock (Farrugio, 1980)
(B): West Atlantic = West stock (Parrack, 1980)
(C): Overall study "Total stock" (Parrack, 1980)
(D): "Total stock" by adding (A) + (B)
(E): East stock by substracting (C) - (B)

Liorzou and Cort (1989) conducted a subsequent evaluation which showed the same trends as those by the Miami working group for juvenile individuals (ages 1-4). On the other hand, the variation in the stock of age 5-9 and 10+ fish was more significant.

The results obtained at the 1988 SCRS indicate a decline in the number of age 5-9 and 10+ fish. It is considered this is due mainly to the following:

- the working group noted unresolvable problems with the indices of older fish and therfore used only indices of abundance of young fish to calibrate VPA, and

- the terminal F obtained from the calibration and applied (F=0.83) is very high and possibly unrealistic with regards the older fish.

Figure IV.10.2 gives the results of the 1989 SCRS (most recent) stock assessment (ICCAT 1990). In this evaluation we observe that the recruitment trend of juvenile bluefin (ages 2-4) has been increasing since 1970. On the other hand, recruitment of the 5-9 age group has remained stable and the size of the 10+ spawning stock has decreased.

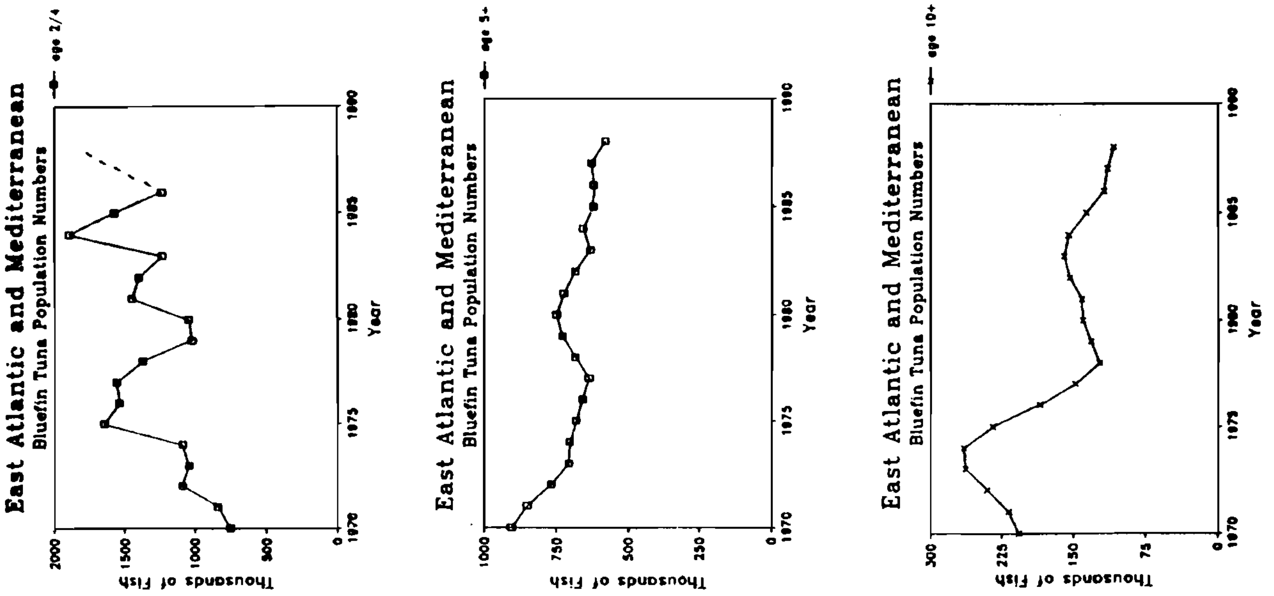

Figure IV.10.2.
Population estimates for bluefin tuna from the East Atlantic and Mediterranean.

The general conclusions of this section can be summarized as follows:

- stock assessment of east Atlantic bluefin tuna is difficult to carry out due to deficient information on the total catch, particularly as concerns the central and eastern Mediterranean fisheries, for which catch and real size composition information is unknown,
- the size of the stock of juvenile fish (ages 1-4) increases from year to year, regardless of the parameters used or how the stock analysis is carried out,
- the intermediate age group (ages 5-9) does not show any clear trend, and
- as regards spawning bluefin (age 10+), we obtain diverse results generally showing a declining trend since 1982.

Finally, the following should be noted: as stock assessments on the eastern Atlantic bluefin tuna stock are still uncertain for the above reasons, it is felt that the projections are not useful for recent years.

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REVIEW OF ASPECTS OF SOUTHERN BLUEFIN TUNA BIOLOGY, POPULATION AND FISHERIES

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FOREWORD

Several international working groups of tuna scientists were established in 1988 to develop background reviews for a proposed Food and Agriculture Organization (FAO) Expert Consultation on Interactions in Pacific Tuna Fisheries. This southern bluefin tuna (SBT) review was developed by the SBT working group. Initially the concept of the review and arrangements for its preparation were coordinated by Jacek Majkowski, then of the CSIRO Division of Fisheries in Hobart, Australia, in his capacity as convenor of the SBT group. However, after his departure to FAO, Rome, Albert Caton of the Bureau of Rural Resources in Canberra, Australia took over. When the need arose for a background review on SBT for the May 1990 World Meeting on Bluefin Tunas at the Inter-American Tuna Commission in La Jolla, California, drafts of completed chapters were distributed to participants. This version, edited for inclusion in the world meeting report, re-arranges some of the original chapters' material and incorporates later drafted sections. Regrettably, some sections proposed for the original review could not be developed in time for inclusion. A notable omission, for instance, is the section on oceanographic features that may affect SBT. Nevertheless, the review presented here contains a considerable amount of new data on SBT and its fisheries, thereby updating material in the earlier comprehensive reviews of Shingu (1978) and Olson (1980). There is a comprehensive reference list included, but other references may also be located in the bibliography of Eckert et al. (1987).

ACKNOWLEDGEMENT

The line drawing of southern bluefin tuna in Fig. 1. is reproduced with the kind permission of the Food and Agriculture Organization of the United Nations from: FAO Species Catalogue, Vol. 2, Scombrids of the World, *FAO Fisheries Synopsis* (125) Vol. 2, FAO, 1983.

1. OVERVIEW

Southern bluefin tuna (SBT), *Thunnus maccoyii*, are large (up to 200 cm and 200 kg), long-lived (more than 20 years) and highly migratory pelagic fish. The species has a general circumglobal distribution between 30° S and 50° S, with a spawning ground between 7° S and 20° S in the north-eastern Indian Ocean south of Java.

Southern bluefin tuna can be distinguished in the field from the bluefin tuna *Thunnus thynnus*, mainly found in the northern hemisphere, by its yellow median caudal keel (dark in *T. thynnus* and other thunnids) and the relatively longer adult pectoral fin (20-23 % of length to caudal fork in *T. maccoyii*, compared with 17-22 % in *T. thynnus*).

A single spawning area, morphological uniformity, and tag return data suggest a single population. Because spawning is restricted in time and space, there is little chance for different populations to develop through reproductive isolation. High vagility (as evidenced by the numerous long-distance tag returns) in relation to the geographical distribution (indicated by the range of longline catches) would also suggest limited potential for population differentiation.

Southern bluefin tuna with an elevated gonad index, are found only in the Indian Ocean. In spite of many years of worldwide tuna longline fishing, no data suggesting spawning have been reported from any waters other than the area of the Indian Ocean south of Java. On the spawning grounds, only large, mature SBT with well-developed gonads are caught. Maturity can occur at about 120 cm fork length, but more commonly at 130 cm - about 8 years old. Fecundity of one fish 158 cm long with a gonad index of 4.31 was estimated to be 14-15 million. Ripe eggs remaining in a 143 cm spent fish were 0.66-1.05 mm. Examinations of sex ratio in catches in various fishing areas, show that as juveniles, females outnumber males; the situation is reversed in adults.

Little detailed research has been carried out on the reproductive biology of SBT. To remedy this biological sampling on the Oka (spawning area) and Oki (adjacent area to the south) fishing grounds is required. It is not known whether spawning has a particular periodicity (such as a lunar cycle), or how spawning intensity is spread throughout the spawning season: ichthyoplankton sampling in the area has not been carried out at the appropriate spatial and temporal scales. However, recent ichthyoplankton surveys suggest that the main spawning period is from January to February, as the highest larval catches have occurred then. The fishing ground to the south (Oki) appears to be the staging area where large SBT with ripening or spent gonads accumulate prior to, during, and after the spawning period (September to March). It is believed that these SBT migrate southwards from the Oki ground after the spawning season.

The limits of the spawning ground have been established by the distribution of adults with ripe gonads and the capture of larvae. The identification of larvae is, however, unreliable, and confusion with other *Thunnus* species can occur. Larval distribution within the spawning ground has not been defined because of insufficient sampling relative to the patchy occurrence of larvae. Juvenile tuna 6-8 cm long, and thought to be SBT, have been collected by Bouke-ami net on the Australian north-west shelf. Larger juveniles (20-60 cm fork length) have been caught by gillnet and trolling further south (22° S - 34° S) on the shelf.

Off the south-west coast of Western Australia (WA), SBT between 1 and 3 years old are common in surface catches. Eastwards, originally as far as New South Wales (NSW), SBT in surface catches commonly ranged from 2 to 6 years old, with individuals to at least 9 years old also taken at times. The younger-aged individuals (1 to 3 years old) seem more closely associated with waters of the coast and continental shelf than are older individuals. Some immature fish (from 3 years old, and progressively for older ages) leave the warmer waters of coastal areas for the wide region of the West Wind Drift where feeding adults are mainly found.

A promising technique for the study of migration patterns, involving the correlation of physical environmental features (particularly temperature) with otolith microchemistry, is under investigation. Also, the adoption of new, high technology tagging techniques - in particular the use of archival tags - could provide new data on continuous three-dimensional movements.

Information about the nutrition of SBT is largely anecdotal. The larval diet, of mainly microcrustacea and macrozooplanktonic crustacea, is similar to that of related tuna species. It includes a degree of cannibalism. Studies show that survival and growth are dependent on the densities of larvae and other prey. Juveniles and adults are opportunistic feeders, chiefly of cephalopods, crustacea, fish and salps. In general, smaller SBT feed mainly on crustacea. Adults feed mainly on fish. Sharks, other tunas, other teleosts, seabirds, whales, and seals are possible competitors, whilst a number of sharks and the killer whale are possible predators.

Tag-recapture data and length-frequency modal analysis have traditionally provided information on SBT age structure and growth rates, and length-at-age estimates for the fished population. There are different age-at-length relationships because of the low numbers of recoveries of fish at liberty for long periods, and the questionable reliability data for some recoveries. The von Bertalanffy growth parameters derived have ranged from 171.5 to 207.6 cm for L_∞, 0.128 to 0.187 per year for K and -0.554 to 0 years for t_0. They produce lengths at 2, 8 and 14 years old ranging between 46.0 and 56 cm (2 years old), 124.7 and 136.7 cm (8 years old), and 157.4 and 174.7 cm (14 years old). Growth variations among individual fish, and seasonal growth (faster during summer and early autumn) have been reported, apparently synchronised with ambient water surface temperature. Recoveries of SBT tagged in 1983-84 all indicated significantly faster growth than previously tagged fish, the increase persisting with increasing time at liberty.

Annual banding has been reported on scales from fish up to 130 cm fork length (which had seven bands) but clarity decreased with increasing fish size. Bands on scales from larger fish (> 130 cm fork length) were unreadable. Daily growth of larvae has been determined from otolith increment microstructure, validated using marginal increment analysis. A burning technique, (validated for 2-4 years old, inclusive) showed annual growth-bands in otoliths from SBT up to 167 cm fork length. For fish younger than about 8 years old, the age-mean length relationship was similar to those derived previously by the methods mentioned above. Recently, X-ray examination of SBT otolith microchemistry has shown conspicuous episodic variations in strontium-calcium ratios for both small and very large SBT, apparently consistent with the expected age of a fish, based on its size and previous estimates of growth rates. This technique may enable reliable age determination of large (> 170 cm fork length) SBT, thus filling the gap left by previous aging techniques. Finally, trial use of computer-based simultaneous analyses of a time series of length frequency distributions to separate modes into age groups (MULTIFAN) has given results consistent with age-at-length relationships from other methods.

Catch age composition has been determined from length composition using an age-at-length relationship. Where length composition is unavailable, catch weight composition and a length-weight relationship have been used to derive length composition and, thereby, age composition. It is more difficult to classify larger, older fish by this method however, raising doubt about the accuracy of estimates of catch age distribution for such fish.

The natural mortality rate (M) of SBT is an input parameter to Virtual Population Analysis (VPA) and is required for yield-per-recruit analyses. Again, there is considerable uncertainty about the appropriate value for SBT and whether M varies by area or age. The most commonly used value has been 0.2. However, assessments have generally incorporated tests to examine their sensitivity to the uncertainty in the parameter. All reliable analyses indicate that the rate of natural mortality is within the range 0.2 ± 0.1 per year. Further analyses may yield closer bounds of M.

Australia, Japan and New Zealand have been the main nations fishing for, or controlling access to, SBT. Incidental troll catches of SBT had been taken off south-eastern Australia for many years before pole-and-live-bait fishing for surface aggregations of juveniles commenced in the early 1950s. Catches steadily increased, and peaked at 21 500 t (about 2.37 million fish) in 1982. Quotas have progressively forced down catches to just over 5000 t by the end of the 1980s. The fishery commenced off NSW, where SBT 2 to 5 years old were common at the edge of the continental shelf. South Australian (SA) activity, on SBT 2 to 4 years old, developed in the mid-1950s, and a WA fishery, mainly for SBT 2 years old, commenced at the end of the 1960s. In the NSW and SA fisheries, aerial spotting developed, activity spread widely and further offshore, purse-seining commenced, and combined poling and purse-seine sets on schools evolved. The age of fish taken increased to about 9 years old. Off WA, in contrast, vessels remained comparatively small (7-15 m) and the fishery was predominantly confined to the continental shelf and to SBT 2 years old. In the early 1980s the NSW fishery failed and in 1990 there were no surface schools remaining there. However, Japanese longline catches continue, albeit at lower hook rates than at the end of the 1970s. The WA fishery has virtually stopped, catches declining from more than 1 million fish in the early 1980s to about 30 000 in 1990 because of the transfer of quota holdings to SA. Areas of SBT availability off SA also contracted during the 1980s but improved to some extent after 1987. Scientists had expressed concern in the early 1980s about declining parental biomass, and as a result a quota had been set for the 1983-84 season. In order to generate finance within the industry by the sale and purchase of quotas, in 1984-85 transferable quotas, allocated to vessels individually, were introduced. Another measure at the time required fishermen to re-direct activities towards older fish. This was only temporarily successful because the declining availability of large fish over several years forced resumption of SA operations on predominantly 3-year-old and 4-year-old SBT, despite their lower value and the increasing economic pressure of reduced quotas.

The Japanese SBT longline fishery commenced in 1952, the catch peaking sharply by 1960-61 at more than 75 000 t (about 1.2 million fish), then declining steadily to 11 000 t by 1988. Quotas reduced the catch to less than 7000 t in 1990. Japanese fishing operations developed on the spawning ground and later off eastern New Zealand, spreading southwards in the Indian Ocean to the West Wind Drift region. They eventually ranged from the east of New Zealand, westwards throughout the West Wind Drift region, to the southern Atlantic. Fishing effort increased steadily from commencement of the fishery, slowed between 1970 and 1980, then declined because of a 20 % reduction in the number of vessels. It subsequently increased slightly as a result of an increasing trend in number of hooks per set. The longline grounds east of New Zealand and off NSW are not as important for SBT as they used to be. The former area is a geographically marginal area for SBT, and the latter has seen an increase in fishing activity directed at yellowfin tuna (*T. albacares*) and marlin (*Makaira* spp.). Activity on the spawning ground and the Oki ground to its south is now directed mainly at bigeye tuna (*T. obesus*). The most important area for the SBT fishery since the 1960s has been the fishing ground south of Africa, where effort reached 50 million hooks in 1979. It has remained around 30-40 million hooks since, with a total of 100-125 million for the entire fishery. The hooking rate continued to decline after the expansion of fishing grounds during the 1960s, and in 1987 it was about 25 % of the early 1970s rate. In contrast to the Australian fishing operations on surface aggregations of juveniles, the Japanese target medium-sized and large-sized SBT (70-180 cm fork length), with the proportion of medium-sized fish increasing when the fishing grounds expanded from the spawning ground. There has been a partial overlap in size composition of the surface and longline fishery catches. In 1971 because of increasing catches of small SBT, voluntary area-closures were adopted in the longline fishery. An area south of the spawning ground was also closed seasonally for the second half of the spawning season to protect migrating adults. Following recommendations by scientists for catch restraints, and several subsequent years of trilateral management discussions among

Australia, Japan and New Zealand, Japan introduced a catch limit of 23 150 t for its 1986-87 season. The Japanese catch limit was reduced, progressively, to 6250 t for the 1990-91 season.

The small New Zealand domestic troll and handline fishery for adult SBT, operating alongside trawlers taking demersal species off the west of the South Island, commenced in 1980. Catches reached 305 t in 1982, declined steadily until 1987, then increased following the diversification of some vessels to small-vessel longlining. Charter operations with Japanese longliners also took place in 1989 and 1990. Since the 1950s, Japanese longliners had fished in areas adjacent to New Zealand, and their operations there came under New Zealand control when the New Zealand 200-mile exclusive economic zone (NZEEZ) was established in 1978. Japanese catches, hooks set, and hooking rate in the NZEEZ have declined steadily since 1980, with catches declining from 7600 t to 1057 t in 1988. Although hooks set halved, the hooking rate declined to one fifth over the same period. Vessels have increased the average number of hooks per set from 2400 to 2900 in an attempt to counteract this decline. Since 1980 the average size of SBT taken has increased (63 kg in 1980; 89 kg in 1988), with a concurrent decline in abundance of 40-50 kg SBT. However, there has been a slight increase in relative abundance of 20-40 kg SBT since 1989.

The access areas for Japanese longliners in the 200-mile Australian fishing zone (AFZ) have reduced progressively since the zone came into effect in 1979. The region around Tasmania has become the main area of longliner operation. With the continued decline of hooking rates in the area to the south, which supported a summer fishery for adults, effort has been re-directed to a winter fishery off eastern Tasmania. In this area there has been an increase in the proportion of pre-adult SBT, probably reflecting increased escapement from the Australian fishery and the progressive reduction in Australian quotas. However, the increase has been later than anticipated. In keeping with Australia's objective of diverting SBT fishing effort to larger fish, an Australia-Japan longline joint venture involving Japanese longliners and Australian quotas operated during 1989 and 1990 off NSW and eastern Tasmania.

Southern bluefin tuna catches by countries other than Australia, Japan and New Zealand have, in the past, been considered relatively trivial. However, the SBT by-catch of driftnetters from Taiwan, and of longliners from Taiwan, Indonesia and Korea may be more significant than previously thought, especially in comparison with the considerably reduced catches of Australia, Japan and New Zealand.

Landed catch by boat, date of landing, port of landing and destination (purchaser) have been recorded for the Australian surface fishery from its inception, and is currently recorded in conjunction with the monitoring of cumulative catch in relation to quota during a season. A logbook for details of fishing location and effort was not firmly established until the early 1980s. Southern bluefin tuna length composition has been sampled routinely in the south-eastern fishery from 1963-64, the sampling taking account of the sorting of fish at sea. Length frequency of the catch, by 1 cm length class and for each half-month, is available for NSW, SA, Albany and Esperance (or WA, when these could not be discriminated). Spotter aircraft have been used to some extent in the NSW and SA sectors of the Australian SBT fishery since the very early days. Attempts to introduce an aircraft logbook met with little success until 1989 but some spotters' private records are available for recent years. By means of radio reports and log books, catch and effort data for SBT have been collected from Japanese longline vessels operating in the AFZ since 1979. From 1989 longliners have been required to measure length to caudal fork of each SBT taken in the AFZ. Observers occasionally join vessels to check that catch reporting procedures are understood and properly maintained.

Japanese tuna longliners maintain logbooks daily, detailing fishing location, catches (in number of fish by species) and hooks set. Data tabulated by 5 degree grid squares, have been published from 1962 to 1980. Since 1981, data have been provided directly from the Far Seas Fisheries Research Laboratory to CSIRO Australia and Fisheries Research Centre, New Zealand. At first, catch length composition had to be sampled at Yaizu and Tokyo markets but subsequently lengths were measured at sea by cooperative fishermen or derived from individual weight data from fishing masters' private logbooks. The data have been used to generate catch length frequency for each statistical area and for each yearly quarter in 2 cm length classes, although there is a lag of about one and a half years before catch and length distribution data become available. For up-to-date stock assessment and fishery management, more timely collection and processing of catch, effort and length data are needed, and it is also desirable to improve the recovery rate of length data from commercial longliners.

New Zealand vessels are required to complete a catch, effort and landings logbook. Catch data are verified independently against records maintained by licensed fish receivers. The logbook records fishing method, area or position of fishing, number of hours fishing, number of lines used and number of hooks or lures on each line, target species, estimated total unprocessed weight of all fish caught and the estimated unprocessed weight of the five most important species caught by weight in decreasing order. At the time of landing all fish on board must be accounted for. Data on individual fish length, weight and sex are collected by a research logbook distributed to the freezer vessel and filled in voluntarily by the crew. Japanese vessels fishing in the NZEEZ record catch and effort statistics on a set by set basis in a logbook considerably more detailed than the logbook required by Japan. This includes information on environmental factors, target species, size composition and by-catch. A limited observer program begun in 1987 was formalised in 1989. It extends from April to September for an estimated total of approximately 240 observer days per year. Observers record details of the fishing method and catch composition, they measure and weigh all tuna and billfish species caught and they collect various biological samples for ongoing research programs.

Scientists at trilateral discussions since 1982 have continued to express concern about the biological state of the SBT stock, in particular its capacity to continue to maintain satisfactory levels of recruit production. Assessments of stock condition have been carried out by VPA but attention has also been drawn to a range of direct indicators from the commercial fishery. Both sources point to a severe decline in the population. The indicators identified at the 1988 trilateral scientific discussions were: the extent and persistence of the decline in catches and hooking rate in conjunction with high fishing effort; contraction in the area of the surface fishery and the extent of productive areas of the longline fishery; and major declines in the abundance of pre-adult SBT. Catch and hooking rates have declined further, but there has been a slight increase in the extent of productive areas in the longline fishery, apparently linked to an increase in the pre-adult SBT population, mainly off the coast of Tasmania.

Assessments based on VPAs have generally concentrated on trends in the parental biomass and in recruitment at age 1 estimated from VPAs. In particular, attention has focussed on the size of the current parental biomass in relation to its initial level, and on projected stock trajectories based on a fitted stock-recruitment relationship and a range of possible future catches. Annual variations in the Australian fishery for juvenile fish probably prevent reliable use of backwards VPA from ages less than 7 years old to estimate recruitment. Consequently, while parental biomass can be estimated from the VPAs from 1960 to the latest year for which catch data are available, estimates of recruitment at age 1 are not available for the last six years.

Results of VPAs are subject to the uncertainty inherent in input parameters such as natural mortality rate and terminal fishing mortality. Use of a range of feasible values of natural mortality rate generate quite different interpretations on state of the stock. The catch age structures and terminal ages adopted have been questionable because of uncertainty about growth parameters used for determining age-at-length. Again, the consequences for assessments of state of the stock are significant. Values of terminal fishing mortalities adopted have been 'tuned' using fishing mortality rates estimated independently from tag-recapture experiments, by taking account of change over time in the concentration of effort in areas of operation of the longline fishery and by making assumptions about levels of recruitment in the early period of the fishery. However, it has not yet been possible to develop a satisfactory series of effective effort data for the fishery; therefore the tuning remains questionable and the stock assessments uncertain. Despite these shortcomings, VPAs have consistently indicated continuing decline of parental biomass to historically low levels, with the decline persisting to at least 1990. On the other hand, the nature of trends in recruitment has been less clear, some analyses suggesting that recruitment declines had already occurred during the 1970s. This uncertainty in the parent stock-recruit production relationship, and the variability introduced by uncertainties in VPA input parameters, have prevented reliable projection of stock response under various catch regimes. In turn they have led to considerable uncertainty in advice to managers about appropriate quota levels. In summary, some projections have indicated that the stock will recover with the current quota levels, whereas others have indicated a continuing decline.

Estimated population parameters from the Australian tagging program do not refer to the global population, but rather to the sub-population that is vulnerable to the Australian fisheries. Tagging of SBT in Australian waters began in 1959. In the 1960s and 1970s, more than 50 000 fish were tagged in the three main fishing grounds (off NSW, SA and WA). The purpose was to delineate stock boundaries, show migration paths, confirm growth rates and assist stock assessment. New releases in 1983-84 were directed more at quantitative aspects, such as mortality rates, interactions among fisheries, estimates of the local population and survival to maturity. Special attention was also given to factors such as effects of shrinkage on growth estimates, short-term and long-term effects of tagging on growth and consequences of tag-shedding.

Comparative recovery rates suggest that 2-year-old SBT off WA migrate at a higher rate into ocean waters than those off SA, supporting the hypothesis that a significant proportion of fish do not travel from the WA fishing grounds to the more eastern surface fishery grounds. Less than 15 % of SBT tagged between 1959 and 1980 have been recaptured and reported, 0.7 % by the Japanese longline fishery. In comparison, over 40 % of the fish tagged in 1983-84 were reported as recaptured by Australian fishermen, indicating very high fishing activity during the early 1980s. A substantial fraction of the fish then passing through the Australian fishing grounds as juveniles would not have survived to reproductive maturity. The year-classes of fish tagged in 1983-84 are now becoming part of the parental stock, which has already been reduced to a level where there is concern about adequate young fish production, so the situation is likely to deteriorate further. Quota reductions since 1984 should have reduced this problem dramatically. Nevertheless, the decline in the parental biomass may not be reversed if recruitment has declined at a rate faster than catches have been reduced, or if SBT escaping Australian fishing grounds are subsequently caught at a higher rate than usual in order to maintain the catches of the longline fishery.

The number of young fish recruited to Australian fisheries was estimated from the 1983-84 tagging data by the Peterson method. This number could be an underestimate, however, because some recruits may not pass through the WA fishing grounds. The need for a real-time index of recruit abundance has been highlighted. The Japan Marine Fishery Resource Research Center (JAMARC) commenced a 5-year troll and poling survey in 1988 along the west and south coasts of Australia, based on the assumption that all juvenile SBT travel along the WA coast, mainly in November-December. The objectives were to assess if troll and pole surveys are effective as a means of developing a synoptic recruit abundance index; to determine patterns of occurrence-distribution of recruits; to determine what association exists between physical environmental factors and recruits and to tag recruits to determine the level of recruitment.

It is still unclear as to whether a sufficiently precise index of recruit abundance will be obtained. Future transect lines will be established only over shelf areas, and in the area where the 30-45 cm fish are distributed. Working with these parameters, all inshore areas between latitudes 27°-34° S on the west coast and between longitudes 115°-120°E on the south coast will be covered. Since oceanographic conditions may change from year to year, the migration pattern of young SBT along the WA west and south coasts could also change every year. Accordingly, it has been agreed to enlarge the JAMARC survey to cover a wider area and a longer period. It will now include a tagging survey in collaboration with Australia, which will extend to the SA fishery region. An aerial survey in progress in SA may provide an additional index if factors influencing fish occurrence at the surface can be clarified. Even so, comprehensive research surveys to determine if there are recruits which migrate directly to the central part of the Indian Ocean from the spawning ground off Java or from the west coast of Australia, are needed.

2. CLASSIFICATION

NOMENCLATURE

Specific name

Thunnus maccoyii (Castelnau, 1872) - Fig. 1.

Synonymy

Thynnus maccoyii Castelnau 1872: 104 (original description; Melbourne, Australia).
Thunnus phillipsi Jordan and Evermann 1926:13 (original description; Bay of Islands, New Zealand).
Thunnus maccoyii: Jordan and Evermann 1926: 13 (new combination).
Thunnus (Thunnus) maccoyii: McCulloch 1929: 263 (new combination).
Thunnus thynnus maccoyii: Serventy 1956:13 (new combination).
Thunnus thynnus maccoyi: Talbot and Penrith 1962: 558 (amended).
Thunnus thynnus orientalis (not Temminck and Schlegel): Jones and Silas 1960: 381-382 (misidentification).

Sources of this synonymy are Iwai, Nakamura and Matsubara (1965), Collette and Nauen (1983) and Collette (1986a). Following current nomenclatural procedures (Ride et al. 1985: Zoological Code of Nomenclature, Article 31a), the specific name should be *maccoyi* as it is based on a noun in the genitive case. Also Article 58 would deem *maccoyi* and *maccoyii* to be homonyms if they were used for different nominal taxa. However, *maccoyii* should be preserved because its spelling is that used when the species-group name was established (Articles 32a and 33d of the Zoological Code).

Vernacular names

Southern bluefin tuna, bluefin, bluefin tuna, southern tunny, tunny (English); minami maguro, indo (Goshu) maguro (Japanese); thon rouge du sud (French); atun del sur, atun (Spanish); suidelike blouvin tuna (Afrikaans); avstralijskaya tunets (Russian).

AFFINITIES

Suprageneric affinities

- Phylum Chordata
  - Class Osteichthyes
    - Subclass Actinopterygii
      - Order Perciformes
        - Suborder Scombroidei
          - Family Scombridae
            - Tribe Sardini

The bony fish family Scombridae, comprising various mackerels, bonitos and tunas, is among the most extensively researched teleost family. The supraspecific structure of the group, however, is not adequately defined and will undoubtedly undergo modification as additional morphological and ontogenetic information becomes available (Johnson 1986). Important recent contributions to the systematics of the family have been made by Godsil and Holmberg (1950), Collette and Gibbs (1963), Iwai and Nakamura (1964), Gibbs and Collette (1967), Talbot and Penrith (1968), Fischer and Whitehead (1974), Collette and Chao (1975), Collette (1978, 1986a, 1986b), Collette and

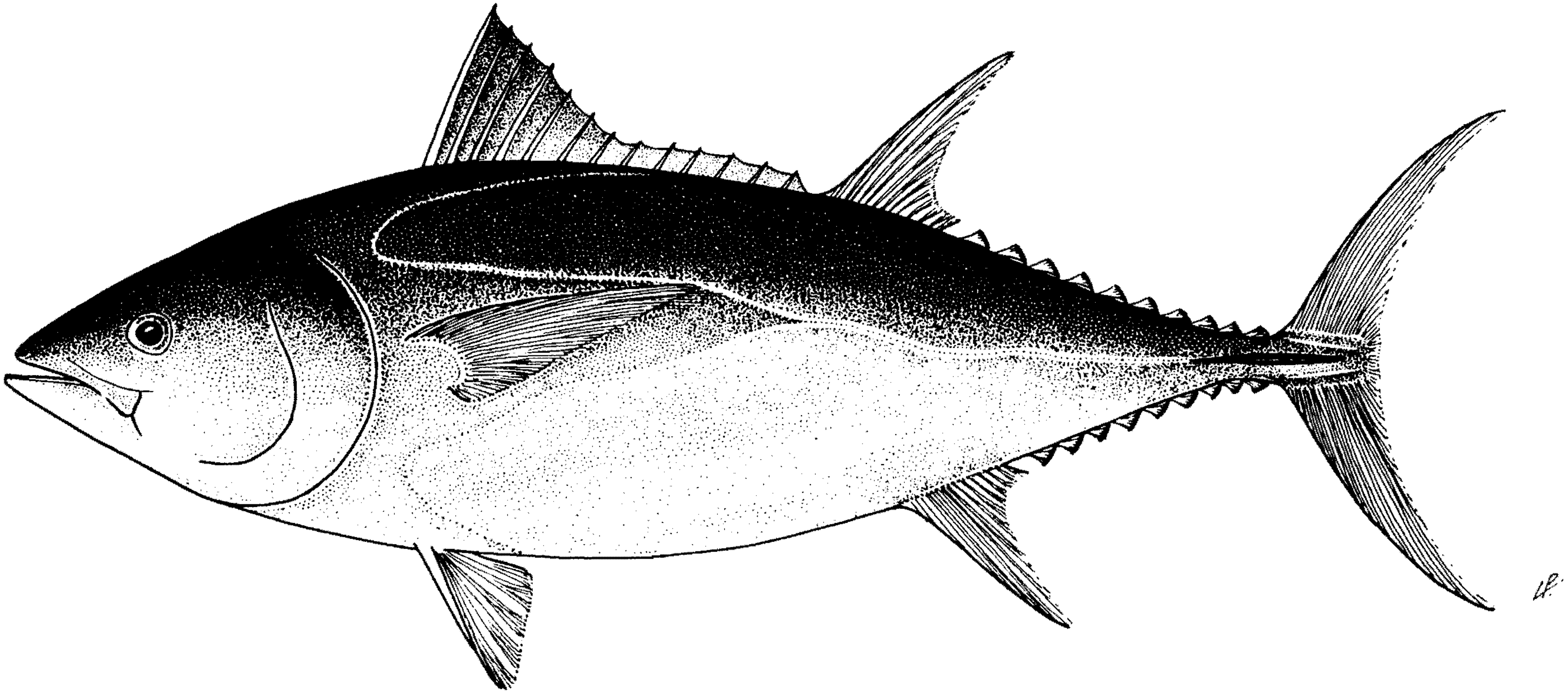

Fig. 1. Southern bluefin tuna, *Thunnus maccoyii* (Castelnau, 1872).
(Line drawing courtesy FAO; from: FAO species catalogue, Vol. 2. Scombrids of the world; an annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date by B.B. Collette and C.E. Nauen, *FAO Fisheries Synopsis* No. 125 (1983), 137 pp.)

Nauen (1983), Collette et al. (1984) and Johnson (1986). The above classification follows Johnson (1986) and Nelson (1984) above subordinal level.

Collette and Chao (1975) and Collette and Nauen (1983) recognized two scombrid subfamilies: the monospecific Gasterochismatinae, and the Scombrinae containing the remaining members of the family. The Scombrinae was further divided into four tribes (Thunnini, Sardini, Scomberomorini and Scombrini) with the Thunnini, or tunas, including four genera, *Thunnus*, *Katsuwonus*, *Euthynnus* and *Auxis*. Collette et al. (1984) relocated *Allothunnus* from the Sardini to the Thunnini. Johnson (1986) has since proposed amendments to this scheme which include the subsumption of the tribe Thunnini within the Sardini (including *Gymnosarda*, *Sarda*, *Cybiosarda* and *Orcynopsis*) and the omission of a subfamilial category on the basis of his cladistic classification.

Generic affinities

Thunnus South 1845

Thynnus Cuvier 1817 (preoccupied).
Thunnus South 1845: 620.
(Substitute name for *Thynnus* Cuvier; type species *Scomber thynnus* Linnaeus 1758, by absolute tautonomy.)

Sources of this synonymy are Iwai, Nakamura and Matsubara (1965), Collette and Nauen (1983) and Collette (1986a).

Description. Members of the genus are distinguished from other members of the family by the following combination of characters: the body is fusiform, elongate and slightly compressed; the teeth are small, conical and in a single row in each jaw; two cartilaginous ridges are present along the upper surface of the tongue; very small scales are present on the body with an obvious corselet of slightly larger and thicker scales anteriorly; the small pelvic fins do not recess into grooves; the eyes lack adipose eyelids; the caudal peduncle has two small keels with a larger median keel between; the dorsal fins are barely separated; the fleshy process between the pelvic fins is long and not bifurcated; 11-14 dorsal-fin spines; 7-10 dorsal and anal finlets; 30-36 pectoral-fin rays; 19-43 gill rakers on the outer gill arch; 39 vertebrae; the body lacks dark spots and longitudinal stripes.

Specific affinities

Thunnus maccoyii (Castelnau)

Diagnosis. A member of the genus *Thunnus* in which the liver is striated ventrally and the central lobe is larger than the left and right lobes; the gill raker count is relatively high (31-40 rakers on the first gill arch); the pectoral fin is relatively short (less than 80 % of head length and 20.2-23 % of fork length); the first ventrally directed, bony process (parapophysis) of the backbone is located on the 9th vertebra; and the median caudal keel is yellow.

Comparisons. The species of *Thunnus* have been widely researched. The most comprehensive accounts of *Thunnus* have been given by Iwai, Nakamura and Matsubara (1965) and Collette and Nauen (1983). Seven species, *Thunnus albacares* (Bonnaterre), *T. alalunga* (Bonnaterre), *T. atlanticus* (Lesson), *T. obesus* (Lowe), *T. thynnus* (Linnaeus), *T. tonggol* (Bleeker) and *T. maccoyii*, are recognised as valid species. *Thunnus* species can be grouped on the form of the liver. The livers of *T. maccoyii*, along with *T. alalunga*, *T. obesus* and *T. thynnus*, have an enlarged central lobe and prominent striations on the ventral surface. The liver in the remaining species is smooth and the right lobe is much longer than either the central or left lobes. The species group with striated livers (which includes *T. maccoyii*) have sympatric distributions.

Adult *T. alalunga* and *T. obesus* have longer pectoral fins (greater than 80 % of head length) and lower gill raker counts (23-31 rakers on the first arch) than *T. maccoyii* and *T. thynnus*. *Thunnus thynnus*, which is primarily a Northern Hemisphere species, consists of two subspecies, *T. thynnus thynnus* (Linnaeus) and *T. thynnus orientalis* Temminck and Schlegel (Collette and Nauen 1983). Some authors have regarded *T. maccoyii* as a subspecies of *T. thynnus* (Serventy 1956, Munro 1958, Robins 1963) but, although rarely sympatric, the two species are distinct. *Thunnus maccoyii* can be distinguished in the field by the yellow median caudal keel (dark in *T. thynnus*) and a relatively longer pectoral fin in the adult (16.8-21.7 % of fork length in *T. thynnus*). Identifications of *T. thynnus* from the Southern Hemisphere should be confirmed by examining the location of the first ventrally directed parapophysis - on the 8th vertebra rather than the 9th vertebra as for *T. maccoyii*.

There is also biochemical evidence to suggest that the subspecies of *T. thynnus* may be a valid species. Sharp and Pirages (1978) have shown, in an electrophoretic study of 15 muscle proteins, that the subspecies are more biochemically divergent than are *T. thynnus orientalis* and *T. maccoyii*.

3. EARLY LIFE HISTORY

IDENTIFICATION OF THE LARVAE

Species of larval tuna between 3.0 and 12.0 mm standard length are distinguished by the distribution of melanophores on the body and caudal fin. Larvae smaller than 3.0 mm have not developed the pigment patterns that are used to distinguish them, and by 12 mm secondary pigment patterns develop in all species making them indistinguishable. Three SBT larvae 4.6-7.6 mm long were described by Yabe et al. (1966). Nishikawa (1985) described the variation and differences in melanophore patterns in three *Thunnus* species, *T. thynnus, T. maccoyii* and *T. obesus*. The following description of melanophore patterns in *T. maccoyii* larvae is taken from Nishikawa and Rimmer (1987): small, faint, black pigment spots (0-4, usually 1) on dorsal edge of tail and 1-4 (usually 1 or 2) more distinct black pigment spots on ventral edge of tail; 1-4 (usually 2 or 3) black pigment spots on caudal fin, 1 (rarely 2) of which may be above the notochord. The dorsal tail pigments are very tiny and difficult to see. If this pigment is not detected some specimens may be confused with *T. obesus*. Richards et al. (in press) demonstrated the difficulty in separating *Thunnus* species by melanophore patterns and suggested that osteological characters needed to be used when separation by melanophore patterns failed. Graves et al. (1988) have demonstrated the utility of electrophoresis to distinguish juvenile *T. albacares* when juvenile pigmentation obscures the larval melanophore pattern.

DISTRIBUTION OF THE LARVAE

Presence of larvae indicates that SBT spawn south of Java in the East Indian Ocean but ichthyoplankton sampling has not been carried out at the appropriate spatial and temporal scales to define distribution within the spawning ground. Some fine-to-coarse-scale horizontal and vertical distribution patterns have been resolved, partly as a result of determining optimum sampling procedures to estimate larval abundance. Southern bluefin tuna larvae are restricted to the mixed-layer when a strong picnocline is present (Davis et al. 1990). When the picnocline is not well-defined SBT larvae are not restricted to the mixed layer, but very few are found below 35 m. Southern bluefin tuna larvae undergo a diel vertical migration within the mixed layer. The proportion of larvae in the upper 2 m increases during the day and decreases at night (Davis et al. 1990). This vertical movement may be associated with feeding, which occurs only during the day (Young and Davis 1990). The depth range traversed by the larvae could be small, but sufficient to markedly reduce the proportion of larvae in the surface 2 m at night, or a larger-scale diel vertical migration might be occurring. Fine-scale vertically stratified sampling is required to resolve the extent of vertical movement. These diel vertical movements are also confounded by changes in net avoidance by the larvae between day and night. An increase in net avoidance during the day was indicated by reduced catches in oblique tows made over the entire depth range of the larvae (0.27-0.3 times the size of catches at night) and the reduced proportion of large larvae in daytime catches (Davis et al. 1990).

The horizontal distribution of SBT larvae is patchy. Patch sizes ranged from 1 to 15 km in diameter with a dominant patch size of 5 to 15 km (Davis et al. in press). Lloyd's index of patchiness ranged from 3.0 to 5.3 within a 1-degree-square grid (Davis et al. in press). A similar index was found during a concurrent large-scale survey (Yukinawa 1987), which would suggest that the same scales of patchiness may predominate over the entire spawning ground.

LARVAL ABUNDANCE

Davis et al. (in press) have shown that SBT larvae are more abundant than suggested by previous surveys. Their observations have been possible because of improvements in sampling equipment and procedures (Davis et al. 1989), but are also influenced by the design of contemporary surveys, which do not provide adequate coverage of both the temporal and spatial scales needed to estimate larval abundance (Davis et al. in press). It was estimated that a patch 15 km in diameter (Fig. 2) contained 3.58 x 10^{10} larvae 7-8 days old (Davis et al. submitted). These were spawned over a 2-day period. It is not known whether this same intensity of spawning occurred throughout the spawning ground. It is very difficult to produce a synoptic view of larval distribution because larval density at any site may change daily. An order of magnitude change in estimated abundance was observed at the same site over a 4-day period due to processes such as advection, dispersion and mortality (Davis et al. in press). It was also clear that one sample did not adequately describe the density of tuna larvae in an area 1 degree square (the sampling interval imposed on most larval surveys) because the dominant scale of patchiness affecting tows was 5-15 km (Davis et al. in press). It was suggested that unless key areas could be identified as being representative of the entire spawning ground, and that unless it could be demonstrated that most of the spawning activity was in a relatively small part of the spawning period, then the amount of sampling required to provide adequate spatial and temporal coverage to estimate larval abundance would not be practicable (Davis et al. in press).

GROWTH AND MORTALITY OF THE LARVAE

The age of SBT larvae has been determined from otolith microstructure using light and scanning electron microscopy (Jenkins and Davis 1990). The daily formation of growth increments was validated by the marginal increment method and by following the daily progression of increment number on otoliths of larvae collected on 6 successive days. The larvae ranged from 7-18 days old and the larval stage appeared to last about 20 days. Growth curves could not be fitted to size at age data due to a large variance in size-at-age and violation of assumptions for parametric tests. The growth of larvae was approximately linear and relatively slow (mean of 0.32 mm per day) although growth trajectories of the oldest larvae showed a curvilinear increase in the days immediately preceding collection. Growth trajectories back-calculated for three late-stage larvae appear in Fig. 3. The first increment probably is formed 3 days after hatching as observed in laboratory reared skipjack tuna (Radtke 1983), and should be added to the increment number to provide age in days. It is thought that the rapid growth attributed to young stages of tuna must occur at the late larval - juvenile stage rather than the early larval stage in this species (Jenkins and Davis 1990).

Davis et al. (submitted) located a large patch of 7-8-day-old SBT larvae which was sampled intensively over a 6-day period. They modelled advection, dispersion and mortality in this patch. Mortality (Z) was estimated to be 0.66 per day, which is a daily rate of 52 %. Mortality may have been higher than expected due to density-dependent processes. Young and Davis (1990) suggested that a significant reduction of prey populations would have been likely near the patch centre, on the basis of larval abundances, larval feeding rates, and prey abundance, and that competition for food would have been possible. Jenkins et al. (submitted) found that the growth rate of larvae was significantly different between stations and was positively correlated with feeding incidence and negatively correlated with larval abundance. They proposed that density dependent control of larval growth through competition for food may be a significant determinant in encouraging young SBT.

DISPERSAL OF THE LARVAE

Davis et al. (submitted) modelled the drift of a patch of 7-8 day old larvae over 4 days. The patch drifted approximately 4.6 km per day. This was quite different to the drift trajectory of a satellite tracked buoy, drogued at 20 m depth, which was intended to flag the patch of larvae. No information is available on dispersal and recruitment in post-larval tuna of any species as no adequate method has been developed to sample these later stages. Post-larval SBT probably remain on these spawning grounds before migrating south along the continental shelf. Juvenile tuna

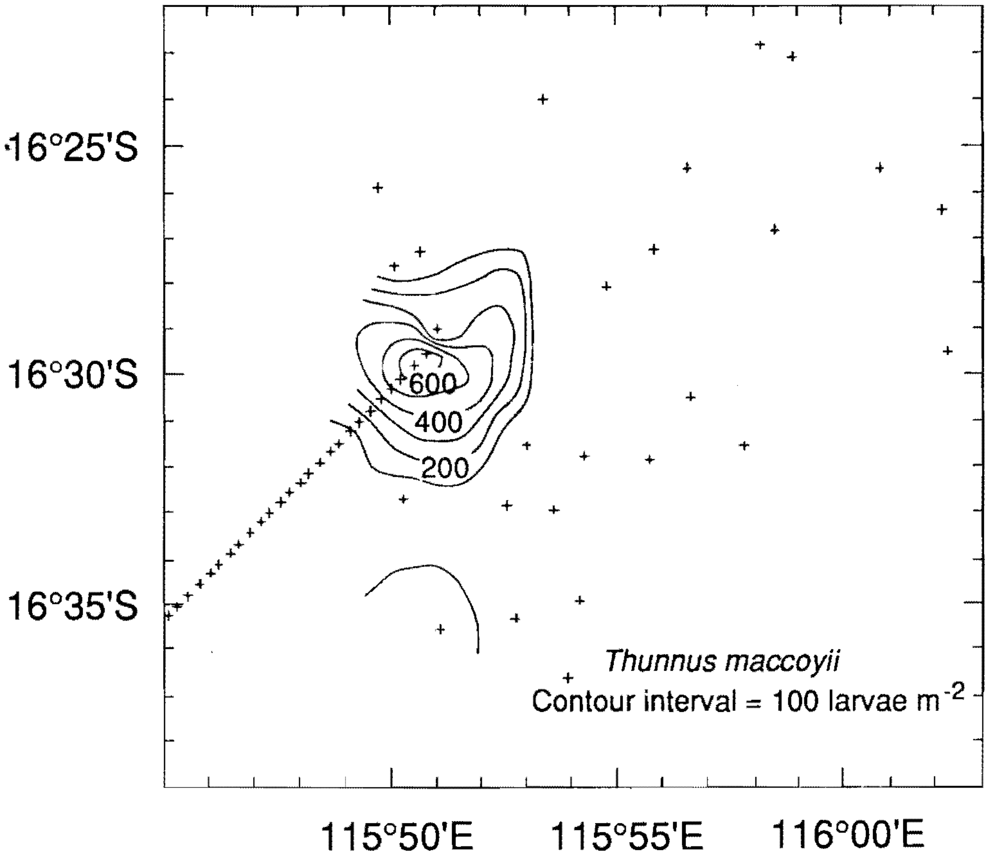

Fig. 2. Estimated concentration and distribution of southern bluefin tuna larvae in a patch, based on a transect of surface tows and tows made at random relative to a drifter marking the patch. Station positions are denoted '+' and densities (numbers per square metre) are marked on major contours (after Davis et al. submitted).

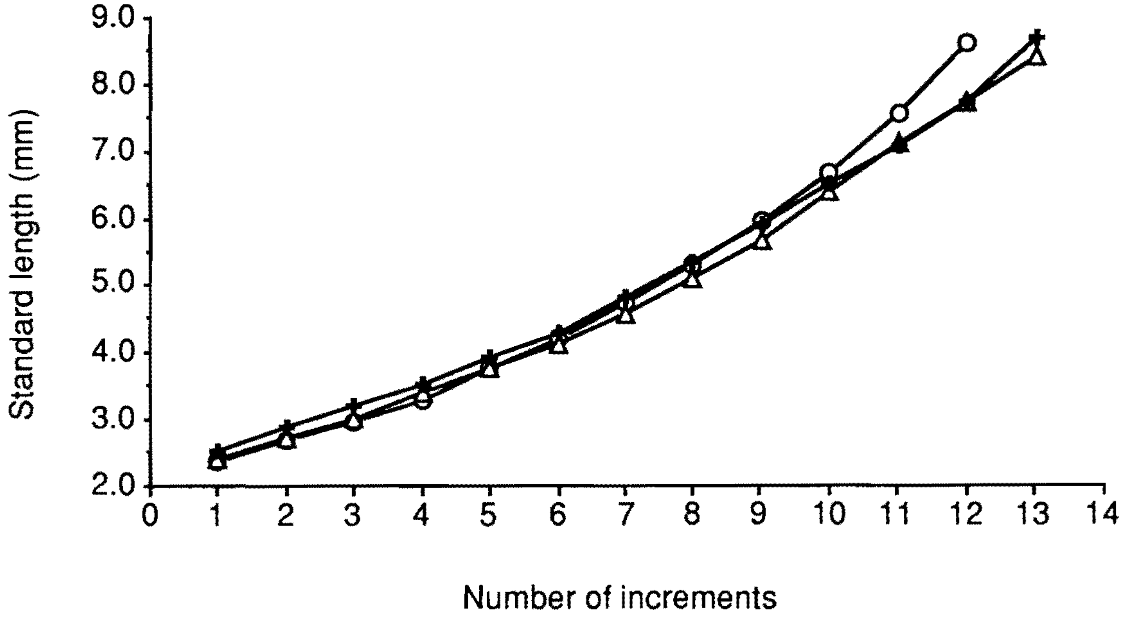

Fig. 3. Relationship between standard length and number of daily increments for three late-stage southern bluefin tuna larvae (from Jenkins and Davis 1990).

4. TROPHIC RELATIONSHIPS

INTRODUCTION

Dragovich (1969) pointed to the need for a thorough knowledge of the feeding ecology of tuna to understand the factors affecting regional and local aggregations. Some progress has been made, particularly on the larval stages. However, the majority of data relevant to the feeding of juvenile and adult SBT is anecdotal. Specific details are lacking, such as the relationship between fish length and prey size in juveniles and adults. Similarly, there is little information either on diel feeding patterns or the relationship between depth and feeding. The information on competitors and predators of SBT is largely based on speculation. Of particular interest is the relationship of SBT to physical oceanographic features. They are known to aggregate at surface fronts in the Tasman Sea (Hynd 1968, Shingu 1978). Tranter et al. (1983) advanced the hypothesis that these aggregations may be the result of nutrient enrichment and so have a trophic association. However, there has been no attempt to examine this hypothesis.

LARVAE

Larvae of SBT feed mainly on micro-crustacea and macrozooplanktonic crustacea, chiefly copepod nauplii, calanoid and cyclopoid copepods, and cladocerans (Uotani et al. 1981, Young and Davis 1990). They also eat appendicularians and fish larvae (Uotani et al. 1981). Preflexion larval SBT have been identified from the stomachs of postflexion siblings, indicating cannibalism (Young and Davis 1990) but this has not been studied quantitatively. Larvae select for species of copepod nauplii and cyclopoids, and against calanoid copepods (Uotani et al. 1981, Young and Davis 1990). Young and Davis (1990) suggest that selectivity is probably size-related as prey size is positively correlated with mouth width in the larvae. In their study the relative proportions of prey items change with increasing size, from a diet of copepod nauplii in fish less than 4 mm, to calanoid copepods in larger larvae (Fig. 4). The larvae feed only during daylight hours, and mainly in the morning and early afternoon. Of the larvae from daytime samples, 52 % contained food. The proportion of larvae with food in their stomachs increased with larval size. A gut evacuation rate of approximately 4 hours was estimated for the congeneric species *Thunnus alalunga*. Using this value, and the average amount of prey eaten per unit of time, a consumption rate of approximately 30 % of body weight per day was calculated (Young and Davis 1990).

The diet of larval SBT is similar to related species of tuna (e.g. *Katsuwonus pelamis* and *Thunnus alalunga*), but there are sufficient differences to suggest that interspecific competition is reduced by differences in diet (Uotani et al. 1981, Young and Davis 1990). Intraspecific competition within patches of larval SBT, however, may be more important. Densities of larvae in the area during the spawning season can be relatively high (Davis and Clementson 1989). In contrast, prey densities are low. Young and Davis (1990) calculated that in areas of high larval abundance these larvae would be able to reduce the numbers of available prey, and in so doing increase the pressure on their own survival through density-dependent larval growth (Jenkins et al. submitted).

The importance of predation on larval fish generally is indicated by the high estimates of mortality of fish eggs and yolk sac larval stages, which subsist on their own reserves and are therefore not affected by starvation (Lasker 1981). Both invertebrates and fish are known to be important predators on fish larvae (Alvarino 1980, Hunter and Kimbrell 1980). However, predation on larval SBT has not been examined.

6-8 cm long, thought to be SBT, have been caught at latitude 20° S. Larger juveniles (23-60 cm long) have been caught in coastal waters between 22° S and 34° S, their lengths increasing with latitude (Fishery Agency of Japan, Research Division 1989). The Leeuwin Current has been linked with the southward dispersal of juvenile SBT (Shingu 1967, Maxwell and Cresswell 1981). An alternative dispersal pathway towards Africa was suggested by Harden Jones (1984) who considered it likely that some larvae would be carried west by the South Equatorial Current. Juvenile tuna could subsequently reach Australian waters via the West Wind Drift completing the southern Indian Ocean gyral. For larvae to be found in either the Leeuwin or South Equatorial current would depend largely on the location and timing of spawning, and the influence of these currents, which may vary from year to year.

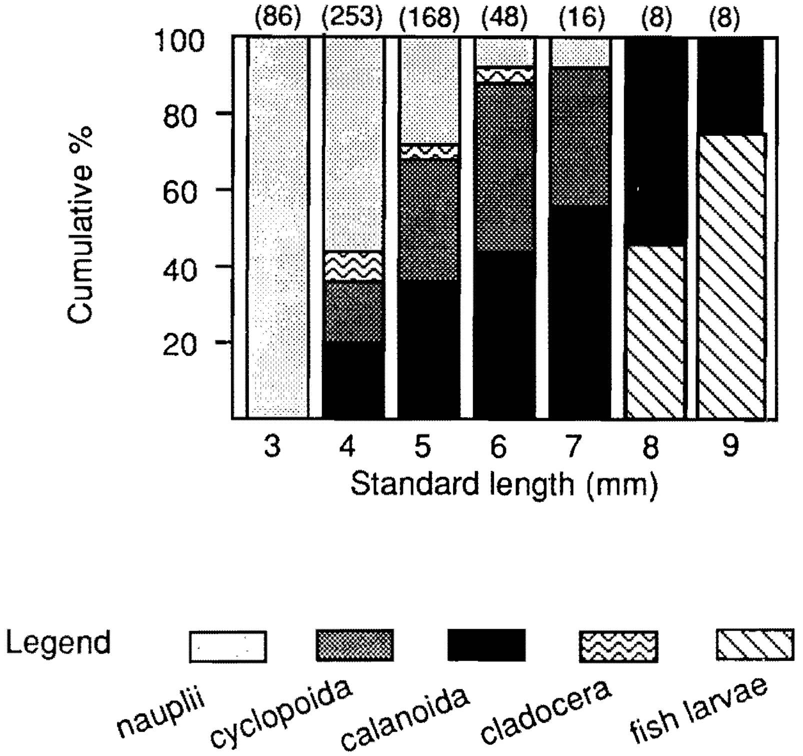

Fig. 4. Frequency of occurrence of major prey taxa in relation to size class in southern bluefin tuna. Prey taxa in legend are listed in order of increasing size. Number of larvae examined in each size class are given in brackets (adapted from Young and Davis 1990).

JUVENILES AND ADULTS

Juvenile and adult SBT are considered opportunistic feeders, their diet generally reflecting the composition of the macroplankton and micronekton of a particular area (Serventy 1956, Shingu 1978). They feed chiefly on cephalopods, crustacea, fish and salps, the proportions of which depend on the area where they are found. For example, off south-eastern Australia euphausiids (*Nyctiphanes australis*) and jack mackerel (*Trachurus* spp.) are common prey items whereas larger crustaceans (*Funchalia woodwardi*), fish and cephalopods dominate off South Africa (Serventy 1956, de Jager et al. 1963). Webb (1972) noted the presence of salps (*Salpa* spp. and *Pyrosoma* spp.) and fish (mainly *Brama brama*) in the stomachs of SBT caught in New Zealand waters. Both food items were noticeable in these waters at the time of capture. Prey size ranges from small pelagic amphipods and euphausiids (< 20 mm) to jack mackerel 350 mm in length. However, a detailed examination of prey size in relation to size of tuna has not been made, nor has the diet of larger SBT yet been adequately examined. Generally, smaller SBT feed mainly on crustaceans whereas older fish feed mainly on fish (Robins 1963). However, these differences do not appear to be clearly defined and little difference was found in the size of food organisms in 2-year-old and 3-year-old fish (6-20lb) (Serventy 1956).

Talbot and Penrith (1963) deduced from long line casts that SBT feed mainly in the morning. It is not clear from the literature at what depths they feed, but food types eaten suggest that it is mainly in the upper 100 m. Nevertheless, the presence of bottom dwelling fish , e.g. bellowsfish (*Macrorhamphosus molleri*) and deepwater crustaceans (*Funchalia woodwardi*) in their diet, suggests that they may also feed at greater depths and on the sea bed.

Feeding incidence in SBT varies, from 52.6 % to 76.4 % of fish with food in their stomachs in samples examined from South African waters (de Jager et al. 1963, Talbot and Penrith 1963) to 29.1 % off New Zealand (Webb 1972). However, as no mention of times of collection was made, these values have little meaning. There are no estimates of food consumption for adult SBT. Estimates for other *Thunnus* species range between 1.08 % and 3.18 % of body weight per day (Palomares and Pauly 1989). Using data on stomach filling from Serventy (1956), a tuna would need to fill its stomach approximately once per day.

Sharks, other tunas, a variety of teleosts, seabirds, whales and seals have been listed as possible competitors of adult SBT off south-west Africa (de Jager et al. 1963). A number of sharks and the killer whale were also listed as possible predators, although no supporting data was given in either case. Robins (1963) cited predation as a controlling factor for SBT size and population density but gave no supporting evidence.

5. AGING AND GROWTH OF JUVENILES AND ADULTS

Reliable estimates of SBT ages and growth rates are required for understanding its biology, ecology, and productivity (Serventy 1956, Murphy 1977, Murphy and Majkowski 1981, Hampton et al. 1984). These are also important for planning future management strategies.

In common with many other tuna species (Hayashi 1958, Bell 1964, Prince and Pulos 1983, Radtke and Morales-Nin 1989), there are a number of problems in determining the age of SBT directly, in particular for mature fish.

As a result, data from tag-recapture programs (Majkowski and Murphy 1983) and modal analysis of length-frequency samples (Kirkwood 1983, Majkowski and Hampton 1983a, Shingu 1978) have traditionally provided information on age structure and growth rates, and the former is still the method most commonly employed in obtaining length-at-age estimates for the fished population.

However, there are a number of disadvantages in using these methods for the routine determination of age and growth. Tag-recapture methods are a risky and relatively costly means of obtaining age and growth rate data. Unless conducted regularly, they are also insensitive to changes in growth rate that may result from changed environmental conditions and/or population responses to fishing pressure. Also, in long-lived species, such as SBT, which has been reported to live in excess of 20 years (SBF tuna... 1981), tag recoveries from older fish are comparatively rare; thus, the precision of growth rate estimates for large, mature fish is low.

Much the same is true for the estimation of age and growth rate from length-frequency data. In long-lived species, these methods are severely limited by the decline in growth rate with age, which causes length-frequency modes to become increasingly irresolvable with age (Majkowski and Hampton 1983a). In addition, considerable individual variability in growth rate, even in young fish, further weakens the precision of this method (Murphy 1977).

In the light of these limitations, new methods and technology to age SBT are now being investigated.

AGING AND GROWTH FROM CALCIFIED TISSUES

Given the scarcity of published data on direct aging of SBT using calcified tissues, this review includes information on other tuna species, both as an introduction to the problems involved and as an illustration of the potential of other techniques.

Optical resolution of growth-banding

Growth-banding in skeletal structures has been used as an indicator of age and growth rate in a wide range of marine organisms e.g. scleractinian corals (Dodge and Vaisnys 1980), polychaetes (Olive 1980), cephalopods (Kristensen 1980), bivalves (Lutz and Rhoads 1980), barnacles (Bourget and Crisp 1975) and teleosts (Brothers et al. 1976).

Considerable attention has been given to developing methods of revealing and reading growth-banding in mineralised tissues (primarily scales and otoliths, but also vertebrae, fin spines, cleithra and hypurals) of SBT .

Scales. Yukinawa (1970) examined scales from 2508 SBT over a period of 5 years and reported annual banding in a proportion of scales from fish up to 130 cm fork length (seven bands). However, the clarity of the banding decreased with increasing fish size, and bands on scales from larger fish (> 130 cm fork length) were unreadable. Thorogood (1983 unpublished) also encountered difficulty in resolving growth bands in SBT scales. Furthermore, the caudal peduncle was the only body area which yielded 'readable' scales and within this area there was considerable variability in scale shape and dimension, thus hindering consistency in sampling. Teleost scales are also susceptible to osteolysis, or resorption of mineralised tissue (Mugiya and Watabe 1977), which, if undetected, can lead to inaccurate age estimates taken from growth-band counts. Similarly, scale loss and subsequent regeneration is known for SBT (Thorogood 1983 unpublished) and places further doubt on the use of scales as indicators of age in this species.

Otoliths. The 'reading' of growth-bands, or growth-increments, in otoliths is a routine technique for age and growth rate determination in many teleosts (Pannella 1980). Two types of banding are routinely counted in aging studies. Daily increments, deposited each day as part of a diel physiological rhythm, are most commonly used in determining age, in days, of larval and juvenile fish. Annuli, bands reflecting seasonal variability in growth rate (in response to changes in temperature, food availability, etc.) are commonly read as a means of estimating the age, in years.

In SBT, information on daily growth characteristics of larvae in the east Indian Ocean has been obtained through the investigation of otolith increment microstructure (Jenkins and Davis 1990). In this study the daily periodicity of increment formation in SBT larvae has been validated using marginal increment analysis.

Daily increments have also been reported to occur in otoliths of the larvae and juveniles of other species of tuna (Radtke and Morales-Nin 1989 for *Thunnus thynnus thynnus*, Brothers et al. 1983 for *Thunnus thynnus*, Inter-American Tropical Tuna Commission 1988 for *Thunnus albacares*).

As far as annuli are concerned, the SBT literature is scant. Yukinawa (1970) found no evidence of growth-banding in sagittae. However, Thorogood (1987), using a modification of Christensen's (1964) burning technique, reported (and validated for years 2-4, inclusive) annual growth-bands in sagittae from SBT up to 167 cm fork length. For fish younger than about 8 years, Thorogood's (1987) age-mean length relationship, was similar to those derived previously by other methods (Kirkwood 1983, Murphy 1976, Shingu 1978, Yukinawa 1970). However, there was significant divergence among the growth curves for older fish. Much of this divergence can be attributed to the paucity of large, mature fish in all the data sets on which these curves are based.

Optical resolution of annuli near the margin of the otoliths of older fish has consistently proven difficult for both SBT and other tuna species. At large sizes, SBT growth is slow and annuli , if present, should be very closely spaced, making them both difficult to read and extremely difficult to validate. It has become apparent that an alternative method should be developed to provide reliable age estimates for large SBT and validation for the estimates already obtained for young fish.

Other bony structures. Thorogood (1983 unpublished) also examined vertebrae, fin spines, cleithra and hypurals of SBT for growth-banding. Although some banding was evident in fin spines and vertebrae following staining of sections with Alizarin Red S., these investigations were not continued owing to evidence of osteolysis with age in the spines, and difficulty in obtaining samples of vertebrae.

Microchemical analysis of mineralised tissues: an alternative method of determining age from calcified tissues

The concentrations of chemicals in calcified tissues are known to vary significantly throughout the life of many marine organisms. Environmental, genetic and physiological factors are thought to play a role, and the interactions between these factors are complex (and, to a large degree, not understood). However, variability in the physical characteristics of the environment has been shown to be important in the composition of the calcium-protein matrices of otoliths and other calcified tissues. For example, it has been demonstrated that the strontium-calcium ratio (Sr/Ca) in coral skeletons is negatively correlated with the water temperature at the time of calcium deposition (Smith et al. 1979, Schneider and Smith 1982). The same relationship of Sr/Ca to water temperature appears to apply to teleost otoliths. Calaprice et al. (1971) were the first to speculate upon the potential of Sr/Ca analysis for aging of fish and later Calaprice (1985) reported some preliminary data, collected using proton induced X-ray spectroscopy, on the annual nature of variability in Sr/Ca ratios in the northern bluefin tuna, *Thunnus thynnus*. Using electron microprobe X-ray analysis across the growth axis of otoliths of the Antarctic fish, *Notothenia larseni*, Radtke and Targett (1984) found cyclic patterns in Sr/Ca which were interpreted to be related to seasonal variability in water temperatures. Radtke and Morales-Nin (1989) reported Sr/Ca ratio variations on a small sample (n = 4) of juvenile northern bluefin tuna, *Thunnus thynnus thynnus*, that they assumed were related to variations in water temperature. Likewise, Gauldie et al. (1986), using proton probe X-ray analysis, found variation of Sr/Ca in otoliths of chinook salmon, *Oncorhynchus tshawytscha*, that they concluded were linked to differences in water temperature.

Recently, Thresher et al.(in press) have used electron microprobe X-ray analysis (wave-dispersive spectroscopy) to examine the microchemistry of otoliths from SBT caught in Australian waters. Conspicuous episodic variations in Sr/Ca, across the otolith growth axis, have been found for both small and very large SBT. The number of such variations in an otolith appears to be consistent with the expected age of a fish, based on its size and previous estimates of growth rates of SBT. Furthermore, with the capacity of the electron microprobe for analysing very small areas (down to 9 μm^2), these episodic variations can be resolved, even near the margin of the otoliths of large fish. To validate the annual frequency of the 'episodes', variation in Sr/Ca, at the margin of otoliths from SBT sampled over a period of at least 12 months is required (Thresher et al. in press). If these variations in microchemistry are proved to be linked to seasonal changes in water temperature, X-ray microanalysis of otoliths should enable reliable age determination of large (> 170 cm fork length) SBT, thus filling the gap left by previous aging techniques.

AGING AND GROWTH FROM TAG-RELEASE / RECAPTURES

Annual growth of SBT

For age (or time), t, the length, L, of a fish expressed assuming the von Bertalanffy growth equation is

$$L = L_\infty [1-\exp\{-K(t-t_0)\}] \qquad \text{...................(1)}$$

where L_∞ is the length to which fish grow asymptotically, K is the rate at which growth declines exponentially and t_0 is the hypothetical age at which the fish size is zero.

Suppose a fish of length L_1 is tagged at time t_1 and recaptured at time t_2 with length L_2. From equation (1) the estimate of the growth increment, ΔL (i.e. $L_2 - L_1$), over the time-at-liberty , Δt (i.e. $t_2 - t_1$), given L_1, is

$$\Delta L = [L_\infty - L_1] [1 - \exp\{-K\Delta t\}] \qquad \text{...................(2)}$$

Lucas (1974) estimated L_∞ and K for SBT by the least squares fit [equivalent to the Fabens (1965) method] of the right hand side of equation (2) to growth increments (ΔL) of recaptures by Japanese longliners (Table 1). He assumed a value of zero for t_0. He excluded 11 recaptures from the analysis as they were considered to be incorrect because the growth of each was very small, possibly due to measurement of fish without heads. This explanation is consistent with evidence, presented in Hearn (1982), that many of these fish had recapture lengths that were low for their weights.

Murphy (1977) also estimated L_∞ and K from all SBT recaptures (Table 1). The parameter t_0 was estimated from the knowledge that tuna are 3 mm long at hatching. The growth curve represented by these parameters tends to be slower for fish up to 160 cm long than the curve in Lucas (1974).

Hearn (1979) estimated L_∞ and K (Table 1) by least-squares fit, using a heavily edited subset of SBT recapture data (less than 25 % of those analysed by Murphy 1977). He analysed length-frequency modes and estimated the hypothetical times (called 'birth dates') when lengths were zero. The average 'birth date' was 26 December, which is equivalent to a t_0 value of - 0.014 years for a 1 January time origin. This growth curve is a little faster than that of Lucas (1974).

Kirkwood (1983) estimated growth curves separately from the 1960-70s length-at-age and tag-recapture data sets by fitting them to equations (1) and (2), respectively. He also estimated a common growth curve by jointly fitting equations (1) and (2) to the length-at-age and tag-recapture data (Table 1). The length-at-age data set was determined from prominent modes of the commercial catch length-frequencies. Kirkwood (1983) took the time origin to be 1 January, which is about the middle of the SBT spawning season.

Other growth curves were obtained in Kirkwood (1983) by fitting data, separately and jointly, to the inverses of equations (1) and (2), namely

$$t = t_0 - \ln\{1 - L/L_\infty\}/K \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

and

$$\Delta t = - \ln\{1 - \Delta L/(L_\infty - L_1)\}/K \qquad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Age is the dependent variable in equation (3), i.e. age is determined from length. Tests showed that the tag-recapture and age-at-length data sets were not consistent with respect to this regression. The age compositions of the commercial catch can be estimated by knife-edge partitioning of the commercial catch length-frequency samples using equation (3) and the age-length parameters from Table 1. The age compositions have been extensively used in SBT stock assessments.

Of the tag-recapture data analysed in Kirkwood (1983) there were only 10 recaptures with reliable data for which the length at recapture was at least 150 cm. Majkowski and Hampton (1983a) examined the effect that statistical uncertainties in the Kirkwood (1983) age-at-length relationship have upon the estimates of the age-composition of catches. They concluded that uncertainties in catch number estimates were too high for fish aged 2 years and less, or 14 years and older.

There were no recaptures with reliable data for fish that were at liberty more than 11.5 years, although some were at liberty for up to 18 years. Hearn (1986) argued that the age-at-length regression (Kirkwood 1983), derived from a data set having a limited range of times-at-liberty, systematically underestimates the ages of large fish. This view was supported by Sandland (1987). Some recent recaptures with much longer times-at-liberty than those analysed in Kirkwood (1983) but not longer recapture lengths, also support this interpretation.

Table 1. Estimates of von Bertalanffy annual growth parameters L_∞, K and t_0 from southern bluefin tuna tagged in the 1960-70s.

Author	Estimation method	L_∞ (cm)	K (yr^{-1})	t_0 (yr)	Length at 2 years (cm)	Length at 8 years (cm)	Length at 14 years (cm)
Lucas (1974)	Fabens (1965)	171.5	0.187	0	53.5	133.1	159.0
Murphy (1977)	Fabens (1965)	180.8	0.146	-0.011	46.0	124.7	157.4
Hearn (1979)	Fabens (1965) t_0 separately	178.6	0.177	-0.014	53.6	135.4	163.7
Kirkwood (1983)	Joint estimation length-age	184.4	0.157	-0.215	54.2	133.6	164.6
Kirkwood (1983)	Joint estimation age-length	207.6	0.128	-0.394	54.8	136.7	174.7
Hampton (1989)	Model (3) t_0 separately	186.9	0.140	-0.544	56.0	130.4	162.5

Growth variations between individual fish

Individual fish fish grow differently from each other, and this should be allowed for in growth models. Hampton (1989) compared maximum likelihood fits of seven growth models to tag-recapture data from SBT tagged in the 1960-70s. He showed that four of the models, all better than the other models, fitted the data almost equally well; the best, his 'model 3' - an extension of the model in Kirkwood and Somers (1984), incorporated variability into L_∞ and added model error. It was the least complex of the acceptable models. The parameter t_0 was estimated by maximum likelihood from age-at-length data, with the other parameters assumed fixed. This model has been used to estimate age compositions for input into SBT stock assessments.

From Hampton 1989, Table 6.2, it can be calculated that growth based on his 'model 3' would be able to separate 3-year-old and 4-year-old length-frequency modes, but not older ones. Kirkwood (1983) states that modes in length-frequencies of catches in NSW and SA are clear up to 5 years of age (i.e. that length modes for 5-year-old SBT and 6-year-old SBT can be separated). Thus there appears to be inconsistency between the best growth model fitted to tag-recapture data and one fitted to modes in length-frequency data.

Seasonal variation in the growth of juvenile SBT

Seasonal variation in the growth of fish is often induced by influences such as temperature, food supply, migration, and reproduction. Serventy (1956) reported modal progression evidence of little growth during winter and fast growth during summer for juvenile SBT caught from southern NSW to Tasmania from 1938 to 1942. The growth of the giant bluefin (*Thunnus thynnus*) is similarly reported to be faster during summer than winter (Mason 1976).

The Pitcher and Macdonald (1973) growth curve was used to describe seasonal growth. For tag-recapture data the least-squares estimation procedure of Shepherd and Hearn (1983) was followed. The growth increment ΔL, given L_1 (length at tagging), t_1 (time of tagging) and t_2 (time of recapture), is

$$\Delta L = [L_\infty - L_1]\,[1 - \exp\{-K(\Delta t + A\sin\{2p(t_2 - e)\} - A\sin\{2p(t_1 - e)\})\}], \quad ....(5)$$

where $\Delta t = t_2 - t_1$, A is the amplitude of the seasonal component of growth and $2pe$ is its phase angle with respect to 1 January (e is the time of the year when growth is fastest for fish of a given size). Seasonality is deemed to occur if parameter A is significantly greater than zero using a 1-sided student's t-test.

The parameter L_∞ was estimated by Hearn (1986) from the long-time-at-liberty Japanese recaptures. He obtained an L_∞ value of 184.5 cm and a K value of 0.1624 per year. This value of L_∞ was subsequently used as an assumed value in equation (5). The parameters K, A and e were estimated from reliable Australian recapture data obtained in the 1960-70s from fish that were at liberty for at least 60 days. This allowed time for them to recover from any possible trauma of tagging.

No significant difference ($p > 0.05$) was found between curves fitted to 1960-70s data from tuna that were tagged in NSW and SA (Table 2). However, these were significantly different ($p < 0.01$) from the curve fitted to data from fish tagged off WA during the 1960s. Data from fish that were tagged by fishermen under contract were excluded from these analyses, but they were separately analysed and parameters are listed in Table 2. In all cases parameter A is significantly greater than zero ($p < 0.01$).

Table 2. Estimates of growth parameters K, A and e with standard errors (in brackets), given L_∞ = 184.5 cm, for southern bluefin tuna tagged at various sites. Periods at liberty ≥ 60 days. Shrinkage of tagged fish before measurement is put at 0.6%. The date given is an alternative way of expressing e. An estimate of L_∞ = 230.6 cm was obtained from age-length data.

Tagging location	K (yr^{-1})	A (yr)	e (yr)	t_0 (yr)	Number analysed	$\Delta L_{min} / \Delta L_{max}$ [1]
Tagged by CSIRO staff						
WA	0.153 (0.003)	0.117 (0.024)	-0.074 (0.023) (6 December)	-	411	0.375
SA	0.153 (0.003)	0.126 (0.020)	0.120 (0.055) (14 February)	-	184	0.343
NSW	0.146 (0.003)	0.082 (0.025)	0.163 (0.034) (1 March)	-	245	0.517
SA+NSW	0.149 (0.002)	0.105 (0.017)	0.171 (0.022) (4 March)	- 0.512 (0.022)	429	0.420
Tagged by fishermen						
SA+NSW	0.139 (0.001)	0.086 (0.006)	0.111 (0.010) (11 February)	-	2863	0.500
Commercial age-length data						
SA+NSW	0.110 (0.015)	0.149 (0.014)	0.266 (0.012) (8 April)	- 0.564 (0.104)	628	0.261

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[1] $\Delta L_{min} / \Delta L_{max}$, the ratio of slow to fast growth rate, provides an indication of the strength of seasonality in growth. The degree of seasonality decreases as the ratio increases.

Modes of length-frequencies were used to estimate the parameter t_0 (-0.512 ± 0.022 years), where the other parameters were regarded as fixed. Hearn (1986) also estimated seasonal parameters (Table 2) for SBT in NSW and SA waters from peaks in commercial length-frequencies.

In all three independent estimates (Table 2), fish in SA and NSW waters were found to grow fastest (for a given length) during late summer and early autumn. For SBT tagged in WA, the maximum growth rate (for a given length) was found to occur in early summer (Table 2). Of the fish tagged in WA in the 1960s, almost all recaptures were from NSW or SA fisheries so it is not possible to quantify the growth of SBT in WA from these data.

The converse of the fast growth period of late summer and early autumn is a slow growth period in late winter and early spring, which should result in seasonal growth rings being laid in hard parts such as scales and otoliths. This correlates with the estimate by Yukinawa (1970) that growth rings in the scales of SBT are laid down in September-October.

For SBT in NSW and SA the seasonal growth rate appears to be synchronised with the ambient surface water temperature. It thus seems that water temperature has an important effect on the behaviour and growth of SBT. Additionally, the fast growth over summer could be partially due to a seasonal increase in the food supply because of the SA summer upwelling.

Indications of recent rapid growth

The CSIRO tagged 3223 juvenile SBT during January-February 1984 in the Great Australian Bight. A few months later, during May-June 1984, about 250 of these were captured near Port Lincoln and some 150 were reliably measured.

Hearn (1986) examined the 120 recaptured tuna which, at tagging, were classified as 2 + (i.e. between 2 and 3 years old) by the Kirkwood (1983) age-at-length regression. They grew from 58.7 cm to 74.0 cm on average during this short period at liberty (or from 4.3 kg to 8.5 kg). For comparison, the growth increment predicted from the Kirkwood (1983) parameters is only 42 % of the experimental result. Even when allowance was made for seasonal variations in growth, the predicted growth increments were still less than 65 % of the experimental value.

Hampton (1989) made a more detailed analysis of growth of fish tagged in 1983-84. He used the concept of a 'growth differential' to analyse data and explain his results and conclusions. It is calculated by

$$\text{Growth differential} = \frac{[\text{expected } \Delta L - \text{observed } \Delta L]}{\text{standard deviation } \Delta L} \qquad \text{....................(6)}$$

where ΔL is the growth increment. The growth differential is essentially a standardised residual, with expected ΔL being estimated from the application of his 'model (3)' to the 1960-70s tag-recapture data. Hampton (1989) shows, for all combinations of 1983-84 tagging sites and subsequent recapture sites, that growth is significantly faster for SBT tagged in 1983-84 than previously. The increase in growth was found to persist with increasing time-at-liberty.

However, for each combination of tagging and recovery location, Hampton (1989) then proceeded to compare growth differentials over time-at-liberty. He used expected ΔL obtained from the 1960-70s data and, for fish tagged at all sites in 1983-84, reached the conclusion that growth was slow soon after tagging. Following comment that the expected ΔL used was incorrect, Hampton (pers. comm.) re-analysed the data using the expected ΔL from the 1983-84 data and found in no case was there any evidence of short-term slowing of growth in the 1983-84 data. He mentioned that there may have been a seasonal effect for SBT tagged and recaptured in SA. An inspection of Hampton's revised growth differentials also indicates that there is little or no seasonal growth in

SBT tagged off Albany or Esperance and recaptured in WA waters. This could be due to the uniformity of surface water temperatures throughout the year in the WA fishing grounds, because of the warm winter Leeuwin Current.

In considering whether juvenile SBT are suitable for aquaculture one could assume that the highest growth rates in the wild population will be attained under controlled aquaculture conditions. Equation (2) was fitted by least-squares to growth-increment data of fish tagged in SA in early 1984 and recaptured by mid-1984. The growth parameters estimated were 152.3 cm for L_∞ and 0.5338 per year for K. If this growth curve were valid for a longer period, a 51.8 cm fish would be expected to grow to 93.5 cm in only one year (i.e. from 3.0 to 16.6 kg). Thus this rapid growth may make SBT suitable for aquaculture.

Hearn (1986) argued that inter-annual variations in the SA upwelling may provide an explanation for the exceptionally fast growth of juvenile SBT evident in early 1984. One possible cause could be changes in the SA summer south-easterly winds that are reported to occur during the time of El Nino events (Pariwono 1986). Alternatively, both Hearn (1986) and Hampton (1989) suggested that the rapid growth during the 1984 SA fishing season may be due to more food per tuna; juvenile SBT numbers were probably low in Australian waters during the early 1980s because of heavy fishing.

The recapture length of 1983-84-tagged SBT which were caught after more than three years at liberty by Japanese longline boats, tends to be longer than that predicted by the Kirkwood (1983) growth curve. Evidence suggests that SBT growth varies between individuals, seasons, regions and years, and that the variation persists with age. Consequently, there needs to be a careful evaluation of growth-change implications for stock assessment.

AGING AND GROWTH FROM LENGTH-FREQUENCY DATA

It is possible to derive information on growth rate from length-frequency data, particularly when well-formed modes are clearly visible. Serventy (1956) and Robins (1963) examined SBT catch length frequency data and assigned ages to length modes. Robins formulated a tentative growth curve, from which Shingu (1970) estimated the von Bertalanffy growth equation parameters (222.5 cm for L_∞, 0.14 per year for K, and 0.011 years for t_0); he later (Shingu 1978) compared them with results from scale readings (Yukinawa 1970; 219.7 cm, 0.135 per year, and - 0.04 years) and from tagging (Murphy 1977, see Table 1). Kirkwood (1983) estimated von Bertalanffy growth curve parameters using length increment data from tag recaptures, supplemented by age-length data from catch length composition modes (Table 1). Taking Kirkwood's values and their variances, Majkowski and Hampton (1983a) examined the effects of such uncertainties when the age-length relationship was used for estimating the composition of catches by age.

Initially graphical methods were used for visually distinguishing single age-class modes in a distribution. However more recently, computer-based methods (e.g. Macdonald and Pitcher 1979, Schnute and Fournier 1980, and Fournier and Breen 1983), using a maximum likelihood estimation procedure, were developed. They separate a single length-frequency data set into normal or log-normal components that are assumed to represent cohorts. The newest technique is called MULTIFAN (Fournier et al. 1990) and it has been applied promisingly to SBT (Fournier et al. 1990) and albacore (Hampton et al. 1990) length frequency data. A major feature of MULTIFAN is its capacity to analyse simultaneously a time series of length-frequency samples, and thereby take into account information not necessarily available when analysing the samples in isolation; within sample spacing of modes, and between-sample progression of modes can all be accommodated. It incorporates systematic testing of different hypotheses relating to growth and the structure of the length-frequency data.

The SBT parameter estimates obtained in the trial use of the procedure (Fournier et al. 1990) gave good agreement with estimates from tag return data, scale analysis and otolith analysis.

RELATIONSHIP OF WEIGHT TO LENGTH

Weight to length conversions

Shingu (1978) summarised the relationships between body length and weight of SBT reported by Australian and Japanese scientists. The Australian relationship [Robins 1963; length is length to caudal fork (LCF) and weight is whole weight (Robins, pers. comm.)] was based predominantly on immature (< 130 cm LCF) SBT. The Japanese relationships discriminate between SBT less than and greater than 130 cm and, for the latter, between pre-spawning and post-spawning fish [Warashina and Hisada 1970, Shingu 1978; length is LCF (Warashina, pers. comm.) and weight is gilled and gutted weight].

Table 3 shows the various relationships and, for lengths from 30 cm to 200 cm, provides corresponding weights based on the relationships. In addition to the processed weight specified in the Japanese relationships, the table also provides whole weights calculated using a processed weight:whole weight ratio of 1:1.15 (Ishizuka pers. comm.).

As Japanese scientists have found longline catch length-composition increasingly difficult to sample, they have sampled processed-weight-composition, subsequently converting it to length, then to age, for incorporation in stock assessments. Reference to the length:weight relationship used is contained in Majkowski and Morris (eds) 1986, but the equations are incorrect ($L = 2.406 \times 10^4 \times GW^{-2.8160}$ for SBT < 130 cm, and $L = 8.190 \times 10^5 \times GW^{-3.5399}$ for SBT > 130 cm, where GW is gilled and gutted weight in kg and L is fork length in cm). Ishizuka has advised that the equations currently used by Japanese scientists 'for the calculation of whole weight (W) from fork length (L)' are:

for SBT < 130 cm

$W = 3.1309 \times 10^{-5} \times L^{2.9058}$ (i.e. Robins 1963)

and, for SBT > 130 cm

$W = 1.15 \times 1.2205 \times 10^{-6} \times L^{3.5399}$ (Warashina and Hisada, pers. comm.)

Transformed in order to predict length from weight these equations become:

for SBT < 130 cm

$L = 3.5491 \times 10 \times W^{0.3441}$

and, for SBT > 130 cm

$L = 4.5016 \times 10 \times W^{0.2825}$

These relationships are shown in Fig. 5.

Allometric relationships

New Zealand has examined allometric relationships between fork length and processed weight (equal to approximately 0.85 of the whole weight), derived using the nonlinear curve fitting procedures in the SAS statistical package. The model was repeated a number of times using different initial parameter estimates to ensure that they were robust. The parameters are summarised in Table 4 by fishery, area and sex for the model:

$$W = a\ L^{b},$$

where W is processed weight in kg and L is fork length in cm. As can be seen from the summary statistics, the empirical models frequently result in statistically significant parameter estimates for different fishery areas and for sexes between areas. Population analyses currently rely on age distributions computed from lengths predicted from recorded weights, so the differences in allometry between sexes and areas are important. The uncertainty in the prediction of length from

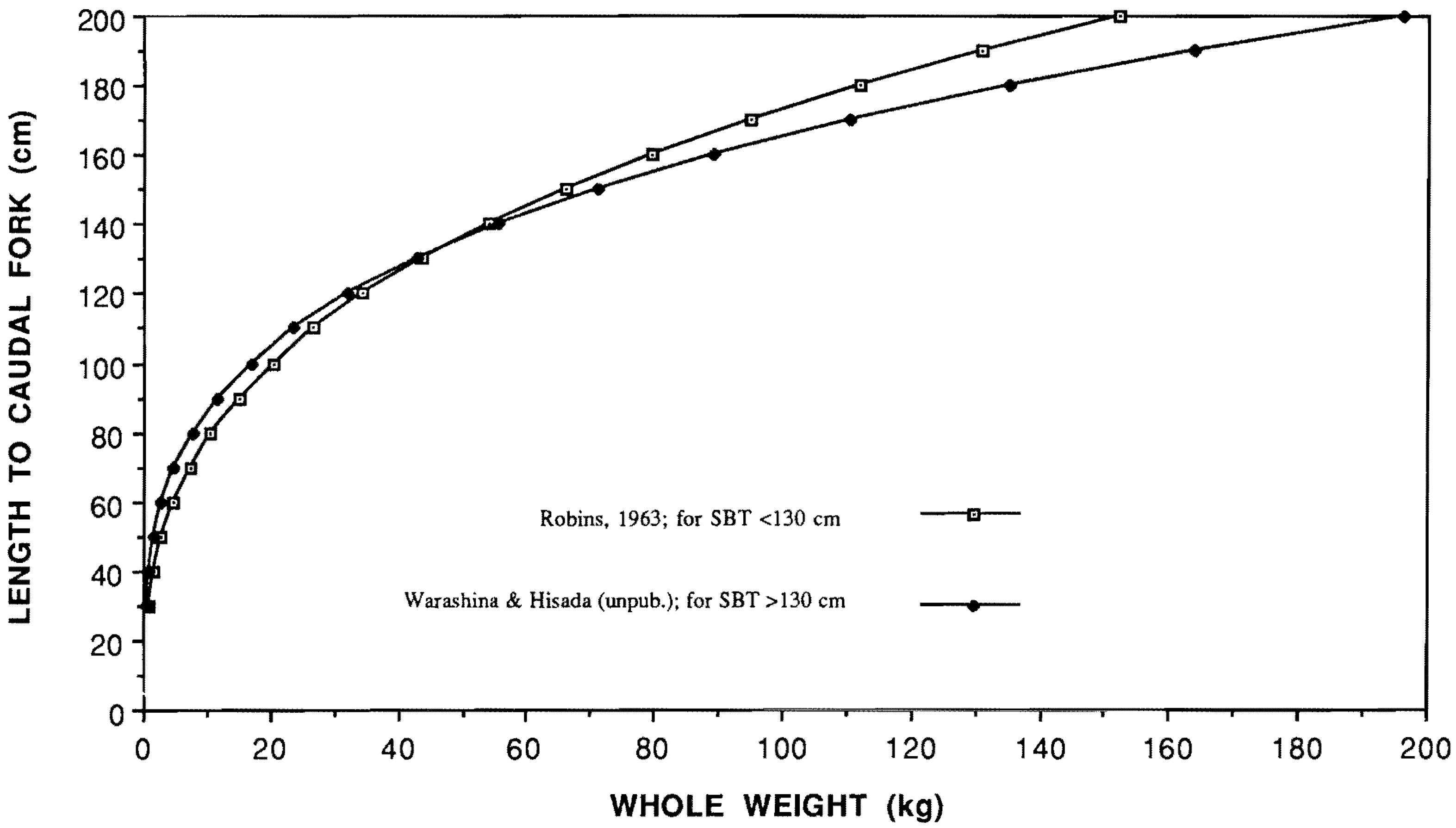

Fig. 5. Relationships currently used to convert southern bluefin tuna weight to length; the relationship for southern bluefin tuna >130 cm has been adjusted from a processed-weight:length relationship to a whole-weight:length relationship using a 1:1.15 ratio of processed to whole weight.

Table 3. Southern bluefin tuna length:weight relationships[1], with a comparison of the conversions for a range of lengths. In practice the relationships are usually transformed in order to predict length from weight.

WT1 - Robins, 1963; whole weight
$W = 3.13088 \times 10^{-5} \times L^{2.9058}$

WT2 - Warashina and Hisada, 1970, for SBT < 130 cm; gilled and gutted weight
$W = 4.159 \times 10^{-5} \times L^{2.8160}$

WT3 - WT2 converted to whole weight, using a processed : whole weight ratio of 1:1.15
$W = 4.7829 \times 10^{-5} \times L^{2.8160}$

WT4 - Warashina and Hisada, 1970, for SBT >130 cm; gilled and gutted weight
$W = 2.178 \times 10^{-6} \times L^{3.4229}$

WT5 - WT4 converted to whole weight, using a processed : whole weight ratio of 1:1.15
$W = 2.5047 \times 10^{-6} \times L^{3.4229}$

WT6 - Warashina and Hisada, 1970, for pre-spawning SBT >130 cm; gilled and gutted weight
$W = 5.392 \times 10^{-7} \times L^{3.7232}$

WT7 - WT6 converted to whole weight, using a processed : whole weight ratio of 1:1.15
$W = 6.2008 \times 10^{-7} \times L^{3.7232}$

WT8 - Warashina and Hisada, 1970, for post-spawning SBT >130 cm; gilled and gutted weight
$W = 2.942 \times 10^{-6} \times L^{3.3438}$

WT9 - WT8 converted to whole weight, using a processed : whole weight ratio of 1:1.15
$W = 3.3833 \times 10^{-6} \times L^{3.3438}$

WT10- Warashina and Hisada (unpublished) for SBT > 130cm; gilled and gutted weight
$W = 1.2205 \times 10^{-6} \times L^{3.5399}$

WT11- WT10 converted to whole weight, using a processed : whole weight ratio of 1:1.15
$W = 1.4036 \times 10^{-6} \times L^{3.5399}$

LCF	WT1	WT2	WT3	WT4	WT5	WT6	WT7	WT8	WT9	WT10	WT11
30	**.6**	.6	.7	.2	.3	.2	.2	.3	.3	.2	.2
40	**1.4**	1.4	1.6	.7	.8	.5	.6	.7	.8	.6	.7
50	**2.7**	2.5	2.9	1.4	1.6	1.1	1.3	1.4	1.6	1.3	1.5
60	**4.6**	4.2	4.9	2.7	3.1	2.2	2.6	2.6	3.0	2.4	2.8
70	**7.2**	6.5	7.5	4.5	5.2	4.0	4.6	4.3	5.0	4.1	4.8
80	**10.6**	9.5	10.9	7.1	8.2	6.6	7.6	6.8	7.8	6.7	7.7
90	**14.9**	13.2	15.2	10.6	12.2	10.2	11.7	10.1	11.6	10.1	11.6
100	**20.3**	17.8	20.5	15.3	17.6	15.1	17.3	14.3	16.5	14.7	16.9
110	**26.8**	23.3	26.8	21.2	24.3	21.5	24.7	19.7	22.7	20.6	23.6
120	**34.5**	29.8	34.3	28.5	32.8	29.7	34.2	26.4	30.3	28.0	32.2
130	43.5	37.3	42.9	37.5	43.1	40.0	46.0	34.5	39.6	37.1	**42.7**
140	53.9	46.0	52.9	48.3	55.6	52.7	60.7	44.1	50.8	48.3	**55.5**
150	65.9	55.8	64.2	61.2	70.4	68.2	78.4	55.6	63.9	61.6	**70.9**
160	79.5	67.0	77.0	76.3	87.7	86.7	99.7	69.0	79.3	77.4	**89.0**
170	94.8	79.4	91.3	93.9	108.0	108.7	125.0	84.5	97.2	96.0	**110.4**
180	112.0	93.3	107.3	114.2	131.3	134.5	154.6	102.3	117.6	117.5	**135.1**
190	131.0	108.6	124.9	137.4	158.0	164.4	189.1	122.6	140.9	142.3	**163.6**
200	152.1	125.5	144.3	163.8	188.3	199.0	228.9	145.5	167.3	170.6	**196.2**

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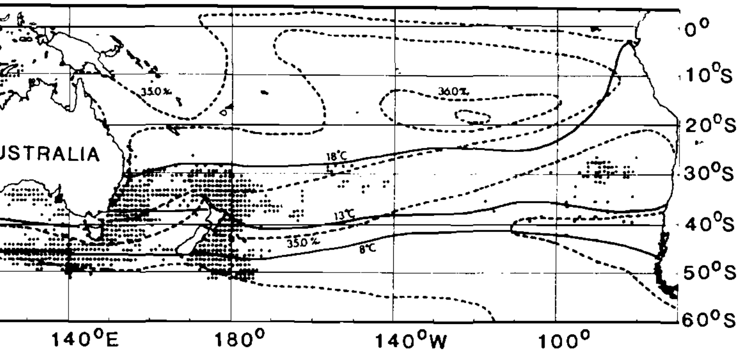
[1] Note that length to caudal fork (LCF) in cm is used for each of the relationships specified; weights are in kg. The ranges of weights in bold font in the table indicate the conversions and ranges currently used for conversion from weight to length for estimation of catch length composition. As is evident, different conversions are adopted for fish less than, and greater than, 130 cm.

Table 4. Allometric relationships between fork length and processed weight (equal to approximately 0.85 of the whole weight) for southern bluefin tuna caught in New Zealand waters. Sample size for each relationship is 1500 fish.

		a (x10^{-3})	Standard error (a) (x10^{-3})	b	Standard error (b)
Domestic fishery					
south-west coast	females	0.021	0.005	2.956	0.042
	males	0.020	0.004	2.966	0.039
west coast pooled sexes		0.009	0.003	3.114	0.047
Japanese longline fishery					
north-east coast	females	0.917	0.238	2.208	0.051
	males	1.025	0.239	2.184	0.046
south-east coast	females	2.642	0.625	1.994	0.046
	males	0.933	0.235	2.203	0.049
east coast pooled sexes		1.088	0.264	2.173	0.047

weight for larger, older, fish can be easily seen in Fig. 6. This means that age prediction will also be difficult, especially for older fish (Hampton et al. 1984). As the average age of SBT caught in the western South Pacific is 10-11 years old, it is not possible to accurately estimate age distributions, at least for that part of the population fished in the area.



e longline vessels, data from all years combined. Solid and
face in February. (Source: Shingu 1978).

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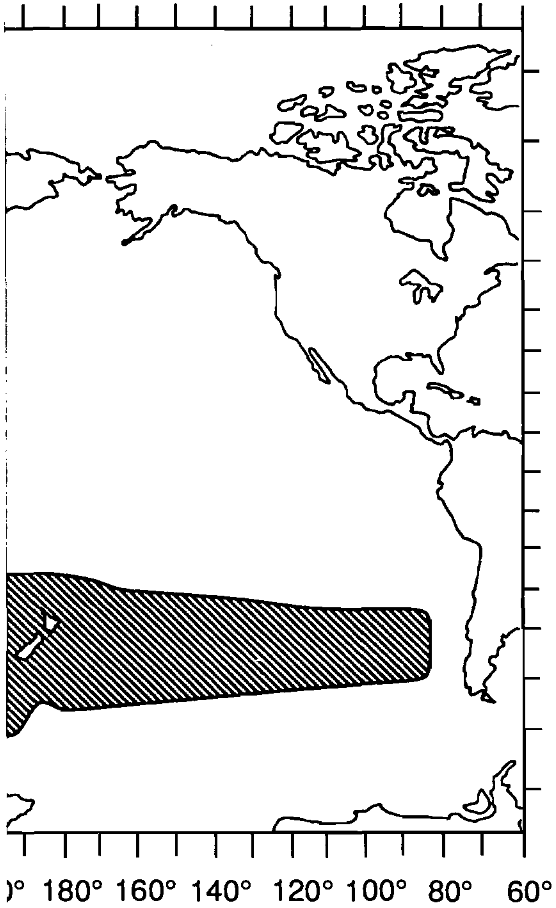

spawning ground (shaded). (after Collette and

Processed Weight (kg)

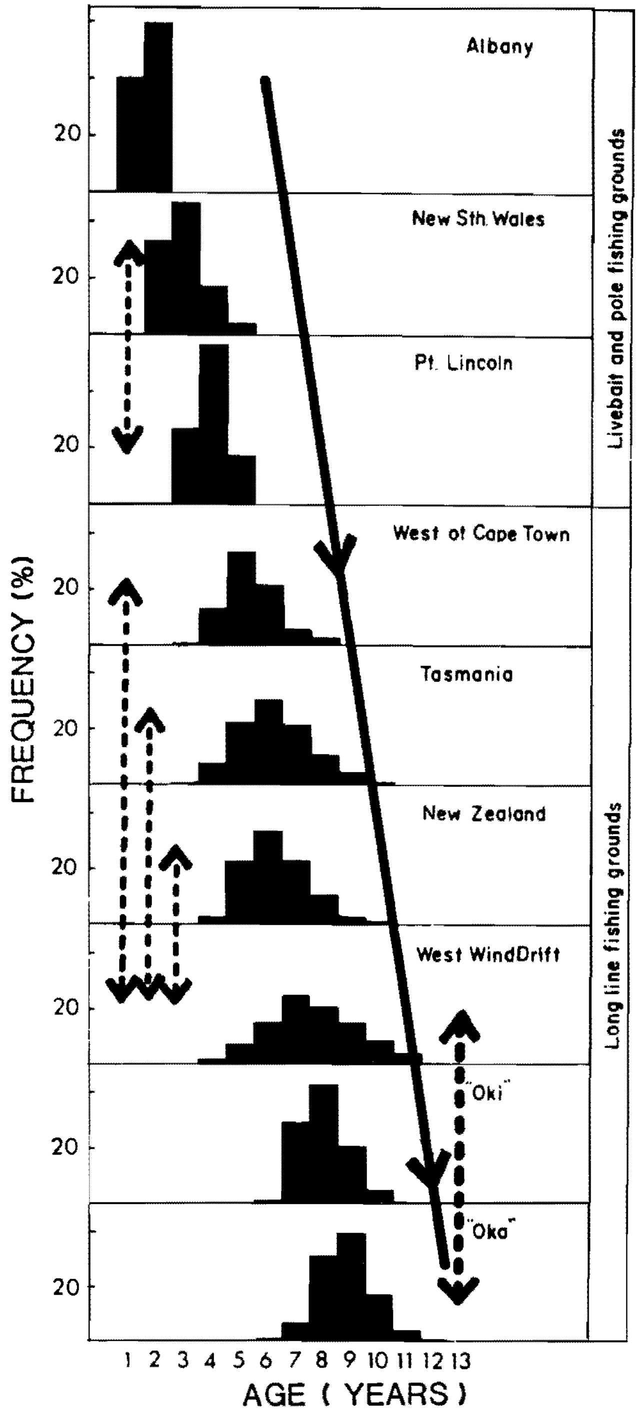

Fig. 11. Average age compositions of southern bluefin tuna caught in the nine fishing grounds, 1952-66, and the supposed migration routes. Solid line: migration between feeding and spawning areas. Thin dotted line: seasonal migration. (Source: Shingu 1978). (Note that to generate this figure a different age scale was used from that which is now used, and that surface fishery age composition changed when the range of the fishery increased.)

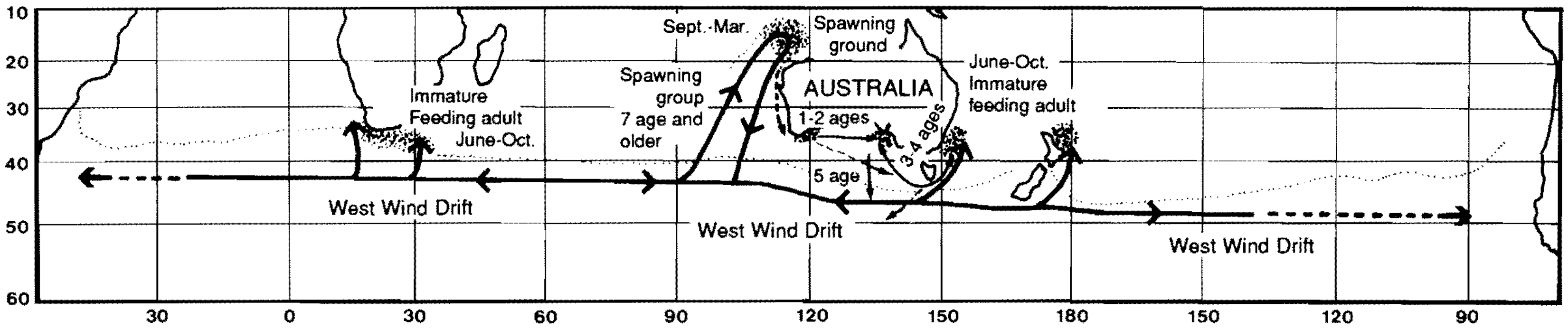

Fig. 12. Schematic representation of the presumed migratory routes of southern bluefin tuna. Dotted line marks the northern boundary of the West Wind Drift. Broken arrow denotes possible migratory route. Dotted area shows main distribution range out of the West Wind Drift. (Source: Shingu 1978). (Note that the increased range of the surface fishery has generated a need to review the migratory routes.)

the spawning season) and its speed are consistent with juvenile SBT reaching the southern west coast of Australia as 1-year-old to 2-year-olds (Harden Jones 1984).

The Fig. 12 representation of the subsequent pattern of juvenile distribution requires review. Generally, 1+ to 2+ fish are common in surface catches on the continental shelf of south-western WA. Ages commonly ranged from 2+ to 6+ beyond the continental shelf in the far south-east of WA and across southern Australia to NSW, with individuals to at least 9+ also taken at times. As a rule the younger-aged fish (1+ to 3+) seem more closely associated with waters of the continental shelf than are older ones.

Southern bluefin tuna nearing 3 years old were common in surface catches off south-eastern Australia until the early 1980s when they disappeared abruptly from the NSW catch. As a result the NSW component of the Australian surface fishery failed and has still not recovered (Caton and Williams 1991).

While seasonal movements of immature SBT occur throughout the region of the surface fishery, the presence of immature fish in longline catches indicates a tendency (as early as 3 years of age for some, and progressively for older ages) for these fish to leave the coastal areas and distribute themselves widely in the middle layer of offshore waters of lower temperature. These immature SBT inhabit the West Wind Drift region until they become adults, but move northward seasonally to the areas north of 40° S in the east of Australia, in the east of New Zealand and off South Africa. This northerly movement takes place usually in the southern winter. Mature SBT (see Table 5) pass by way of the Oki fishing ground (adjacent to North West Cape, WA) to the Oka fishing ground (in the north-eastern Indian Ocean south of Java) arriving there between September and March, whereupon they spawn. During the feeding stage they are distributed in the West Wind Drift and some of them migrate seasonally northward as do the immature ones. The movements between the sea areas in different seasons and for spawning are indicated by dotted arrows in Fig. 11.This does not mean that all the fish move from south to north, but it appears that the distribution area expands seasonally northwards. Likewise, throughout the spawning period, adults can be found in the spawning ground as well as in the West Wind Drift.

STOCK STRUCTURE, DISTRIBUTION AND MIGRATION AS INDICATED BY TAG RETURN DATA

It is well established from the results of tagging experiments carried out by the CSIRO that SBT undergo extensive migrations (Hynd 1969, Murphy 1977, Murphy and Majkowski 1981, Majkowski and Murphy 1983). Juvenile tuna tagged in the surface fisheries in WA, SA and NSW have been recaptured as far afield as the east coast of New Zealand and south of the Cape of Good Hope (South Africa). These data, and observations of the geographical and size distribution of longline-caught fish, have led various authors to propose models of SBT migration (Shingu 1967, 1970, 1978, Hynd 1969, Nakamura 1969, Murphy 1977). These are discussed with reference to tagging experiments carried out by the CSIRO between 1959 and 1980.

In the traditional model (Fig. 13), young southern bluefin move down the west coast of Australia from the spawning ground, after which they first appear in surface fishery catches as 1-year-old to 2-year-olds off south-western Australia.

The numbers of SBT recaptured by area, for releases in WA, SA and NSW, are shown in Table 6. Juveniles reside in continental shelf waters off the south coast of WA for 1-2 years; few recaptures of SBT tagged in WA have been recorded in the release area after one year at liberty. The 2-year-olds and 3-year-olds move rapidly eastward into the Great Australian Bight, where, within one year of release, large numbers of recaptures of WA releases have been recorded in the SA fishery and smaller numbers in the NSW fishery. Larger numbers of WA releases were recaptured in the

Table 5. Southern bluefin tuna fishing grounds divided into ten areas (modified from Shingu and Hisada 1971).

Area number	Name of fishing ground	Location	Main ocean current	Starting year of fishing	Fishing season*	Characteristic features of the catch
1	Oka fishing ground	10-20° S 100-130° E	South equatorial current	1952	III,IV,I	Spawning adults
2	Oki fishing ground	20-35° S 80-120° E	South equatorial current and West Australian current	1958	III,IV,I,II	Spawning adults
3	Fishing ground along South Australia	north of 30° S 120-140° E	West wind drift with seasonal occurrence of warm waters	1968	I,II	Youngs and immatures (major fishing ground of surface fishery)
4	Fishing ground along New South Wales	30-40° S 140-170° E	Central Tasman waters and East Australian current	1961	II,III,IV	Immatures and young (also major fishing ground of surface fishery in addition to longline fishery)
5	Fishing ground off north New Zealand	30-40° S 170°E-170° W	-----	1956	II,III	Immatures
6	Fishing ground around south New Zealand	40-50° S 165°E-170° W	West wind drift	1967	I,II,III,IV	Feeding adults and immatures
7	Fishing ground around Tasmania	35-50° S 120-170° E	West wind drift	1962	II,III,IV,I	Feeding adults and immatures
8	Fishing ground in south-central Indian Ocean	35-50° S 60-120° E	West wind drift	1966	III,IV,I,II	Feeding adults and immatures
9	Fishing ground south of Africa	35-50° S 20°W-60° E	West wind drift	1967	II,III,IV,I	Feeding adults and immatures
10	Fishing ground off Argentina	35-50° S 70-20° W	West wind drift	1969	I,II	Feeding adults

* I: January-March; II: April-June; III: July-September; IV: October-December

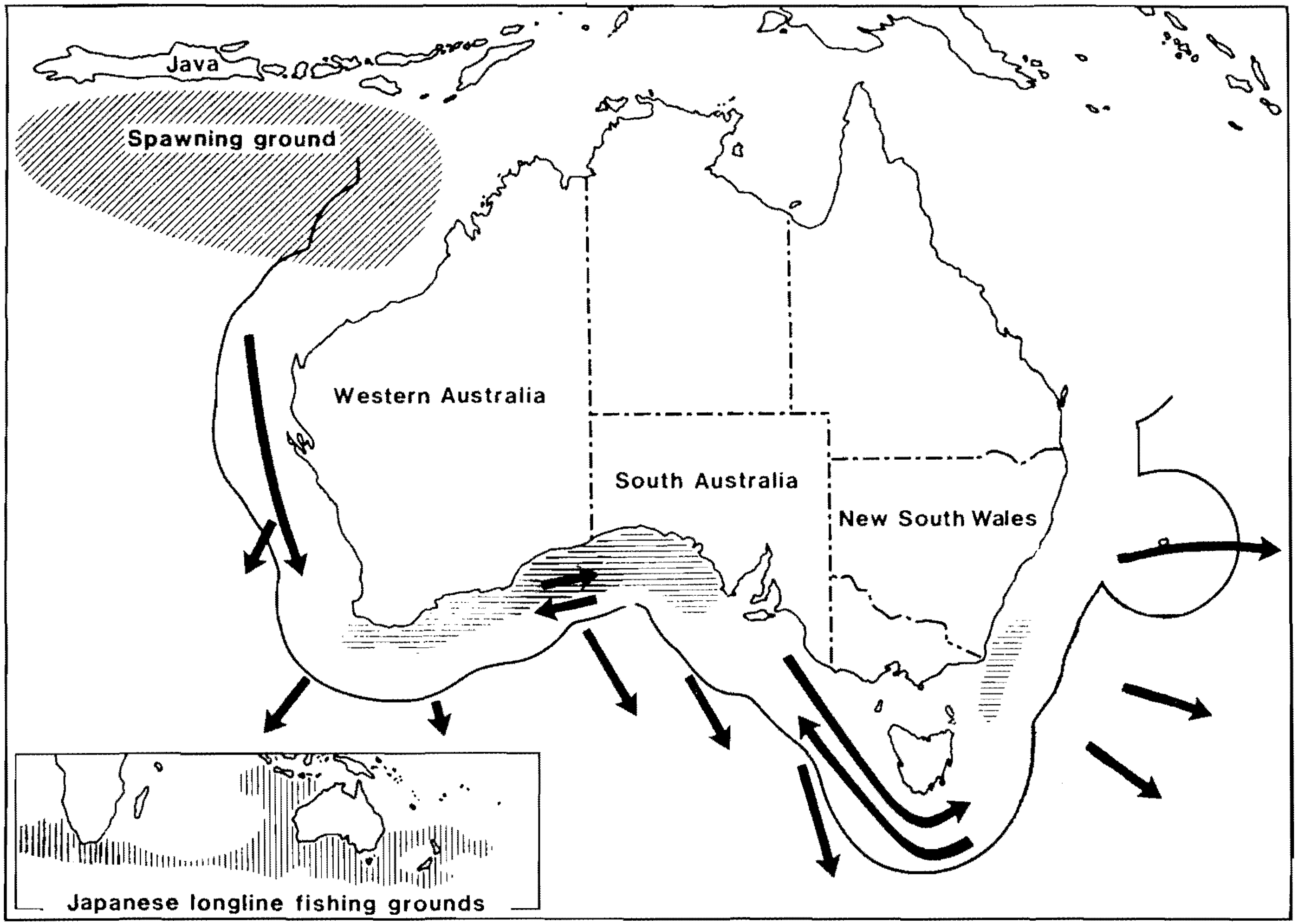

Fig. 13. Southern bluefin tuna spawning ground and migration pattern within and out of Australian waters. The 200-mile Australian fishing zone is indicated by the solid line and the horizontal hatching indicates the composite distribution of the Australian surface fishery. The general distribution of Japanese longline fishing is inset. (Modified from Majkowski et al. 1988).

NSW fishery during their second year at liberty. The tag return data also indicate that some fish move offshore from WA to the south and west and become available to the Japanese longline fishery as 2-year-olds to 5-year-olds.

Table 6 suggests that SBT remain available to the SA fishery for about two years, but substantial numbers of fish also move into the NSW fishery during this time. In contrast, a tagging experiment in SA in 1984 produced recaptures in that fishery for four years, with only four recaptures reported from the NSW fishery (CSIRO unpublished data). There appears to be relatively little movement back to WA inshore waters from the SA fishery. On the other hand, there is some movement of 2-year-olds and 3-year-olds from the SA fishery into the West Wind Drift areas of the Indian and Southern Oceans and the Tasman Sea. The data in Table 6 suggest that offshore movement to the east is more likely from SA than from WA, with larger numbers of SA releases being recaptured in the Tasman Sea and east of New Zealand. Nevertheless, there also seems to be some movement from SA into the Indian Ocean soon after tagging, and subsequently into the fishing area off South Africa.

Juvenile SBT live in eastern Australian waters for up to three years, during which time there is some return movement to SA waters and into the Tasman Sea and the Southern Ocean. Fish tagged in NSW have been recaptured by Japanese longliners to the east of New Zealand after two years at liberty. There have been relatively few recaptures of these fish in the Indian Ocean and none in the WA domestic fishery; however, most tagging in NSW was carried out before the start of commercial tuna fishing in WA.

Although there have been no recaptures of tagged fish in the spawning area (Japanese longline effort in this area was greatly reduced at the time when recaptures of adult fish might have been expected), adult SBT are thought to move northward from the West Wind Drift into the spawning grounds during late spring and summer (Shingu 1978).

A variation on the model illustrated in Fig. 13 has been proposed by Murphy (1977), who suggested that a large part of the juvenile population moving down the west coast of Australia turns to the west and never enters the Australian surface fisheries. This hypothesis is supported by the observation that the Japanese longline catch rate of 2-year-olds to 4-year-olds off South Africa, while not as great as that in the Tasman Sea (6.5 fish per 1000 hooks compared with 9.4 fish per 1000 hooks over the period 1969-1985), is nonetheless substantial. Murphy reasoned that, if these small fish are similarly vulnerable to longlining in both areas and originate from the only known spawning area, the simultaneous presence of large numbers of the same cohort in fishing grounds separated by more than 10 000 km must indicate a major divergence in migratory path. A recent analysis of tagging data by Ishizuka (1987) supports this conclusion.

The hypothesis of an east-west cohort separation was enlarged upon by Harden Jones (1984), who suggested that some larvae might be carried westwards in the South Equatorial Current directly from the spawning ground and enter African waters, while others might continue in the southern Indian Ocean gyral and approach Australia from the west. The drift of satellite-tracked buoys (Creswell and Golding 1979) suggests that the latter journey could be accomplished in 2-3 years, which is consistent with the appearance of fish of this age off south-western Australia.

A further variant of the traditional migration model was proposed by Harden Jones (1984), who suggested that movement from the Pacific to the Atlantic Ocean via Drake Passage (which separates South America from Antarctica) might be possible. In support of this hypothesis, Harden Jones cited an observation by Hynd (1969) that 'all fish tagged between 1962 and 1965 were prevented in some way from moving westward (but not eastward) up till 1966; after this dispersion to the westward became possible ...'. Harden Jones suggested that the delay in the capture of tagged SBT to the west of Australia was consistent with the time needed to make the journey across the Pacific Ocean, into the Atlantic Ocean via Drake Passage and into the Indian Ocean past the Cape of

Table 6. Geographical distribution of recaptures of southern bluefin tuna tagged between 1959 and 1980, by time at liberty. The numbers of releases were Western Australia (WA): 29 169; South Australia (SA): 9716; and New South Wales (NSW): 13 533. (from Hampton 1989).

		Number of recaptures								
		Australian surface fisheries			Japanese longline fishery					
Release area	Years at liberty	WA	SA	NSW	South Africa (Area 9,10)	Indian Ocean (Area 8)	Southern Ocean (Area 3,7)	Tasman Sea (Area 4)	New Zealand (Area 5,6)	Total
WA	0-1	609	245	58	0	2	2	2	0	918
	1-2	13	211	152	1	2	1	0	0	380
	2-3	1	25	26	10	6	12	6	0	86
	3-4	1	3	5	2	3	10	7	1	32
	4-5	0	2	1	15	4	3	3	3	31
	5-6	0	2	2	15	3	1	0	0	23
	6-7	0	1	1	3	1	1	1	1	9
	>7	0	0	0	6	1	5	2	2	16
	Total	624	489	245	52	22	35	21	7	1495
SA	0-1	12	1004	160	1	4	2	7	0	1190
	1-2	0	118	43	1	3	9	12	1	187
	2-3	0	8	22	1	8	8	9	2	58
	3-4	0	3	2	6	5	2	7	5	30
	4-5	0	0	1	8	5	6	1	4	25
	5-6	0	0	0	3	5	3	0	1	12
	6-7	0	0	0	2	0	5	0	2	9
	>7	0	2	0	8	2	5	0	3	20
	Total	12	1135	228	30	32	40	36	18	1531
NSW	0-1	0	70	3416	0	0	3	8	1	3498
	1-2	0	43	996	0	1	9	10	0	1059
	2-3	0	11	92	2	1	8	10	6	130
	3-4	0	0	5	1	0	1	2	3	12
	4-5	0	0	0	2	1	1	1	2	7
	5-6	0	0	1	0	0	0	0	0	1
	6-7	0	0	1	0	1	2	0	3	7
	>7	0	1	0	1	2	6	0	4	14
	Total	0	125	4511	6	6	30	31	19	4728
Total	0-1	621	1319	3634	1	6	7	17	1	5606
	1-2	13	372	1191	2	6	19	22	1	1626
	2-3	1	44	140	13	15	28	25	8	274
	3-4	1	6	12	9	8	13	16	9	74
	4-5	0	2	2	25	10	10	5	9	63
	5-6	0	2	3	18	8	4	0	1	36
	6-7	0	1	2	5	2	8	1	6	25
	>7	0	3	0	15	5	16	2	9	50
	Total	636	1749	4984	88	60	105	88	44	7754

Good Hope. A simpler and more plausible explanation is that there was very little Japanese longline effort in the southern Indian Ocean between Australia and South Africa until 1967; the probability of recapturing tagged SBT in this area before 1967 was therefore very small. This is readily seen from Table 7, which shows a strong correlation between the geographical distribution of tags recovered by Japanese longliners and the geographical distribution of effort.

STOCK STRUCTURE, DISTRIBUTION AND MIGRATION AS DETERMINED FROM OTHER METHODS

For the last several years a means of determining directly the migration patterns of individual SBT has been in progress. This technique takes advantage of the effects of a seasonally and spatially variable environment on the chemical composition of fish otoliths. Considerable work has demonstrated that the isotopic and elemental composition of calcified structures in marine organisms (e.g. molluscs, foraminiferans, corals and fishes, including tuna - see Radtke et al. 1987) is dependent upon environmental conditions such as water temperature. To the extent that habitats differ, the composition of otoliths of fishes living in those habitats will also differ. Hence, if juvenile SBT migrate along two different routes, each of which cross different water masses, then otoliths of fishes in the adult population should show evidence of two different patterns of composition. If there are adults that fall outside the range of composition found in juveniles collected from the known spawning-nursery areas, then it implies strongly that all of those juvenile habitats have not been identified.

Data on the effects of temperature on otolith microchemistry have been provided for several species of fish, including cod (*Gadus morhua*), striped mullet (*Mugil cephalus*) and the Antarctic cod (*Notothenia larseni*). The use of such environmentally induced 'fingerprints' for stock discrimination and analysis of migration patterns has also been attempted for several species. In a study similar in concept to that for SBT, environmentally induced variations in the composition of scales and vertebrae were used to identify stocks of the sockeye salmon, *Oncorhynchus nerka*, in Canadian rivers (Lapi and Mulligan 1981, Behrens Yamada et al. 1987). Gauldie et al. (1986) found evidence of separate stocks of a cheilodactylid and of salmon off New Zealand, based on differences in the iron content of their otoliths. Calaprice (1980-85) has used microchemical analysis to investigate stock structure and movements of Pacific yellowfin tuna (*Thunnus albacares*) and Atlantic bluefin tuna (*T. thynnus*), providing strong evidence of regional differences in composition and of patterns of individual movement by bluefin tuna across the Atlantic. Local variations in elemental composition have been used to discriminate among stocks of striped bass off the eastern United States (Mulligan et al. 1987) and snapper off WA (Edmonds et al. 1989).

Emphasis to date on SBT has been mainly on the development of analytical techniques that provide precise and accurate data on composition. The analytical technique chosen, wave-dispersive X-ray microanalysis, has the resolution to provide data on trace element variations in otoliths. However, there has not been a rigorous examination of the analytical procedures, their sensitivity, and the biases associated with the application of the technique to aragonitic structures (e.g. otoliths). Examination of the large number of SBT required to provide answers to the questions on migration patterns posed above has only recently begun. Thus far, 'life history' traces for otoliths of approximately 50 juvenile and adult SBT have been determined, and the complex multi-element trajectories produced are currently being analysed statistically.

Results to date suggest a consistent pattern of ontogenetic variation in composition for juveniles in Australian coastal waters. This pattern is evident in a large majority of the adult otoliths examined to date. Nonetheless there are also a few otoliths that appear to be 'different', in terms of the absolute values of elemental ratios and in the patterning of these ratios across the axis of an otolith. This individual variability cannot, as yet, be explained unambiguously. The data suggest considerable interannual variability in the composition of otoliths of fishes migrating along the

Table 7. Geographical distribution of recaptures (R) of southern bluefin tuna (SBT) tagged in Australian waters between 1959 and 1980 and recaptured by Japanese longliners, by year of recapture. Japanese longline effort (E) is also given. Total effort for 1963 to 1979 includes effort in Areas 1 and 2. Effort in these areas directed at SBT is negligible after 1980. (from Hampton 1989).

Number of tag returns and amount of effort[1] (million hooks) by Japanese longliners

Year of recapture	South Africa (Areas 9,10)		Indian Ocean (Area 8)		Southern Ocean (Areas 3,7)		Tasman Sea (Area 4)		New Zealand (Areas 5,6)		Total	
	R	E	R	E	R	E	R	E	R	E	R	E
1963	0	0.3	0	0.0	0	1.7	2	7.7	0	1.4	2	36.6
1964	0	0.2	0	0.0	2	1.4	7	5.2	0	1.2	9	33.4
1965	0	1.5	0	0.0	5	2.5	15	7.0	1	2.5	21	40.4
1966	0	1.2	0	1.3	10	15.4	22	9.0	4	3.3	36	51.6
1967	0	1.7	28	28.1	5	6.8	15	5.1	1	3.4	49	66.1
1968	6	6.3	10	24.2	20	24.2	8	4.5	3	3.0	47	77.4
1969	34	23.8	8	19.8	11	16.1	4	3.6	7	11.2	64	79.5
1970	15	26.0	2	14.4	15	23.9	3	2.9	9	11.2	44	89.8
1971	7	15.2	4	13.6	10	34.1	5	7.4	4	20.0	30	101.3
1972	6	25.2	1	8.2	7	31.5	4	7.0	8	18.3	26	91.7
1973	4	33.0	1	14.5	3	26.1	1	8.2	4	11.2	13	96.6
1974	4	32.0	1	10.1	4	23.9	0	6.1	0	14.0	9	93.9
1975	2	26.9	1	18.3	3	19.5	0	2.5	0	12.6	6	86.9
1976	0	23.7	2	26.9	1	24.3	0	3.1	1	28.1	4	107.2
1977	3	19.8	2	30.5	3	17.1	0	2.0	0	17.2	8	87.6
1978	2	39.4	0	12.5	3	18.6	1	4.0	0	2.8	6	79.0
1979	1	48.4	0	13.7	2	17.9	0	5.0	0	18.0	3	104.3
1980	2	43.1	0	21.3	0	27.0	1	4.2	2	26.2	5	121.8
1981	1	45.9	0	13.2	1	19.0	0	5.4	0	18.2	2	101.7
1982	0	44.9	0	16.1	0	8.2	0	6.3	0	22.0	0	97.5
1983	0	46.1	0	22.8	0	14.6	0	6.1	0	14.9	0	104.5
1984	0	49.0	0	28.4	0	15.3	0	3.7	0	14.0	0	110.4
1985	1	41.1	0	36.4	0	18.6	0	1.8	0	11.9	1	109.7
Total	88		60		105		88		44		385	

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[1] Source: Annual Reports of Effort and Catch Statistics by Area for Japanese Longline Fishery, 1963 to 1979, Japan Fishery Agency, Tokyo, Japan. Effort statistics for 1980 to 1985 are from Kono (1987).

Australian coast; until this factor is evaluated, the limits of 'typical' Australian fishes cannot be defined completely.

It is anticipated that an analysis of SBT data will be completed within the next two years, provided that additional material from other areas can be obtained. One problem was the very limited availability of otoliths from adult fishes caught well outside the Australian fishing region. Samples which had already been collected are more limited in scope than previously thought. A thorough assessment of the variability in otolith composition will require samples of fish from other parts of the Southern Ocean. In particular, such material from the southern African region has been sought since there are persistent reports of 3-year-old to 4-year-old SBT in that region. It is unlikely that these juveniles participate in the full migration along the Australian coast; they could provide an outgroup for the comparison of elemental variations with known Australian fishes.

CONCLUSIONS ON STOCK STRUCTURE

A single spawning area, morphological uniformity, and the tag return data are strongly suggestive of a single, circumpolar population. The restricted nature of spawning in both time and space offers little opportunity for population differentiation by way of reproductive isolation. High vagility (as evidenced by the numerous long-distance tag returns) in relation to the geographical distribution indicated by the range of longline catches would also suggest limited potential for population differentiation. It is interesting to note that before tagging data clearly demonstrated the degree of movement between the WA, SA and NSW fisheries, it was commonly thought that separate populations of SBT existed in southern and eastern Australian waters (Serventy 1956, Robins 1963).

8. NATURAL MORTALITY

The natural mortality rate (M) of SBT is required for the understanding of its biology, population dynamics and management. It is an input parameter to the method of cohort analysis or virtual population analysis (VPA) and is required for yield-per-recruit analyses.

Hayashi et al. (1969) mentioned that Shingu and Hayashi (1966) estimated M to be 0.23 per year from the linear relationship between fishing effort and total mortality of 8-year-old fish. The relationship had been observed, but not quantified, by Kamimura et al. (1966: 775). Using Tanaka's (1960: 166) graph of M plotted against the oldest age for five fish species, and assuming the oldest age of SBT to be 13-15 years, Hayashi et al. (1969) calculated M to be 0.15-0.18 per year. Using the Taylor (1958) method of estimating M on the basis of the growth parameter K, Hayashi et al. (1969) concluded that the two parameters were approximately equal i.e. a value of 0.15 per year for M. On the basis of these three different approaches Hayashi et al. (1969) assumed M to be 0.20 per year.

Virtual population analyses require input values of M. The effect of uncertainties in M upon SBT population estimates, was first assessed in Majkowski and Hampton (1983b) by assuming M to be 0.2 ± 0.1 per year. Since then sensitivity of VPA results to M have been evaluated in this way.

Hearn et al. (1987) developed a method for estimating M from tag recapture data without assumptions about the fishing effort, except that it continue while tagged fish are still alive. The method was applied to SBT tagged in the 1960s. Assuming full reporting of tags and the Kirkwood (1981) tag shedding rate, Hearn et al. (1987) estimated M to be 0.465 (S.E. 0.036) per year. Assuming a 50 % reporting rate they estimated M to be 0.410 (S.E. 0.030) per year.

The method of Hearn et al. (1987) was found by Leigh (1988) to estimate M with infinite variance if fishing mortality was lower than natural mortality. Barndorff-Nielsen et al. (1989a, b) investigated this matter further and Leigh (1989) found that a small variation to the Hearn et al. (1987) method would allow estimates of M from experiments where fishing mortality was down to about 40 % of M. The low proportion (17.2 %) recovered of fish double tagged in the 1960s, indicates that the Hearn et al. (1987) method is likely to be unsuitable for estimating M from SBT tag recapture data.

Hampton (1989) estimated M from recovery data from four tagging experiments in the 1960s, where

- (a) fish were tagged off NSW by CSIRO;
- (b) fish were tagged off NSW by a fisherman under contract to CSIRO;
- (c) fish were tagged off SA by CSIRO; and
- (d) fish were tagged off WA by CSIRO.

The tag shedding rate was estimated separately for each experiment and these are listed in Hampton and Kirkwood (1990). Assuming full reporting, estimates of M were 0.199-0.417 per year, whereas for 50 % reporting they were 0.115-0.371 per year. For one assumed tag-shedding model, estimates of M from fish tagged in SA and WA [experiments (c) and (d)] were close to the high end of the range of M values, as were estimates from those tagged off NSW by CSIRO [experiment (a)]. For a different tag-shedding model, estimates of M from experiment (a) and from fish tagged off NSW under contract were close to the low end of the range of M values. Hampton (1989) argued that the difference between the low and high values of M could be attributed to the tag-shedding model used, with the model that assumed constant shedding rate corresponding to low estimates of M, and the one that assumed a decreasing rate corresponding to high estimates of M.

The Sibert (1984) method for analysing interacting fisheries was extended by Hampton (1989).

The model requires that fish be tagged in two fisheries, and that recaptures be made in either of these fisheries or a third fishery. Natural mortalities, catchability, and transfer coefficients (all assumed constant) can be calculated from tag recapture and effort data. In applying the model to SBT, Hampton (1989) let the first fishery be the NSW fishery where tagging was done by contract [i.e. 'experiment (b)'], and the third fishery be the Japanese longline fishery. The second fishery was alternatively taken to be the SA and the WA fisheries. M was assumed constant. In the first analysis (with SA as the second fishery) an estimate of M of 0.230 per year was obtained, but in the second analysis (with WA as the second fishery) the estimate for M was 0.1997 per year. Full reporting of tags was assumed in both cases. For the assumption of 50 % reporting, the corresponding estimates for M were 0.119 per year and 0.061 per year. No explanation is given as to why the extended interaction model was not applied to data from fish tagged by the CSIRO off NSW in the 1960s [experiment (a)].

Hearn (1988) applied the Petersen method to data from fish tagged in 1983-84 to estimate population numbers. The numbers of the 1979-80, 1980-81 and 1981-82 year-classes were estimated and are compared, in Tables 8 and 9, with VPA estimates from commercial catch statistics. In Table 9 it can be seen that the population estimates from tagging are little affected by the assumed value of M. However, the equivalent VPA estimates are very sensitive to uncertainties in M. If one interpolates the population number as a linear function of M for both methods until they are equal, an estimate of M may be obtained. These estimates range from 0.11 to 0.25 per year.

The population numbers in Table 9 that are derived from tagging data refer to the fraction of the global population that passes through Australian waters and so are likely to be underestimates. Consequently, the values of M estimated by this method could be underestimated.

The estimates of catch numbers in the year-classes considered are estimated by using the Kirkwood (1983) age-length growth curve derived from recaptures of fish tagged in the 1960s. However, Hearn (1986) and Hampton (1989) showed that growth of fish tagged in 1983-84 was considerably faster than those tagged in the 1960s. Consequently, the catch numbers of the year-classes since 1979-80 should be recalculated using growth information from recaptures from the 1983-84 releases. This would allow population estimates of Table 9 to be recalculated to produce new estimates of M.

Since 1988, more commercial catch information has become available for the year-classes considered in Table 9. Consequently, VPA estimates for the year-classes being considered would be more accurate, thus leading to more certain estimates of M.

All reliable analyses indicate that the rate of natural mortality is within the range 0.2 ± 0.1 per year. Further careful analyses may yield closer bounds of M.

Table 8. Estimates and coefficients of variation of recruitment at age 1, derived using data from the 1983 and 1984 southern bluefin tuna tagging program and corresponding catch information, for 3 year-classes, 3 tagging sites and 3 values of natural mortality rate. The Petersen method was used to obtain a population estimate from Port Lincoln returns of tagged fish and commercial catches. Recruitment estimates were derived from this information and they are compared with those from virtual population analysis (VPA) of the global catch.

Year class	Tagging site	Age at tagging (years)	Number (thousands) recruited at age 1 if natural mortality rate (M) per year is			Coefficient of variation (%)
			0.1	0.2	0.3	
1979-80	Esperance	3.1	3714	4478	5417	8.6
	VPA		2700	4429	10 622	
1980-81	Esperance	2.1	6518	7270	8106	5.2
	Albany	2.8	3974	4642	5425	5.6
	Port Lincoln	3.1	3682	4431	5322	8.6
	VPA		2700	4453	10 867	
1981-82	Albany	1.8	3403	3652	3915	7.6
	Port Lincoln	2.1	2722	3048	3413	4.0
	VPA		2602	4287	10 492	

Table 9. Estimates of recruitment at ages 2 and 3 years (derived using data from the 1983 and 1984 southern bluefin tuna tagging program, for fish that were tagged when close to the age of recruitment) and corresponding catch information, for 3 values of natural mortality rate. These estimates are compared with those from virtual population analysis (VPA) of the global catch.

Year class	Tagging site	Age at tagging (years)	Number (thousands) recruited at age 1 if natural mortality rate (M) per year is: 0.1	0.2	0.3
			.... Recruited at age 2		
1980-81	Esperance	2.1	5898	5952	6005
	VPA		2443	3646	8050
1981-82	Albany	1.8	3079	2990	2900
	Port Lincoln	2.1	2463	2496	2528
	VPA		2354	3510	7750
			.... Recruited at age 3		
1979-80	Esperance	3.1	3041	3002	2973
	VPA		2211	2969	5829
1980-81	Albany	2.8	3254	3112	2977
	Port Lincoln	3.1	3015	2970	2921
	VPA		2211	2985	5964

9. THE SOUTHERN BLUEFIN TUNA FISHERIES

THE AUSTRALIAN SBT SURFACE FISHERY

Development

At certain times of the year, juvenile SBT form large surface schools off southern and south-eastern Australia. The Australian surface fisheries for SBT have been characterised by a major expansion phase which lasted almost three decades from the mid-1950s, and was followed by rapid contraction after 1983 resulting from management action and changes in fish abundance and distribution.

Although occasional catches of SBT were recorded off the NSW coast before the 1950s, the fishery there did not become commercial until the mid-1950s when pole and live-bait techniques were introduced from the United States. The NSW and SA fisheries developed along similar lines throughout the 1960s (Table 10). The NSW fishery operated from September to January, whereas the SA fishery operated from December to May.

The SA SBT fleet consisted largely of single-purpose pole and live-bait vessels. Some vessels moved seasonally to other fisheries, but most fished SBT off NSW during the season there, then returned to SA for the local season. The NSW fleet was predominantly multi-purpose. Some vessels fished both the NSW and SA SBT seasons but many remained in NSW after the SBT season and converted from pole and live-bait gear to trawling or Danish seining for other species. During the 1960s, the NSW catch was dominated by 2-year-old SBT whereas the SA catch was dominated by 3-year-olds and 4-year-olds.

Major changes took place in the 1970s. The SA fishing activity spread westwards and the dominant ages of fish in the catch shifted to 2-year-olds and 3-year-olds, with a considerable number of younger fish as well. In the NSW catch, 2-year-olds were usually dominant but in several years 4-year-olds and 5-year-olds dominated. In the 1970s the number of fish 6 years old and older in the catch increased. NSW fishers began searching further offshore because fewer fish were found in the traditional fishing area. The move was accelerated by the introduction of larger pole boats, purse-seining vessels and the use of long-range spotter aircraft. Because of concerns about the possibility of a rapid increase in effort, purse-seining boats were limited to six.

Aerial spotting of SBT schools had begun with a small number of aircraft in the 1960s in NSW and SA. The number increased to more than 10 by the 1980s, by which time longer-range aircraft with efficient navigation and communication equipment could direct vessels more accurately to surface schools in distant areas. This increased the effective fishing effort by reducing searching and re-locating time, an important factor when fish were scarce.

The successful use of purse-seiners from the mid 1970s had a major impact on NSW and SA fisheries. Purse-seiners operating independently had been able to make occasional successful sets on SBT. In contrast, almost every set was successful when a pole boat kept a school feeding at the surface with live bait, while the purse-seiner completed its set around the fish and pole boat. Such fishing techniques led to an increase in the catches of larger SBT, as purse-seiners were more effective in capturing them than were pole fishing vessels. Since the late 1970s the surface fishery has been heavily dependent on combined pole vessel and purse-seine sets.

The WA fishery for SBT developed more recently than the NSW and SA fisheries. Commercial trolling operations commenced in 1968 but the fishery evolved to a pole fishery, using dead bait. Small trolling vessels were steadily replaced with larger, longer-ranging pole vessels (purse-seining for SBT was prohibited in WA) but, in general, vessels in the WA fleet remained far

Table 10. Southern bluefin tuna catch by state, and by quota year, 1951-52 to 1989-90.

Quota year	Western Australia		South Australia		New South Wales	
	Tonnes	Number	Tonnes	Number	Tonnes	Number
1951/52			20	1 344	49	4 132
1952/53			30	2 030	244	19 643
1953/54			5	316	479	37 858
1954/55			24	1 620	419	33 019
1955/56			199	13 637	298	24 243
1956/57			387	26 548	765	60 763
1957/58			554	38 017	877	70 715
1958/59			700	48 043	1 768	140 121
1959/60			1 396	95 843	1 786	142 023
1960/61			2 255	154 835	2 149	169 290
1961/62			3 377	231 888	1 423	112 530
1962/63			3 589	246 447	1 259	101 626
1963/64			5 517	378 883	2 610	251 282
1964/65			4 730	288 659	2 261	227 602
1965/66			5 994	416 813	2 246	162 451
1966/67			3 385	245 253	2 144	166 149
1967/68			2 926	263 376	3 672	362 347
1968/69	299	69 219	3 255	427 716	5 129	665 188
1969/70	708	189 015	3 123	333 705	5 885	628 736
1970/71	600	121 405	2 817	343 550	3 611	537 385
1971/72	757	128 537	4 374	454 015	5 033	371 471
1972/73	308	63 946	6 835	506 172	6 133	288 436
1973/74	273	59 799	6 988	756 126	1 811	83 481
1974/75	1 142	202 828	4 842	599 045	5 276	310 630
1975/76	395	43 033	6 938	865 455	2 466	195 544
1976/77	841	103 716	8 789	1 159 693	308	37 067
1977/78	1 846	528 157	4 934	548 020	4 814	243 398
1978/79	2 311	450 000	4 338	631 782	4 332	223 555
1979/80	2 358	366 055	6 855	1 082 576	3 611	159 157
1980/81	2 822	516 116	9 877	819 400	3 427	137 519
1981/82	3 816	651 964	12 748	1 184 435	3 267	117 172
1982/83	5 478	1 113 144	13 831	1 244 140	1 648	122 121
1983/84	4 516	774 782	10 419	831 794	899	20 521
1984/85	2 097	321 189	11 271	727 230	118	2 480
1985/86	1 146	186 074	12 088	887 054	4	89
1986/87	1 234	212 592	10 029	640 665	45	1 095
1987/88	1 104	207 069	9 849	871 514	24	790
1988/89	426	55 220	4 872	412 805	2	100
1989/90	200 (est.)	35 000 (est.)	4 199	285 022	19*	

*Includes predominantly the catches of small trolling vessels operating off eastern Tasmania; a small proportion represents New South Wales longline catch.

smaller and more diversified in their fishing activities than those in the NSW and SA tuna fleets. The average size of SBT taken by the WA fleet (2-year-olds) was the smallest of any of the Australian fisheries.

By 1982/83, the geographic expansion, and increased effective effort of the Australian fishery, culminated in the peak catch of 21 000 t. Whereas most of the earlier westwards activities in the SA fishery had been directed at 'lumps' (submerged reefs) on the continental shelf, activities expanded further westwards and offshore beyond the shelf. Southern bluefin tuna from these 'wide' grounds were substantially larger than those on the 'lumps'. The WA fishery catch had expanded rapidly during the late 1970s and early 1980s because activities had extended to include waters beyond the continental shelf and eastwards to the western side of the Great Australian Bight, some vessels linking with SA based activities.

In the NSW fishery, in contrast, the catch slumped in 1982-83 to less than half of the average for the preceding five years. Also, the average size of fish caught increased, productive areas diminished and became more scattered, and the season shortened. By 1985 the NSW fishery failed completely, and surface catches had not resumed at the time of writing.

Quotas were introduced to the Australian fishery in 1983, and were progressively reduced in subsequent years. This resulted in a major restructuring of the SBT fleet and fishery. Virtually all activity is now centred in SA, and the fleet has many fewer boats. Restructuring off WA and SA was largely driven by economics, but the underlying reason for reduced activity off NSW was the decreasing availability of fish.

Quota management in the Australian SBT fishery

Quota management in the Australian fishery was not introduced, in its present form, until 1 October 1984. It followed an unsuccessful trial of a licence freeze for the second half of the 1970s. Management was introduced as a result of international scientific concern at the status of the SBT parent stock which was estimated, at the time, to be possibly as low as 25 % of its pre-exploitation level. Subsequent meetings of scientists have been held annually and more recent indications are that the stock has been depleted even further (in 1989 stock was estimated at between 8 % and 25 % of the 1960 level).

At international meetings in 1982 (Wellington) and 1983 (Tokyo), representatives of three SBT fishing nations (Australia, Japan and New Zealand) agreed on the need for some type of internationally coordinated management policy. It was recognised that with a highly migratory species such as SBT there was a real risk that benefits of unilateral action by one nation could be dissipated if there were increased catches by other fleets. This commitment to an internationally coordinated approach has been repeated in the trilateral forum but is not yet formally in place.

The Australian SBT Fishery Management Plan was introduced after extensive consultation with state governments, scientists and industry organisations. In recognition of the urgency of the global situation Australia adopted an interim management plan for the twelve months from 1 October 1983 for the domestic fishery. This was to halt any increase in the total Australian catch (21 000 t) pending the finalisation of the current plan. The interim plan was based on a total allowable catch, with the understanding that fishing would cease on its achievement.

The current plan is based on individual transferable quotas, in the first instance allocated to eligible fishermen. To be eligible, fishers had to demonstrate a commitment to and dependence on the SBT fishery over the three years (1980-81 to 1982-83) preceding the introduction of the plan (i.e. at least 15 t in any of the three years).

It was recognised at the outset that catches would have to be reduced and that it was therefore inevitable that some economic disturbance would occur. Scientific advice, however, was that the stock would be in jeopardy should open access continue.

Implementation of the plan was achieved by the allocation of percentages of an annually reviewable total allowable catch. This was set at 14 500 t for 1984-85. The allocation of shares was determined by an objective formula which took account of both the best catch in any of the three 'eligibility' years and the value of boat and gear. The formula was weighted 3:1 in favour of the catch.

The choice of the three years was discussed in detail by the formal council of Australian fisheries ministers because this would have a major impact on the distribution of quotas. The structure of the fishery had changed significantly over the preceding ten years with the NSW tuna fleet, previously the main sector, recording progressively lower catches while the catches by WA boats had been increasing. The majority of initial quota allocations went to South Australian vessels. Many of the NSW boats were dual-purpose vessels taking tuna in season and also trawling for other species. They were able to increase their efforts in trawling and therefore to ameliorate the impact of their reduced permissible SBT catches. Many WA vessels left the fishery.

In South Australia the tuna fleet was showing signs of over-capitalisation prior to the introduction of quotas. As the initial allocations were only 40-60 % of each vessel's best annual catch during the eligibility period, vessels in general required additional quota to remain viable. The transferability of quotas provided a mechanism for this, with the purchase of quota by vessels remaining in the industry financing the withdrawal of other vessels. Clearly the biological objective of the plan, the major objective, could have been achieved by the application of a total quota.

The Australian industry considers that it has accepted severe hardships in the management regime and that cuts of the magnitude considered necessary have not been matched by the New Zealand and Japanese industries. The Japanese catch is lower than when the Australian plan was introduced but the perception of the Australian industry is that this represents a function of depletion of the stock (the general downward trend began long before the commencement of the trilateral discussions) rather than Japanese restraint. This view was reinforced by the fact that even after the application of a global quota, the Japanese fleet has been unable to fill it and the progressive reductions in the quota have generally followed reductions in catch. Australian catches, on the other hand, have always been restrained by the quota (Table 11).

It should be emphasised that it is unlikely that in the absence of the plan the Australian catches would have been maintained at the 1982-83 level. Scientific evidence suggests that catches would have eventually declined as a consequence of declining recruitment. It is believed that the introduction of the plan, accepting the regrettable but inevitable short-term economic impact, will provide improved escapement from the surface fishery; this should give the stock a chance to recover and the industry the possibility of viable catch levels in the future.

Further information about the development of the fishery and management can be found in Murphy (1979), Caton (1985), Franklin (1987), Caton (1988), Geen and Nayer (1989) and Caton, et al. (1990).

THE JAPANESE LONGLINE FISHERY

Development of the fishery

The Japanese SBT fishery is a longline fishery. Its geographical development is shown in Fig. 14, based on the distribution of longliners' fishing effort.

Table 11. Southern bluefin tuna catch limits, periods of catch limit operation, and catches realised for Australia, Japan and New Zealand since 1983.

Neg. year: negotiation year, the year when the catch limit indicated was determined. *Op. period*: operating period, the period for which the catch limit applied. The Australian limit commences on 1 October of the negotiation year, the New Zealand limit on 1 January in the subsequent year, and the Japanese limit on 1 March of that subsequent year. *Catch limit* and *catch realised*, given in tonnes unless indicated otherwise. Abbreviations: est., estimate; SNC, season not completed.

Neg. year	Australia Op. period	Australia Catch limit	Australia Catch realised	Japan Op. period	Japan Catch limit	Japan Catch realised	New Zealand Op. period	New Zealand Catch limit	New Zealand Catch realised
1983	1.x.83 to 30.ix.84	21 000[A]	15 843	Nil	Nil	23 323 (1984)	1.i.84 to 31.xii.84	10 000[B] (fish)	93
1984	1.x.84 to 30.ix.85	14 500[C]	13 486	Nil	Nil	20 393 (1985)	1.i.85 to 31.xii.85	10 000 (fish)	94
1985	1.x.85 to 30.ix.86	14 500	13 237	1.iii.86 to 28.ii.87	23 150	15 522 (1986)	1.i.86 to 31.xii.86	1 000	82
1986	1.x.86 to 30.ix.87	11 500[D]	11 308	1.iii.87 to 29.ii.88	19 500[D]	13 955 (1987)	1.i.87 to 31.xii.87	1 000[D]	59
1987	1.x.87 to 30.ix.88	11 500[D]	10 976	1.iii.88 to 28.ii.89	19 500[D]	11 422	1.i.88 to 31.xii.88	1 000[D]	93
1988	1.x.88 to 30.ix.89	6 250[E]	6 118[F]	1.iii.89 to 28.ii.90	8 800[E]	8 984 (est.)	1.i.89 to 31.xii.89	450[E]	424[G]
1989	1.x.89 to 30.ix.90	5 265[H]	4 450[I] (est.)	1.iii.90 to 28.ii.91	6 065	SNC	1.i.90 to 31.xii.90	420	SNC

[A] The 1983–84 Australian catch limit provisions consisted of a total quota of 21 000 t, with 4000 t allocated to the Western Australian fishery (where no purse seining was permitted), and 15 000 t to the south-eastern (i.e. New South Wales and South Australian) fishery; the purse-seine component in the latter was limited to 5000 t. A further 2000 t was set aside as reserve/developmental quota for activities specially diverted towards larger fish. 500 t of fish larger than 70 cm from the Western Australian fishery were debited against that component.

[B] New Zealand had previously maintained a quota of 5000 fish for its domestic southern bluefin tuna catch.

[C] The 1984–85 Australian catch limit was distributed among vessels as individual transferable quotas; this arrangement has continued for subsequent Australian seasons.

[D] Australia and Japan maintained national quotas of 14 500 t and 23 150 t respectively but agreed to a global catch limit of 31 000 t. Additionally they agreed that their national catches would not exceed 11 500 t and 19 500 t respectively. A 'development' quota of 1000 t was reserved for New Zealand.

[E] Joint-venture longlining arrangements were established between Japan and Australia, and Japan and New Zealand. The subsequent deployment of catch limits was: Australia, 6250 t (5480 t domestic; 770 t joint-venture); New Zealand, 450 t (150 t domestic; 300 t joint-venture); Japan, 9870 t (8800 t domestic; 1070 t joint-venture).

[F] Value comprises 5434 t from domestic surface fishery and 684 t from Australia/Japan joint-venture longline vessels.

[G] Value comprises 134 t from domestic handline/troll fishery and 290 t from New Zealand/Japan joint-venture longline vessels.

[H] Joint-venture longline arrangements were established between Japan and Australia. The subsequent deployment of catch limit was: Australian domestic, 4865 t; Australia/Japan joint venture, 400 t.

[I] Estimate of Australian domestic catch; data for joint venture not yet complete.

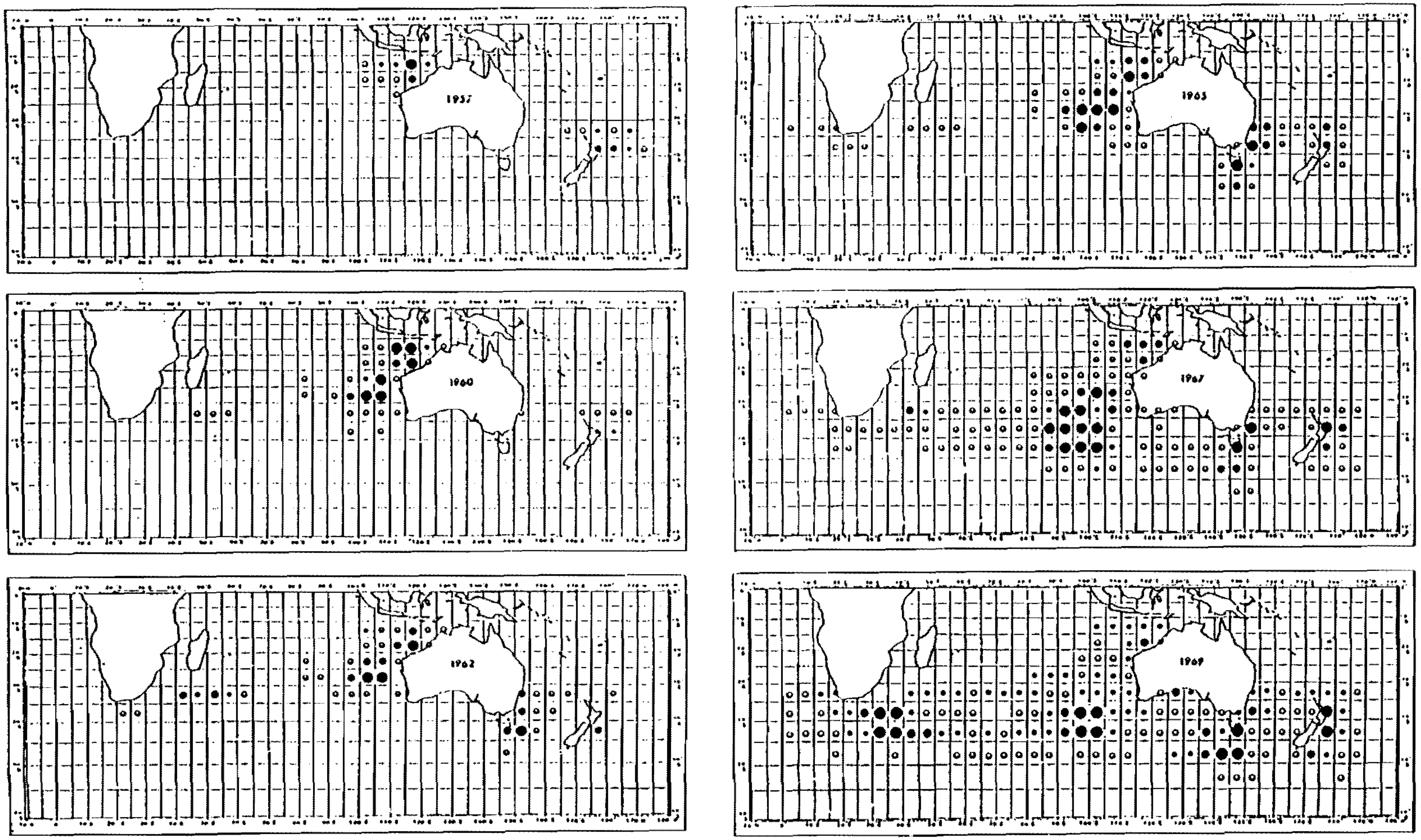


Fig. 14. Nominal fishing effort expended by Japanese longline fishing for southern bluefin tuna, 1957-69. (Source: Shingu and Hisada 1971).

The fishery started in tropical waters of the eastern Indian Ocean south of Java in 1952 and the fishing grounds progressively expanded towards temperate and subantarctic waters. In 1957 a new fishing ground was developed in the offshore waters east of New Zealand. In the late 1950s, the fishing grounds expanded to temperate waters west of Australia from 20° S to 35° S and from 80° E to 11° E. In the 1960s, they gradually expanded eastwards and westwards along the belt of the West Wind Drift. Substantial fishing operations for SBT started in the areas off NSW from 1962 and in the waters off South Africa from 1965. (The longline fishery off South Africa around 1962 as shown in Fig. 14 targeted albacore.) The fishing grounds were thus already established in the late 1960s in the West Wind Drift waters, extending in a belt from about 170° W in the South Pacific, westwards to nearly the centre of the South Atlantic Ocean. Since then, the longline fishing has been conducted in these waters. The most recent fishing grounds are shown in Fig. 15.

Further detailed information about the development of the fishery are found in Shingu (1970), Shingu and Hisada (1971) and Shingu (1978). The annual variation in the Japanese catch is shown in Fig. 16 and Table 12.

Characteristics of the fishing grounds, and voluntary restriction of the fishery

The fishing grounds for SBT are divided into ten sea areas as indicated in Fig. 17 according to the location, the fishing season and the characteristics of the catch. The characteristic features of these ten sea areas are shown in Table 5. Areas 1, 2, 8 and 10 are the fishing grounds where large fish predominate, whereas in areas 3, 4, 5 and 9 small fish form the majority. Areas 6 and 7 are grounds where both large and small fish are caught.

Taking the above-mentioned characteristics of the fishing grounds into consideration, the Japanese tuna industry voluntarily closed the areas shown in Fig. 18 from 1971 to restrict the catching of small fish (their exploitation causes an effective reduction of recruitment to parental biomass), and to protect adults which migrate from the south to the spawning ground. The closures did not include the restriction of fishing effort, so were inadequate for controlling stock. Nevertheless, they represented the start of a management regime towards the rational utilisation of the SBT stock. Further information on the voluntary restrictions of the fishery are detailed in Far Seas Fisheries Research Laboratory (1972) and Warashina and Hisada (1974).

Management of the fishery by the Australia-Japan-New Zealand tripartite meeting

Every year since 1982, Australia, Japan and New Zealand, the major SBT fishing countries, have held tripartite scientific and administrative meetings on the SBT stock. At the scientific meetings, stock status is discussed and management recommendations for biological requirements are made for consideration at the subsequent administrative meeting. In the administrative meeting, managers from the three countries consider both the recommendations of the scientific meeting and socio-economic factors of the three countries, and decide management measures for the stock.

The management measure adopted for the Japanese longline fishery has been the restriction of the catch. Catch limits were 23 150 t for the 1986 fishing year (1 March 1986 to 28 February 1987), 19 500 t for the 1987 and 1988 fishing years, 8800 t for the 1989 fishing year, and 6250 t for the 1990 fishing year (Fig. 16 and Table 11). Recommendations from the scientific meetings, where scientists had expressed serious concern about the state of the stock, led to this drastic reduction.

During each fishing season, the cumulative catch is monitored by the method described in the summary record of discussions of trilateral management consultations among Australia, Japan and New Zealand (1986). When the cumulative catch in a fishing year reaches the limit, the SBT fishing grounds are closed until the opening of the next fishing season.

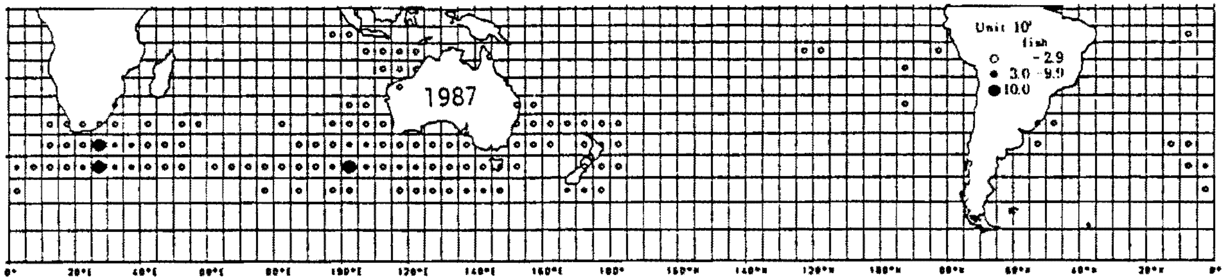


Fig. 15. Geographical distribution of southern bluefin tuna catch by Japanese longline fishery, 1987. (Source: Kono and Warashina 1989).

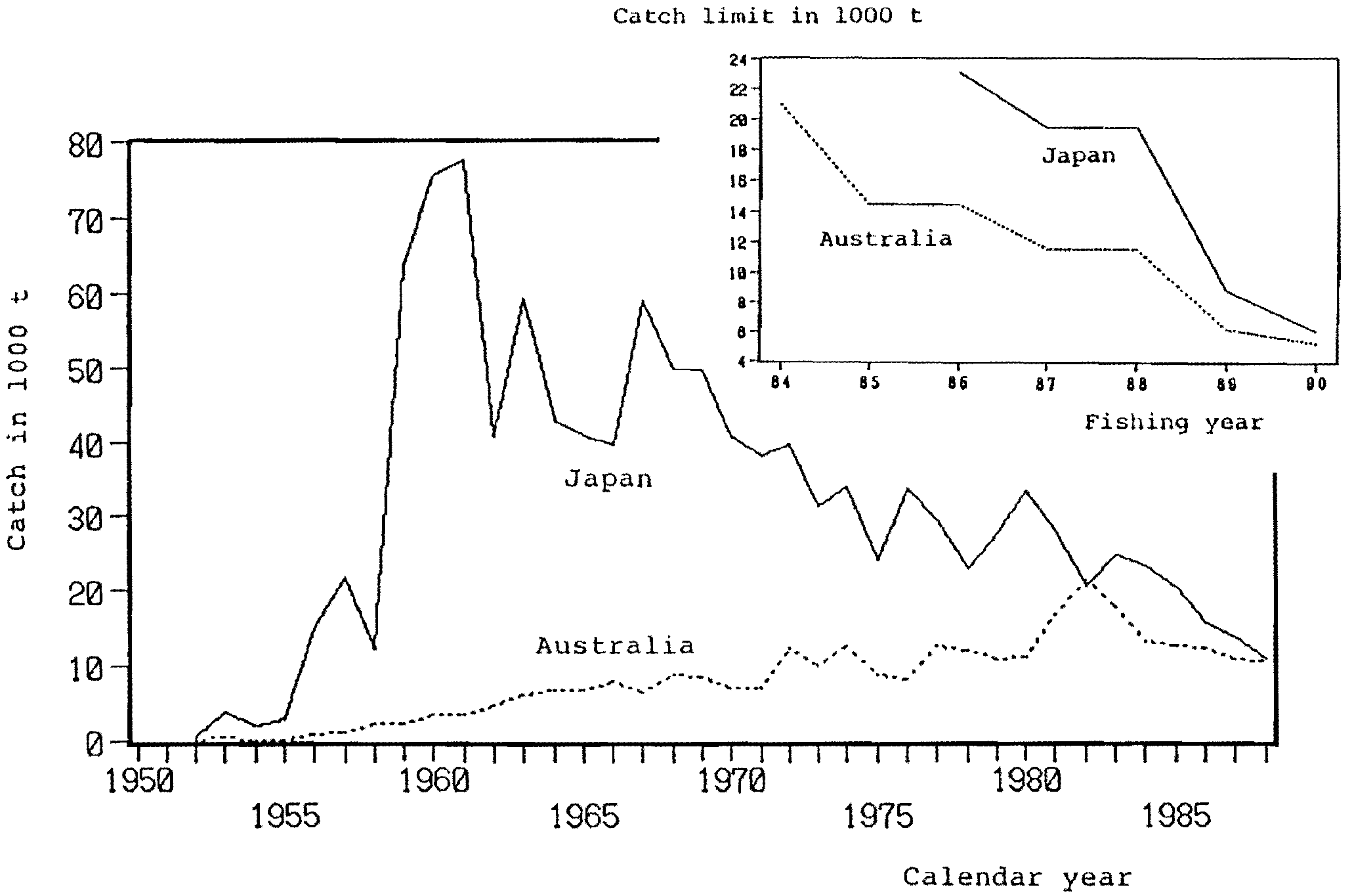


Fig. 16. Annual change in catch and catch limit of southern bluefin tuna for Australia and Japan.

Table 12. Calendar-year catch (t) of southern bluefin tuna by country, 1952 to 1989.

Sources. Australia, Japan and New Zealand: data provided to trilateral scientific discussions on southern bluefin tuna; data for Japan are values which have been amended from the historical catch series, taking account of a 1990 revision of Japanese statistical areas for the southern bluefin tuna fishery. Korea, China (Taiwan): Indian Ocean and Southeast Asian tuna fisheries data summary for 1988; IPTP Data Summary No. 10. April 1990, Colombo, Sri Lanka. Indonesia: fishing ground and distribution of southern bluefin tuna (*Thunnus maccoyii*) in south Java and Nusatenggara waters; (Doc. No. 16) Third Southeast Asian Tuna Conference, Bali, Indonesia, 22–24 August, 1989. n.a. = not available

Year	Australia	Indonesia	Japan	Korea	New Zealand	China (Taiwan)	Total
1952	264		565				829
1953	509		3 890				4 399
1954	424		2 447				2 871
1955	322		1 964				2 286
1956	964		9 603				10 567
1957	1 264		22 908				24 172
1958	2 322		12 462				14 784
1959	2 486		61 892				64 378
1960	3 545		75 826				79 371
1961	3 678		77 927				81 605
1962	4 636		40 397				45 033
1963	6 199		59 724				65 923
1964	6 832		42 838				49 670
1965	6 876		40 689				47 565
1966	8 008		39 644				47 652
1967	6 357		59 281				65 638
1968	8 737		49 657				58 394
1969	8 679		49 769				58 448
1970	7 097		40 929			100	48 126
1971	6 969		38 149	500		17	45 635
1972	12 397		39 458	100		12	51 967
1973	9 890		31 225	100		1	41 216
1974	12 672		34 005	182		9	46 868
1975	8 833		24 134	99		2	33 068
1976	8 383		34 099	28		1	42 511
1977	12 569		29 600	7		20	42 196
1978	12 190	4	23 632	94		53	35 973
1979	10 783	10	27 828	0		64	38 685
1980	11 195	8	33 353	0	150	40 (179)[E]	44 746[F]
1981	16 843	3	27 981	0	199	22 (259)[E]	45 048[F]
1982	21 501	2	20 789	6	305	37 (366)[E]	42 640[F]
1983	17 695	3	24 881	0	132	20 (323)[E]	42 731[F]
1984	13 411	1	23 328	1	93	96 (607)[E]	36 930[F]
1985	12 589	0	20 396	0	94	12 (2389)[E]	33 091[F]
1986	12 531	4	15 182	0	82	266 (531)[E]	28 065[F]
1987	10 821	3 (20)[B]	13 964	0	59	62 (1001)[E]	24 909[F]
1988	10 591	3 (20)[B]	11 422	0	93	29 (1046)[E]	22 138[F]
1989	6 118[A]	n.a. (100)[B]	8 800[C]	n.a.	424[D]	n.a. (1486)[E]	n.a.

[A] 5434 t from domestic surface fishery; 684 t from Australia/Japan joint-venture longline vessels.
[B] Indonesian catch is uncertain; estimates as high as 100 t for 1989 have been provided.
[C] Provisional value.
[D] 134 t from domestic handline/troll fishery; 290 t from NZ/Japan joint-venture longline vessels.
[E] Values in parentheses were provided to the Australian Fisheries Service by the Taiwan Fisheries Bureau as southern bluefin tuna catch, but appear to include all bluefins. For 1989, statistics on catch by ocean and by gear suggest that 879 tonnes of the 1486 were southern bluefin tuna.
[F] Provisional total; ignores values in parentheses for China (Taiwan) and Indonesia.

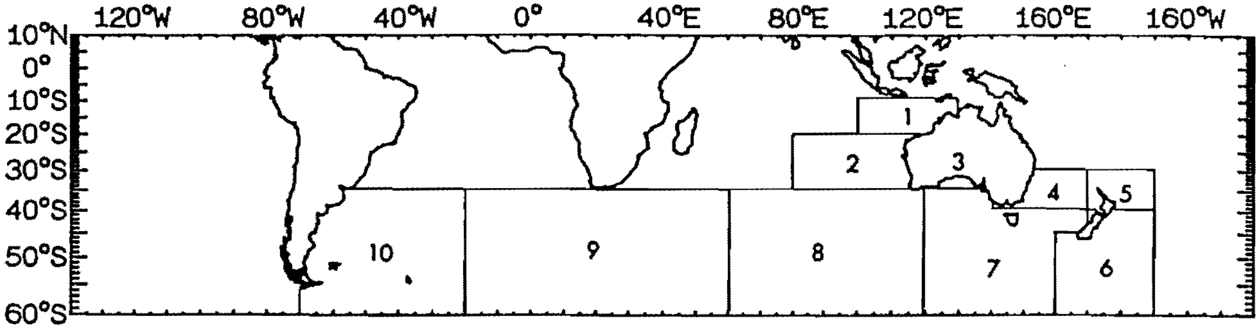


Fig. 17. Southern bluefin tuna fishing grounds divided into ten statistical areas. Numerals denote area number. (Source: Warashina 1990).

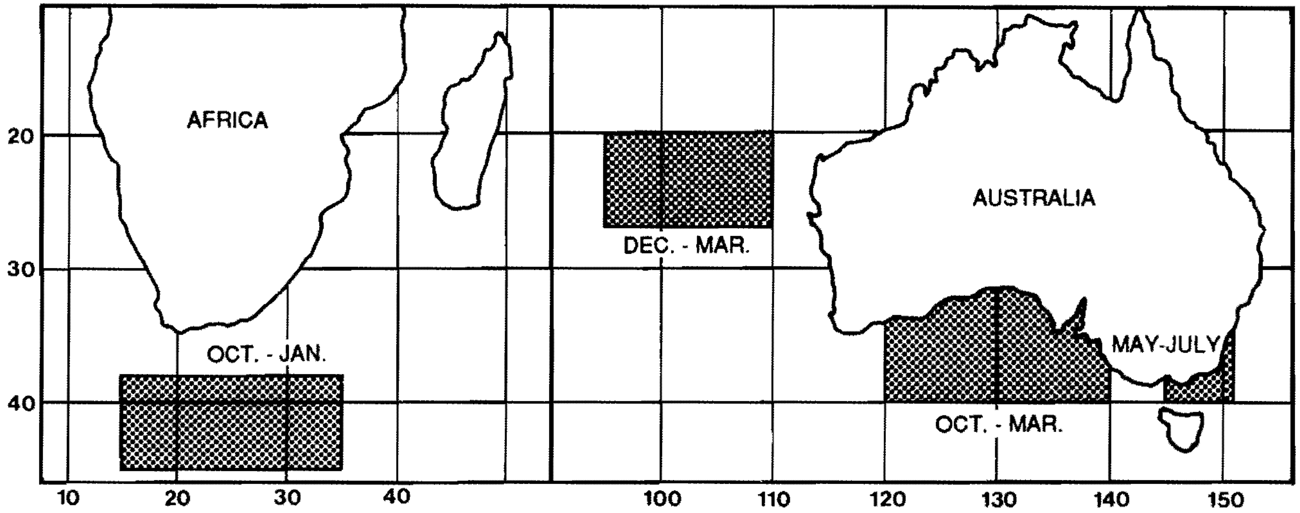


Fig. 18. Regions and periods of the southern bluefin tuna fishing grounds closed by voluntary restrictions. (Source: Shingu 1978).

Japanese longlining within the 200-mile Australian fishing zone

As a signatory to the United Nations Convention on the Law of the Sea, Australia has a responsibility to make its excess fisheries resources available on suitable terms and conditions to distant water fishing nations. Japanese longliners have operated in the area now delineated by the Australian fishing zone (AFZ) since the 1950s and have continued to operate there under licence since its proclamation on 1 November 1979. Activities by the Japanese fleet are governed by a head agreement with the specific terms and conditions detailed in annually renegotiated subsidiary arrangements. These cover such aspects as access fees, port access, areas of access, reporting requirements, boat numbers, etc.

The areas open to the Japanese fleet have been progressively reduced over time as the Australian fishery has expanded. The area restrictions influencing Japanese SBT longlining have been applied particularly in waters south of 34° S, at the northerly limit of distribution of SBT off the east coast of Australia.

In 1984, the first year of the Australian SBT Management Plan, when Japan was unable to implement a global quota for its fleet, Australia excluded the vessels from all AFZ waters south of 34° S. Australian industry had been subjected to a stringent management regime and the Australian Government was not prepared to permit a foreign fleet to operate within the AFZ under terms and conditions more favourable than those applying for the domestic fleet. At the time of the fishing prohibition it was reported in Japan that this was a means whereby Australia was attempting to gain a marketing advantage. This was clearly incorrect because the Australian supply of SBT to the Japanese market was insignificant and the Japanese fleet took only a small portion of its global SBT catch from the AFZ (annual Japanese SBT catch in the AFZ since it came into operation had not reached 20 % of the global Japanese SBT catch until the 1989-90 quota year). Nevertheless access had been very important for maintaining seasonal continuity of Japanese fishing campaigns.

When Japan introduced quotas for its fleet in 1985 the vessels were permitted re-entry to specified AFZ waters south of 34° S, generally adjacent to Tasmania. Access to other SBT waters was not permitted as there was a high probability of competition with domestic vessels. Like most coastal nations, Australia's policy is to give preference to its domestic industry.

In 1989, for the first time since 1979, the access agreement lapsed. The agreement period had been 1 November to 31 October but as a result of a stalemate in the 1989 trilateral discussions regarding global quota limits it was not possible to progress with the bilateral negotiations. Australia recognises that there is a distinction between the fora and that the SBT conservation issue is best addressed in the trilateral forum but the matter was so important and so inter-related with bilateral access that it was not possible to divorce the two subjects. The bilateral access agreement was eventually re-established in December 1989.

When the AFZ was established in 1979 Japanese longliners operated broadly around eastern, southern and western Australia. Large SBT were targeted off southern Tasmania from November to January. In April and May smaller SBT were targeted south of 35° S in the Great Australian Bight. From June to September various sizes of SBT were fished off southern NSW. In addition to SBT fishing activities bigeye were fished off NSW and south-western WA, and yellowfin and billfish off Queensland and northern NSW. The gradual extension of closures forced SBT longliners to divert activities in the AFZ to other species. In consequence, the north-west of WA (including the Cocos and Christmas Islands, where bigeye were the target) became a more important area as the 1980s progressed. For SBT, eastern and south-western Tasmania are now the main fishing areas.

The Japanese AFZ SBT operation survived through the late 1980s, despite very low catch rates, because of the high value of SBT and the importance of seasonal access to the AFZ for maintaining continuity of broader Southern Ocean SBT fishing operations. In the two most recent quota years (1987-88 and 1988-89), there has been an improvement in SBT catch rates in the AFZ off eastern Tasmania, because of increased numbers of younger SBT in the catch. This presumably reflects the improved escapement from the Australian fishery flowing from catch restraints.

One of the objectives of AFZ management was to encourage the progressive development of Australian activities to replace foreign ones. In an effort to diversify into longlining and hence shift effort away from smaller SBT, some Australian quota holders entered into joint longlining venture arrangements with the Japanese industry. As a result 770 t of Australian-owned 1988-89 season quota were made available to the 20 longliners participating in the Australia-Japan joint venture.

Further information about the development and management of Japanese longlining within the 200-mile Australian fishing zone can be found in Caton (1985), Franklin (1987), Caton (1988), and Caton, et al. (1990).

Development and management of the Japanese fishery within the 200-mile New Zealand exclusive economic zone

New Zealand established its 200-mile exclusive economic zone (NZEEZ) in 1978 but Japanese longliners have been fishing for SBT inside the present NZEEZ area since 1962. Currently, two foreign licensed tuna longline fisheries operate within the NZEEZ, the 'southern' fishery which targets SBT and the 'northern' fishery which targets albacore, bigeye tuna and swordfish.

The southern longline fishery is comprised solely of Japanese tuna longline vessels targeting SBT along the south and east coasts of New Zealand between 25° and 50° S. The number of vessels operating within the NZEEZ has steadily declined from a high of 87 vessels in 1980 to about 30 in recent years. In most years fishing begins in January in the south, the fleet moving northwards from May through September when they leave the NZEEZ. Peak catches occur from May to July with the largest number of fish caught usually caught in June or July. Highest catch rates have always been in July although the highest fishing effort has usually been in April and May. The timing of fishing and the fleet distribution pattern vary from year to year but most effort and the highest catches occur between March and August. Every year the fishing pattern is separated into two distinct 'fishing grounds', one south of the Chatham Rise (about 45° S) usually fished from January to June and one north of the Chatham Rise (about 42° S) fished from May to September.

The northern longline fishery is comprised of a variable number of vessels from Japan and the Republic of Korea. Korean vessels target albacore and yellowfin and do not report a by-catch of SBT. Japanese vessels target both bigeye tuna and swordfish and since 1985 have reported a small but regular by-catch of SBT (86 fish for the period 1985-88). The northern fishery is restricted in the area and time during which it can operate. The area closure was introduced at the start of the fishery in 1981 to minimise the catch of SBT. It appears to be effective for the Korean fleet but has been less so for the Japanese fleet since they increased their fishing effort and the frequency of sets for bigeye tuna (beginning in 1985). A seasonal closure for all foreign licensed longlining was instituted in 1988 whereby vessels in the northern fishery can not fish before June. This seasonal restriction was introduced to limit the incidental catch of billfishes and conflict with a domestic recreational fishery for marlin. The seasonal closure should not affect the catch of SBT based on our current understanding of fish movement and fleet fishing pattern.

In addition to the time and area closure for northern New Zealand waters, foreign vessel access is restricted to 38 vessels in the southern longline fishery and 40 vessels for the northern fishery. No foreign licensed fishing vessel may fish within the 12-mile territorial sea. The areas from which the foreign longline fishery takes SBT are shown in Fig. 19.

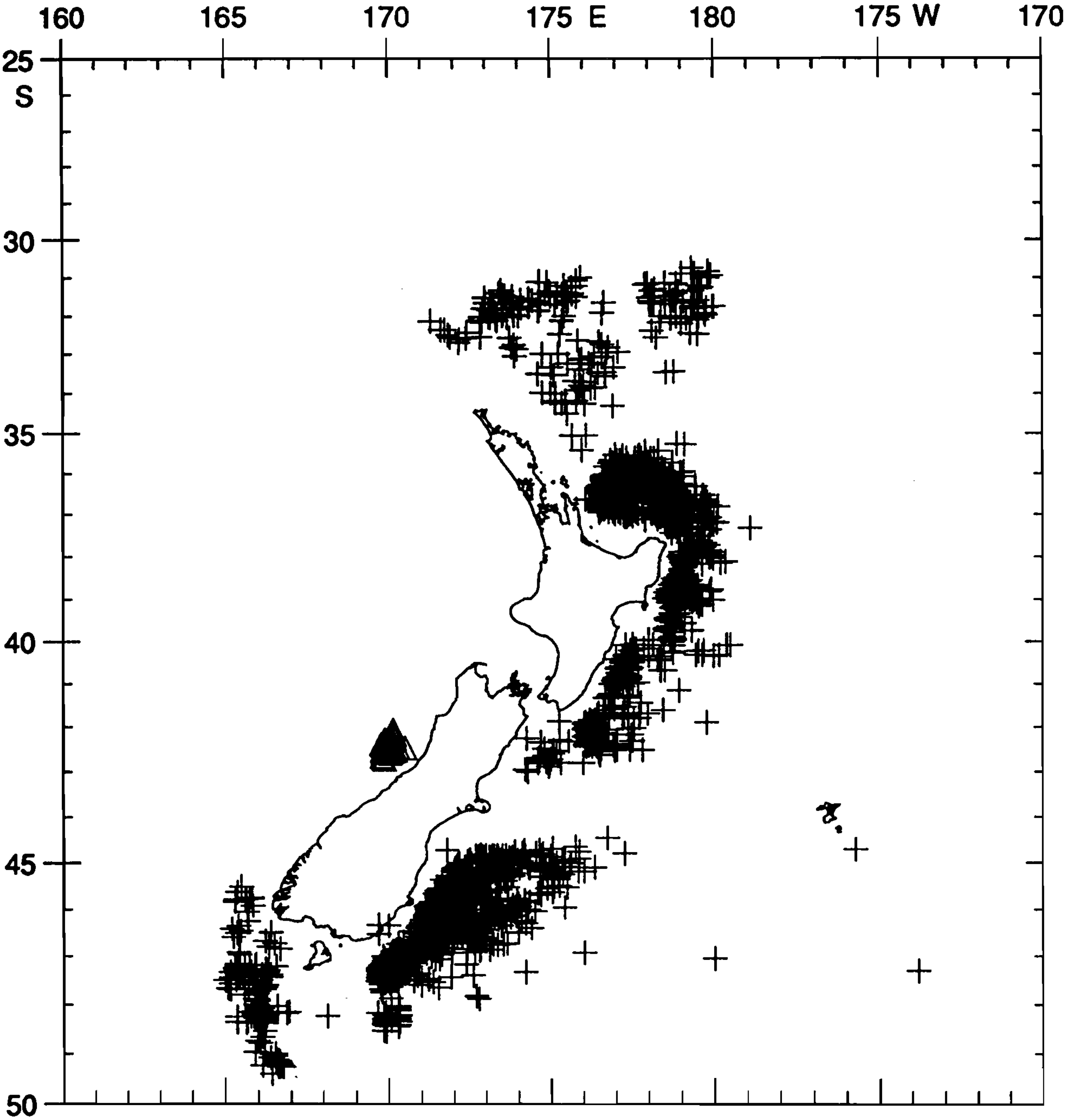


Fig. 19. Locations of catch of southern bluefin tuna by New Zealand domestic (triangles) and foreign (crosses) vessels; positions represent locations of daily position reports by domestic vessels and start-of-set locations for longliners, for the period 1980 to 1988.

THE NEW ZEALAND FISHERY

The domestic New Zealand fishery for SBT has operated off the west coast of the South Island since 1980, primarily between latitudes 41° and 44° 30' S (Fig. 19) between June and September. The domestic troll and handline fishery has traditionally been associated with a winter trawl fishery for hoki (*Macruronus novaezelandiae*) with individual tuna vessels fishing in close proximity to factory trawlers. Most fishing has been done by handline but in recent years trolling has become increasingly important in the domestic fishery. Coincident with the increase in trolling has been an increase in the by-catch of large (> 20 kg) albacore.

The domestic fishery has been diversifying in recent years to include the use of monofilament longlining, an increase in trolling and in the 1989 and 1990 seasons the charter of Japanese tuna longline vessels. Domestic and chartered vessels fish competitively for the New Zealand quota (450 t in 1989; 420 t in 1990). Chartered vessels, like foreign licensed vessels are prohibited from fishing within the 12-mile territorial sea.

Further details on the New Zealand domestic fishery can be found in Murray and Burgess (1990).

CATCHES BY OTHER NATIONS

Southern bluefin tuna catches by countries other than Australia, Japan and New Zealand have in the past been considered trivial. In statistics published by the Indo-Pacific Tuna Management and Development Program (IPTP), small quantities of SBT have been reported as taken by longline and drift gillnet vessels from Taiwan, and longline vessels from Indonesia and Korea (Table 12). However, there are unconfirmed reports that the SBT by-catch of southern Indian Ocean and, to a lesser extent, south-west Pacific Ocean driftnetting is much more significant than the IPTP statistics indicate. Statistics of 'bluefin' catches published in Taiwan do not discriminate between Northern Hemisphere bluefin (*T. thynnus*) and SBT. However, regions from which the 'bluefin' catches originate suggest that perhaps about 880 t of the reported 1989 1486 t catch may be SBT. Recent discussions between Australian and Indonesian fisheries officials indicate that the Indonesian longline fishery is expanding and that increased SBT catches may occur. It is also possible that an SBT component may be developing in the South African tuna fishery. These developments require close monitoring with a view to incorporating their impact into stock assessments. The catches now represent a substantial component of the global catch, given recent major reductions in Australian and Japanese catches.

10. CATCH, CATCH COMPOSITION AND EFFORT DATA COLLECTION ARRANGEMENTS

AUSTRALIAN SBT DATA COLLECTION

Surface fishery landings data

Landings information for the Australian surface fishery from its inception until 1983-84 was gathered from processing companies by CSIRO staff or by cooperating agencies (e.g. WA Department of Fisheries for WA catches). Details are provided in Majkowski (1982) and Majkowski and Morris (1986). Landed catch has been recorded by boat, date of landing, port of landing and destination (purchaser).

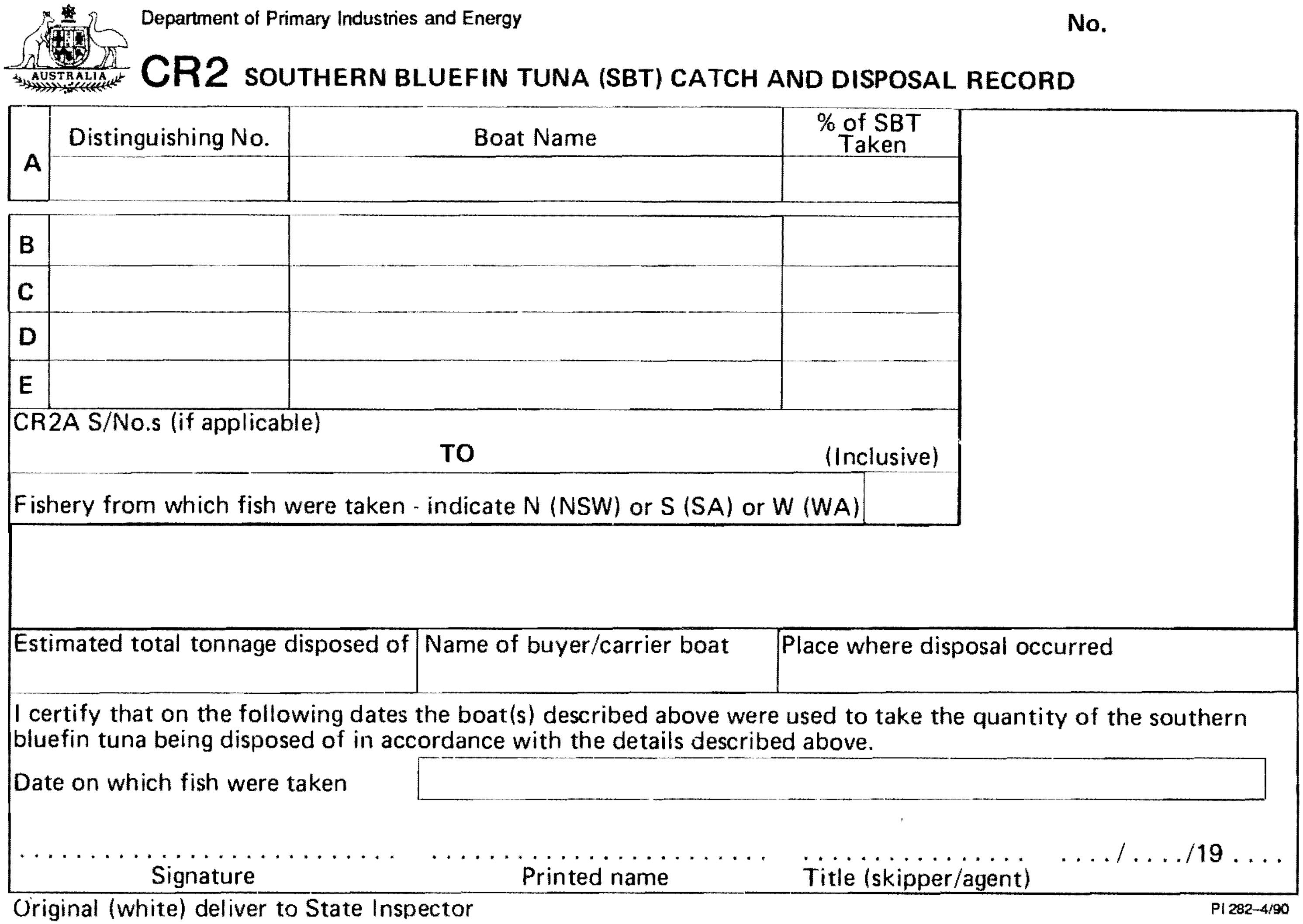
With the introduction of quotas to the Australian fishery in 1983-84, and the subsequent annual maintenance of a system of individual transferable quotas, responsibility for catch monitoring was taken over by the Australian Fisheries Service (AFS). All catches of SBT must be covered by a 'CR2' (catch report) form (Fig. 20), a copy of which remains with each landing of fish until the fish are weighed (e.g. as a load to a cannery, or on a fish-by-fish basis on a processing vessel), whereupon the form is forwarded to an AFS representative for adjustment of the quota register. While catch data gathered in this way provide progressive total catch during a season, they are not directly compatible with the prior CSIRO landings data. A landing may be made on behalf of more than one quota holder or more than one catching vessel (for example where pole vessels and a purse-seiner work in conjunction on the capture of a school). Sorting of catch into sashimi-grade and cannery-grade fish prior to landing, frequently with the former passing to processor vessels on the fishing grounds, has become commonplace now, whereas 1970s landings more commonly represented the results of a single vessel's activity. It is necessary to refer to logbook data in conjunction with 'CR2' data to determine individual vessel catches in relation to effort.

Surface fishery logbooks

Majkowski (1982) and Majkowski and Morris (1986) describe the development of logbook collections in the Australian surface fishery for SBT. A voluntary logbook for provision of data daily on fishing activity, location and catch was introduced in the south-eastern fishery in the 1960s but had lapsed by 1969. Attempts by the CSIRO and the then Department of Primary Industry in the mid-1970s to re-introduce it were not effective until the establishment in 1979 of the computer-based Australian Fishing Zone Information System. By the early 1980s a reliable south-eastern fishery collection was established, and a logbook was also successfully introduced to the WA fishery. The provision of logbook data is mandatory but the response rate has been governed by the extent to which the collection has been supported by field liaison. Generally, more than 90 % of catches have been covered. The initial logbooks required completion of a page per day, with a breakdown of each day's operations (steaming, searching, poling, baiting). They were rarely properly completed. The current logbooks (for example the south-eastern Australian poling logbook; Fig. 21) require a line per day for pole vessels (or per set for purse-seiners), and record date, activity (i.e. fishing, baiting or in port) fishing location, vessel-hours searching, and catch. Vessel and fishing gear details are collected as a 'once-off' exercise when logbooks are issued. Otherwise, logbook data sheets must be returned monthly to the AFS.

Surface fishery catch length composition

The CSIRO sampled SBT length composition routinely in the south-eastern fishery from 1963-64 and, in collaboration with the WA Department of Fisheries, in the WA fishery from 1969. Details are provided in Majkowski (1982) and Majkowski and Morris (1986). Sampling was undertaken at processing establishments or receival depots. Under ideal conditions, 200 fish were measured per



Department of Primary Industries and Energy

No.

AUSTRALIA

CR2 SOUTHERN BLUEFIN TUNA (SBT) CATCH AND DISPOSAL RECORD

	Distinguishing No.	Boat Name	% of SBT Taken
A			
B			
C			
D			
E			

CR2A S/No.s (if applicable)

TO (Inclusive)

Fishery from which fish were taken - indicate N (NSW) or S (SA) or W (WA)

Estimated total tonnage disposed of	Name of buyer/carrier boat	Place where disposal occurred

I certify that on the following dates the boat(s) described above were used to take the quantity of the southern bluefin tuna being disposed of in accordance with the details described above.

Date on which fish were taken

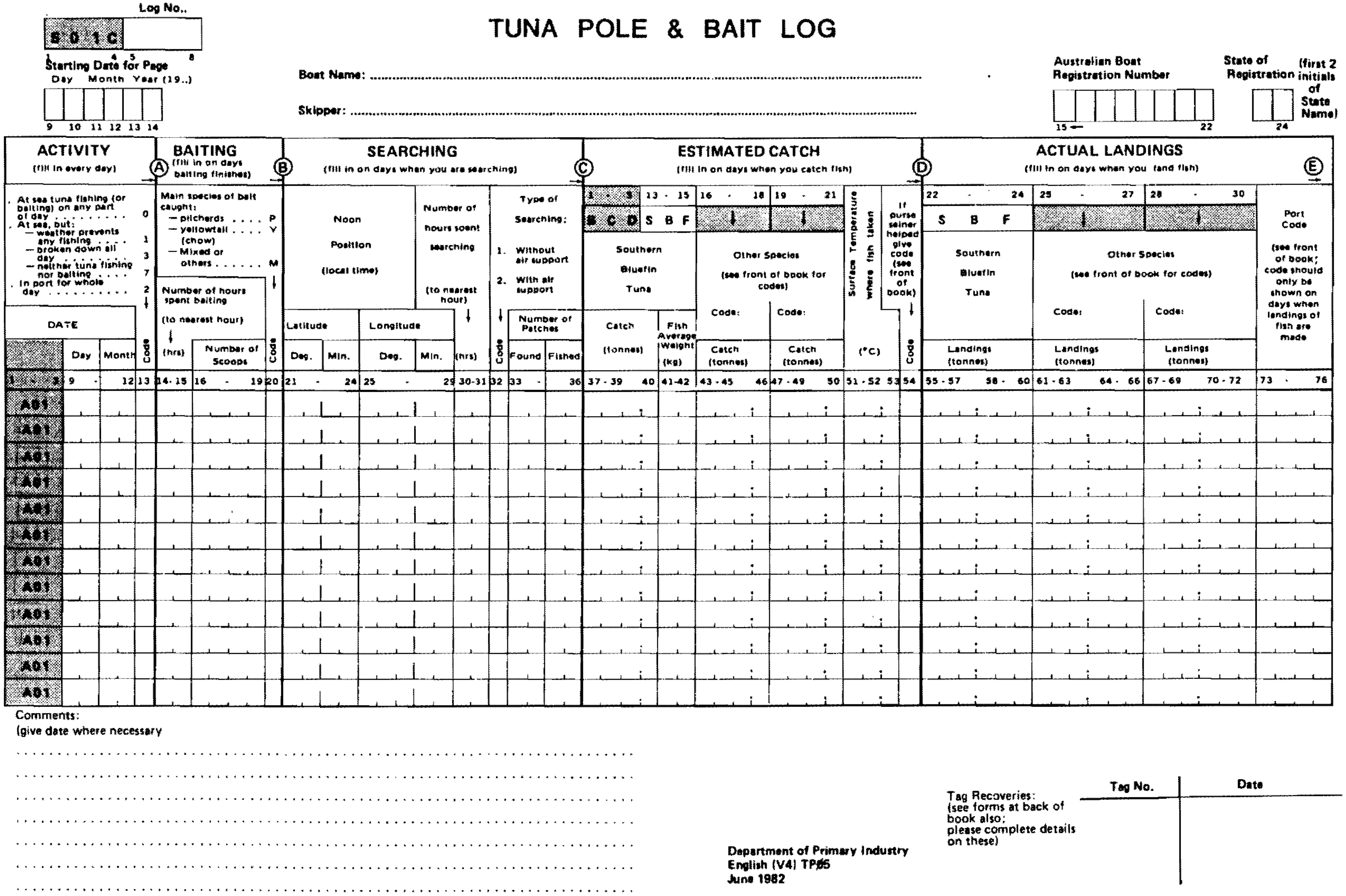
..../..../19....

Signature Printed name Title (skipper/agent)

Original (white) deliver to State Inspector

PI 282–4/90

Fig. 20. Prescribed form for recording disposal of Australian southern bluefin tuna catch.



Log No..

8 0 1 C

1 4 5 8

Starting Date for Page

Day Month Year (19..)

9 10 11 12 13 14

TUNA POLE & BAIT LOG

Boat Name: ....

Skipper: ....

Australian Boat Registration Number

15 — 22

State of Registration (first 2 initials of State Name)

24

ACTIVITY (fill in every day) Ⓐ				BAITING (fill in on days baiting finishes) Ⓑ			SEARCHING (fill in on days when you are searching) Ⓒ								ESTIMATED CATCH (fill in on days when you catch fish) Ⓓ							ACTUAL LANDINGS (fill in on days when you land fish) Ⓔ			
At sea tuna fishing (or baiting) on any part of day .... 0 At sea, but: — weather prevents any fishing .... 1 — broken down all day .... 3 — neither tuna fishing nor baiting .... 7 In port for whole day 2				Main species of bait caught: — pilchards .... P — yellowtail .... Y (chow) — Mixed or others .... M			Noon Position (local time)				Number of hours spent searching (to nearest hour)	Type of Searching: 1. Without air support 2. With air support			1 - 3 B C D	13 - 15 S B F	16 - 18	19 - 21	Surface Temperature where fish taken	If purse seiner helped give code (see front of book)	22 - 24 S B F	25 - 27	28 - 30	Port Code (see front of book; code should only be shown on days when landings of fish are made
DATE				Number of hours spent baiting (to nearest hour)			Latitude		Longitude				Number of Patches		Southern Bluefin Tuna		Other Species (see front of book for codes)				Southern Bluefin Tuna	Other Species (see front of book for codes)		
															Catch	Fish Average Weight	Code:	Code:				Code:	Code:	
	Day	Month	Code	(hrs)	Number of Scoops	Code	Deg.	Min.	Deg.	Min.	(hrs)	Code	Found	Fished	(tonnes)	(kg)	Catch (tonnes)	Catch (tonnes)	(°C)	Code	Landings (tonnes)	Landings (tonnes)	Landings (tonnes)	
1 - 3	9 -	12	13	14 - 15	16 - 19	20	21 -	24	25 -	29	30-31	32	33 -	36	37 - 39 40	41-42	43 - 45 46	47 - 49 50	51 - 52 53	54	55 - 57 58 - 60	61 - 63 64 - 66	67 - 69 70 - 72	73 - 76
A01																								
A01																								
A01																								
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A01																								
A01																								
A01																								

Comments:
(give date where necessary
....
....
....
....
....
....
....

Tag Recoveries:
(see forms at back of book also;
please complete details on these)

Tag No.	Date

Department of Primary Industry
English (V4) TP#5
June 1982

Fig. 21. Prescribed logbook form for use by southern bluefin tuna pole-and-bait fishermen operating off south-eastern Australia.

establishment per day. Length to caudal fork was measured, on a board graduated in centimetres with scale offset 0.5 cm, giving length to the nearest centimetre. Length-frequency of individual landings, by one centimetre length class, were developed from the samples. These individual landings data were used to develop length frequency of the catch for each half-month for NSW, SA , Albany and Esperance (or WA when these could not be discriminated).

In 1983-84 when the SBT Management plan was introduced, responsibility for length monitoring transferred from the CSIRO to the AFS. The plan required Australian fishermen to attempt to divert activities away from smaller SBT, so there was close monitoring of catch size composition.

In the south-eastern fishery (just SA because of the failure by then of the NSW fishery), sampling was adjusted to take account of the sorting of fish at sea. Processing vessels, handling fish individually, were required to record length and weight (the latter was recorded in any case for commercial reasons) of each fish processed. Fish landed ashore for canning were handled in bulk, so samples of at least 200 fish were measured from each landing (perhaps 400 or more from large landings). A proportion of the shore landings was also processed for air freight as fresh sashimi. This part of the catch was sampled separately, again with at least 200 fish per landing measured.

In the WA fishery, length sampling was increased after 1983. Sampling was initially based at Albany and the cannery at Perth, but after 1986 it was done solely at the cannery because most of the Albany and Esperance fish were forwarded there for processing. Diversion of part of the WA catch for processing for sashimi from 1987 and for smoking from 1988 required modification of sampling arrangements, the lengths for these fish being derived from individual weight data using the Robins (1963) length-weight relationship. However, the progressive decrease in WA catch because of transfer or lease of quota to SA has reduced the significance of the WA SBT length sampling exercise; less than 30 000 SBT are taken there annually now, in contrast to the 1-million-plus fish taken when intensive length monitoring was established.

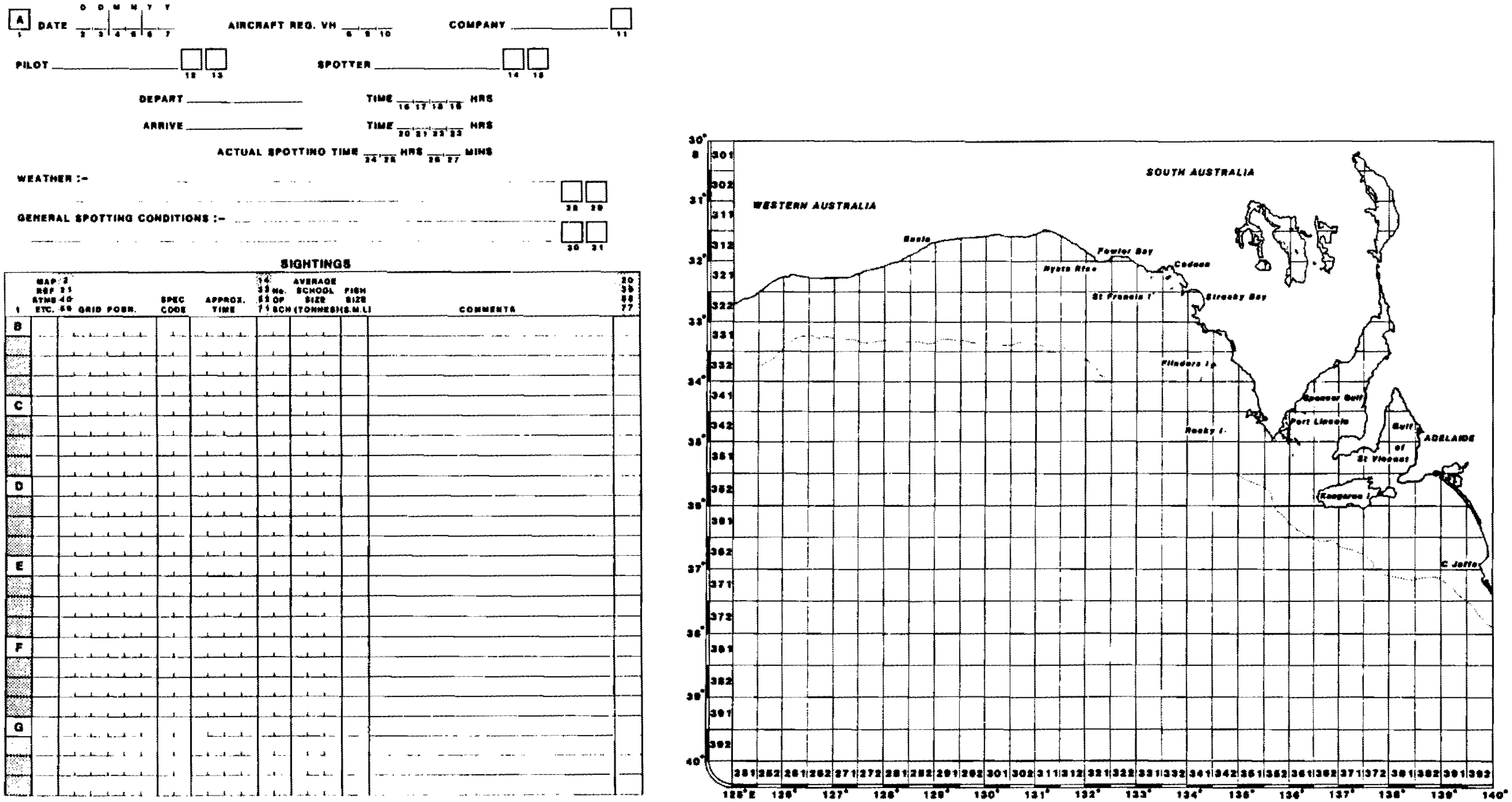
Surface fishery aircraft observation data

Spotter aircraft have been used to some degree in the NSW and SA sectors of the Australian SBT fishery since the very early days. Initially the aerial spotting was carried out by one or two unsophisticated light aircraft with very few electronic aids. By the early 1980s the aircraft fleet had increased both in size and complexity. Twelve aircraft operated at times, nearly all equipped with the most up-to-date communication and navigation systems and, with special long-range fuel tanks, could stay airborne for up to 10-12 hours.

While this marked increase obviously pushed fishing effort up very dramatically it also offered the possibility of another source of fish abundance information. In the early 1980s the CSIRO attempted to formalise the collection of spotting data in developing abundance indices. It was thought that, if properly developed, this large data source may be able to be manipulated to give relative indices of abundance between years and/or areas etc.

A logbook was designed and put into use (Fig. 22). It recorded details of schools sighted, species, size, position, hours flown and area covered. In its early stages the program attracted about a 40 % response rate from spotters or pilots.

Collection lapsed because of staff changes at the CSIRO and among the spotting fleet.
However, data from some spotters' own records from then onwards are still available. Following representations from industry another spotting program is now being devised. While some use is to be made of the historical data the primary plan of attack is to use a line transect approach. Using this technique aircraft record sightings in a similar fashion to the earlier work but fly pre-determined tracks. By using techniques that are comparable from year to year estimates of relative abundance may be possible.



A DATE D D M M Y Y 1 2 3 4 5 6 7

AIRCRAFT REG. VH 8 9 10

COMPANY ☐ 11

PILOT ☐☐ 12 13

SPOTTER ☐☐ 14 15

DEPART

TIME 16 17 18 19 HRS

ARRIVE

TIME 20 21 22 23 HRS

ACTUAL SPOTTING TIME 24 25 HRS 26 27 MINS

WEATHER :- ☐☐ 28 29

GENERAL SPOTTING CONDITIONS :- ☐☐ 30 31

SIGHTINGS

1	MAP REF STNS ETC. 2 21 40 59	GRID POSN.	SPEC CODE	APPROX. TIME	14 33 52 71 No. OF SCH	AVERAGE SCHOOL SIZE (TONNES)	FISH SIZE (S.M.L)	COMMENTS	20 39 58 77
B									
C									
D									
E									
F									
G									

Fig. 22. Logbook form for recording sightings of southern bluefin tuna during commercial aerial spotting flights.

Fishery data from Japanese longliners in the 200-mile Australian fishing zone

Catch and effort data have been collected from Japanese longline vessels operating in the AFZ since it came into effect in November 1979. These data are received in the form of radio reports and logbooks. Details are provided in Majkowski (1982) and Majkowski and Morris (1986).

Japanese longliners fishing in the AFZ were obliged, under the conditions of their licence, to radio their position every two days, and every six days to include details of total catch, catch of SBT and other tunas, black marlin catch, and fishing effort (total hooks set for the 6-day period). All catches were provided in number and weight. Since 1989, they have been required to radio the catch and effort details every two days. Special daily reporting requirements applied to longliners engaged during 1989 and 1990 in Australia-Japan joint ventures so that progress towards quota limits could be monitored.

Japanese longliners have also been required to maintain logbooks (Fig. 23), recording daily GMT noon position in degrees and minutes, catch in number (and since 1984 weight also) by species, number of baskets of gear, and number of hooks set. Completed log sheets are returned at each port call to the AFS, which processes the data.

Since 1989, longliners have been required to measure length to caudal fork of each SBT taken in the AFZ. Reports by observers and preliminary examination of data provided to date, indicate that the method of measurement may vary among vessels, some perhaps recording 'along-the-body' measurements rather than point-to-point measurements. Alternatively, some may not be measuring length to caudal fork.

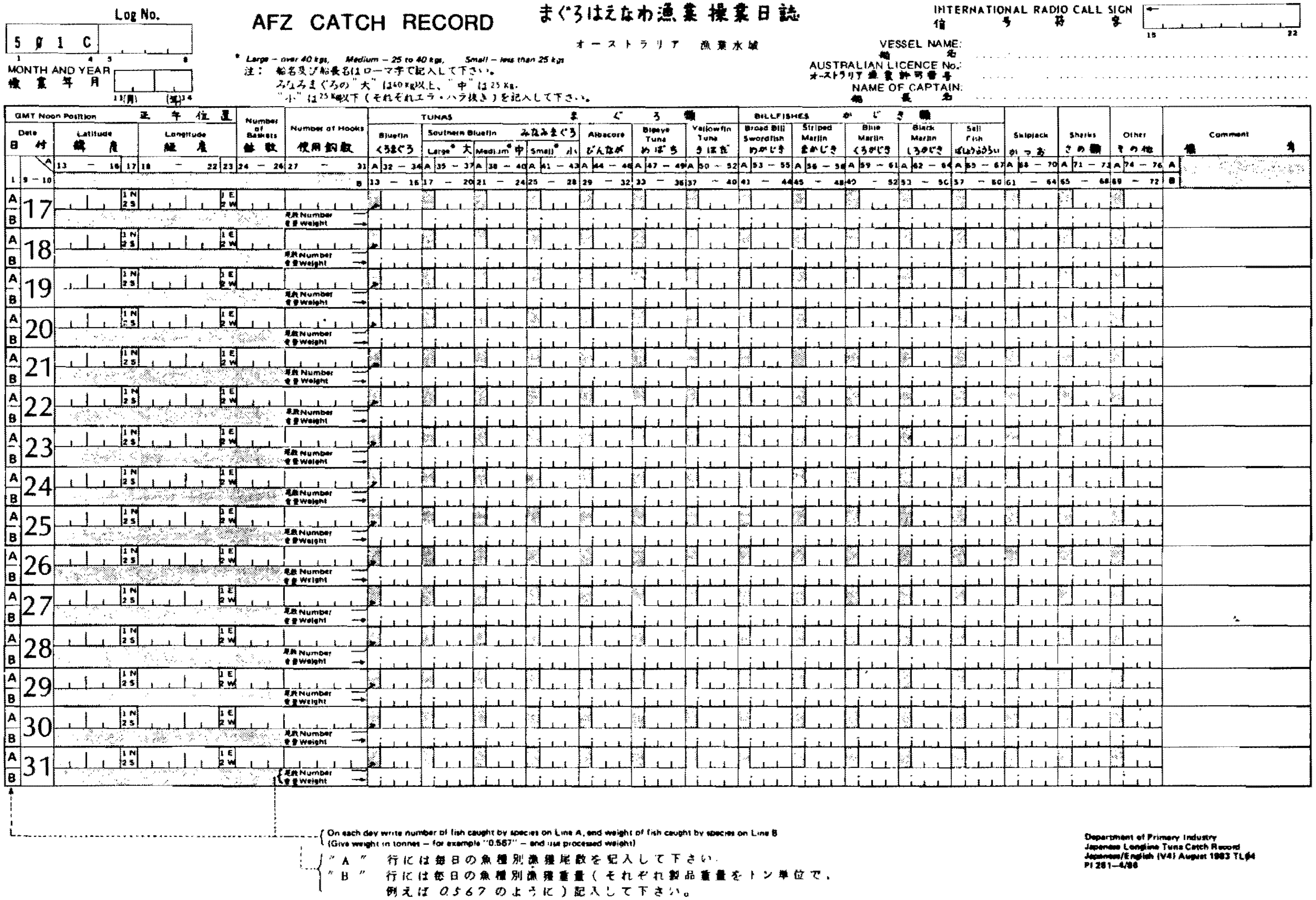
A program of observer coverage was established when AFZ operations commenced in 1979. Initially coverage was quite limited but the boardings have increased in recent seasons. The observer's main function is to check that catch reporting procedures are understood and maintained appropriately. They gather catch species-composition and length-composition information, and have also been able to undertake any special scientific sampling necessary (for example collecting otoliths using portable electric coring-drills).

COLLECTION OF GROSS CATCH, LENGTH FREQUENCIES AND FISHING EFFORT DATA FOR THE GLOBAL JAPANESE FISHERY

Gross catch and fishing effort

Japanese tuna longline boats of over 20 t gross weight are licensed by the Japanese government and under obligation to submit logbook reports to the Fishery Agency of Japan. The logbook reports (Fig. 24) are filled in by captains and/or vessel owners on a daily basis.

In addition to details about the vessel, the information recorded on the log includes noon position, catches and fishing effort. Catches are recorded in number of fish of each species caught. Fishing effort is measured by the number of longline hooks set. A brief description of the longlining operation may be found in Williams (1982a). However, one operation - setting, soaking and hauling - takes about 20 hours, not the 24 hours suggested by Williams. In early years, usually 2000 to 2500 hooks per set were used. More recently this has increased to about 2800. Further details on data collection method are described in the explanatory section of the *Annual report of effort and catch statistics by area on Japanese tuna longline fishery* published by the research division of the Fishery Agency of Japan.



Log No.

5 0 1 C

1 4 5 8

MONTH AND YEAR
操業年月

13(月) (年)14

AFZ CATCH RECORD

まぐろはえなわ漁業操業日誌

オーストラリア 漁業水域

* *Large – over 40 kgs, Medium – 25 to 40 kgs, Small – less than 25 kgs*

注： 船名及び船長名はローマ字で記入して下さい。
みなみまぐろの"大"は40㎏以上、"中"は25㎏.
"小"は25㎏以下（それぞれエラ・ハラ抜き）を記入して下さい。

INTERNATIONAL RADIO CALL SIGN
信号符字

15 22

VESSEL NAME:
船名

AUSTRALIAN LICENCE No.:
オーストラリア漁業許可番号

NAME OF CAPTAIN:
船長名

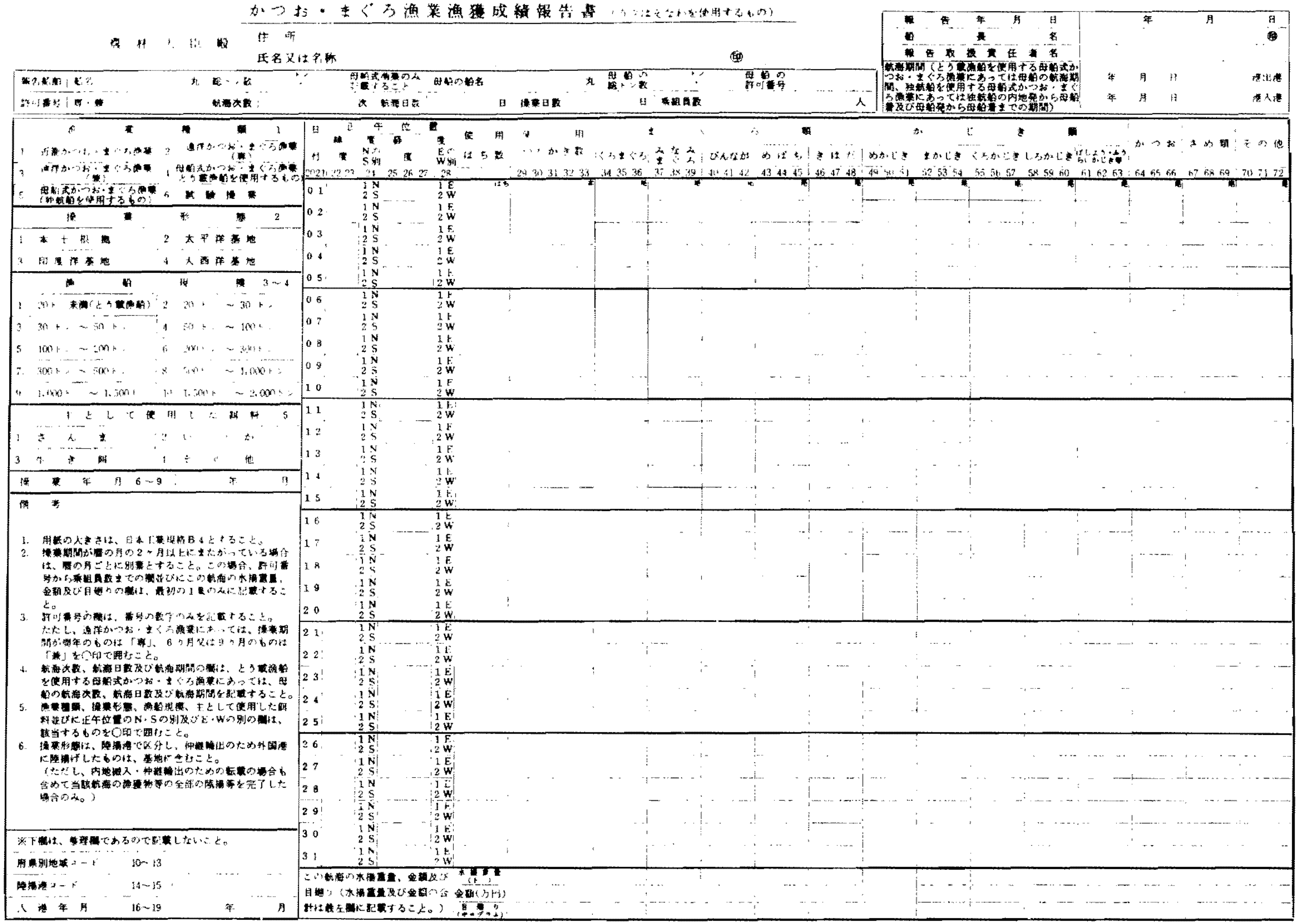
GMT Noon Position 正午位置			Number of Baskets 鉢数	Number of Hooks 使用鈎数	TUNAS まぐろ類							BILLFISHES かじき類					Skipjack かつお	Sharks さめ類	Other その他	Comment 備考
Date 日付	Latitude 緯度	Longitude 経度			Bluefin くろまぐろ	Southern Bluefin みなみまぐろ Large* 大	Medium* 中	Small* 小	Albacore びんなが	Bigeye Tuna めばち	Yellowfin Tuna きはだ	Broad Bill Swordfish めかじき	Striped Marlin まかじき	Blue Marlin くろかじき	Black Marlin しろかじき	Sail Fish ばしょうかじき				
A	13 – 16 17	18 – 22 23	24 – 26	27 – 31	A 32 – 34	A 35 – 37	A 38 – 40	A 41 – 43	A 44 – 46	A 47 – 49	A 50 – 52	A 53 – 55	A 56 – 58	A 59 – 61	A 62 – 64	A 65 – 67	A 68 – 70	A 71 – 73	A 74 – 76	A
1 9 – 10				B	13 – 16	17 – 20	21 – 24	25 – 28	29 – 32	33 – 36	37 – 40	41 – 44	45 – 48	49 – 52	53 – 56	57 – 60	61 – 64	65 – 68	69 – 72	B
A 17	1 N 2 S	1 E 2 W																		
B				尾数 Number 重量 Weight																
A 18	1 N 2 S	1 E 2 W																		
B				尾数 Number 重量 Weight																
A 19	1 N 2 S	1 E 2 W																		
B				尾数 Number 重量 Weight																
A 20	1 N 2 S	1 E 2 W																		
B				尾数 Number 重量 Weight																
A 21	1 N 2 S	1 E 2 W																		
B				尾数 Number 重量 Weight																
A 22	1 N 2 S	1 E 2 W																		
B				尾数 Number 重量 Weight																
A 23	1 N 2 S	1 E 2 W																		
B				尾数 Number 重量 Weight																
A 24	1 N 2 S	1 E 2 W																		
B				尾数 Number 重量 Weight																
A 25	1 N 2 S	1 E 2 W																		
B				尾数 Number 重量 Weight																
A 26	1 N 2 S	1 E 2 W																		
B				尾数 Number 重量 Weight																
A 27	1 N 2 S	1 E 2 W																		
B				尾数 Number 重量 Weight																
A 28	1 N 2 S	1 E 2 W																		
B				尾数 Number 重量 Weight																
A 29	1 N 2 S	1 E 2 W																		
B				尾数 Number 重量 Weight																
A 30	1 N 2 S	1 E 2 W																		
B				尾数 Number 重量 Weight																
A 31	1 N 2 S	1 E 2 W																		
B				尾数 Number 重量 Weight																

On each day write number of fish caught by species on Line A, and weight of fish caught by species on Line B
(Give weight in tonnes – for example "0.567" – and use processed weight)

"A" 行には毎日の魚種別漁獲尾数を記入して下さい.
"B" 行には毎日の魚種別漁獲重量（それぞれ製品重量をトン単位で、
例えば 0.567 のように）記入して下さい。

Department of Primary Industry
Japanese Longline Tuna Catch Record
Japanese/English (V4) August 1983 TL04
PI 261—4/86

Fig. 23. Prescribed logbook form for use on Japanese longline fishing vessels operating in the 200-mile Australian fishing zone.



かつお・まぐろ漁業漁獲成績報告書（はえなわを使用するもの）

農林大臣 殿　住所

氏名又は名称 ㊞

漁船名 丸 総トン数 トン 母船式漁業のみ記載すること 母船の船名 丸 母船の総トン数 トン 母船の許可番号

許可番号 専・兼 航海次数 次 航海日数 日 操業日数 日 乗組員数 人

報告年月日	年	月	日
船長名			㊞
報告取扱責任者名			
航海期間（とう載漁船を使用する母船式かつお・まぐろ漁業にあっては母船の航海期間、独航船を使用する母船式かつお・まぐろ漁業にあっては独航船の内地発から母船着及び母船発から母船着までの期間）	年 月 日 港出港 年 月 日 港入港		

漁業種類 1
1 近海かつお・まぐろ漁業 2 遠洋かつお・まぐろ漁業（専）
3 遠洋かつお・まぐろ漁業（兼） 4 母船式かつお・まぐろ漁業（とう載漁船を使用するもの）
5 母船式かつお・まぐろ漁業（独航船を使用するもの） 6 試験操業

操業形態 2
1 本土根拠 2 太平洋基地
3 印度洋基地 4 大西洋基地

漁船規模 3～4
1 20トン未満（とう載漁船） 2 20トン～30トン
3 30トン～50トン 4 50トン～100トン
5 100トン～200トン 6 200トン～300トン
7 300トン～500トン 8 500トン～1,000トン
9 1,000トン～1,500トン 10 1,500トン～2,000トン

主として使用した餌料 5
1 さんま 2 いか
3 生き餌 4 その他

操業年月 6～9 年 月

備考

1. 用紙の大きさは、日本工業規格B4とすること。
2. 操業期間が暦の月の2ヶ月以上にまたがっている場合は、暦の月ごとに別葉とすること。この場合、許可番号から乗組員数までの欄並びにこの航海の水揚重量、金額及び目廻りの欄は、最初の1葉のみに記載すること。
3. 許可番号の欄は、番号の数字のみを記載すること。ただし、遠洋かつお・まぐろ漁業にあっては、操業期間が周年のものは「専」、6ヶ月又は9ヶ月のものは「兼」を○印で囲むこと。
4. 航海次数、航海日数及び航海期間の欄は、とう載漁船を使用する母船式かつお・まぐろ漁業にあっては、母船の航海次数、航海日数及び航海期間を記載すること。
5. 漁業種類、操業形態、漁船規模、主として使用した餌料並びに正午位置のN・Sの別及びE・Wの別の欄は、該当するものを○印で囲むこと。
6. 操業形態は、陸揚港で区分し、仲継輸出のため外国港に陸揚げしたものは、基地に含むこと。（ただし、内地搬入・仲継輸出のための転載の場合も含めて当該航海の漁獲物等の全部の陸揚等を完了した場合のみ。）

※下欄は、整理欄であるので記載しないこと。

府県別地域コード 10～13

陸揚港コード 14～15

入港年月 16～19 年 月

日付	正午位置 緯度	N・S別	経度	E・W別	使用はち数	使用つりかぎ数	くろまぐろ	みなみまぐろ	びんなが	めばち	きはだ	めかじき	まかじき	くろかじき	しろかじき	ばしょうかじき・ふうらいかじき等	かつお	さめ類	その他
20 21	22 23	24	25 26 27	28		29 30 31 32 33	34 35 36	37 38 39	40 41 42	43 44 45	46 47 48	49 50 51	52 53 54	55 56 57	58 59 60	61 62 63	64 65 66	67 68 69	70 71 72
					はち	本	尾	尾	尾	尾	尾	尾	尾	尾	尾	尾	尾	尾	尾
01		1 N 2 S		1 E 2 W															
02		1 N 2 S		1 E 2 W															
03		1 N 2 S		1 E 2 W															
04		1 N 2 S		1 E 2 W															
05		1 N 2 S		1 E 2 W															
06		1 N 2 S		1 E 2 W															
07		1 N 2 S		1 E 2 W															
08		1 N 2 S		1 E 2 W															
09		1 N 2 S		1 E 2 W															
10		1 N 2 S		1 E 2 W															
11		1 N 2 S		1 E 2 W															
12		1 N 2 S		1 E 2 W															
13		1 N 2 S		1 E 2 W															
14		1 N 2 S		1 E 2 W															
15		1 N 2 S		1 E 2 W															
16		1 N 2 S		1 E 2 W															
17		1 N 2 S		1 E 2 W															
18		1 N 2 S		1 E 2 W															
19		1 N 2 S		1 E 2 W															
20		1 N 2 S		1 E 2 W															
21		1 N 2 S		1 E 2 W															
22		1 N 2 S		1 E 2 W															
23		1 N 2 S		1 E 2 W															
24		1 N 2 S		1 E 2 W															
25		1 N 2 S		1 E 2 W															
26		1 N 2 S		1 E 2 W															
27		1 N 2 S		1 E 2 W															
28		1 N 2 S		1 E 2 W															
29		1 N 2 S		1 E 2 W															
30		1 N 2 S		1 E 2 W															
31		1 N 2 S		1 E 2 W															

この航海の水揚重量、金額及び目廻り（水揚重量及び金額の合計は最左欄に記載すること。）
水揚重量（トン）
金額（万円）
目廻り（キログラム）

Fig. 24. Logbook form used globally on Japanese longline fishing vessels.

Data from the logbooks have been processed by the National Research Institute for Far Seas Fisheries (Shimizu, Japan) and summarised in the *Annual report of effort and catch statistics by area on Japanese tuna longline fishery* published by the research division of the Fishery Agency of Japan. These reports were published from 1962 to 1980.

These annual reports contain estimates of monthly fishing effort (in sets and hooks) and catches (in number) by species. These data are tabulated by 5 degree grid squares, type of operation (individual vessel or mothership plus catcher boats), size of vessel (20-50, 50-100, 100-200, over 200 t class) and type of bait (squid, saury, livebait or other).

The 1962-66 reports contain actual amounts recorded on returned logbooks. Since 1967, total catch and fishing effort for each entry in the annual reports are estimated from the amounts reported in logbooks. From 1967 to 1983, a multiplier equivalent to the number of trips known to have been made, divided by the number of trips with returned logbooks, was applied to all recovered logbook data separately for each type and size of boat, so the Fig.s presented in the reports are the estimated total figuress, corrected for the non-return of a proportion of logbooks. These multipliers were not different for different geographical areas.

Since 1984, however, the multipliers used to convert the amounts recorded in returned logbooks to estimate total catch have been based on the ratio of fishing days reported by radio to the number of fishing days recorded in logbooks, and have been calculated separately for each month and sub-area.

Although fishing started in 1952, data are only available since 1962, when publication of the annual reports began. At present, data up to 1980 have been published. Since 1981, data have been provided directly from Far Seas Fisheries Research Laboratory to CSIRO Australia and FRC New Zealand. Australia and New Zealand are the other member countries of the tripartite meeting on SBT. Due to the long trips of Japanese longliners and the delay in data delivery to the Fishery Agency of Japan, there is a lag of about one and a half years before data become available.

The reliability of the data is affected by the relationship of the catches recorded in returned logbooks to the total catch. More then 90 % of total SBT catches are made by boats over 200 gross t and the rest by 100-200 t boats. According to the annual reports (Fishery Agency of Japan, Research Division, 1982, etc.), recovery rates of logbooks for boats larger than 200 gross t range from 76 % (1973) to 98 % (1970), with an average of about 86 %, but have risen to around 95 % since 1977. Recovery rates from boats in the 100-200 t class were about 60-72 % in the 1960s and early 1970s but have risen to about 85 % since 1975.

See Majkowski and Morris (1986) for further information.

Length frequencies

The Far Seas Fisheries Research Laboratory organises the length-frequency sampling of the Japanese longline catch. Data have been collected by the following methods:

In the early years, when boats made short cruises and fish landed could be easily attributed to a particular area and time of catching, data on length or weight were obtained by measurement at the Yaizu and Tokyo fish markets. About 10 % of landed SBT were sampled. After the early 1970s, longliners, especially those targeting SBT, began to make long cruises and to cover a wide area. This made it difficult to attribute landings to the date and place where they were caught, so fewer landed fish could be used for this purpose. Where necessary, lengths are calculated from weights using the following relationships:

for fish with fork length less than 130 cm (Robins 1963)

$$W = 3.1309 \times 10^{-5} \times L^{2.9058}$$

for fish with fork length greater than 130 cm (Warashina and Hisada, pers. comm.)

$$W = 1.4036 \times 10^{-6} \times L^{3.5399}$$

where L is fork length in cm and W is whole weight in kg.

Since 1970 data have also been collected from about 10 fishing vessels each year that have agreed to record the body length and weight of individual fish as they are caught. The entire SBT fishing ground is divided into ten sub-areas (see Shingu 1978). Generally, fishing boats move around two or three of these sub-areas on each voyage, so that these data cover the total fishing area fairly well.

From 1980 onward, individual weight data by date and location of capture obtained from fishing masters' private logbooks were also collected from about 10 % of SBT longliners. Lengths have been calculated from weight measurements using the equations above.

In 1988, the Far Seas Fisheries Research Laboratory distributed a length data form (Fig. 25) to all SBT longliners. The recording of length data is being done by cooperative fishermen on a voluntary basis. The number of samples obtained from this procedure was estimated to be about 15 % of the total catch in 1988.

The length data and weight data obtained as outlined are combined and the total length-frequency for each sub-area and for each quarter is estimated from the length frequency of the sample, adjusted by the known ratio of total catch (from logbooks) to sample size. The data are presented in 2 cm length classes. Data are processed in this way from 1952 on. Due to the long trips of Japanese longliners and the delay in delivery of logbooks and length-weight data to the Far Seas Fisheries Research Laboratory, there is a lag of about one and a half years before data become available.

See Majkowski and Morris (1986) for further information.

Needs for improvement in collection and processing of data

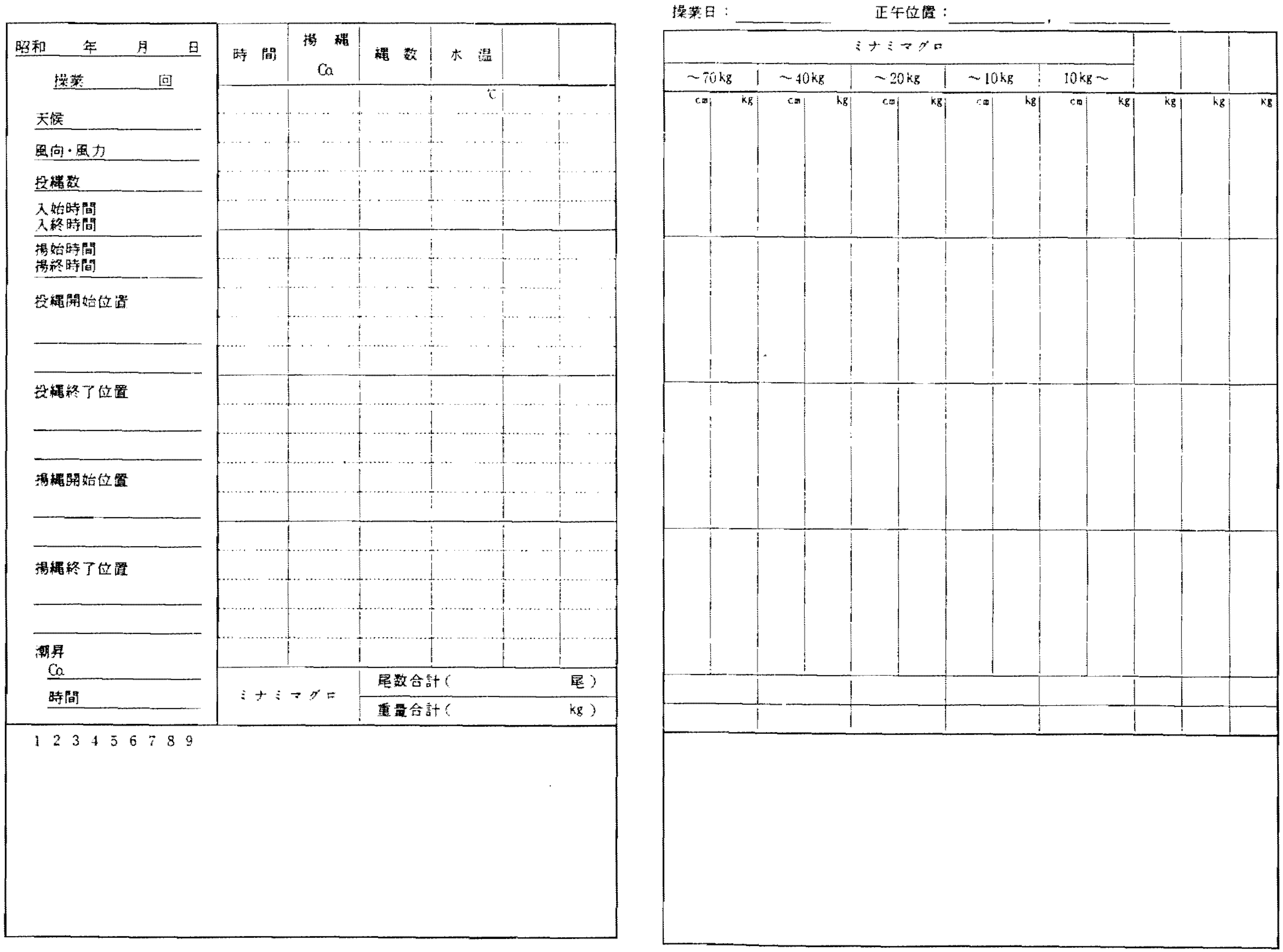
For up-to-date stock assessment and fishery management, more timely collection and processing of catch, effort and length data are needed. In addition, it is necessary to improve the recovery rate of length data from commercial longliners.

NEW ZEALAND DATA COLLECTION PROTOCOLS

Foreign and chartered longliners

Catch and effort statistics are recorded on a set by set basis in logbooks supplied to each vessel with instructions in Japanese for completing forms. The tuna longlining logbook (Fig. 26) is considerably more detailed than the logbook required by the Fishery Agency of Japan. The data collected by New Zealand was designed to provide information on environmental factors which may affect fishing success (wind speed and sea surface temperature), target species, size composition (processed weight) of each SBT caught, and to monitor the by-catch of commercial fish in each set.

The detail of the catch data collected varies approximately in relation to the value of the species with all species falling into one of the following categories:



昭和　年　月　日

操業　回

天候

風向・風力

投縄数

入始時間
入終時間

揚始時間
揚終時間

投縄開始位置

投縄終了位置

揚縄開始位置

揚縄終了位置

潮昇
Co.
時間

時間	揚縄 Co.	縄数	水温		
			℃		

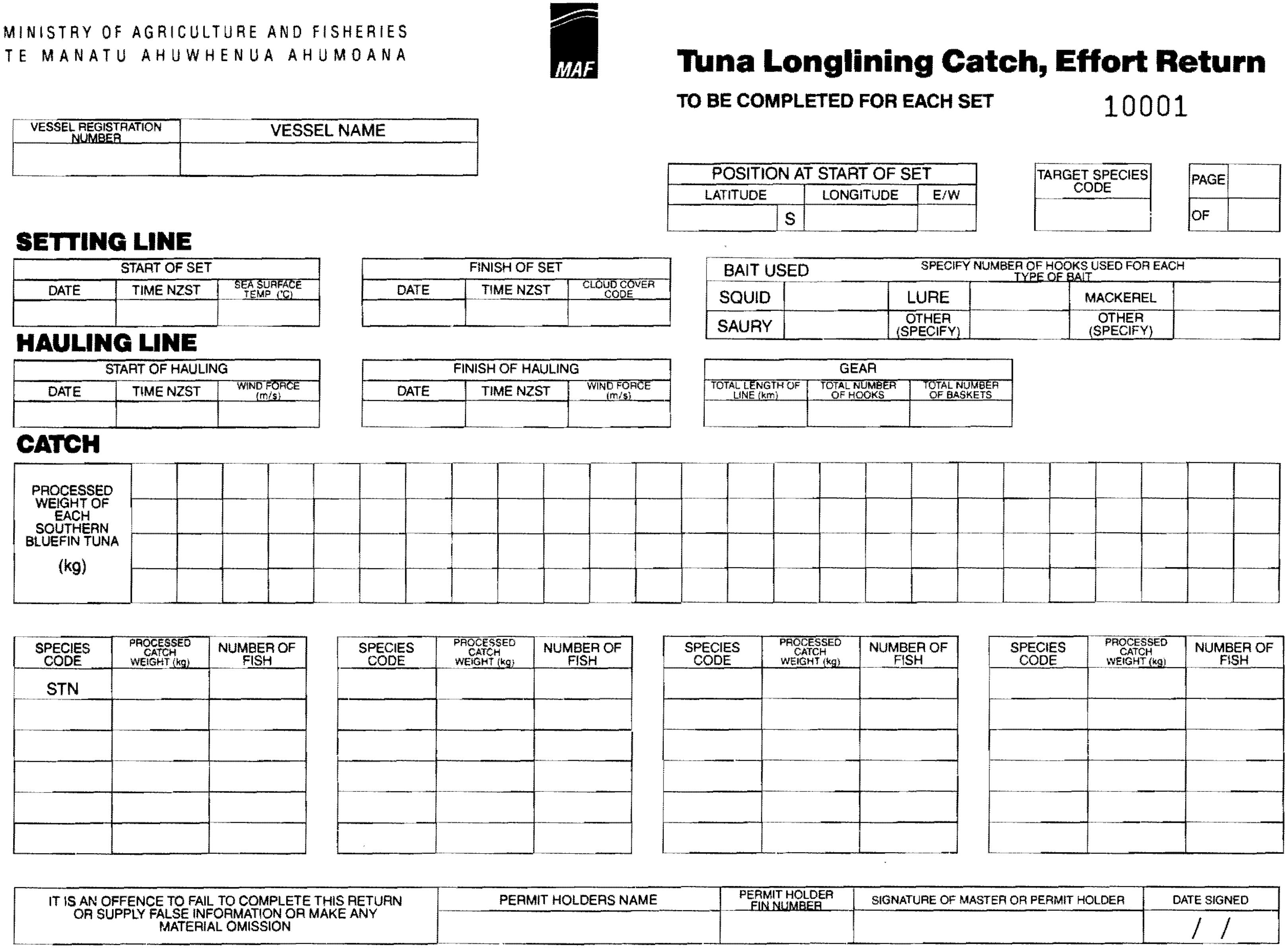
ミナミマグロ	尾数合計（　尾）
	重量合計（　kg）

1 2 3 4 5 6 7 8 9

操業日：　　　正午位置：　　　,

ミナミマグロ												
～70kg		～40kg		～20kg		～10kg		10kg～				
cm	kg	cm	kg	cm	kg	cm	kg	cm	kg	kg	kg	kg

Fig. 25. Form used on Japanese longline vessels for recording southern bluefin tuna length data.



MINISTRY OF AGRICULTURE AND FISHERIES
TE MANATU AHUWHENUA AHUMOANA

MAF

Tuna Longlining Catch, Effort Return

TO BE COMPLETED FOR EACH SET 10001

VESSEL REGISTRATION NUMBER	VESSEL NAME

POSITION AT START OF SET			
LATITUDE		LONGITUDE	E/W
	S		

TARGET SPECIES CODE

PAGE	
OF	

SETTING LINE

START OF SET		
DATE	TIME NZST	SEA SURFACE TEMP (°C)

FINISH OF SET		
DATE	TIME NZST	CLOUD COVER CODE

BAIT USED	SPECIFY NUMBER OF HOOKS USED FOR EACH TYPE OF BAIT				
SQUID		LURE		MACKEREL	
SAURY		OTHER (SPECIFY)		OTHER (SPECIFY)	

HAULING LINE

START OF HAULING		
DATE	TIME NZST	WIND FORCE (m/s)

FINISH OF HAULING		
DATE	TIME NZST	WIND FORCE (m/s)

GEAR		
TOTAL LENGTH OF LINE (km)	TOTAL NUMBER OF HOOKS	TOTAL NUMBER OF BASKETS

CATCH

PROCESSED WEIGHT OF EACH SOUTHERN BLUEFIN TUNA (kg)																									

SPECIES CODE	PROCESSED CATCH WEIGHT (kg)	NUMBER OF FISH	SPECIES CODE	PROCESSED CATCH WEIGHT (kg)	NUMBER OF FISH	SPECIES CODE	PROCESSED CATCH WEIGHT (kg)	NUMBER OF FISH	SPECIES CODE	PROCESSED CATCH WEIGHT (kg)	NUMBER OF FISH
STN											

IT IS AN OFFENCE TO FAIL TO COMPLETE THIS RETURN OR SUPPLY FALSE INFORMATION OR MAKE ANY MATERIAL OMISSION	PERMIT HOLDERS NAME	PERMIT HOLDER FIN NUMBER	SIGNATURE OF MASTER OR PERMIT HOLDER	DATE SIGNED
				/ /

Fig. 26. Prescribed logbook form for use on Japanese longline fishing vessels operating in the 200-nautical-mile New Zealand exclusive economic zone.

(a) The individual processed weight of each fish caught (SBT only);

(b) The total weight and number of fish caught by species (for northern bluefin, bigeye, butterfly tuna, striped marlin, black marlin, shortbill spearfish, sailfish, moonfish, albacore, yellowfin, broadbill swordfish, blue marlin, oilfish, mako shark, sunfish, and slender tuna);

(c) Number of fish only (for blue shark, bronze whaler shark, rays bream, thresher shark, and other unidentified sharks).

A series of range checks are applied to these data and outliers detected graphically. Apparent errors are checked against the original logbook entries. Logbooks are generally completely filled out despite the level of detail required for each set with over 94 % of all data fields completed. Logbook entries are assumed to be accurate unless other information contradicts this assumption. A limited observer program begun in 1987 indicated that the accuracy of catch statistics does vary with species and that logbook entries only recorded the part of the catch retained. Fish struck off before landing or discarded after landing were not recorded. It was further found that the accuracy of catch statistics was extremely high for the target species but under-reported for the incidental catch. Michael et al. (1989) indicate that under-reporting may vary from 0 % (SBT) to over 60 % (mako shark).

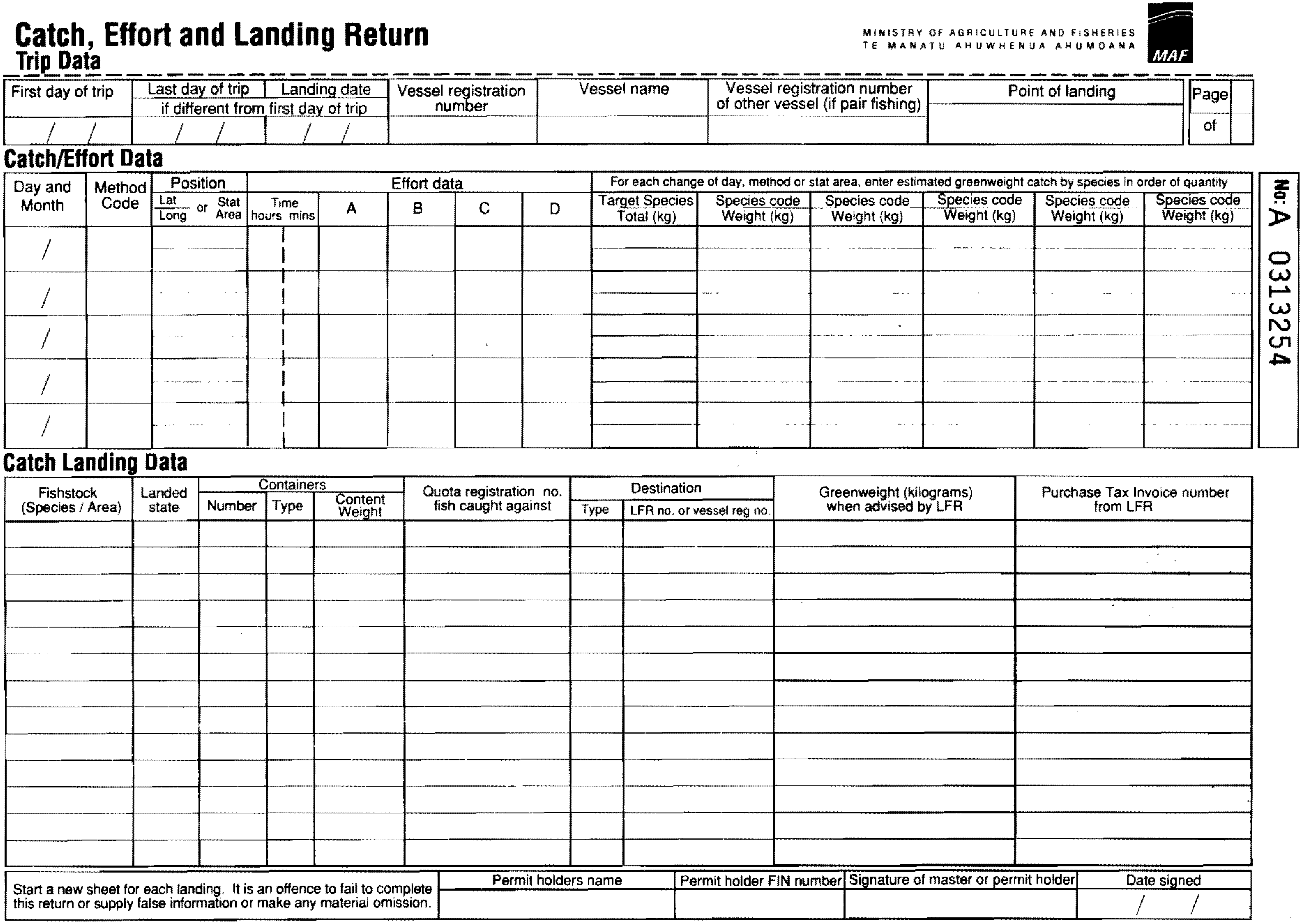
Beginning in 1989, a formal observer program was initiated to monitor at least four vessels each season for a period of approximately three weeks per month. Observer coverage extends from April to September for an estimated total of approximately 240 observer days per year. The observers record details of the fishing method, catch composition, measure and weigh all tuna and billfish species caught, and collect various biological samples as required for ongoing research programs.

Domestic vessels

Domestic vessels are required to complete a catch, effort and landing return logbook (Fig. 27). The logbook includes a form common to most domestic fishing with a method specific template for each fishing type. The current logbook was developed to reduce paperwork for fishermen under the assumption that the simpler the form, the more accurate the data will be. Catch data are verified against a form filled out independently by each licensed fish receiver when the catch is landed. The form is divided into three sections (trip data, catch and effort data, and landing data).

The trip data section consists of a single line recording the first and last day of the trip, the date of landing, the vessel name and registration number, and the point of landing.

The catch and effort section consists of five lines with a new line being used for each change of day, fishing method or statistical area. To allow a single form to be used for all fishing methods the method types are divided into seven broad groups. For each group a template is used which labels some or all of the effort columns so as to provide effort data relevant for that group of fishing methods. For handlining, trolling and pole-and-line fishing the effort section records the fishing method, area or position of fishing, number of hours fishing, number of lines used and number of hooks or lures on each line. In the case of longlining the effort section records the fishing method, area or position of fishing, number of hooks hauled in the 24-hour period, number of sets in the 24 hour period and total number of hooks on gear used in the 24-hour period. The catch section records the target species, estimated total unprocessed weight of all fish caught and the estimated unprocessed weight of the five most important species caught by weight in decreasing order.



Catch, Effort and Landing Return

MINISTRY OF AGRICULTURE AND FISHERIES
TE MANATU AHUWHENUA AHUMOANA
MAF

Trip Data

First day of trip	Last day of trip	Landing date	Vessel registration number	Vessel name	Vessel registration number of other vessel (if pair fishing)	Point of landing	Page
	if different from first day of trip						
/ /	/ /	/ /					of

Catch/Effort Data

No: A 0313254

Day and Month	Method Code	Position	Effort data					For each change of day, method or stat area, enter estimated greenweight catch by species in order of quantity					
		Lat / Long or Stat Area	Time hours mins	A	B	C	D	Target Species Total (kg)	Species code Weight (kg)	Species code Weight (kg)	Species code Weight (kg)	Species code Weight (kg)	Species code Weight (kg)
/													
/													
/													
/													
/													

Catch Landing Data

Fishstock (Species / Area)	Landed state	Containers			Quota registration no. fish caught against	Destination		Greenweight (kilograms) when advised by LFR	Purchase Tax Invoice number from LFR
		Number	Type	Content Weight		Type	LFR no. or vessel reg no.		

Start a new sheet for each landing. It is an offence to fail to complete this return or supply false information or make any material omission.	Permit holders name	Permit holder FIN number	Signature of master or permit holder	Date signed
				/ /

Fig. 27. Catch, effort and landing return form for used by New Zealand domestic fishermen.

The landing section is filled out each time a landing is made when all fish on board must be accounted for. A single line is used for each fish species describing its landed state (e.g. whole, headed and gutted, filleted, etc.), the number type and capacity of containers used to land the fish and the destination of the fish. The quota registration number the fish was caught against, relevant to fish species under the quota monitoring system only, and the licensed fish receiver number that the fish was landed to are also recorded.

Data on individual fish length, weight and sex are collected by a research logbook distributed to the freezer vessel and filled in voluntarily by the crew.

11. TRENDS IN CATCH, CATCH COMPOSITION, EFFORT AND CATCH RATE

TRENDS IN THE AUSTRALIAN FISHERY

Catches in weight and number by area for the Australian SBT surface fishery are shown in Table 10. From origins in NSW the fishery spread to SA then WA, peaking at 21 000 t in 1982-83. Catches off NSW had commenced a decline by 1982-83 and, in 1985, failed completely because of an absence of SBT surface aggregations. In contrast the WA fishery was undergoing rapid increase in catch at the time; catches during 1982-83 exceeded 1.1 million fish (predominantly 2-year-olds; ~55 cm, ~3.5 kg), taking the Australian catch (for all ages) to more than 2 million fish. The subsequent and even more rapid reduction in catches was a consequence of management intervention.

See Caton (1991) and Caton and Williams (1991) for further information.

Distribution of catches in the Australian surface fishery

There has been a substantial reduction in the range of area from which catches have been taken in the SBT surface fishery during the 1980s (Fig. 28). The productive grounds off NSW diminished progressively, became more scattered, and ultimately the fish were no longer found there. The productive fishing grounds off SA contracted westwards progressively and by 1987-88 few fish were taken from eastern SA grounds once important to the fishery. In 1988-89 catching activities were concentrated closer inshore than in the earlier 1980s; however, there was a slight expansion of the catching area eastwards, which continued in 1989-90.

Distribution of, and trends in, surface fishery effort

There is currently no reliable time series of effort data for the fishery. Data on daily landings by vessels are available, but the data provide no indication of days fished, hours searched, hours steaming to grounds, or other qualifiers of the effort represented by a 'landing'. Fishers' cooperation with logbook programs (introduced in the 1960s to obtain catch and effort information) was sporadic until the late 1970s. A more representative collection is now in place. Recently a project was established to identify and collate the various sets of data relating to activity in the fishery.

The distribution of nominal fishing effort, expressed as 'hours searched', has been mapped from logbook data for fishing seasons from 1981-82 to 1989-90 (Fig. 29) and is useful for comparison with changes in areas of catch in the fishery (Fig. 28).

The nature and efficiency of fishing operations changed markedly as the fishery developed. In the south-eastern sector, searching was carried out initially from fishing vessels but this was later augmented by aerial searching, extending the range of the fishery and directing vessels to more productive areas so that a vessel's nominal 'hour searching' became much more efficient. On the other hand the commencement of combined purse-seine and poling operations shortened poling activity on a school, thereby artificially reducing poling catch 'per hour searching'. Purse-seine activities themselves became more efficient in these combined operations. They also facilitated the capture of larger fish.

The lack of effort data, the range of vulnerable ages, the changes in target age, and the evolution of combined aircraft, pole vessel and purse-seine operations present a major obstacle to the development of a quantitative description of the trends in age-specific effort in the fishery.The WA

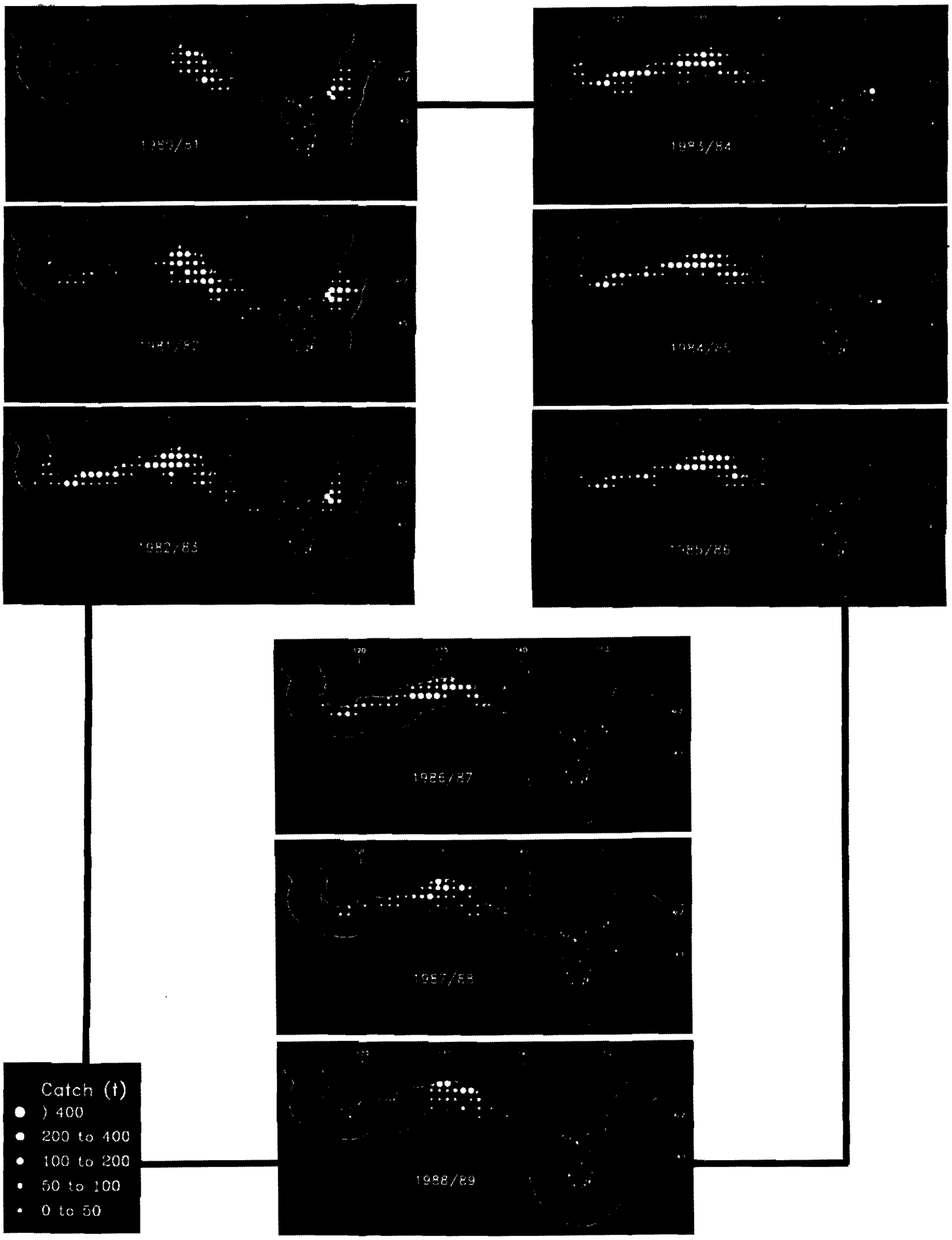


Fig. 28. Distribution of Australian surface fishery southern bluefin tuna catch against quota year, 1980-81 to 1988-89.

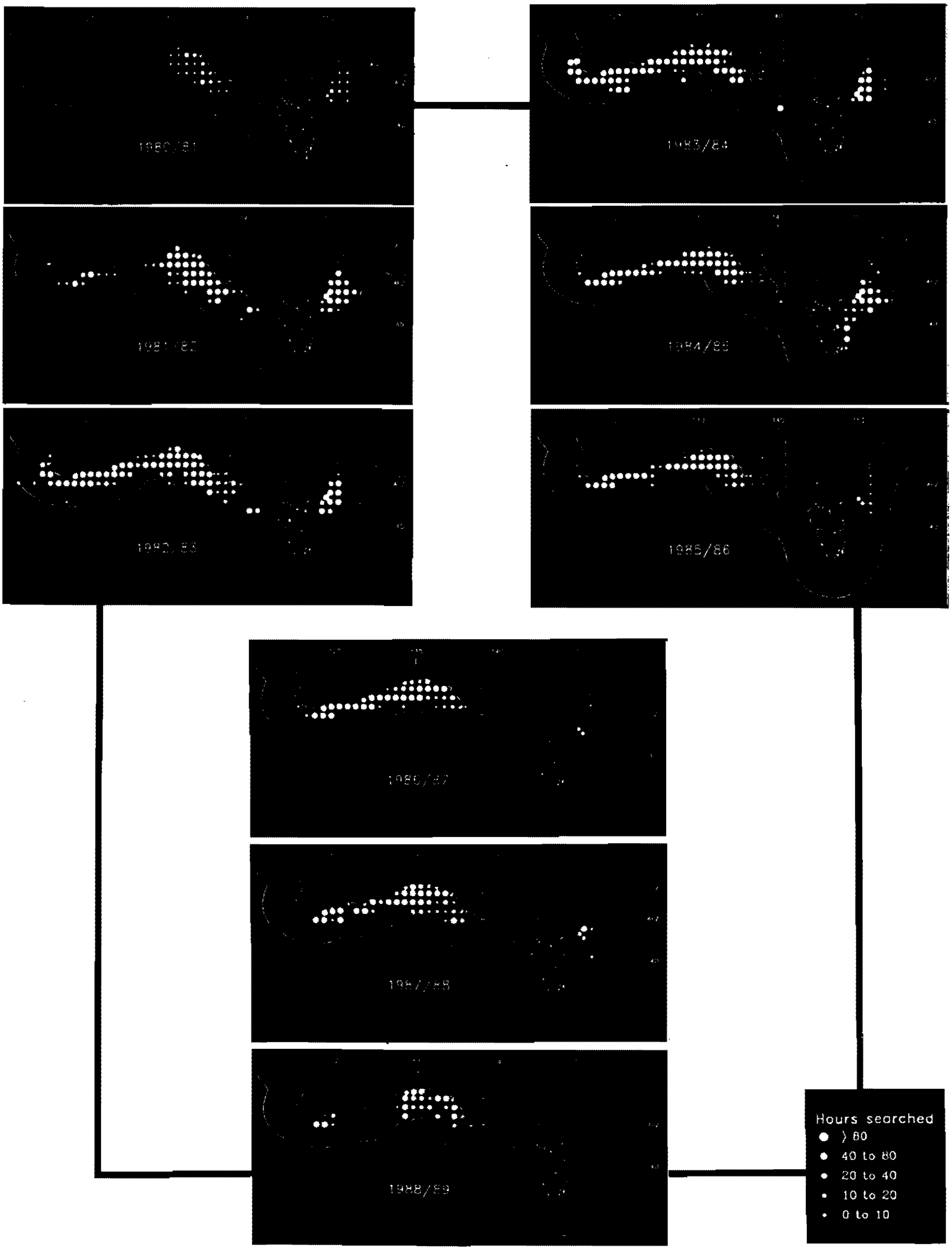


Fig. 29. Distribution of Australian surface fishery southern bluefin tuna effort (hours searching) against quota year, 1980-81 to 1988-89.

catch, on the other hand, consists predominantly of 2-year-old SBT and the fishery does not involve air support or purse-seiners. Detailed effort data are not available but from inception of the WA fishery in 1969 until 1982, records were maintained of catch per month, number of vessels operating per month, catch per boat per month, number of landings, and catch per landing. Catch per landing may provide a useful measure of the WA SBT catch rate.

From 1969 to 1974 inclusive, the WA fishery operated only near the port of Albany, vessels returning each day to deliver catch to the cannery there. In 1975, commercial fishing for SBT commenced in the Esperance area (about 240 nautical miles east of the Albany area). Operations were broadly similar to those at Albany but vessels were fitted out with small refrigerated holds which allowed them to stay at sea for a number of days and cover a wider area than the non-refrigerated Albany day-vessels.

Albany and Esperance catches, number of landings and catch per landing from 1969 to 1982 are shown in Table 13; catches and vessel numbers for the two areas from 1969 to 1988 are shown in Table 14. It would be inappropriate to interpret these gross CPUE data for WA as indicative of the trend in relative abundance of SBT there. As noted above, prior to 1975 fishing in the Albany area was confined to inshore waters. After 1975 many of the vessels fished wider offshore (to the edge of the Continental Shelf and beyond) and extended their range. The number of vessels increased as did their size, their sophistication, and the amount of equipment they carried.

Australian catch size-composition and age-composition

Changes in average length over time in the components of the surface fisheries are shown in Fig. 30. The catch is made up mainly of 3-4 years old SBT (~73 cm, ~8 kg; ~89 cm, 15 kg).

The NSW surface fishery was for most years characterised by the dominance in number of SBT between 2 and 3 years old (Fig. 31), but with the introduction of purse-seining the representation of older fish increased. By the late 1970s representation of the 2-3-year-old fish became more sporadic, until 1983 when they were virtually absent. Catches of older ages were also declining and the NSW fishery subsequently collapsed. Occasional sightings of small numbers of surface schools of larger SBT (5-10-year-olds) have occurred since 1985 but there has been no reappearance of surface schools of the 2 and 3-year-olds.

In addition to setting quotas for the Australian SBT catch, the Australian SBT Management plan, introduced in 1983-84, included a requirement that the average size of fish in the Australian catch should be increased. The intention was to progressively reduce the impact of the Australian fishery on the SBT parental biomass.

The NSW surface fishery failed soon after the commencement of the management plan but there was optimism that escapement generated by quotas would permit the eventual development of a winter longline fishery there. Off WA, attempts to divert activities to larger SBT had little success because there were limited numbers of large SBT. In contrast, the average length of the SA catch increased. Vessels diverted operations westwards beyond the edge of the Continental Shelf, and away from the concentrations of smaller fish which had become progressively more common in the catch during the 1970s. The major reductions in quota after 1983-84, and the establishment of outlets for larger fish at better prices to the sashimi market, provided a further incentive to avoid small fish. There was a substantial increase in the proportion of SBT used for sashimi rather than canning. However, despite this incentive, catching larger fish became more difficult because of their declining numbers (Fig. 32).

Poor weather and higher operation costs may to some extent have reduced SA activity in the areas where larger fish had been common, but their apparent decline was unexpected. The more stringent controls on catch in the Australian fisheries, with prompt and major reductions in take of very

Table 13. Southern bluefin tuna catch, landings, and catch per landing from Albany and Esperance from 1969 to 1982.

	Catch		Landings		Catch per landing	
Year	Albany	Esperance	Albany	Esperance	Albany	Esperance
1969	299		319		.94	
1970	708		1093		.65	
1971	600		1456		.41	
1972	757		1765		.43	
1973	308		989		.31	
1974	321		806		.40	
1975	772	463	853		.91	
1976	228	61	370		.62	
1977	534	448	740	195	.72	2.30
1978	1048	951	1107	391	.95	2.43
1979	1247	1020	1603	516	.78	1.98
1980	1619	1042	2020	547	.80	2.90
1982	2858	1450	2175	441	1.31	3.29

Source: Department of Fisheries, Western Australia.

Table 14. Southern bluefin tuna catch, and number of vessels operating, from Albany and Esperance from 1969 to 1988.

	Albany		Esperance		Total	
Year	Catch	No. of Vessels	Catch	No. of Vessels	Catch	No. of Vessels
1969	299	9			299	9
1970	708	20			708	20
1971	600	30			600	30
1972	757	29			757	29
1972	308	30			308	30
1974	321	27			321	27
1975	772	23	463	10	1235	29
1976	228	20	61	2	289	22
1977	534	27	448	12	982	30
1978	1048	36	951	30	1999	50
1979	1247	59	1020	45	2267	80
1980	1619	73	1042	49	2661	84
1981	1333	73	1958	59	3291	96
1982	2858	77	1450	46	4308	89
1983	2120	69	2440	39	4560	77
1984	1466	58	2254	41	3720	79
1985	1128	28	901	16	2029	35
1986	505	31	566	15	1071	34
1987	730	18	475	15	1205	25
1988	599	25	490	18	1089	33

Source: Department of Fisheries, Western Australia.

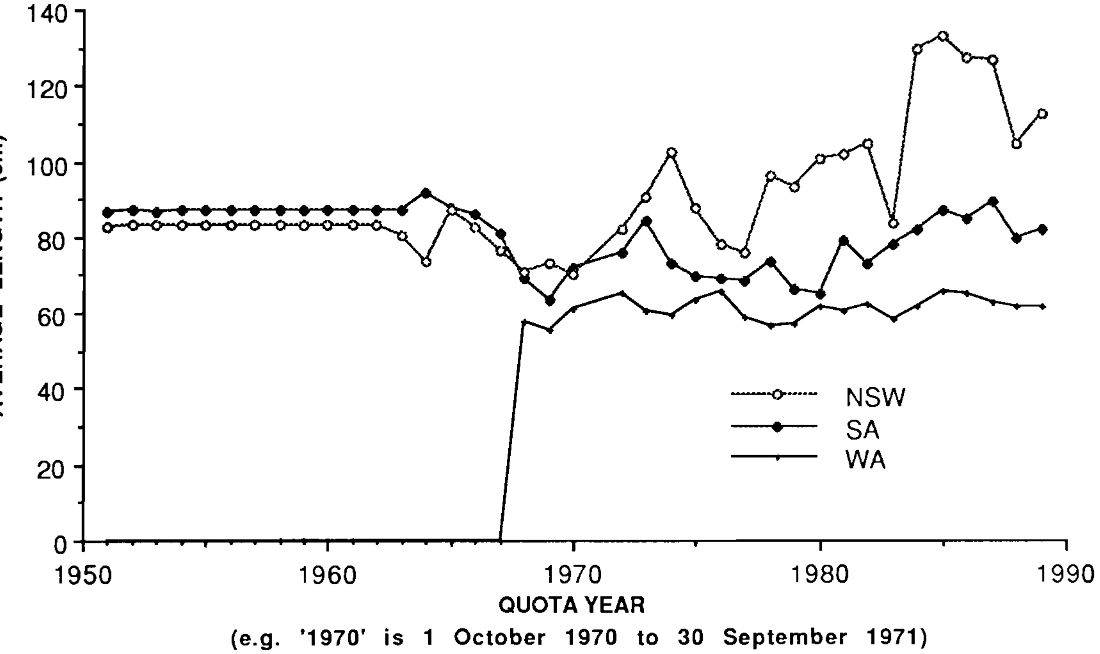


Fig. 30. Southern bluefin tuna average length for New South Wales, South Australia and Western Australia against quota year (1 October to 30 September).

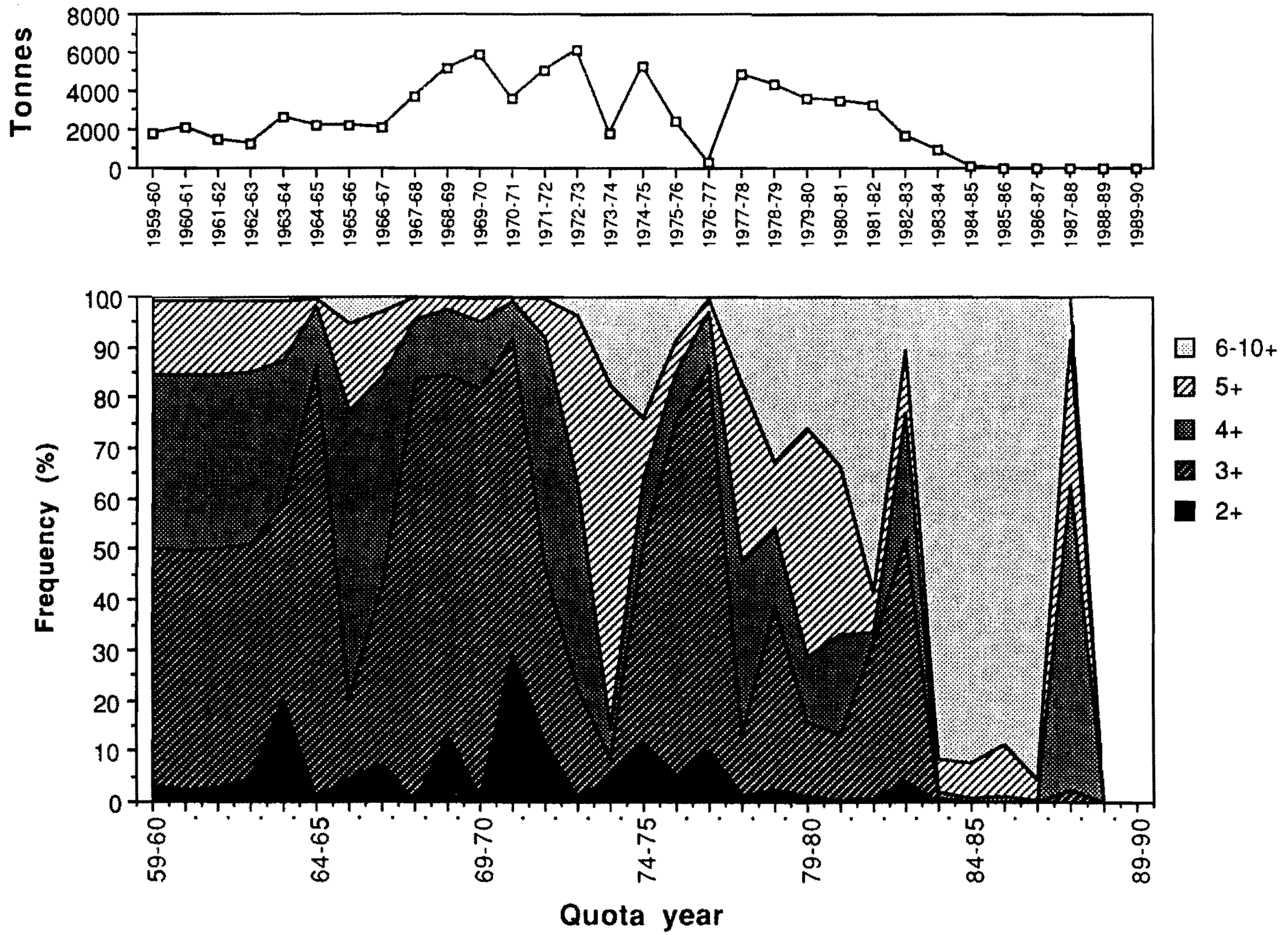


Fig. 31. Percentage catch in number of 2+, 3+, 4+, 5+, and 6+ to 10+ fish in the New South Wales southern bluefin tuna catch for quota years (1 October to 30 September) 1959-60 to 1989-90.

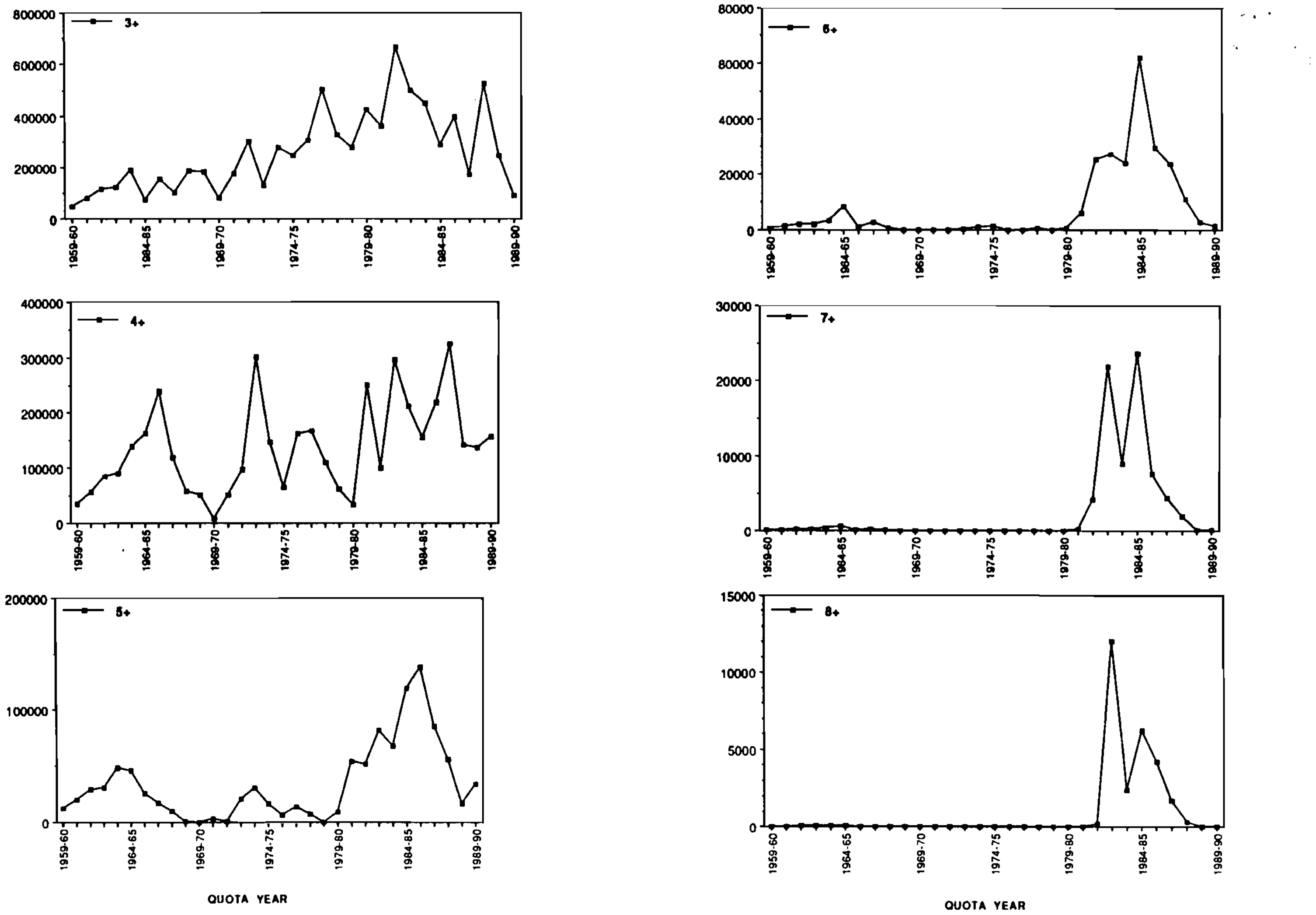


Fig. 32. South Australian southern bluefin tuna catch of six age classes (3+ to 8+) for quota years (1 October to 30 September) 1959-60 to 1989-90.

young fish off WA, should have led quickly to increased young (1-year-old to 3-year-old) fish escapement, reappearance of surface schools off NSW, and improved availability of larger (4-year-old to 8-year-old) fish in the SA and NSW surface fisheries. It was only when the WA catch had been reduced to less than 10 % of the size of the catches of the early 1980s (by 1989-90 the WA catch, predominantly 2-year-old SBT, had been reduced from more than 1 million fish to about 30 000), that reports of improved small fish abundance and distribution in SA were made, suggesting that early quotas had been inadequately stringent in relation to the recruits available.

With the halving of the quota after the 1988-89 season, SA vessels were able to reduce activity on very small fish. There may also have been a small increase in the quantity of larger fish taken. This should mean a reduction in the eventual impact of the SA fishery on parental biomass, but, given the uncertainty of the reason for the reduced absolute catch of larger fish through the 1980s and the delay in recovery of NSW grounds, the possibility that a severe recruitment decline has been in progress, with consequential parental biomass implications, cannot be overlooked.

TRENDS IN THE JAPANESE LONGLINE FISHERY

Trends in overall area

The catch of SBT sharply increased in the initial phase of fishery development with the expansion of the fishing grounds. It amounted to more than 75 000 metric tons (about 1.2 million fish) in both 1960 and 1961. From then on the catch gradually decreased, and presently it amounts to about 11 000 metric tons (about 170 thousand fish) per annum (Table 15).

The relationship between the catch and the fishing effort directed at SBT by the Japanese longline fishery is shown in Fig. 33. Before 1961, when the fishing grounds had been limited to the waters west of Australia and east of New Zealand, and fishing effort was small, the catch increased with increase in the fishing effort, indicating a high hook rate. From 1962 to the end of the 1960s, the catch levelled off while the fishing effort continued to increase, reflecting a rapid decline in hook rate. The continuous decline in hook rate coincides with the expansion of the fishing grounds.

After 1970, the growth of fishing effort slowed. The total number of hooks set fluctuated within the range of 80-125 million from the early 1970s to 1987. During this period, the overall hook rate declined by about 25 %. Decrease in fishing effort in the early 1980s was associated with a voluntary 20 % reduction in the longline fleet in 1981-1982. The subsequent slight increase in effort during the 1980s reflects a trend of increasing number of hooks per set.

Medium and large-sized SBT (70-180 cm in fork length) have been the principal target of Japanese longliners. Fig. 34 shows the length-frequency distributions of the catch. In the early stage of fishery development, catches comprised mainly large-sized fish, with a fork length of 130 cm or more; these fish (i.e. 8 years old and older) represent adult stocks. The proportion of medium-sized fish increased from 1960 to 1970 as the fishing grounds expanded. Although the Japanese longline and Australian surface fisheries are geographically and operationally distinct, there has been a partial overlap in the size composition of their catches (Fig. 34).

Further information on trends in the Japanese fishery are given in Shingu (1978), Yonemori et al. (1983), Yonemori et al. (1985) and Caton et al. (1991).

Trends in each statistical area

Area 1 (Fishing ground south of Java-Oka ground): on this fishing ground, SBT were targeted only from the mid-1950s to the early 1960s. During this period, the catch fluctuated between 100 and 200 thousand fish (Fig. 35), and hook rate on these adults was high at around 2 % (Fig. 36). Since 1962, the target of fishing operations has transferred to other species of tuna (Shingu 1978).

Table 15. Trends in the fishing effort, catch and catch per unit effort for the Japanese longline fishery directed at southern bluefin tuna, 1952 to 1988.

Calendar year	Million hooks set	Catch in thousands	Hook rate[a] (%)	Catch in weight[b] (10^3 tons)
1952	1.0	6	0.63	0.6
1953	4.2	49	1.17	2.2
1955	4.7	36	0.77	2.9
1956	11.9	186	1.57	14.9
1957	10.8	400	3.72	21.9
1958	7.2	225	3.12	12.4
1959	20.4	1032	5.07	63.9
1960	27.5	1188	4.32	75.7
1961	33.5	1209	3.61	77.5
1962	20.2	674	3.33	40.9
1963	36.9	1008	2.74	59.2
1964	34.0	743	2.18	42.7
1965	40.0	721	1.79	40.6
1966	49.4	682	1.38	39.6
1967	66.4	929	1.40	59.1
1968	80.6	827	1.03	49.5
1969	81.6	844	1.04	49.6
1970	82.3	699	0.85	40.6
1971	90.7	694	0.77	38.1
1972	90.4	806	0.89	39.6
1973	95.2	651	0.68	31.2
1974	90.1	670	0.74	33.9
1975	80.3	440	0.55	24.1
1976	105.5	633	0.60	33.7
1977	86.1	536	0.62	29.6
1978	79.0	451	0.57	23.0
1979	104.2	520	0.50	27.7
1980	125.0	585	0.47	33.4
1981	116.0	477	0.41	28.1
1982	99.6	330	0.33	20.8
1983	104.7	423	0.40	24.7
1984	110.5	364	0.33	23.3
1985	109.8	303	0.28	20.4
1986	107.0	212	0.19	14.0
1987	101.4	191	0.19	14.0
1988[c]	-	174	-	11.2

a. Catch in number divided by number of hooks set.
b. Includes incidental catch of this species.
c. Provisional value.

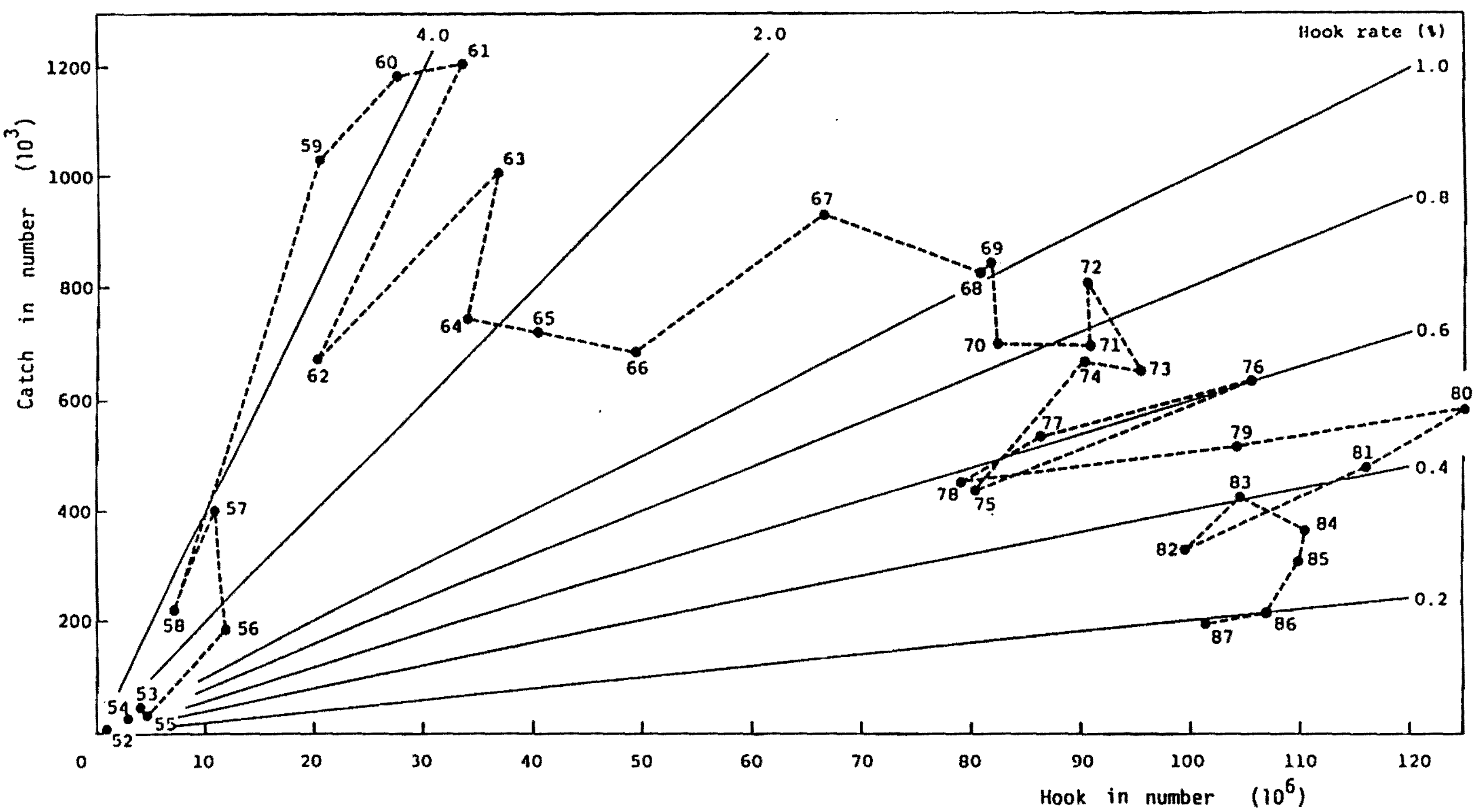


Fig. 33. Historical change in number of hooks used and southern bluefin tuna caught by Japanese longline fishery, 1952 to 1987.

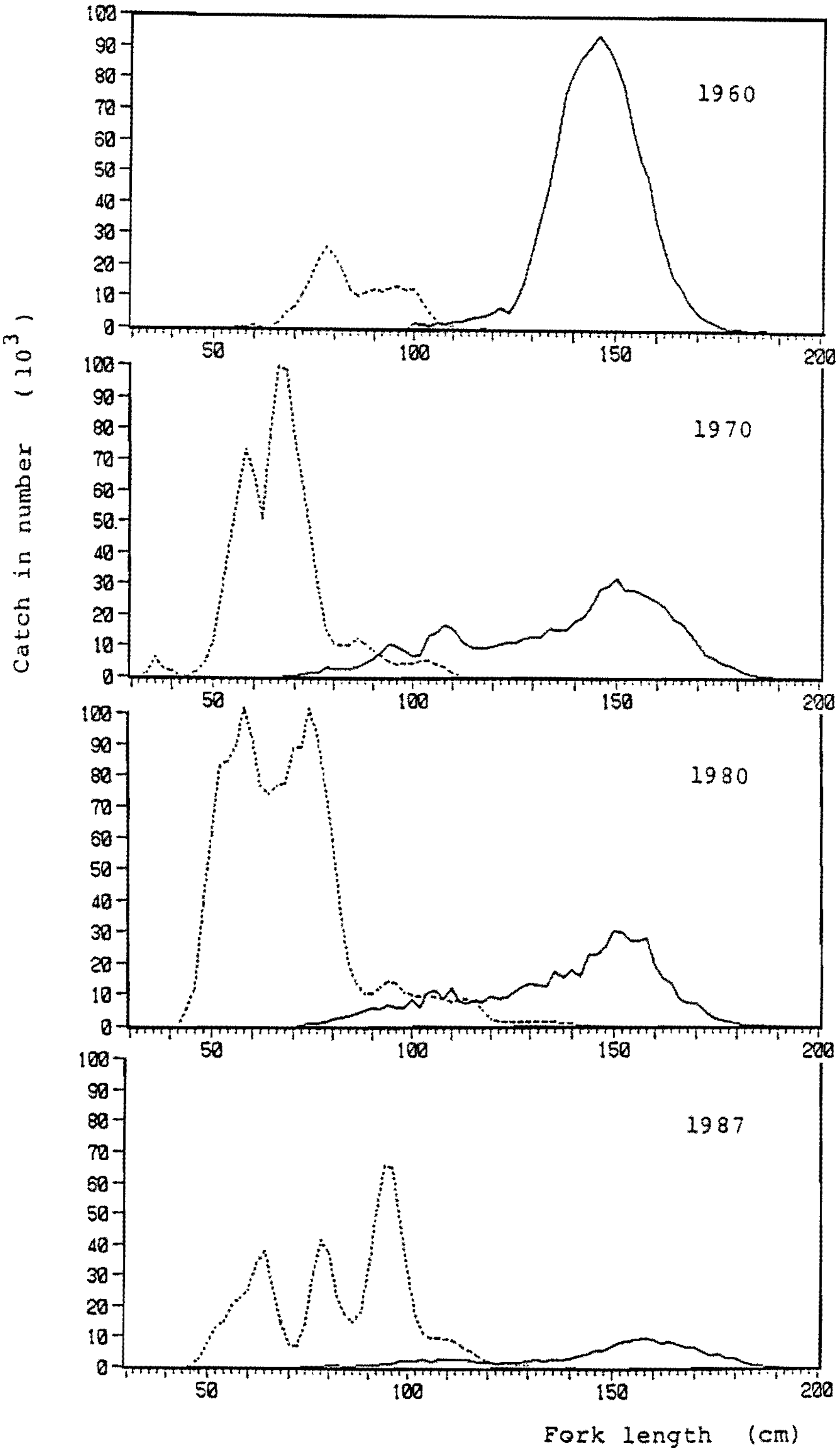


Fig. 34. Length-frequency distribution of southern bluefin tuna caught by Australian surface fishery (dotted line) and Japanese longline fishery (solid line) in 1960, 1970, 1980 and 1987.

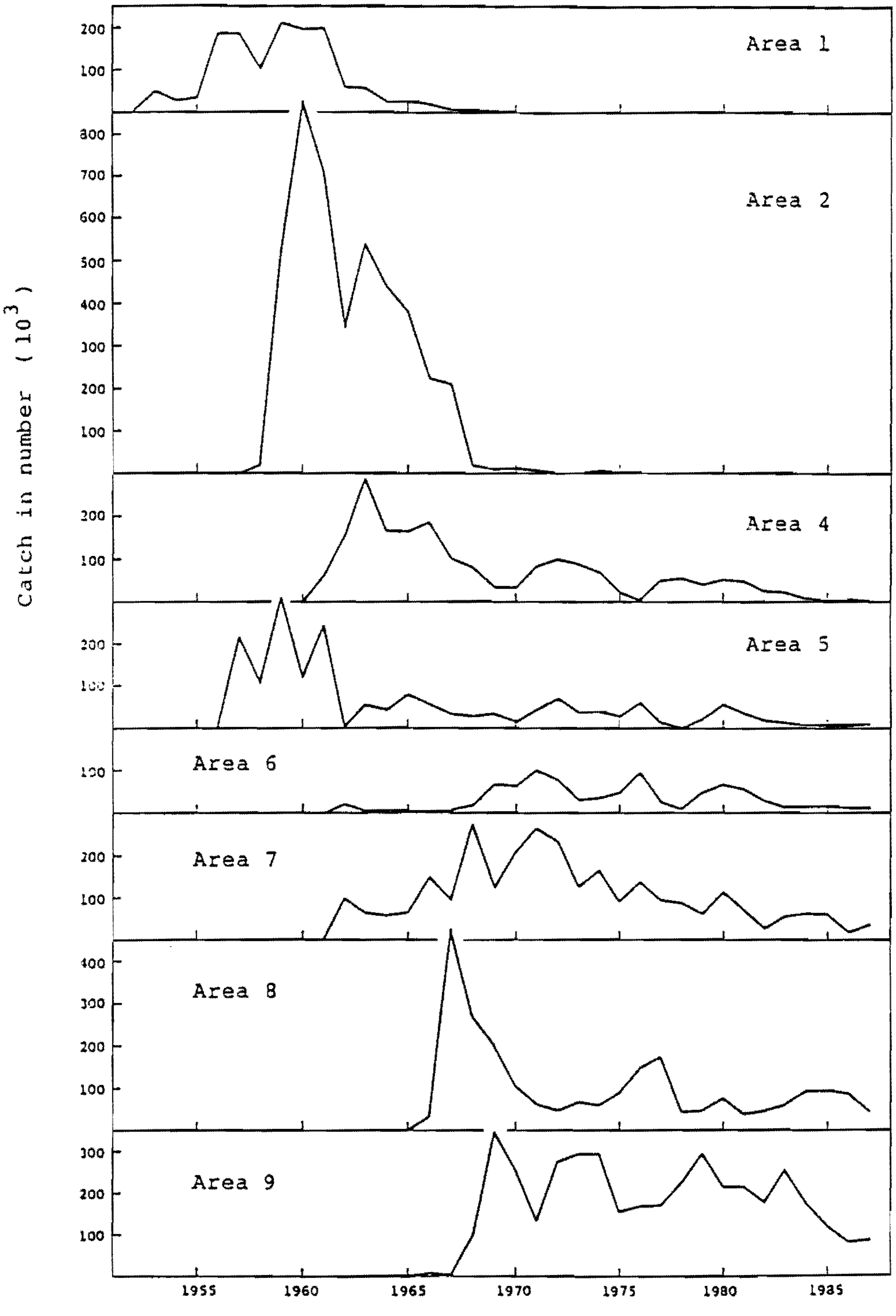


Fig. 35. Annual change of southern bluefin tuna catch in each of the Japanese longline fishery statistical areas.

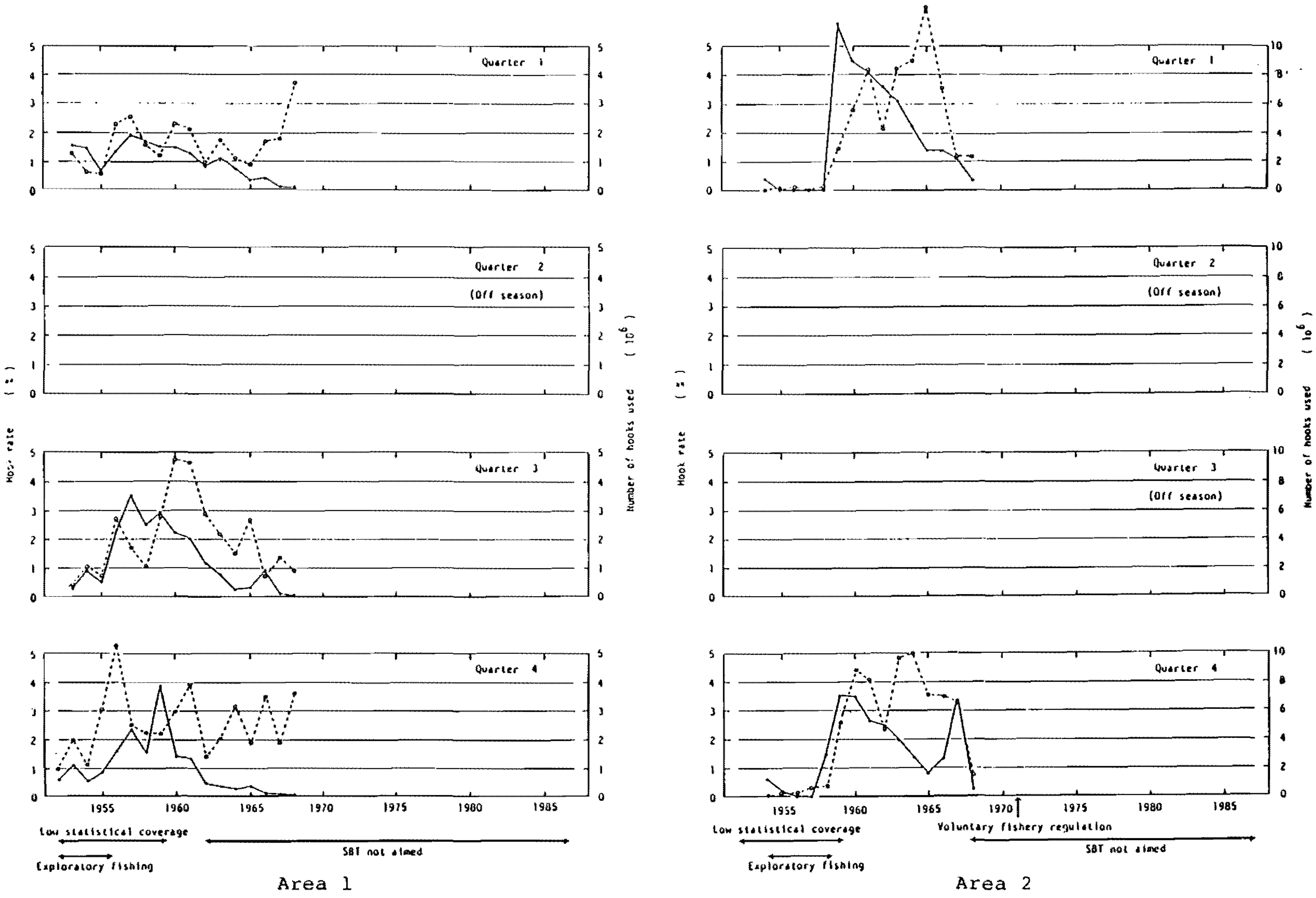
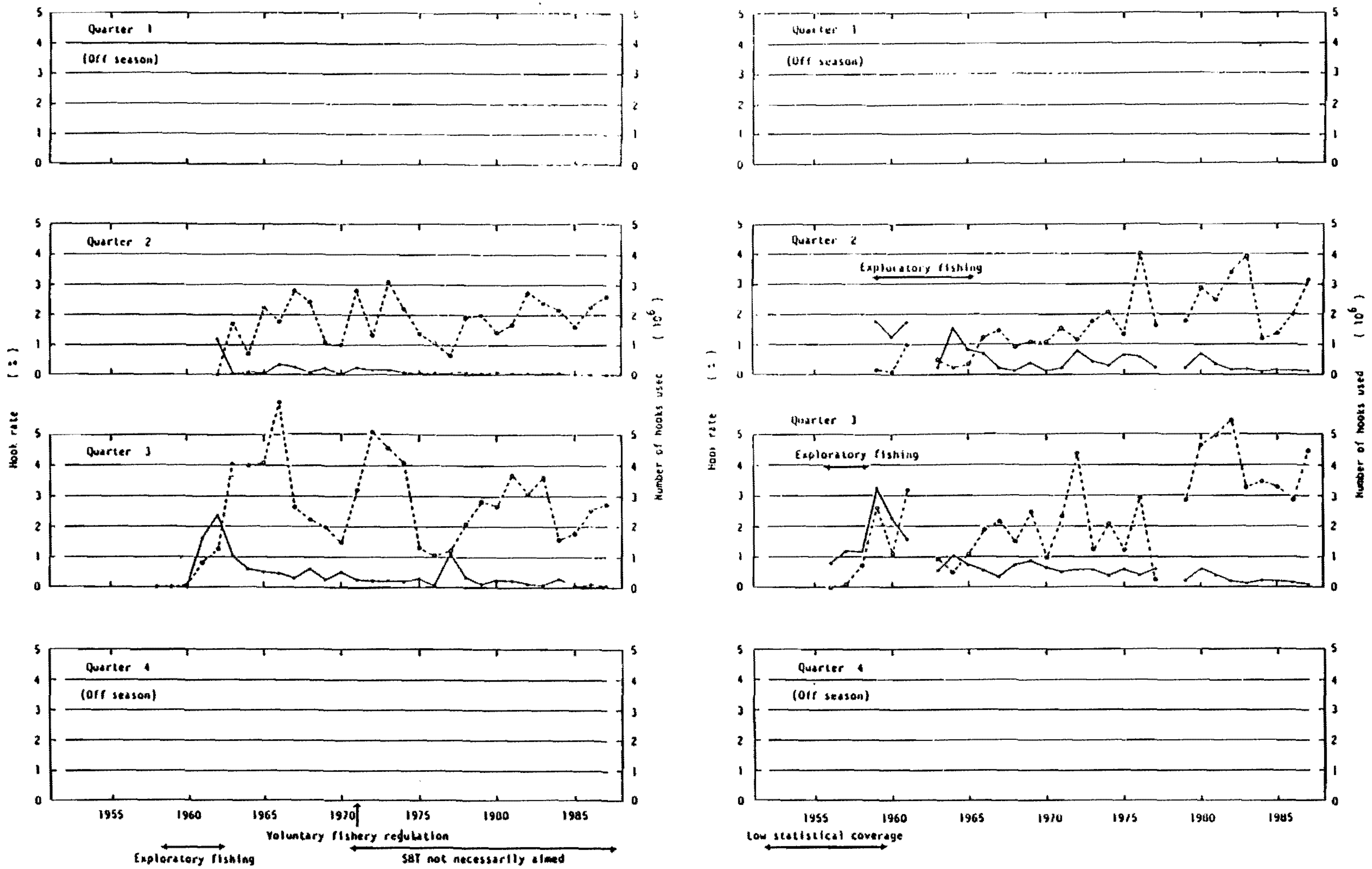


Fig. 36. Annual changes of hook rate (solid lines) for parental stock (age 8 and older) and number of hooks used (broken line).



Area 4

Area 5

Fig. 36 (continued).

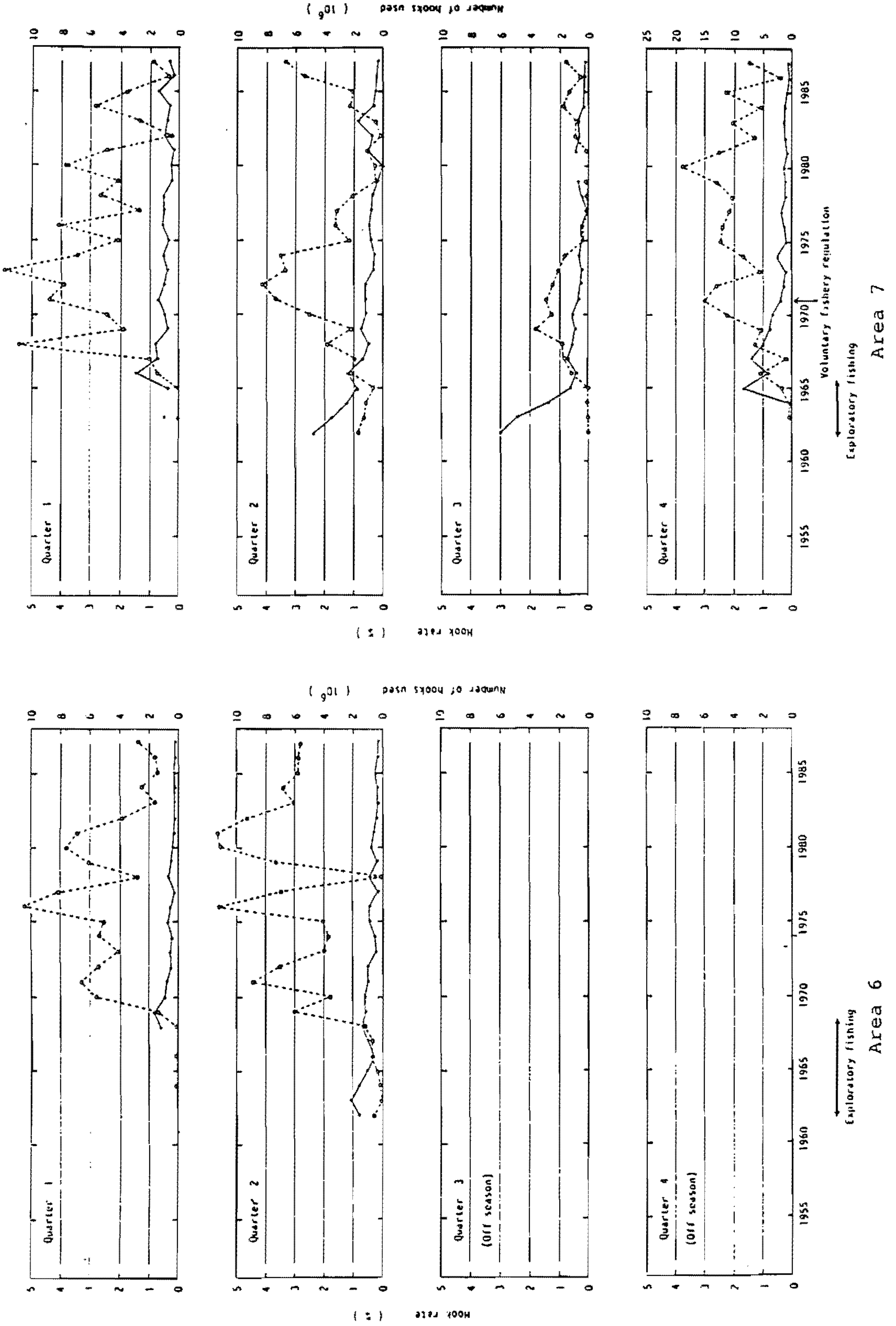


Fig. 36 (continued).

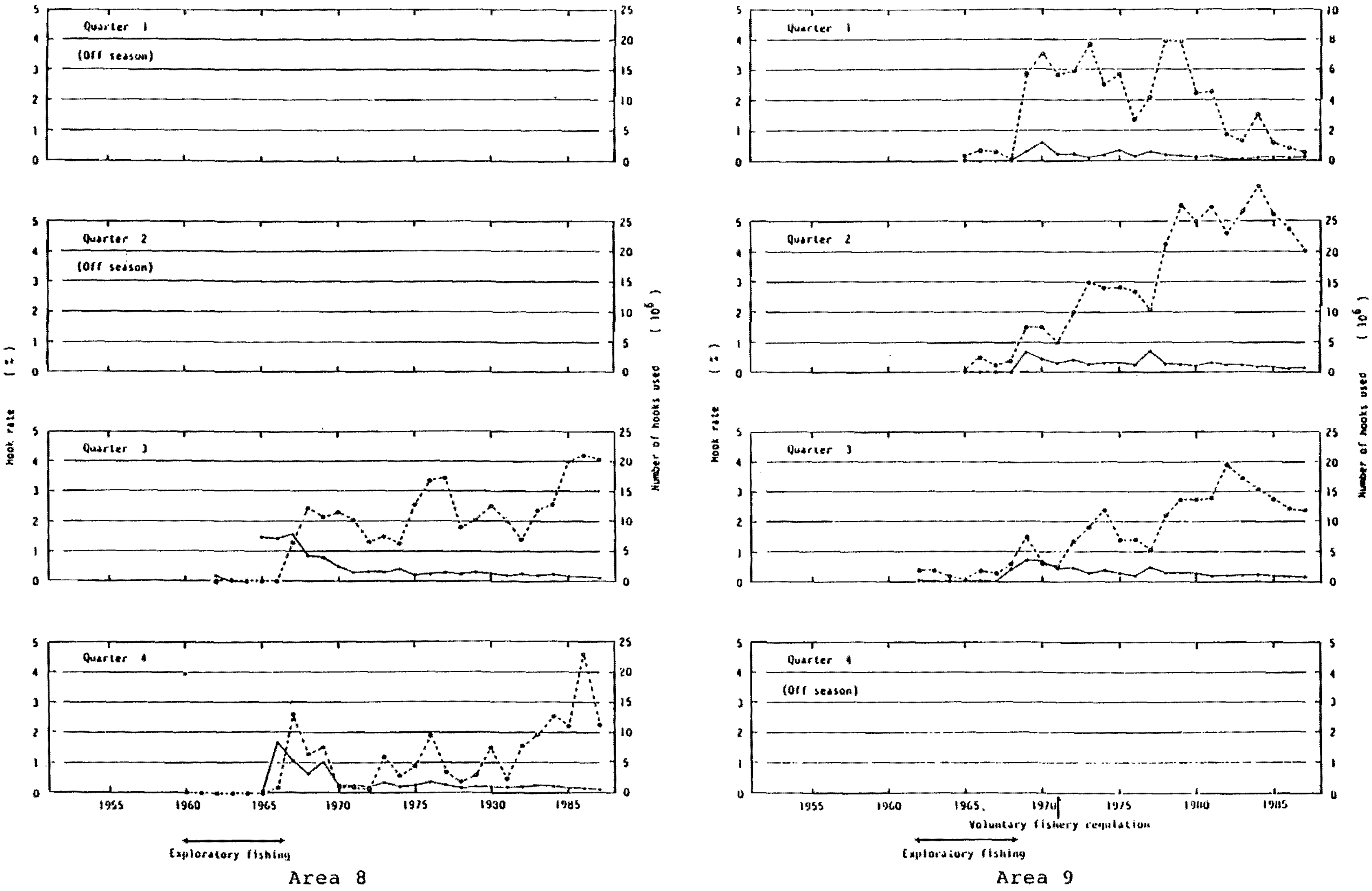


Fig. 36 (continued).

Area 2 (Fishing ground off North West Cape-Oki ground): full scale SBT fishing commenced in the late 1950s in this area. The catch increased sharply, peaking at about 900 thousand fish in 1960. After that it decreased rapidly (Fig. 35). The initial hook rate on adults on this fishing ground was higher than that on the Oka fishing ground, exceeding 5 % (Fig. 36). Since 1968, fishing effort has been directed mainly at bigeye (Warashina and Hisada 1974), so SBT hook rate does not reflect SBT abundance.

Area 3 (Fishing ground in the Great Australian Bight): small SBT were prevalent in this area. A voluntary seasonal closure was adopted in 1971, and when the Australian fishing zone came into operation in November 1979 the area was closed year round.

Area 4 (Fishing ground off NSW): fishing for SBT was conducted from 1963 to 1970. During these years the catch declined substantially (Fig. 35). Hook rate for adults, however, maintained a relatively constant level of less than 1 % (Fig. 36). After the early 1970s, the main target species in this area were yellowfin tuna and marlins.

Area 5 (Fishing ground off north New Zealand): in the early stage of exploitation (from 1957 to 1961), the catch fluctuated around 200 thousand fish. It subsequently maintained levels below 100 thousand fish (Fig. 35). After the period of exploratory fishing, hook rate for adults gradually decreased with the increase of fishing effort (Fig. 36). This tendency of hook rate does not necessarily indicate that of abundance, because the fishing ground is a geographically marginal area of SBT distribution.

Area 6 (Fishing ground off south New Zealand): full scale fishing on this fishing ground started in 1969-70. After that, the hook rate for adults started to decrease (Fig. 36). As in the case of the previously mentioned fishing ground, it should be noted that the hook rate trend for this geographically marginal area does not necessarily coincide with that of SBT abundance.

Area 7 (Fishing ground around Tasmania): full scale fishing commenced from the mid-1960s. The maximum catch (nearly 270 thousand fish) occurred in 1968, subsequently decreasing (Fig. 35). The fishing effort generally increased until the early 1970s when it reached more than 30 million hooks. After that, it gradually decreased. The hook rate for adults generally declined from the mid-1960s to the late 1980s (Fig. 36).

Area 8 (Fishing ground in south-central Indian Ocean): the catch was the highest at the start of exploitation (nearly 470 thousand fish in 1967), then decreased sharply until 1972, and subsequently showed an increasing tendency until 1977 (Fig. 35). These changes reflect those of fishing effort (Fig. 36). Hook rate for adults indicated a steady declining trend from 1967 to 1987.

Area 9 (Fishing ground south of Africa): full scale operations started in 1969. Since then, this area has been the most important fishing ground for the Japanese fishery (Fig. 35). The fishing effort has been large, reaching nearly 50 million hooks in 1979. After that, it began to decrease, and has been around 30 to 40 million hooks in recent years. The hook rate for adults showed a steady decreasing trend for 20 years from the late 1960s to the late 1980s (Fig. 36).

See Shingu (1970), Shingu and Hisada (1971), Warashina and Hisada (1974), Kono and Warashina (1985) and Kono and Warashina (1989) for further information.

Need for improvement in estimation of the fishing effort

The fishing effort mentioned in this section is nominal. To use catch per unit of fishing effort as a density index, effective fishing effort should be estimated, taking the temporal-spatial distribution of relative fish density into consideration.

Trends in the Japanese fishery within the 200-mile Australian fishing zone

Since 1 November 1979 when the AFZ commenced operation, Japanese longliners operating in the zone have maintained daily logbooks. Also, every two days (previously every six), they have radioed their position, catch by main species, and hooks set. Catch trends from radio report data for Australia west of 140° E, south-eastern Australia (south of 34° S), and north-eastern Australia are summarised in Table 16.

The extension of access restraints since establishment of the AFZ has forced Japanese longliners to modify their fishing campaigns, but clearly the south-east of Australia has always been the main area of the AFZ for SBT. In recent years activities directed at SBT have become concentrated around Tasmania (Caton 1991, Caton and Williams 1991).

The south-eastern area has traditionally supported a winter longline fishery for SBT. The catch there by Japanese longliners increased substantially during the winter of 1989 because of a large increase in effort (Table 17). Examination of joint venture SBT catch rate trends adjacent to southern NSW (34° to 39° S), and licensed Japanese activity off Tasmania indicate that, while a recent increase has commenced, catch rates are still low in relation to earlier years (Fig. 37). Whereas the average processed weight of fish taken during the early 1980s had been increasing (Table 17), the weight declined in the late 1980s, indicating an increase in the proportion of smaller fish in the catch now.

A comparison of SBT length distributions for 1982, 1984, 1988 and 1989 (Fig. 38), compiled from samples by observers on longliners off south-eastern Australia, suggests that the trough in frequency in the two recent years (reflecting low representation of medium size SBT) has moved slightly to the right in 1989, with the left peak (representing young fish) enlarged and further to the left than was the case in 1988. The trough encompasses fish from about 7-11 years old, year classes most heavily exploited as young fish during the period 1982 to 1984 (and so most likely to be reduced in abundance in 1989). The left peak represents fish from 4 to about 7 years old. Improved abundance of these pre-adult fish might be anticipated, given the major Australian catch reductions since 1984. The length distribution shows an increase in their proportional presence. This could be caused by an increased abundance of young fish, fewer older fish, activity in areas where younger fish were concentrated, or a combination of all these (Caton 1991, Caton and Williams 1991).

Trends in fishing effort, catch and catch-per-unit-effort for the Japanese fishery within the 200-mile New Zealand exclusive economic zone

Details of trends in the Japanese longline fishery adjacent to New Zealand are provided in Murray and Burgess (1990).

Catch and effort data. Several trends have been monitored in the Japanese SBT longline fishery in New Zealand waters. These include the number and weight of fish caught, the average size of SBT in the catch, the effort, and the catch rate (number of fish per 1000 hooks set). These, and related statistics, are summarised in Table 18. Trends in catch, effort, and catch rate are also shown in Fig. 39. Since 1980, total effort has declined dramatically while the number of hooks and length of longline set by each vessel has increased. Catch rates for SBT have steadily declined, while the average size has increased. Preliminary examination of data collected by observers on five chartered and three foreign licensed longline vessels in 1989 suggest that these trends are continuing.

The total foreign longline catch of SBT within New Zealand waters in 1988 represents less than

Table 16. Japanese longline southern bluefin tuna catch (t processed weight) by Australian Fishing Zone year (1 November to 31 October) in the Zone for north-east (NE), south-east (SE) and western coast (WA) waters. Source: radio reports from Japanese longliners.

AREA	YEAR	TOTAL CATCH NO.	TOTAL CATCH TONNE	SOUTH ERN BLUE FIN NO.	SOUTH ERN BLUE FIN TONNE	ALBA CORE NO.	ALBA CORE TONNE	BIG EYE NO.	BIG EYE TONNE	YEL LOW FIN NO.	YEL LOW FIN TONNE	BLACK MAR LIN NO.	BLACK MAR LIN TONNE	'000 HOOKS	NO. PER '000 HOOKS	TONNE PER '000 HOOKS
NE	7980	89261	3131.7	2373	85.9	13532	156.2	10493	394.7	30303	971.5	7279	397.5	5577	16.0	.56
	8081	143002	4256.0	3365	114.7	38002	433.3	9474	426.4	60733	1781.9	1685	134.9	7749	18.5	.55
	8182	202962	6212.5	1166	40.6	70099	1008.7	12435	456.9	70386	2273.6	3422	276.3	12238	16.6	.51
	8283	162401	4485.4	975	42.5	66848	835.4	10350	347.7	49819	1498.1	3749	311.2	8462	19.2	.53
	8384	147980	3973.0	640	40.7	75598	1089.2	11536	381.3	29016	1018.1	2255	206.3	7508	19.7	.53
	8485	217151	5050.6	770	9.5	97943	1215.6	14654	516.1	71268	1840.6	2040	171.1	8083	26.9	.62
	8586	161445	3987.8	265	11.4	79830	859.1	15513	512.1	36926	1310.5	1278	73.6	6713	24.0	.59
	8687	181146	4300.0	693	29.3	82798	928.0	14750	481.0	54062	1582.2	1285	99.1	7186	25.2	.60
	8788	291500	7474.9	822	51.9	118253	1482.5	19806	598.0	105447	3300.4	2120	168.9	11859	24.6	.63
	8889	182623	4562.4	1205	32.7	82802	1094.5	11274	396.3	60528	1767.3	2457	162.9	7486	24.4	.61
SE	7980	86956	2476.8	57522	2021.4	21380	167.6	720	28.4	502	19.6	53	3.4	5760	15.1	.43
	8081	117750	3999.4	75809	3382.1	32119	238.9	880	38.0	2348	68.4	71	4.1	12985	9.1	.31
	8182	48029	1531.7	26526	1206.9	16445	144.5	655	29.9	518	22.1	33	2.0	6835	7.0	.22
	8283	55184	1451.9	22236	1008.5	29042	251.2	711	31.6	307	12.7	14	1.1	4595	12.0	.32
	8384	47370	2045.3	28885	1708.7	13304	136.1	606	20.3	764	32.3	22	1.4	7146	6.6	.29
	8485	8089	175.5	150	7.0	4871	45.4	842	33.2	235	11.0	2	.1	395	20.5	.44
	8586	25749	792.9	9239	516.9	11832	91.3	1069	46.4	927	25.5	9	.7	4234	6.1	.19
	8687	28443	930.7	10010	580.6	8633	86.6	607	28.0	875	33.4	3	.3	4655	6.1	.20
	8788	31646	1110.1	11277	657.2	12450	121.4	1064	36.3	1853	66.8	13	.9	4772	6.6	.23
	8889	157178	3547.4	52046	2329.2	86664	633.2	1917	72.0	3245	121.0	57	1.3	13779	11.4	.26
WA	7980	31505	699.5	11527	210.6	5518	56.1	9656	257.8	2215	78.9	272	15.3	1261	25.0	.55
	8081	65025	1442.9	21779	380.2	15186	142.2	10753	313.3	11887	372.4	638	35.5	2276	28.6	.63
	8182	35784	1289.4	171	9.9	5791	100.2	11564	323.3	14159	635.5	1213	82.5	2042	17.5	.63
	8283	43503	1482.1	126	5.0	6038	96.6	19288	638.9	13700	502.9	1039	65.4	2390	18.2	.62
	8384	53719	1764.8	605	26.8	7716	128.6	15187	501.4	19546	713.9	2038	96.4	2859	18.8	.62
	8485	73513	2596.0	209	18.4	8335	137.0	23105	724.3	30272	1173.4	3233	177.3	4479	16.4	.58
	8586	65389	2269.5	318	25.9	8583	151.0	20507	657.3	25146	933.6	2111	125.9	4210	15.5	.54
	8687	60168	1998.7	215	17.2	9134	147.7	29123	985.2	15069	549.7	943	62.2	4451	13.5	.45
	8788	30365	1091.0	100	9.1	5627	90.4	6607	227.2	14451	555.4	908	56.9	1663	18.3	.66
	8889	14069	489.6	52	5.5	1684	33.5	3270	119.5	6601	220.9	1037	50.1	853	16.5	.57

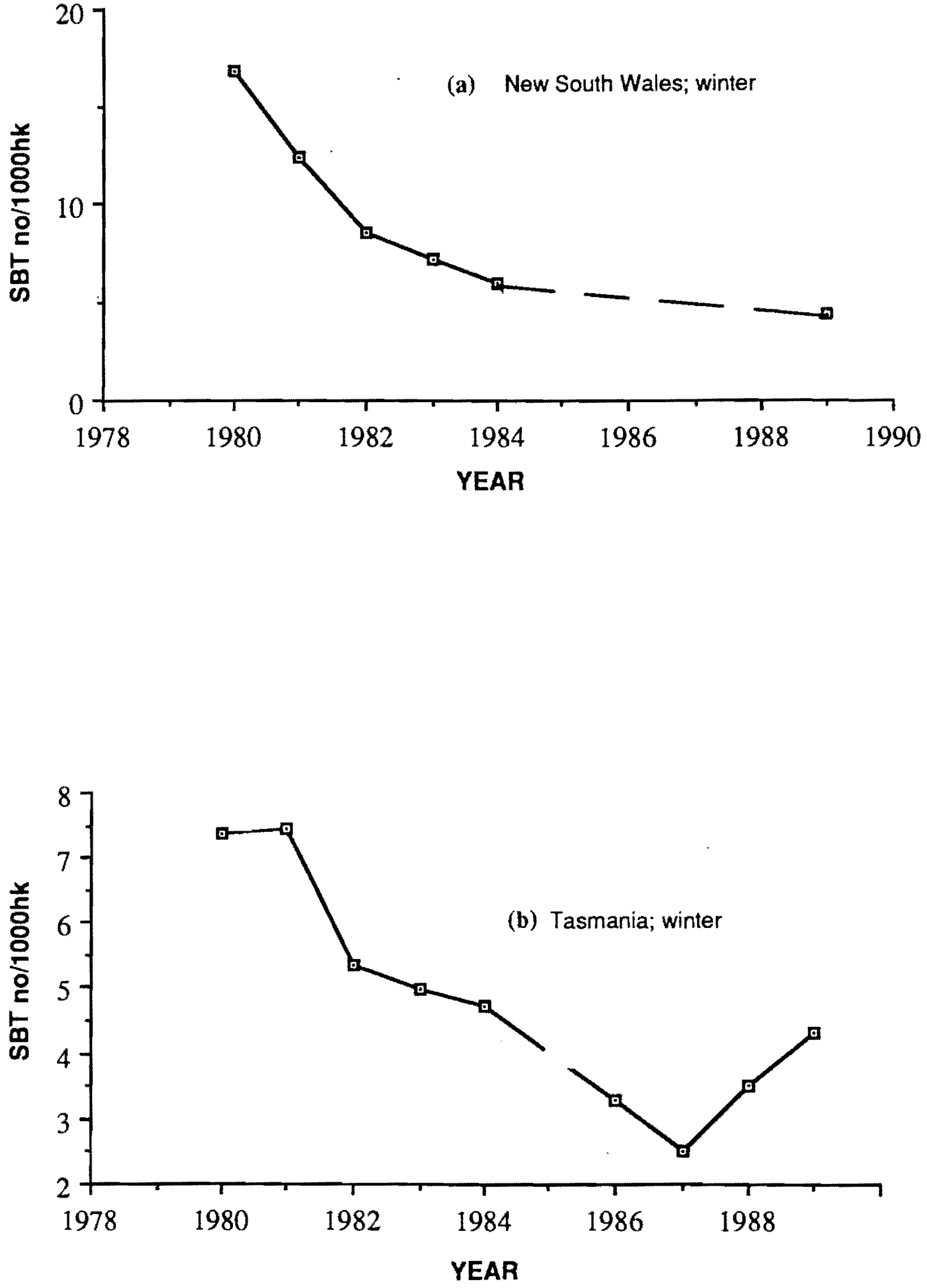


Fig. 37. Southern bluefin tuna catch rate (number per 1000 hooks) in winter by Japanese longline fishing vessels off south-eastern Australia, 1979 to 1989. (Broken line indicates absence of fishing because of closures.)

Table 17. Japanese longline southern bluefin tuna catch (t processed weight) by quota year (1 October to 30 September) off south-eastern Australia east of 147° East in 'summer' (October to April) and 'winter' (May to September). Source: radio reports from Japanese longliners.

SEASON	AREA	YEAR	NO. OF VSLS	TOTAL CATCH TONNES	YELLOW FIN TONNES	EFFORT ('000 HOOKS)	SBT TONNES	SBT NUMBER	SBT AVRG WEIGHT	SBT KG PER 1000 HOOKS	SBT NUMBER PER 1000 HOOKS
SUMMER	NSW	7980	2	8.485	.725	31.985	1.747	52	33.60	55	1.63
		8081	4	38.441	.888	70.905	31.234	957	32.64	441	13.50
		8182	7	11.207	2.988	62.270	4.485	95	47.21	72	1.53
		8283	1	.723	0.000	4.375	.723	10	72.30	165	2.29
		8384	1	.252	0.000	4.650	.252	5	50.40	54	1.08
		8788	5	23.583	12.744	38.480	.766	8	95.75	20	.21
		8889	1	6.719	3.116	1.265	0.000	0	0.00	0	0.00
	TAS	7980	49	164.049	0.000	770.401	156.593	3268	47.92	203	4.24
		8081	85	681.535	1.540	2670.458	657.649	11862	55.44	246	4.44
		8182	56	128.765	.200	962.759	122.612	2090	58.67	127	2.17
		8283	7	9.080	0.000	82.020	9.065	154	58.86	111	1.88
		8384	38	331.791	0.000	1576.270	318.902	5339	59.73	202	3.39
		8586	17	74.518	0.000	483.257	65.953	1102	59.85	136	2.28
		8687	4	8.461	0.000	68.220	6.249	89	70.21	92	1.30
		8788	18	38.491	0.000	266.643	34.261	603	56.82	128	2.26
		8889	26	258.939	0.000	1355.284	234.930	5063	46.40	173	3.74
WINTER	NSW	7980	35	1710.713	18.359	2607.461	1334.214	43916	30.38	512	16.84
		8081	53	1611.035	59.748	2945.182	1145.216	36484	31.39	389	12.39
		8182	24	580.560	3.934	1440.108	427.350	12448	34.33	297	8.64
		8283	27	640.390	4.280	1571.059	419.444	11361	36.92	267	7.23
		8384	25	557.896	24.077	1189.096	364.531	7168	50.86	307	6.03
		8485	2	18.608	2.176	45.480	3.434	90	38.16	76	1.98
		8586	7	43.494	5.286	104.490	8.074	128	63.08	77	1.22
		8687	4	17.647	3.201	46.240	5.445	121	45.00	118	2.62
		8788	8	31.777	4.659	75.510	5.524	114	48.46	73	1.51
		8889	32	1070.375	59.816	2574.129	419.016	11478	36.51	163	4.46
	TAS	7980	6	27.851	.325	69.125	14.522	510	28.47	210	7.38
		8081	13	109.412	1.347	262.701	80.234	1961	40.91	305	7.46
		8182	19	122.859	.551	425.607	104.679	2282	45.87	246	5.36
		8283	15	205.361	1.430	735.829	187.549	3657	51.28	255	4.97
		8384	25	577.531	.608	1745.934	527.062	8231	64.03	302	4.71
		8586	20	290.177	.531	1524.732	240.547	5028	47.84	158	3.30
		8687	33	493.307	.131	2646.826	371.344	6643	55.90	140	2.51
		8788	27	404.927	.055	2047.899	341.180	7185	47.49	167	3.51
		8889	72	1732.922	9.992	7292.007	1408.815	31542	44.66	193	4.33

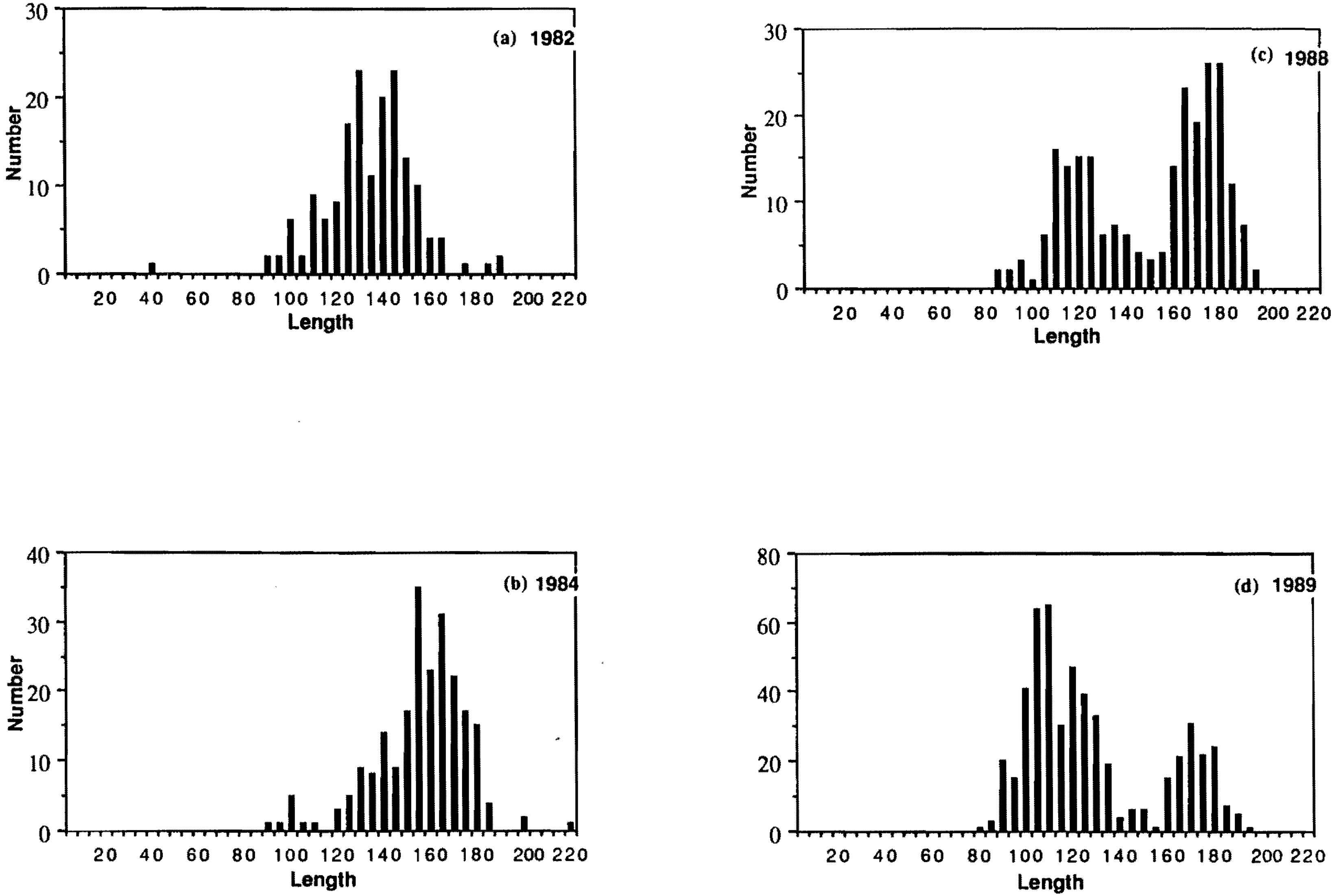


Fig. 38. Southern bluefin tuna length frequency distribution in Japanese longline catch off south-eastern Australia in 1982, 1984, 1988 and 1989.

Table 18. Southern Bluefin tuna catch and effort by Japanese longliners (southern fishery) in New Zealand waters, 1980 to 1988.

Year	Number of fish	Processed weight (t)	Average processed weight per fish (kg)	Number of vessels	Number of sets	Million hooks	Average number of hooks per set	Average line length (km)	Number of fish per 1000 hooks	Tonnes per set
1980	119 643	6605	55.2	87	10 736	25.91	2413	102	4.6	0.6
1981	89 357	5074	56.8	85	10 345	26.17	2530	108	3.4	0.5
1982	46 898	2754	58.7	72	8864	23.51	2652	107	2.0	0.3
1983	26 202	1618	61.8	55	5736	15.60	2719	113	1.7	0.3
1984	23 133	1491	64.5	34	4431	12.65	2856	121	1.8	0.3
1985	25 794	1718	66.6	34	3897	11.27	2891	123	2.3	0.4
1986	18 918	1337	70.7	33	3938	11.41	2898	125	1.7	0.3
1987	21 817	1622	74.3	38	4999	14.66	2933	130	1.5	0.3
1988	11 891	920	77.3	38	4192	12.15	2899	125	1.0	0.2

Fig. 39. Catch and effort in the Japanese southern bluefin tuna fishery off New Zealand, 1980 to 1988.

10 % of the total catch in 1980 and less than 50 % of the catch in the peak month (June) in 1980. During this period, total Japanese longline effort has declined to 46.5 % of the effort in 1980. Table 19 summarises the number of SBT caught each month since 1980 by foreign licensed longliners in New Zealand waters. The decline in catches is evident in every month, and a contraction in the length of the fishing season was noticed as early as 1981.

Vessel specifications. Vessels and fishing gear have changed relatively little since New Zealand first started to monitor them in 1980. Table 20 summarises the major characteristics of gear and vessels over this period. As previously mentioned, although the number of vessels has declined dramatically since 1980, the average length of longlines, and hence the number of hooks per set, has increased. The longline vessels have regularly been replaced, and the average age of vessels is still about 7 years. Length overall has been relatively constant at about 43 m; however, the vessels are bigger, having increased in gross registered tonnage by 36 t to the current 300 t. Freezer hold capacity has also increased by 32 t to about 200 t. Fishing gear has changed slightly with the major differences being a decrease in the distance between floats of 38 m to about 256 m; an increase in snood length to 34 m; and an increase of about 2 hooks per basket to slightly over 5 on average.

Size frequency data. Weight frequency distributions for the Japanese longline catch are presented in Fig. 40. They indicate a continuing decline in the abundance of 40-50 kg fish, with a slight increase in the relative abundance of 20-40 kg fish. Low recruitment to the 20-40 kg weight classes has been a continuing feature of longline catches within New Zealand waters since 1985.

TRENDS IN THE NEW ZEALAND FISHERY

Domestic catch and effort trends are not clearly identifiable due to the rapid changes in vessel number and type since 1980, and due to the diversification of fishing methods. The catch in 1987, taken by handline/troll, was an all time low. It recovered to 92.5 t in 1988 coincident with the introduction of monofilament longline gear and the slightly longer fishing season this method is reported to have allowed (Murray and Burgess 1990). The introduction of chartered Japanese longliners in the 1989 fishing season resulted in New Zealand's quota of 450 t being closely approached for the first time. Over half the domestic catch was caught by Japanese longliners on charter to New Zealand companies. Table 21 summarises the domestic catch of SBT since 1980.

Table 19. Monthly southern bluefin tuna catch by Japanese longliners (southern fishery) in New Zealand waters, 1980 to 1988.

	Number of fish								
Month	1980	1981	1982	1983	1984	1985	1986	1987	1988
Jan	307	139	180	24	1	-	-	3	6
Feb	2832	4407	255	172	183	51	45	198	44
Mar	12 870	8292	4753	2136	1839	1994	1286	2537	578
Apr	26 350	17 558	10 291	5913	4874	4671	3431	3162	2790
May	18 947	16 357	5900	6013	3711	7352	4648	5150	2003
Jun	27 664	18 944	12 559	6820	3989	4633	4116	4631	3357
Jul	26 001	23 036	10 857	4928	7216	5921	5223	5406	3013
Aug	4616	2036	1895	188	1618	1160	161	724	100
Sep	159	155	208	8	22	12	8	6	-
Oct	-	-	-	-	-	-	-	-	-
Nov	-	-	-	-	-	-	-	-	-
Dec	-	-	-	-	-	-	-	-	-

Table 20. Comparison of Japanese longline vessel and gear characteristics from data supplied in 1980 and 1987.

s: standard deviation
n: number of vessels
ns: no significant change

	1980 data value (s; n)	1987 data value (s; n)	Significant change
Vessel Characteristic			
Vessel age (years)	6.98 (3.12; 84)	6.81 (4.38; 37)	ns
Vessel length (LOA; m)	42.76 (3.99; 84)	43.24 (3.85; 37)	ns
Gross registered tonnage	264.50 (40.3; 84)	300.44 (56.2; 37)	+35.9 t
Hold capacity (t)	175.84 (39.4; 84)	207.41 (44.3; 37)	+31.6 t
Hold temperature (°C)	-51.16 (4.52; 84)	-50.88 (3.07; 37)	ns
Gear Characteristic			
Distance between floats (m)	293.7 (32.7; 84)	255.65 (39.0; 37)	-38.1 m
Distance between snoods (m)	48.48 (7.23; 82)	48.03 (3.61; 37)	ns
Length if float line (m)	16.55 (12.6; 83)	14.12 (2.32; 37)	ns
Length of snood line (m)	29.69 (6.6; 84)	33.96 (11.3; 34)	+4.2 m
Hooks per basket	5.19 (0.39; 84)	5.35 (0.59; 37)	+1.8

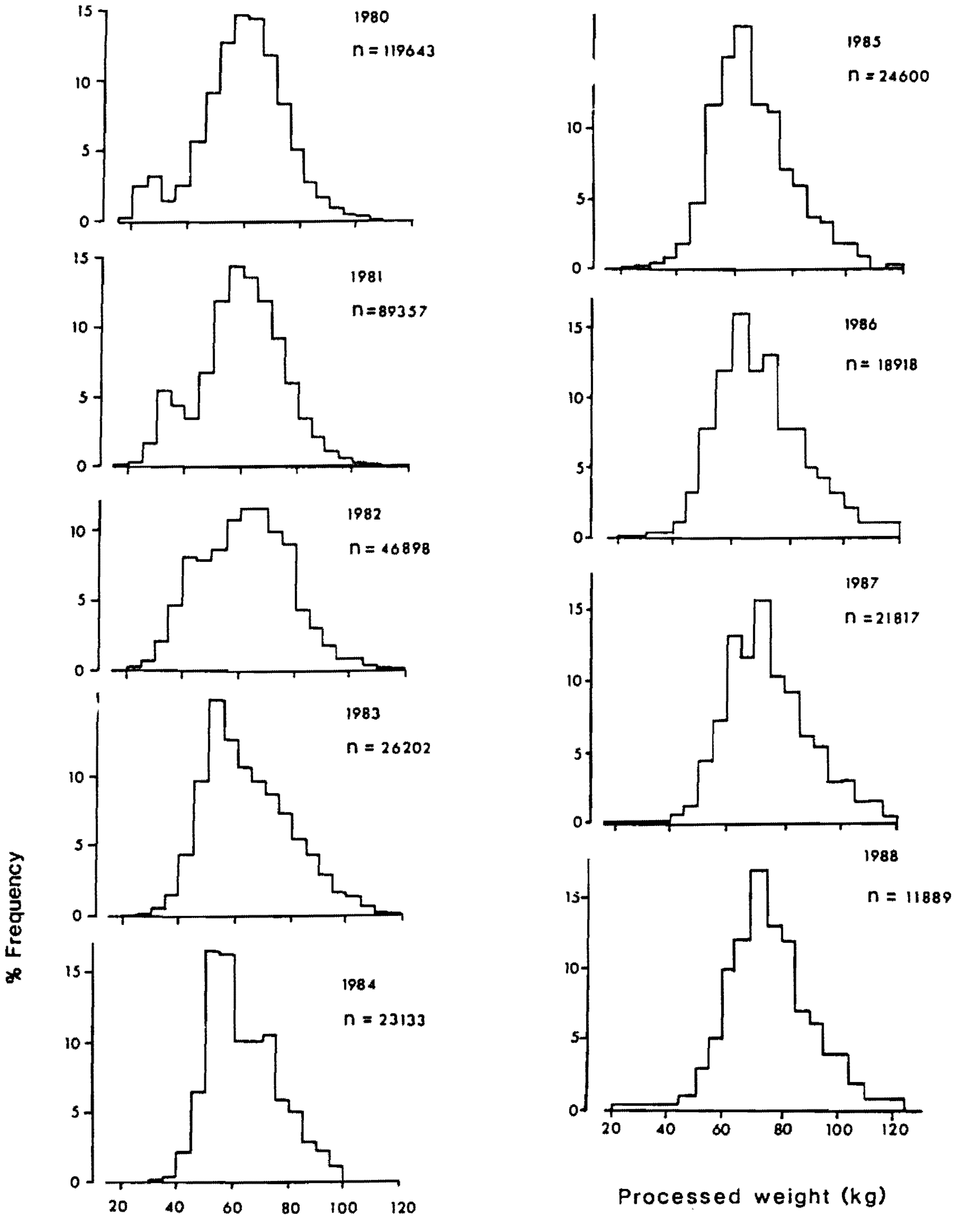


Fig. 40. Weight frequency distributions of Japanese southern bluefin tuna catches in New Zealand waters, 1980 to 1988.

Table 21. Domestic catches of southern bluefin tuna in New Zealand waters, 1980 to 1988.

Year	Number of fish	Processed weight	Average processed weight per fish (kg)
1980	-	130	-
1981	-	173	-
1982	3507	265.0	75.6
1983	1543	114.8	74.4
1984	1014	80.4	79.3
1985	1061	82.1	77.4
1986	884	71.0	80.3
1987	631	51.5	81.6
1988	1057	80.4	76.1
1989 'traditional' fleet	(1499)	(116.7)	(77.9)
1989 joint venture fleet	3559	252.2	70.9
1989 total	(5058)	(368.9)	(72.9)

(Figures in parentheses are provisional)

12. STATUS OF THE POPULATION

STATUS OF THE POPULATION AS DETERMINED DIRECTLY FROM COMMERCIAL FISHERY DATA

The report of trilateral scientific discussions on SBT in 1988 (Bureau of Rural Resources 1989) listed a range of indicators from commercial fishery data pointing to the severity of the decline in the SBT population. These were:

(a) reduction in hook rate in the Japanese longline fishery between 1983 and 1986 of 50 %;
(b) contraction in the area of Japanese fishing effort to [virtually] two of the nine fishing areas;
(c) reduction from the peak Japanese longline catch to less than 20 %;
(d) reduction in the abundance of 4-year-old to 7-year-old fish in the longline fishery from 1972 to 1986 to 10 %;
(e) reduction in the abundance of 8-year-old to 10-year-old fish in the longline fishery since 1980 to about 30 %;
(f) reduction in the hook rate in the Japanese longline fishery off New Zealand between 1980 and 1987 to 33 %;
(g) disappearance of small fish from the Japanese longline fishery in New Zealand waters;
(h) reduction from the peak New Zealand handline/troll fishery catch to less than 25 %;
(i) sudden and continued absence of [surface schools of] SBT from the NSW coast;
(j) continued contraction in the area of occurrence of juvenile SBT in the Australian waters to 40 %;
(k) high exploitation rate (40 %) in the Australian fishery; and
(l) progressive reduction in the availability of large fish to the Australian [surface] fishery since 1982-83.

At the 1989 trilateral scientific session, further details were available in relation to some of the indicators:

(a) Japanese longline fishery hook rate declined again in 1987 (Fig. 33);
(b) While still the dominant fishing areas, the two areas highlighted above were proportionately less dominant in 1987 (Fig. 41);
(c) Japanese longline catch declined again in 1987 and in 1988; a further decline in 1989 was a result of quota impact, whereas previous declines represented years in which the fishery could not achieve the quota set (Table 11);
(d) Perhaps a slight improvement in the 4-year-old to 7-year-old fish abundance index to that for 1986 (Fig. 42);
(e) No improvement in the abundance index of 8-year-old to 10-year-old fish in 1987 (Fig. 43);
(f) Further decline in the hook rate in the Japanese longline fishery off New Zealand (Fig. 39);
(g) A very slight re-appearance of small fish in the Japanese longline fishery in New Zealand waters (Fig. 40); and
(h) Domestic New Zealand SBT vessel catch improved but this was the consequence of the introduction of longlining because of poor handline-troll catches (Table 21).

STATUS OF THE POPULATION AS DETERMINED FROM VIRTUAL POPULATION ANALYSIS

Virtual population analysis (VPA)

Virtual population analysis has been the primary method used for assessing the state of the SBT stock. This technique, introduced by Gulland (1965), calculates estimates of numbers at age in the

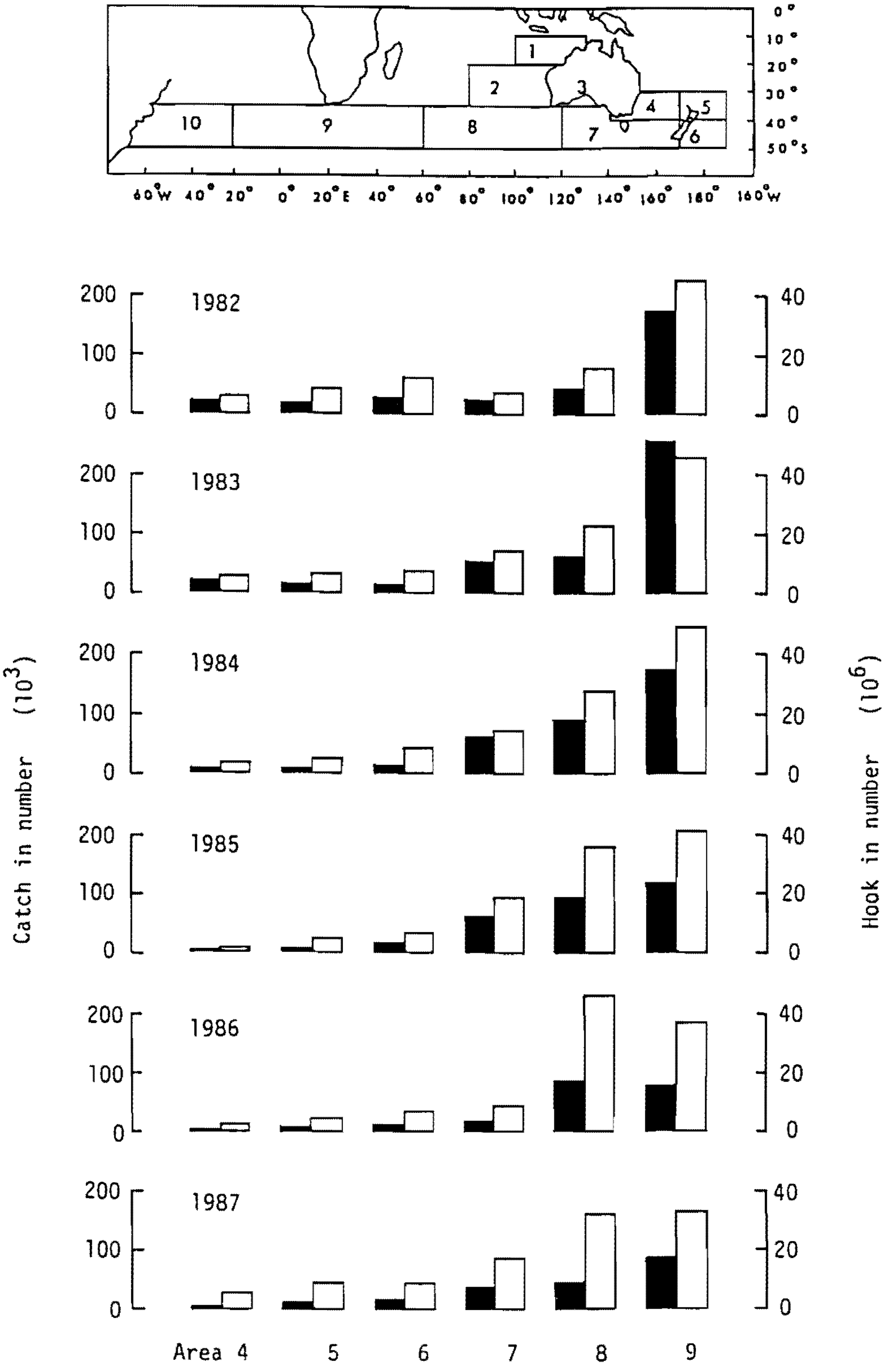


Fig. 41. Statistical areas (top), catch (black) and hooks set (white) by Japanese southern bluefin tuna fishery, 1982 to 1987.

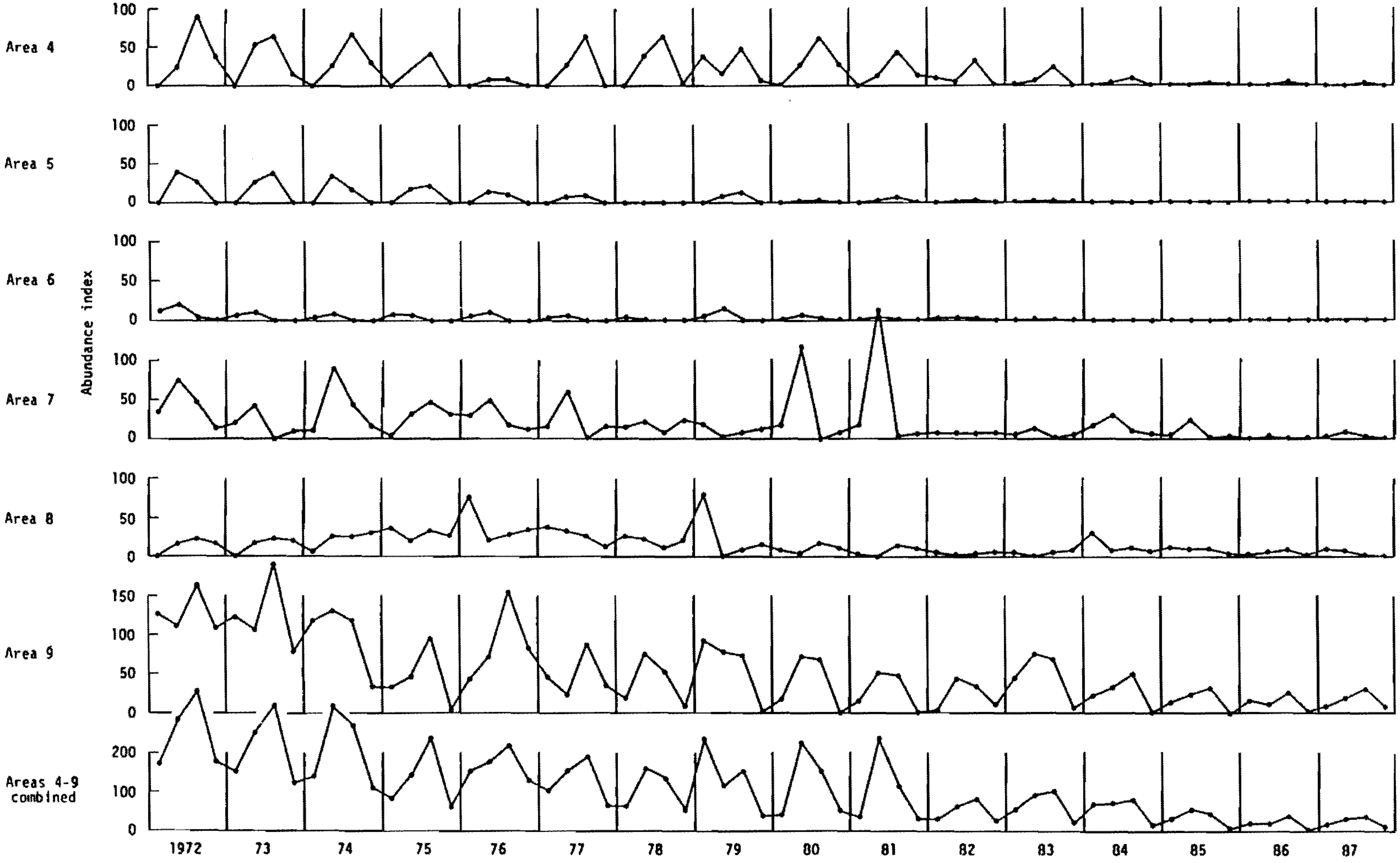


Fig. 42. Abundance indices, for 4-7 year old southern bluefin tuna combined, developed by using Japanese longline fishery hook rates multiplied by the number of 5-degree square blocks occupied.

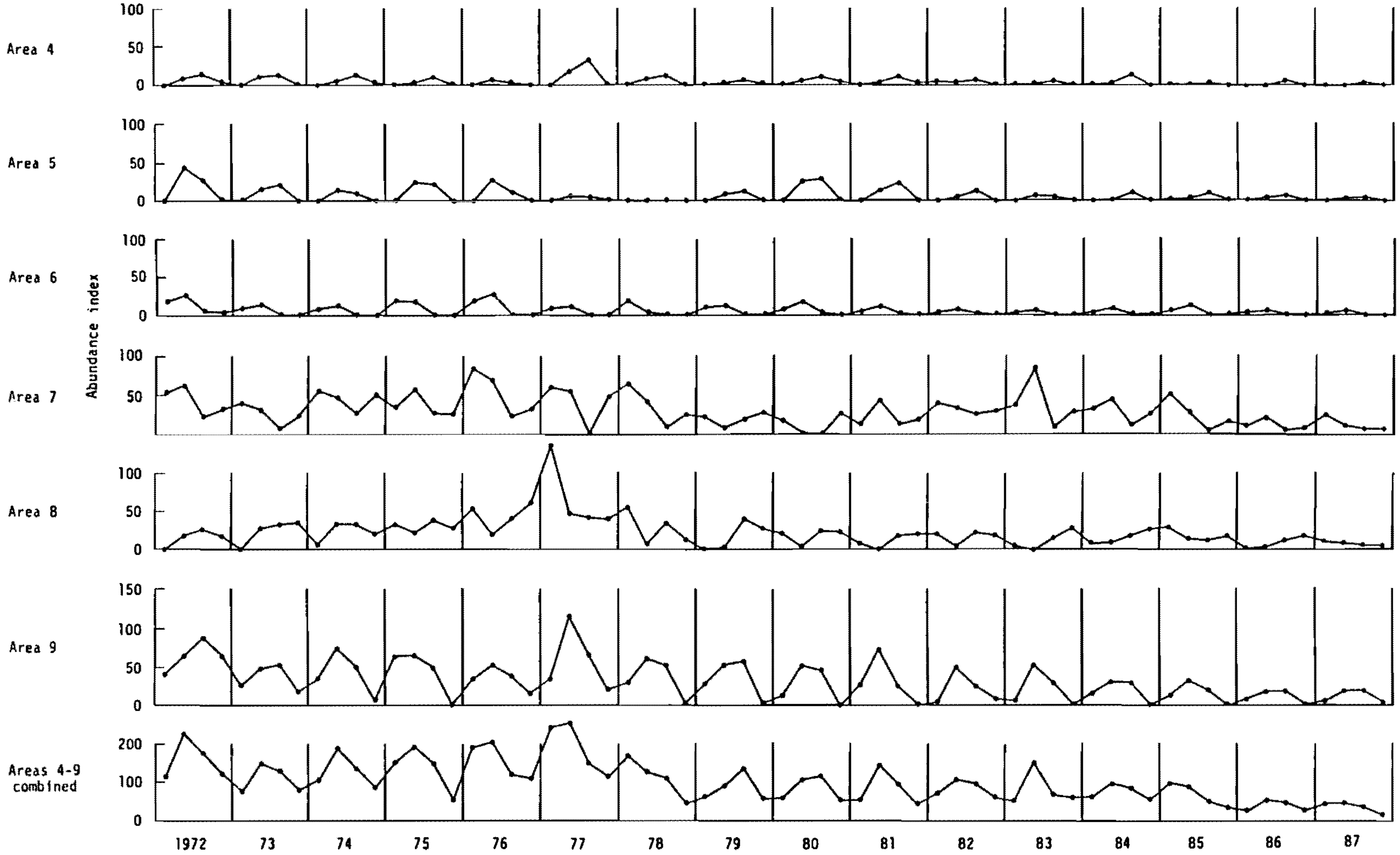


Fig. 43. Abundance indices, for 8-10 year old southern bluefin tuna combined, developed by using Japanese longline fishery hook rates multiplied by the number of 5-degree square blocks occupied.

population based on estimates of the age structure of the catches, the natural mortality rate (M) and the annual fishing mortality rates (F) applied to the 'terminal' age class. Since the early 1980s, scientific advice on management of SBT has generally been based on trends in the parental biomass and in recruitment at age 1 estimated from VPAs. In particular, attention has focussed on the size of the current parental biomass in relation to its initial level, and on projected future stock trajectories based on a fitted stock-recruitment relationship and a range of possible future catches.

For SBT, the estimated age structure of catches by Australian and Japanese fishermen back to 1952 has been derived from their estimated length-frequency distributions using a growth curve. In most assessments, the Kirkwood (1983) growth curve has been adopted, although in some the alternative Hampton (1987) curve has been used. Recoveries of tagged SBT have demonstrated that they can live for at least 20 years, and in early VPAs a terminal age of 20 years was used. However, the examination by Majkowski and Hampton (1983a) of errors in aging using the Kirkwood (1983) growth curve suggests that these errors increase rapidly after age 12. Consequently, the terminal age generally adopted in recent VPAs has been 12+ (fish aged 12-13 years) or younger.

For those cohorts in which at least the first 12 age classes appear in the catches, estimates of numbers at age for ages 1+ to 12+ are obtained using backwards VPA from the terminal age, and by forwards VPA from the terminal age class for ages 13+ to 20+. Estimates of parental biomass are calculated from estimated numbers and average weights of fish aged 8+ to 20+. For the latest year in which estimates of catches at age are available, backwards VPA is also conducted from ages 11+ down to 7+, using values of terminal F based on estimates of F for the same ages in the immediately preceding year or years. Annual variations in the Australian fishery for juvenile fish are considered sufficient to prevent reliable use of backwards VPA from ages less than 7+. As a consequence, while parental biomass can be estimated from the VPAs from 1960 to the latest year for which catch data are available, estimates of recruitment at age 1 are not available for the last 6 years.

These VPAs provide series of estimates of parental biomass and recruitment. A variety of stock-recruitment relationships has been fitted to these estimates, principally those proposed by Shepherd (1982), Ricker (1975), and Beverton and Holt (1957). Possible stock trajectories under alternative future catch regimes are then calculated using forward VPA either from ages 7+ and older in the current year, or from age 1+ using recruitments predicted by the fitted stock-recruitment relationship. Forward VPA techniques have also been used to estimate catch levels that would result in eventual stabilisation of the parental biomass, for given patterns (e.g. catch size-composition) of fishing (Majkowski and Hampton 1983b; Yonemori et al. 1983).

Tuning of VPAs

A key requirement for producing a reliable stock assessment using VPAs is appropriate selection of the set of values of terminal F. For SBT, the approach taken to tuning the VPAs has relied on comparisons with fishing mortality rates estimated independently from tag-recapture experiments, on catch and effort data from the Japanese longline fishery, and on hypotheses about likely levels of early-exploitation and pre-exploitation recruitment.

Large scale tag-recapture experiments were carried out in Australia in the 1960s.The initial analyses of recovery data for these experiments suggested that the average total mortality rate (Z) exerted on the tagged fish by the Japanese longline fishery was in the range 0.3-0.5 per year. A subsequent analysis by Kirkwood et al. (1989) taking account of tag shedding indicated that the average Z for fish in the 1959-67 cohorts 7-14 years old was 0.29 per year with S.E. 0.65 per year. Depending on the value adopted for the natural mortality rate, these independent estimates of Z have been used to set values of terminal F in base years (1971-75) in the VPAs.

In the VPAs carried out in the early 1980s (e.g. Hampton et al. 1983, Yonemori et al. 1983), the values of terminal F were held constant at the value selected for the base years using tagging estimates of Z. In subsequent VPAs (e.g. Hisada and Kono 1984, Hampton 1984), the values of terminal F for years other than the base years were adjusted proportionally in line with changes in the recorded levels of Japanese longline fishing effort. A feature of the historical development of the Japanese longline fishery for SBT has been major shifts in the concentration of fishing effort among different areas. An alternative method for setting the values of terminal F that attempted to take account of these shifts in effort between areas was proposed by the CSIRO (1988). In this method, the values of terminal F in each year were treated as sums of area-specific partial rates of fishing mortality. These partial F values were assumed to be products of annual area-specific fishing effort and year-independent area-specific catchability coefficients with respect to the global abundance of the terminal year class. If these assumptions are correct, terminal F values for each year can be estimated given a catchability coefficient for a base area and year, and annual area-specific catch and effort data for the longline fishery.

In the early years of the Japanese longline fishery, very high levels of catch-per-unit-effort were achieved as each new area was fished. Typically, these catch rates initially declined rapidly before settling down to a slower rate of decline as the fishery expanded. Both of the above methods for tuning values of terminal F using effort data assume that catch-per-unit-effort is directly proportional to abundance. Given the initially rapid declines in observed catch rates, application of either method of tuning leads to extremely high VPA estimates of recruitment and parental biomass in the early years of the fishery, and in particular to estimates of recruitment in the 1950s much higher than those in the early 1960s. As large catches of SBT were not taken until the early 1960s, these early recruitment and biomass trends seem at odds with a stock that was only very lightly exploited during the 1950s. A possible explanation for this discrepancy is that, for the early years, trends in catch rates do not directly reflect trends in abundance. To take account of this hypothesis, CSIRO (1988) recalculated estimates of numbers at age from cohorts up to the 1960 cohort, using forwards VPA from an assumed constant level of recruitment up to 1960. This procedure was further modified by Kirkwood et al. (1989) to incorporate iterative fitting of a non-linear relation between catch-per-unit-effort and abundance, and a slightly different method of estimating early recruitment levels.

Most recent VPA methodology

In the most recent VPA assessments conducted for the SBT stock, Kono and Ishizuka (1989) used a range of terminal ages and set terminal fishing mortality rates proportional to the annual number of longline hooks, using estimates of targeted effort and several base year terminal F values. A natural mortality rate of 0.2 per year was adopted. Further tuning was achieved by selecting only those VPAs where the estimated decline in parental biomass between 1972-73 and 1986-87 lay within the range of declines estimated from abundance indices, and where recruitment did not show a significant correlation with year between 1960 and 1975. Future projections based on current catches and quotas were carried out using fitted Ricker (1975) and Beverton and Holt (1957) stock-recruitment relationships.

The VPA assessments conducted by Kirkwood et al. (1989) used a terminal age of 12 years and set terminal F values on the basis of area-specific catch and effort data and base year terminal Z values estimated from the tagging data. A range of natural mortality rates was used (0.1-0.3 per year). Forward VPA was used for initial cohorts to allow for the hypothesis that the stock prior to 1960 had been only lightly exploited, and a power model relating catch per-unit-effort to abundance was iteratively fitted. Additional checks were made on the consistency between estimates of F values and recruitment from VPAs and those obtained from analysis of the 1983-84 tagging data. Future projections based on current quotas were carried out using fitted stock-recruitment relationships (Shepherd 1982). In the fitting procedure, two alternative weighting schemes were used: equal weighting for each year, and greater weighting for the most recent years.

Results of VPA assessments

Results of VPA stock assessments have been discussed annually since 1982 by trilateral scientific meetings on SBT. Reports of the 1982-88 trilateral scientific meetings have been published in one volume by the Bureau of Rural Resources (1989). These reports record increasing concern at the extent of reduction in the parental biomass of SBT, at the consequent likelihood of recruitment declines if this trend continues (if such declines had not already occurred), and the need to set catches at levels that would allow the parental biomass to stabilise at higher levels for which satisfactory historical recruitment has been observed. From 1982 to 1988, both catch quotas and realised catches generally declined, with the quota reduction being particularly substantial in 1988, following very strong recommendations from the trilateral scientific meeting in that year.

Virtual population analyses were presented to the 1989 trilateral scientific meeting by Kono and Ishizuka (1989) and Kirkwood et al. (1989). These confirmed the indications from previous analyses that the parental biomass had declined severely since 1960, and that this decline would continue at least until 1989-90. The parental biomass in 1980 was estimated to be between 8 % and 25 % of its 1960 level, with the 1960 level being less than the initial unexploited level by an unknown amount. Both sets of VPAs indicated that recruitment had declined between 1975 and 1980. However, while this was seen as part of an overall declining trend in most of the VPAs reported in Kirkwood et al. (1989), this was not the case with the Kono and Ishizuka (1989) analyses.

Projections of future stock trajectories under then current quotas for Japan (8800 t) and Australia (6250 t) were carried out by Kono and Ishizuka (1989) using fitted Ricker and Beverton and Holt stock-recruitment relationships. These all indicated that both parental biomass and recruitment would recover in the future. Similar recoveries were predicted in their supplementary analysis of projections based on continuation of then current estimated catches by Australia (5550 t), Japan (9800 t), New Zealand (150 t), Taiwan (300 t) and Indonesia (50 t).

Projection of future trends under then current Japanese and Australian quotas were carried out by Kirkwood et al. (1989) using fitted Shepherd (1982) stock-recruitment relationships. When equal weighting was given to the stock and recruitment estimates for each year, the stock was predicted to recover under current quotas when aging was based on the Kirkwood (1983) growth curve, but in an example when aging was based on the Hampton (1987) growth curve, the stock continued to decline. In almost all cases where recovery occurred, recruitment in the first few years after 1980 was predicted to be substantially higher than the most recent levels estimated from VPAs. When greater weight was given to the later estimates when fitting the stock-recruitment relationship, so as to more closely match recent VPA recruitment trends, the stock was projected to continue to decline under current quotas.

STATUS OF THE POPULATION AS DETERMINED FROM TAG-RELEASES RECOVERIES

Introduction

Analyses described in this sub-section are based on information derived from the Australian 1983-84 tagging program in which fish were tagged off Esperance (WA), Albany (WA) and Port Lincoln (SA). Consequently, the estimated population parameters do not refer to the global population, but rather to the sub-population that is vulnerable to the Australian fisheries. An unusually high percentage (over 40 %) of 10 179 fish tagged were reported as recaptured by Australian fishermen (Eckert and Majkowski 1987). In comparison, less than 15 % of 52 294 SBT tagged between 1959 and 1980 have been recaptured and reported (Majkowski and Murphy 1983). The high recapture rate from the later experiment appears to indicate a very high fishing pressure, which is investigated in Hearn et al. in prep. (a). It also raises questions regarding the proportion of fish passing through Australian waters that would survive to reach reproductive maturity (Hearn et al. in prep. (a)), the level of recruitment to the global fishery, and the proportion of fish that does not pass through the Australian fishing grounds.

When tagged, 99 % (10 105 fish) of SBT were either 3-year-old members of the 1979-80 year-class, 2-year-old and 3-year-old members of the 1980-81 year-class, or 1-year-old and 2-year-old members of the 1981-82 year-class. Off Esperance the 1979-80 and 1980-81 year-classes were predominant while the 1980-81 and 1981-82 year-classes were mainly tagged at each of the other locations, giving six sub-sets of data. Almost all these fish were double-tagged so that tag-shedding could be evaluated. Data were analysed separately for each year-class and each tagging location.

Assumptions of the tag-release / recovery experiment

In the analyses described in this sub-section, the tag-release/recovery experiments are required to satisfy assumptions that tagging does not significantly affect fish, tags are durable and do not shed, all tagged fish caught are reported, or that non-compliance with these assumptions can be allowed for.

A constant rate of natural mortality (M) is assumed and it is expected to be between 0.1 and 0.3 per year (Majkowski et al. 1984). The sensitivity of parameter estimates to the uncertainty in the value of M was examined over its range of expected values.

The sensitivity of results was assessed with an assumed 10 % rate of non-reporting. Tag shedding was estimated for each data sub-set by analysis of double-tagged fish.

An additional assumption is required for these studies; that there is random mixing of tagged and untagged fish in Australian waters by the beginning of the SA fishing season (i.e. 1 December) after the completion of tagging for each location. To facilitate this mixing fish were tagged from 314 schools over a wide geographic area within each location.

Hearn et al., in prep. (a), considered tagged and untagged fish to be mixed at some time after tagging if, for a particular year-class, it can be shown that fish tagged at various locations are mixed with each other. Analyses in Hearn et al., in prep. (a), indicates that fish tagged at the Albany and Port Lincoln sites have mixed, but not fish tagged at the Esperance site.

For each year-class, comparisons were made between numbers of tagged and untagged fish in SA catches and they were found to be significantly different. It is considered that this difference is not an indication of non-mixing but an artifact of the aging techniques used to identify the year classes in the length-frequencies of the commercial catches. The aging methods use growth estimates derived from tag-release/recovery experiments conducted in the 1960s and 70s when growth was much slower than in the 1980s.

Fishing mortality

For each experiment and year-class, the number of live tagged fish at any specified time is estimated from forward cohort analysis (Hearn et al. in prep. (a)). From this information the annual rates of fishing mortality are calculated. To allow time for mixing to occur, the rates are not estimated until the first calendar year following the completion of tagging. Calendar years are chosen to allow comparison with VPA results.

It was calculated by Hearn et al. in prep. (a), for M = 0.2 per year, that the annual rates of fishing mortality (F) for the sub-population vulnerable to the Australian fisheries are on average 0.21 per year for 2 year old fish; 0.19 per year for 3 year olds; 0.16 per year for 4 year olds and much less for older fish. The estimates of F are relatively robust to the uncertainty in M.

Compared with values of F calculated on the basis of VPA for the 1969-70 to 1975-76 year-classes (Hampton et al. 1984), the values of F presented in Hearn et al. (in prep.) for the 1979-80, 1980-81, and 1981-82 year-classes up to 5 years old are at least 50 % higher. However, F values from VPA of the 1976-77 year-class have approached the values obtained in this experiment. It is expected that the values of F calculated from VPA of the global population would be lower than those derived from tagging, which refer to the proportion of fish passing through the Australian fishing grounds.

Compared with fish tagged on the Port Lincoln fishing ground, the estimated values of F are lower on average (F_{av}) for SBT tagged off Esperance or Albany once they have migrated from the WA fishing grounds. This is particularly so for fish that are tagged at ages close to two years off Esperance and Albany from which the values of F_{av} for ages 3 to 6 years are less than half the corresponding value of F_{av} from fish tagged off Port Lincoln. This suggests that 2-year-old SBT off WA migrate at a higher rate into ocean waters than those off SA. These results support the Murphy (1977) hypothesis that a significant proportion of fish do not travel from the WA fishing grounds to the Australian fishing grounds. This may be also be explained by some unknown differential mortality, whether of natural or human origin. The lower estimates of F from fish tagged off Esperance and Albany are expected to be closer to, but still higher than, those for the global population since there is likely to be some emigration when juvenile fish travel down the west coast of WA before reaching Albany or Esperance. F_{av} increased by about 20 % when an allowance of 10 % was made for average non-reporting rate.

Impact of fishing on survival to reproductive maturity

The high values of F from the 1983-84 experiment means that a substantial fraction, of the fish that pass through the Australian fishing grounds as juveniles, does not survive to reproductive maturity. The impact (R_x) of fishing upon the number of fish surviving from a specified age (x) to reproductive maturity (8 years) are calculated from the forward cohort population estimates (Hearn et al., in prep. (a)). It is relative to the numbers of fish that would have survived from age x to reproductive maturity if they had not been fished.

The recovery of tags from fish caught by the longline fishery is uncertain because of the long time lags involved and the lack of any field surveillance by experienced field scientists. Therefore, in the analysis, a given fishing mortality rate was deemed to operate upon fish from ages 6 to 8 years. From the VPA analyses of Hampton et al. (1984), the range of F for fish of these ages was about 0.05 to 0.15 per year.

The reduction, due to fishing, in the numbers of tagged fish surviving to reproductive maturity at the age of 8 years (R_x) is on average 48 % for x = 2 years; 43 % for x = 3 years and 31 % for x = 4 years. It varies by ± 20 % for values of M between 0.1 and 0.3 per year, and by ± 30 % if F_6 has values between 0.05 and 0.15 per year. R_x is increased by up to 17 % if a 10 % non-reporting rate is assumed.

The above values of R_x should be regarded as underestimates of the total impact of catching. juvenile fish upon the survival of these fish to reproductive maturity, because fish are caught at ages younger than x in all cases. Such high values of R_x give cause for concern, because the year-classes of fish tagged in 1983-84 are now being recruited to the parental stock, which is at a dangerously low level (Caton and Majkowski 1987).

Exploitation of SBT by Australian fishermen since the end of tagging operations has declined significantly due to the management catch restrictions that were instituted in order to rebuild the parental stock. Most reductions have occurred in the catches of small fish (3 years of age or less), which is sound from the biological point of view as these catches have the highest impact on the number of fish reaching reproductive maturity. Nevertheless, the decline in the parental biomass may not be reversed if fish leaving Australian fishing grounds are subsequently exploited at a higher rate than usual to maintain the catches of the longline fishery.

Recruitment to the Australian fishing grounds

The number of young fish recruited to the Australian fisheries was estimated from the 1983-84 tagging data using the method proposed by Hearn (1988). Fish from a particular year-class are tagged and, after sufficient time for mixing, the number of live tagged fish is estimated from forward cohort analysis. This number and the numbers of tagged and untagged fish of the same year-class that are subsequently caught by the SA fishery allows the population size to be estimated by the Peterson method. This population size becomes the starting value in estimating the number of recruits at age one from commercial catch data using backward cohort analysis. However, this number could be an underestimate because some recruits may not pass through the WA fishing grounds.

The recruitment estimates for the 1979-80, 1980-81 and 1981-82 year-classes are listed in Table 8 and compared with the VPA (VPA1) recruitment estimates obtained in CSIRO (1988). The recruitment estimates from tagging data are quite sensitive to M, but most sensitivity is removed if the age of recruitment is made close to the age of tagging (Table 9). The corresponding recruitment estimates from VPA (Table 9) are more sensitive to M, which allows the possibility of estimating M by equating the recruitment estimates from both tagging and VPA.

STATUS OF THE POPULATION AS DETERMINED FROM RESEARCH SURVEYS

One of the primary gaps in the knowledge of the SBT stock is data on recent recruitment trends. This is the main reason the SBT recruitment monitoring survey was originated. Initially, this survey was recommended at the Australia-Japan-New Zealand tripartite scientific meeting on SBT held in Shimizu in June 1986 and further considered at a workshop of Australian and Japanese scientists in Canberra in September 1986. From 1988 on, this survey has been conducted as a successive five-year program by Japan Marine Fishery Resource Research Center (JAMARC) as a study entrusted to it by Far Seas Fisheries Research Laboratory (Fishery Agency of Japan).

The first year's program (November-December 1988)

The aims of the program were:

(a) To assess if troll and pole surveys are effective as a means of developing a synoptic recruit abundance index,
(b) To determine patterns of occurrence/distribution of recruits,
(c) To determine what association exists between physical environmental factors and recruits, and
(d) To tag recruits to determine the level of recruitment.

The survey was commenced on 1 November 1988 and terminated on 17 December 1988. The survey areas were from 31°10' S to 33°30' S along the west coast and from 117°20' E to 119°40' E along the south coast of Australia (Fig. 44). This was based on the assumption that all SBT recruits travelled along the WA coast mainly in this season.

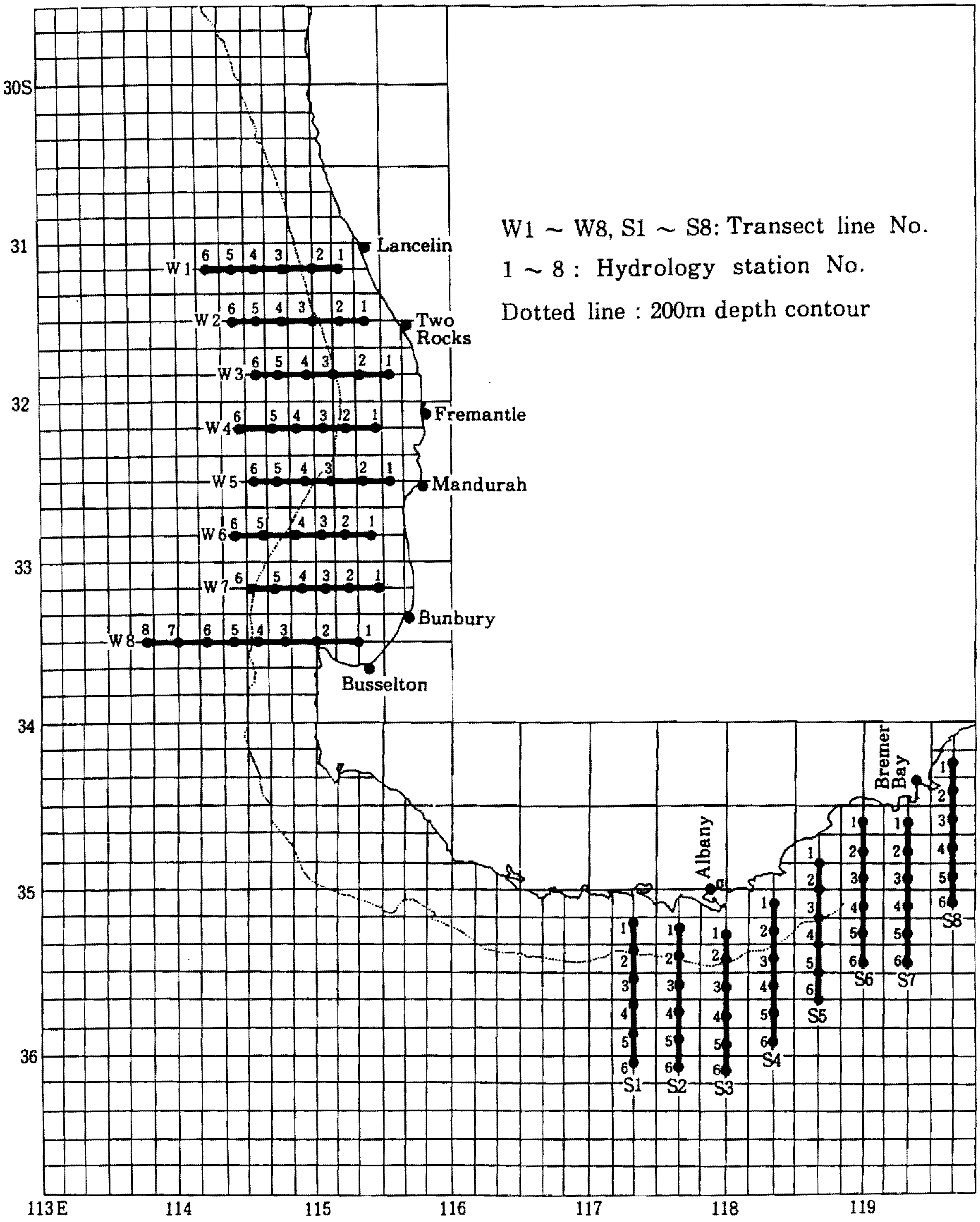


Fig. 44. Survey areas and transect lines for the 1988-89 trolling survey to estimate southern bluefin tuna recruit abundance off south-western Australia.

Transect lines were set apart at 20 minutes of latitude and hydrology stations at 10 mile intervals along each transect line (Fig. 44). Four tuna pole-and-line vessels chartered for the surveys carried out trolling, poling, sightings and hydrological observations (temperature and salinity determination at 10 m intervals down to a maximum of 100 m) along the transect lines. Further information are given in Japan Marine Fishery Resource Research Center (1989).

Length-frequency distributions of SBT caught in the first year's survey are shown in Fig. 45. These fish were classified into two groups (Table 22) : younger than just 2-year-old, 59 cm and smaller (Robins pers. comm.) and older than just 2-year-old (greater than 59 cm). With examination of these two size (age) classifications, it can be seen that the CPUE derived from trolling, even though the numbers of fish taken are low, shows close agreement between the two areas (0.051 on the west coast and 0.054 on the south coast). From this result, it is suggested that catch-per-hour-trolled could afford a measure (index) of relative abundance of SBT recruits.

The workshop on the SBT recruitment monitoring survey held in June 1989 in Hobart reviewed the results of the fist year's survey and recommended the following for the second year's survey :

> The JAMARC survey offers the possibility of developing an independent index of recruit abundance. While some doubt exists as to whether a sufficiently precise index of recruit abundance will be obtained from the JAMARC survey, it was agreed that every effort should be made to identify areas where the best information can be gained and formulate a plan along those lines. Hence it was agreed to cover the apparent area of distribution of the 30-45 cm fish and maintain transect lines over shelf areas only. This entails covering all inshore areas between latitudes 27o-34o S on the west coast and between longitudes 115o-120o E on the south coast. Also the period would be restricted to December which the Shoyo-Maru cruises showed to be a suitable time

(Fishery Agency of Japan, Research Division (in press)).

The second year's program (December 1989 to January 1990)

The second year of the JAMARC SBT recruit survey commenced on 1 December 1989 in the area shown in Fig. 46. The survey was designed to comply with the recommendations made by the 1989 workshop. Transect lines were set apart at 10 minutes of latitude, with hydrology stations at 5 mile intervals along transect lines.

Needs for improvement in research survey

Since oceanographic conditions may change from year to year, the migration pattern of SBT recruits along the west and the south coasts of WA could also change every year. Accordingly, it is desirable to enlarge the JAMARC survey to cover a wider area and a longer period. Furthermore, a tagging survey should be added to the JAMARC survey to determine the level of recruitment of SBT.

Comprehensive research surveys to determine if there are recruits which migrate directly to the central part of the Indian Ocean from the spawning ground off Java or from the west coast of Australia are needed.

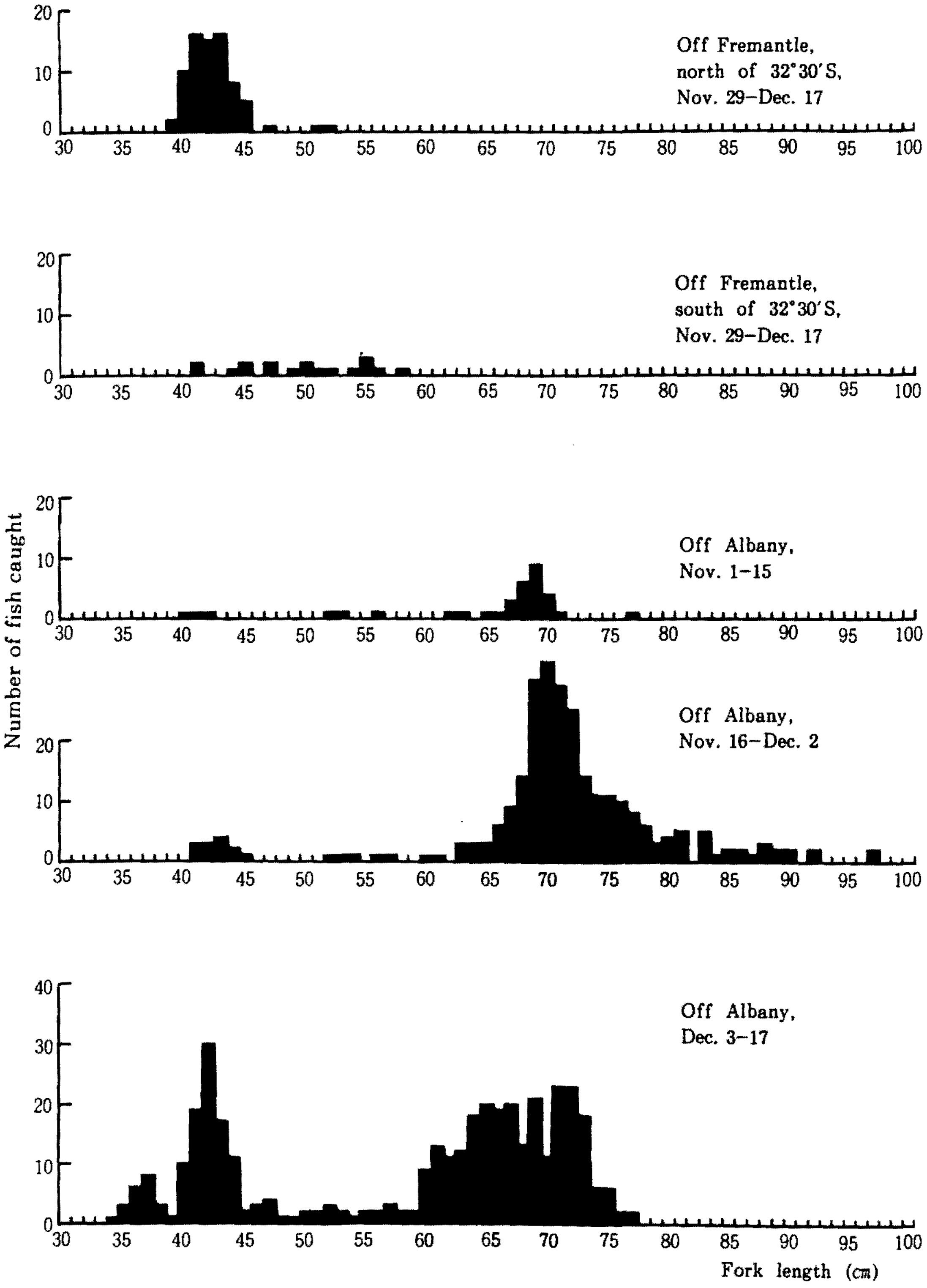


Fig. 45. Length-frequency distributions of southern bluefin tuna caught during the 1988-89 recruitment monitoring survey off south-western Australia.

Table 22. Catch per unit of effort (CPUE) of southern bluefin tuna caught off south-western Australia during the survey period, 1 November to 17 December, 1988.

<u>Area</u>: West coast of Western Australia

		.... Vessel	....	
Fishing method		Jean's Pride	Stormraker	Both vessels
Trolling	Size group	≤59 cm	≤59 cm	≤59 cm
	Catch (number)	6	39	45
	Effort (hours trolled)	397.16	484.26	881.42
	CPUE	0.015	0.081	0.051
Poling	Size group:	≤59 cm	≤59 cm	≤59 cm
	Catch (number)	38	10	48
	Effort (hours trolled)	2.42	0.45	2.87
	CPUE	15.702	22.222	16.724

<u>Area</u>: South coast of Western Australia

		.... Vessel	....	
Fishing method		Jean's Pride	Stormraker	Both vessels
Trolling	Size group	≤59 cm	≤59 cm	≤59 cm
	Catch (number)	19	28	47
	Effort (hours trolled)	400.46	460.14	860.60
	CPUE	0.047	0.061	0.054
Poling	Size group	≤59 cm	≤59 cm	≤59 cm
	Catch (number)	115	3	118
	Effort (hours trolled)	6.15	2.75	8.90
	CPUE	18.699	1.091	13.258
Trolling	Size group	>59 cm	>59 cm	>59 cm
	Catch (number)	9	18	27
	Effort (hours trolled)	400.46	460.14	860.60
	CPUE	0.022	0.039	0.031
Poling	Size group	>59 cm	>59 cm	>59 cm
	Catch (number)	393	107	500
	Effort (hours trolled)	6.15	2.75	8.90
	CPUE	63.902	38.909	56.180

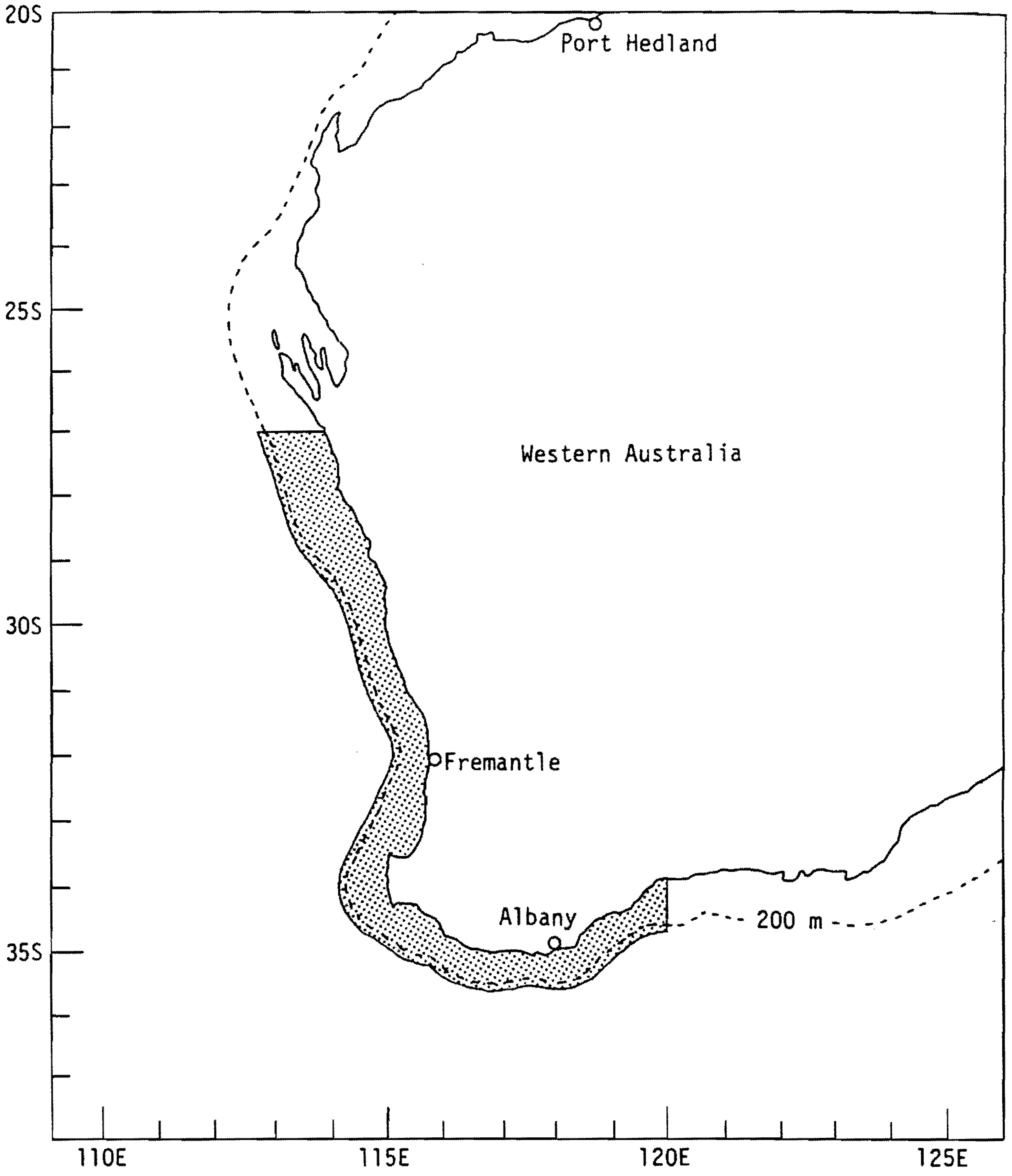


Fig. 46. Survey areas for the 1989-90 southern bluefin tuna recruitment monitoring survey off south-western Australia.

13. TAG RELEASES AND RECOVERIES

EXPERIMENTAL DESIGN, DATA COLLECTION, AND DATA PROCESSING IN SURFACE FISHERY TAG PROGRAMS

Objectives

Tagging of SBT in Australian waters began in 1959. Hynd and Lucas (1974) stated that the objectives of the experiments were to delineate stock boundaries, show migration paths, confirm growth rates obtained by other methods and, they hoped, to be of assistance in stock assessment. In the 1960s and 1970s the tagging operations were undertaken in a somewhat *ad hoc* manner, due to limitations by time and area in the availability of fish. More than 50 000 fish were tagged in three main fishing grounds in waters off (a) East Australia - from southern NSW to eastern Tasmania (mainly off Eden, NSW), (b) SA - from the Great Australian Bight to Kangaroo Island (mainly off Port Lincoln, SA), and (c) WA - from Fremantle to Esperance (mainly off Albany, WA).

In the three tagging programs in 1983-84 there was more interest in quantitative aspects, e.g. mortality rates, interactions among fisheries, estimates of the local population and survival to maturity. Consequently, tagging was conducted over each of the fishing grounds off Esperance (WA), Albany (WA) and in the Great Australian Bight to the west of Port Lincoln (SA). Fish were tagged from as many schools as possible with up to about 50 fish being tagged in each school. Numbers of tagged fish released and recaptured from 1959 to 1990 are given in Table 23.

Tagging procedure

The tagging methods used are described in Hynd and Lucas (1974), Kirkwood (1981) and Williams (1982b). Most fish tagged were caught by the pole and line method, but considerable numbers were caught by troll lines. After a fish had been hooked it was hauled aboard the boat where it was placed on a vinyl cradle (after 1980), measured, tagged and returned to the water within 30 seconds. Records were kept of the date, geographical location, tag numbers and lengths of the tagged fish.

The dart tags used were made of 12 cm by 3 mm diameter polypropylene tubing with a moulded nylon dart head glued into one end. Tags were applied by stainless steel tubing sharpened at one end. The tag was inserted into the fish about 4 cm to the rear of the second dorsal fin at an angle of 45° to the body and pointing towards the head of the fish. The dart head should be buried about 2.5 cm into the fish and be anchored in or around the basal bone elements of the fin rays. Since 1963 almost all SBT have been double-tagged, with a tag attached to each side of the fish.

During the early 1960s many fish were injected with the antibiotic oxytetracycline to help the fish combat tag shock, handling and infection. More recently this practice has only been used to mark the calcareous tissue of the tagged fish to validate aging of fish from its hard parts.

Recovery procedure

Recovery of tags from Australian fishers has mainly relied on field officers having close liaison with fishermen and processing workers. For each tag returned, tag finders were given the corresponding release information and also a monetary reward.

For the 1983-84 tagging program, good publicity was possible because since then there have been relatively few vessels fishing SBT and few companies processing them. Meetings were held with

Table 23. Numbers of juvenile southern bluefin tuna that were tagged in Australian waters and those subsequently recaptured, according to fishery, year and location of tagging and region of recapture. The Australian fishing grounds are (i) Western Australia (WA), (ii) South Australia (SA) and (iii) Eastern Australia (EA). The longitudes of operations of the Japanese longline fisheries are (iv) West $\leq 60^{o}$E , (v) 60^{o}E < Mid $\leq 120^{o}$E and (vi) 120^{o}E $\leq$ East.

Year tagged	Location of tagging	Number tagged	Numbers of fish recaptured						Total
			Australian fishery			Japanese fishery			
			WA	SA	EA	West	Mid	East	
1959	EA	132	-	2	9	-	-	1	12
1960	EA	43	-	-	-	-	-	-	-
1961	WA	169	-	6	4	-	-	-	10
	SA	18	-	1	-	-	-	-	1
	EA	270	-	1	30	-	-	4	35
1962	WA	4999	104	65	32	1	1	7	210
	EA	323	-	1	17	-	-	-	18
1963	WA	5422	85	108	33	11	8	22	267
	SA	1432	-	19	4	-	1	2	26
	EA	912	-	3	60	-	-	6	69
1964	WA	4606	20	62	55	9	7	9	162
	SA	2859	-	95	13	13	19	45	185
	EA	1056	-	15	239	-	-	10	264
1965	WA	1999	2	28	42	9	1	9	91
	SA	507	-	11	2	-	3	1	17
	EA	381	-	6	30	-	-	6	42
1966	WA	634	1	2	-	1	-	-	4
	SA	1079	-	37	3	7	8	34	89
	EA	2274	-	16	636	-	2	15	669
1967	WA	5018	79	80	50	16	5	13	243
	SA	20	-	-	-	-	-	-	-
	EA	2443	-	40	860	1	2	17	920
1968	SA	502	-	79	28	-	-	2	109
	EA	3988	-	19	2193	5	-	6	2223
1969	SA	2387	8	694	157	9	2	8	878
	EA	1444	-	18	397	-	2	15	432

Continued on the next page.

Table 23 Continued.

Year tagged	Location of tagging	Number tagged	Australian fishery WA	SA	EA	Japanese fishery West	Mid	East	Total
1970	WA	1328	74	5	3	-	-	-	82
	EA	145	-	4	35	-	-	-	39
1971	WA	14	-	-	-	-	-	-	-
1972	WA	296	1	2	-	-	1	-	4
1973	WA	951	41	13	1	-	-	1	56
1974	WA	796	43	11	6	2	-	1	63
1975	WA	838	24	55	11	2	1	-	93
1976	WA	308	1	-	-	-	-	-	1
1977	WA	219	11	7	1	-	-	-	19
	SA	908	3	199	22	-	-	2	226
1978	WA	1019	39	22	2	-	-	-	63
1980	WA	555	100	43	5	2	-	-	150
1983	WA	6956	1279	1390	4	6	7	5	2691
1984	SA	3223	23	1369	-	13	7	5	1417
1986	SA	6	-	1	-	-	-	-	1
Total	WA	36127	1904	1899	249	59	31	67	4209
	SA	12941	34	2505	229	42	40	99	2949
	EA	13411	-	125	4506	6	6	80	4723
TOTAL		62479	1938	4529	4984	107	77	246	11881

fishers and articles published (Majkowski and Murphy 1983, Williams 1983) explaining the need for the tagging program. Reward posters and postage-paid envelopes, with forms for the recapture information sought, were sent to quota holders and processing establishments.

Non-reporting

In November 1986, a questionnaire on tag reporting was sent to the skippers of all 119 boats who had held SBT licences at some time since the beginning of tagging in 1983. There was a 60 % response rate from skippers, most of whom chose to identify themselves. Most of the larger operators responded, covering 70 % of the total tonnage. Of skippers who responded, 90 % indicated that they had returned all tags or had allowed processors on shore to remove tags.

The number of tags returned per tonne of SBT caught by skippers who identified themselves and said that they returned all tags, was less than that for all other skippers. If one assumes that those who identify themselves are reliable this result supports the hypothesis that the rate of non-reporting of tags was generally low.

During the 1986-87 season, a tuna tag lottery was conducted to maintain interest in returning tags and to flush out unreported tags that had been caught in previous years. The combined effect of the survey and lottery was that tags were returned from 18 fish that had been caught in previous seasons.

A small amount of deliberate non-reporting is believed to have occurred in WA soon after tagging began.

With this level of surveillance and precautions it is thought that a non-reporting rate greater than 10 % could not escape detection.

Data processing

Most tags are returned by finders with recapture information to the CSIRO Division of Fisheries, but a substantial proportion of tags are handed to field officers who request recapture information and assess its reliability.

All documents that accompany each tag returned are examined for inconsistencies, which may indicate data of doubtful accuracy. The data and codes indicating information quality are entered onto computer files. The tagging data are recorded in various files, both paper and computer, which are listed in Majkowski (1982, Table 1).

Until 1986, data for each fish was stored as a record, by order of release date, in a sequential file. Consequently, data entry, data validation, editing and inspection were processed as batch jobs. Details of the past data processing system are given in Majkowski (1982).

Since 1986, computer processing, editing and data storage have involved a completely redesigned computer system which provides interactive data entry and editing. This system has been implemented on the CSIRO Division of Fisheries' VAX 11/750 computer in Hobart, Tasmania.

EXPERIMENTAL BIASES: EFFECT OF TAGGING, TAG SHEDDING AND SHRINKAGE.

Condition factor after tagging

One way to investigate if tagging affects fish is to monitor their weight condition for a short time after tagging. This can be done for wild fish caught at a particular time by comparing weights of

Table 24.

Southern Bluefin Tuna Tagging Data
Data Record Description (1988)

Character Position	Length of Record	Data Type	Item Recorded	Comments
1	1	C	Primary tag colour	R(ed), Y(ellow), B(lue) or X
2	5	C	Primary tag number	Right justified number with leading zeros.
7	1	C	Companion tag colour	R(ed), Y(ellow), B(lue) or X
8	5	C	Companion tag number	Right justified number with leading zeros. Blank if no companion tag used.
13	6	C	Release date	Date format: YYMMDD
19	2	C	Release vessel code	Alpha-numerical code.
21	4	C	Latitude (degrees, minutes)	Leading zeros.
25	1	C	Constant S (south)	
26	4	C	Longitude (degrees, minutes)	
30	1	C	Constant E (east)	
31	1	C	Oxytetracycline injection	Blank if none.
32	1	C	Antiseptic used	Blank if none (applicable to old tagging program).
33	1	C	Injury indicator	Blank, M or S.
34	1	C	Species tagged (Blank, 1, 2 or 3)	(See codes and indicators).
35	2	I	Length at tagging (cm)	
37	2	I	Oxytetracycline dosage	
39	2	I	Length of time fish was out of the water	Applicable to 1959 to 1980 tagging program.
41	2	I	Tag catalogue book number	
43	4	I	Page number in tag catologues	

Table 24 (cont'd)

Position	Length	Data Type	Item Recorded	Comments
47	4	I	Release quality bit mask	(See codes and indicators).
51	6	C	Recapture date	Date format: YYMMDD.
57	4	C	Recapture Latitude (degrees, minutes)	Leading zeros.
61	1	C	Constant S (south)	
62	5	C	Recapture longitude (degrees, minutes)	Leading zeros.
67	1	C	E or W (east or west)	
68	2	C	Recapture vessel/tag finder code	Alpha numerical codes.
70	1	C	R, Y, B or X if primary tag recovered	Blank otherwise.
71	1	C	R, Y, B or X if companion tag recovered	Blank otherwise.
72	1	C	Re-release/recapture code 1, 2 , 6	Blank if none (See codes and indicators).
73	2	I	Recapture length (cm)	
75	4	R	Recapture weight to 0.1 kg	
79	4	I	Recapture quality bit mask	(See codes and indicators).
83	2	C	Tag finder's initials	
85	18	C	Tag finder's surname	
103	27	C	Tag finder's address (part 1)	Address in two parts.
130	35	C	Tag finder's address (part 2)	
165	6	C	Recapture data base entry date	

tagged and untagged fish of the same length. For a schooling fish, such as juvenile SBT, sufficient numbers of tagged fish can be caught at one time for statistical comparisons to be made. An important advantage of this approach is that shrinkage (see next sub-section) and weight loss due to bleeding and dehydration can be disregarded if all fish from a catch are handled in the same way.

Hearn (1986) reported and analysed an experiment designed by G. Murphy and conducted by CSIRO Division of Fisheries in which juvenile SBT were tagged off Port Lincoln (SA) in early 1977 (K. Williams, field leader). Many of these fish were recaptured by fishermen within a month of tagging or during the following season. On landing many had their lengths (to the nearest cm) and weights (to the nearest 100 g) measured by experienced CSIRO staff. Lengths and weights were similarly measured on untagged fish (controls) for some of the landings which contained recaptured tagged fish.

For recaptured fish with periods of freedom from 13 to 24 days a direct comparison of weights was made between the tagged and the untagged fish. Only 1 of 42 ($p < 0.001$) of these recaptured tagged fish was heavier than the median weight of untagged fish of the same length from the same landing.

Le Cren's (1951) relative condition factor (which does not assume a cubic length-weight relationship) was used to quantify this loss of weight in the first two to four weeks after tagging. Using this approach Hearn (1986) defined the relative condition factor of an individual SBT as the ratio of the measured fish weight to its weight as estimated from the Robin's (1963) length-weight relationship. The condition factors of individual fish, from landings which contained tagged fish, were pooled into two sets; one each for tagged and untagged fish. There was a significant loss in weight of 11.6 ± 0.8 % for tagged fish in comparison with untagged fish of similar lengths.

No confidence interval is given for the exponent of length in Robins' (1963) length-weight relationship. However, sensitivity analysis showed that exponent values between 2.6 to 3.3 in the length-weight relationship made no difference to the significance tests and little difference to the estimate of condition factor loss.

During early 1983, juvenile SBT were tagged off Esperance, WA (K. Williams, field leader), and data were collected in a similar way to the 1977 experiment, but weights were measured more accurately (to the nearest 50 g). These data were analysed by Hampton (1986, 1989) to obtain the extent of the weight condition loss. He used a length-weight relationship obtained from the untagged fish, which is preferred to the relationship used by Hearn (1986) which was not obtained from the data being compared. The tagged fish analysed by Hampton (1986) had times at liberty up to about 4 weeks, with about 50 % of cases being less than 2 weeks.

In the 1983 experiment the condition factor loss was found by Hampton (1986) to be 6.8 ± 0.4 % as compared with 11.6 ± 0.8 % from the 1977 experiment. The substantial difference between these results could be explained in a number of ways:

(a) improved tagging techniques in the 1983 experiment; for example, in 1983 tagging cradles were used to firmly hold the tuna during tagging, whereas in 1977 they were tagged on a measuring board;

(b) the temperature, food supply or the fish condition at tagging may not have been suitable for fish to quickly recover from the trauma of tagging in the 1977 experiment;

(c) in either or both experiments, bias may have occurred if fishermen handled tagged fish differently from untagged fish; and

(d) the periods at liberty of tagged fish analysed may be a contributing factor.

Hampton (1986) found that the greatest condition loss occurred in fish recaptured 6 to 20 days after tagging, which coincides more with that of the data Hearn (1986) analysed. Nevertheless, for tagged fish the condition factor losses taken from Hampton (1986, Table 2) were less than that estimated by Hearn (1986) for all periods of liberty.

Hampton (1986) found that SBT which were up to 60 cm long when tagged lost more condition than larger fish. He postulates that this is due to size-related activity when tagging because fish less than 60 cm long frequently struggled violently whereas larger ones tend to lie quietly after capture.

The results of both experiments agree to the extent that the relative condition factor is reduced shortly after tagging and this should be taken into account when analysing SBT tagging data. However, variations in results between experiments, sizes at tagging and periods at liberty suggest that the loss in the relative condition factor of SBT after tagging may correlate with a number of factors and so it should be interpreted with caution.

Hearn (1986) reported that SBT caught about one year after tagging show no difference between the relative condition factors of tagged and untagged fish. Thus it is reasonable to infer that tagging has no long-term undesirable effects on the condition and growth of SBT.

Shrinkage of SBT after death

Bias in length measurements of tagged fish could distort growth rate estimates in cases where the growth increments are small, as, for example, in determining the short-term effects of tagging on growth or seasonal variability in growth. Fisheries scientists have noted that fish species typically contract by about 1 % to 2 % in length after death when stored on ice, frozen or preserved in formalin.

In Hearn's (1979) report it was noted that tuna which were tagged in 1977 and caught a few days afterwards exhibited significant ($p < 0.001$) negative growth. They had been chilled on capture and measured by scientific staff some days later. The bias was considered to be due to shrinkage, but it could have been caused by faulty measurement procedures. In earlier experiments fish that were recaptured soon after tagging and immediately measured by scientists, showed positive growth.

An experiment to confirm shrinkage was conducted off Port Lincoln by the CSIRO Division of Fisheries (K. Williams, field leader), which is reported in Hearn (1986). Fish were tagged on three separate days. On being caught each fish was measured and a tag attached round its body, just forward of its tail. The size range of the fish tagged was 86 cm to 107 cm. They were left on deck and re-measured after death. The fish were then stored under chilled brine spray for 3 to 6 days, depending on the time of tagging, and on arrival at Port Lincoln all fish were re-measured before freezing. On thawing, 9 days later, they were measured again.

It was found that fish soon after death were 0.38 ± 0.07 % (mean ± % standard error) longer than when they were alive. It is not certain why length should increase after death. From death to landing there was an length shrinkage of 0.95 ± 0.11 %. A significant ($p < 0.05$) linear trend in shrinkage according to time after death was also reported. From landing to thawing there was a further contraction of 1.14 ± 0.12 %. As before, a significant linear trend of shrinkage with time occurred. On average the living to landing shrinkage was 0.57 ± 0.13 % and a total shrinkage of 1.71 ± 0.14 % from living to thawing was found. Recapture data derived from tagged tuna after freezing and thawing were not used for growth studies.

Gibson (1982) states that chilling SBT slows rigor mortis considerably, thus the amount and speed of shrinkage could depend on handling and storage techniques. The juvenile SBT used in the study were large, for Australian catches, consequently it would be of interest to repeat the experiment on 50 to 70 cm fish.

Tag-shedding

The technique, originated by Beverton and Holt (1957), of double-tagging experiments in which two tags are attached to each fish, is a well established means of providing a measure of the extent to which tags are shed, by observing the proportion of recaptured tagged fish that have one tag. In theory, this allows an estimate of the unobservable number of caught fish that have shed both tags.

The standard theory of estimating tag shedding rates, (e.g. Kirkwood 1981, Wetherall 1982 and Kirkwood and Walker 1984) involves the following implicit assumptions :

(a) Tags attached to the same fish may be regarded as a random sample from the collection of all tags.

(b) The shedding of any tag occurs independently of the shedding of other tags, including the one attached to the same fish.

(c) Natural mortality, migration, catchability and reporting of tags by fishermen are independent of the number of tags attached to a fish.

Estimates of the number of fish that have lost all their tags is necessary in many analyses of SBT tag-recapture data (e.g., Hearn et al. 1987; Majkowski et al. 1988). Hynd (1969) estimated the tag shedding rate (assumed to be constant) of SBT to be 0.26 per year. Kirkwood (1981) developed a model that does not assume the same probability of shedding for each tag, but assumptions (a) to (c) are implicit. It allows for the possibility that some tags are never shed, which is based on biological evidence indicating that tags become firmly embedded in SBT after a few years. According to Kirkwood (1981) about 56 % of tags were shed by 4 years after tagging.

Hampton and Kirkwood (1990) made estimates of tag shedding for eight SBT double-tagging data sub-sets to allow further analyses of these data to estimate population parameters. Their objective in data classification was to ensure that, within experiments, the geographical area, fish size, tagging and fishing methods and tagging personnel were as similar as possible. They used the maximum likelihood procedure of Kirkwood and Walker (1984) for estimating parameters for various shedding models, which only requires the time at liberty and the number of tags on recaptured fish. The most striking result they found was that the predicted probability of shedding after four years was about 0.2 per year for the 1983-84 experiments, whereas it was 0.5 - 0.7 per year for the earlier experiments.

Hearn et al. (1987) suggested that the Kirkwood (1981) and other similar models may result in biased estimates of the proportion of SBT that shed tags if tagging operators were not equally proficient, i.e. violating assumption (a). Hearn et al. in prep. (b), analysed biases that may follow if data are pooled from experiments with dissimilar tag shedding rates. They found that the bias in tag shedding estimates, due to pooling, may be substantial if shedding is high and the tagging technique varies greatly between experiments.

Hearn et al. (in prep. (b)), found that SBT tagged by different operators often shed tags at different rates. The inexperience of tagging operators was found to be an important factor. Applying shedding estimates from pooled SBT tagging data leads to serious bias in some cases.

In some situations comparisons of tag recovery rates between experiments may also be used to support the existence of variability in shedding rates. For similar SBT tagged at about the same time and location, high shedding tended to correspond to low proportions recovered, as expected.

The approach of Hampton and Kirkwood (1990) of estimating shedding rates for separate data sub-sets is a useful bias reduction technique for estimating the number of SBT that shed both tags. However, there are limitations with this approach, which restricts the use of the SBT tagging data:

(a) For most SBT the tagger cannot be identified and so inadvertent pooling may lead to bias. The magnitude of bias due to pooled data increases with the degree of heterogeneity and the general shedding rate. The level of tag shedding from the 1963-80 tagging is about three times that from the 1983-84 tagging (Hampton and Kirkwood 1990). Consequently, one would expect more bias from inadvertent pooling in the former experiment than the latter.

(b) Many analysis methods are sensitive to bias in estimates of tag shedding involving long periods between release and recapture. The data analysed are from SBT that were recaptured up to 15 years after release, but the information is somewhat sparse for periods at liberty greater than five years. Therefore, data sub-division makes results pertaining to old fish very uncertain. This aspect is considered in Hampton and Kirkwood (1990) for SBT.

(c) In some cases a high proportion of fish may lose both tags soon after tagging which does not allow shedding to be estimated with any certainty to determine if it could be the cause of the low proportion of recoveries.

From the evidence presented in Hearn et al. in prep. (b), it is clear that results of previous analyses (e.g. Majkowski 1982, Hearn et al. 1987, Majkowski et al. 1988, Hampton 1989) need re-evaluation.

The analyses presented by Hearn et al. in prep. (b), essentially relied on circumstantial evidence. Therefore, it would greatly clarify the matter if a double-tagging experiment were conducted with each fish having one tag attached in the ideal manner (Williams 1982b), and the other inserted into the musculature only, as mentioned in Hampton (1986).

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APPENDIX 2

PROVISIONAL AGENDA

Meeting Theme: Stock Assessment of Bluefin Tunas: Strengths and Weaknesses

25 May, morning: Overview--Summary presentations and questions about the three REVIEW PAPERS prepared for the meeting.

25 May, afternoon, to 26 May, afternoon: Discussion and comparisons regarding BASIC DATA. Data include catch and effort statistics, size-frequency data, sex ratios in the catches, survey data, and tagging data. There are a number of questions we can address: How are the data collected? What is the quality of the data we have? Have there been technological innovations in the fisheries which make it more difficult to monitor trends in relative abundance? Does catchability vary? Three rapporteurs, one for each of the stocks, would summarize this section.

26 May, afternoon, through 28 May: Discussion and comparisons regarding PARAMETER ESTIMATES. Parameters include growth, natural mortality, conversion of length frequencies to age frequencies, length-weight relationship, migration, and reproduction. Questions we can address include the following: What methods are used to estimate parameters? What is the quality of the estimates we have? Do bluefin exhibit sexually dimorphic growth or mortality? How do estimates compare among stocks? Three rapporteurs, one for each of the stocks, would summarize this section.

Note: There is no meeting scheduled on Sunday, 27 May.

29 May through 30 May: Discussion and comparisons regarding STOCK ASSESSMENT. This includes all the ways in which we use biological and other research to assess the abundance and status of stocks. Methods to be discussed can include yield-per-recruit analysis, production models, spawner-recruit comparisons, spawner-per-recruit analysis, and catch-at-age (size) models. This topic brings together the previous two days of discussions and identifies which data and parameters are important for stock assessment and whether those items are well estimated. We can also address the question of what can be said about the condition of stocks. Three rapporteurs, one for each of the stocks, would summarize this section.

31 May: Formulation of GENERAL RECOMMENDATIONS on desired directions of future research. We could discuss strengths and weaknesses of present research and identify some areas where we would like to learn more. One rapporteur would summarize this section.

We will have a 2-hour break each day for lunch, which will allow some time for other forms of dialogue, such as for computer demonstrations and additional analyses of data. IATTC will provide an IBM-compatible personal computer and access to the IATTC VAX at our conference site. Additional dialogue can take place on Sunday, 27 May, when there are no scheduled meetings. Anyone interested in submitting a contributed paper will be given time to present his work, but we will not publish such contributed papers. We will produce a report of the meeting, which will include the review papers and summaries written by the rapporteurs.

The meeting will focus on scientific issues and we will avoid discussions of specific management strategies and/or management regimes, as IATTC believes that management issues are the prerogative of the countries involved.

APPENDIX 3

LIST OF ORIGINAL REVIEW DOCUMENTS AND BACKGROUND PAPERS

Review Documents

1. Bayliff, William H. 1990. Status of northern bluefin in the Pacific Ocean.

2. Clay, Douglas (editor). 1990. Atlantic bluefin tuna (*Thunnus thynnus*, L.): a review.

3. Majkowski, Jacek (editor). 1990. Southern bluefin tuna population and fishery: a critical review of information in support of fisheries management.

Background Papers

1. Murphy, Garth I. 1990. A review of the evidence of stock structure in Atlantic bluefin tuna with an alternate hypothesis. manuscript.

2. Hearn, William S., and Jacek Majkowski. 1990. Interactions of the Australian southern bluefin tuna fisheries: predictions from a modified tag-release/recovery method. manuscript.

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

4. Report of the eighth meeting of Australian, Japanese and New Zealand scientists on southern bluefin tuna. Shimizu, Japan, September 4-10, 1989.

5. Cort, José Luis. Age and growth of the bluefin tuna, *Thunnus thynnus* (L.), of the northeast Atlantic. manuscript.

6. Eckert, G. J., J. Kalish, J. Majkowski, and R. Pethebridge. 1987. An indexed bibliography of the southern bluefin tuna (*Thunnus maccoyii* (Castlenau, 1872)). CSIRO, Mar. Lab., Rep., 185: 49 pp.

7. Caton, A., K. McLoughlin, and M. J. Williams. 1990. Southern bluefin tuna: scientific background to the debate. Austral. Bur. Rural Res., Bull., 3: 41 pp.

8. Anonymous. 1990. Inter. Comm. Cons. Atlan. Tunas, Ann. Rep. for 1988-89, Part 2 (1989): 153-162 and 328-338.

9. The trap fishery. manuscript.

10. Murray, Talbot, and David Burgess. Southern bluefin tuna fisheries in New Zealand waters since 1980. manuscript.

11. Hearn, William. series of maps and tables

12. Majkowski, Jacek, and Graeme Morris. 1986. Data on southern bluefin tuna (*Thunnus maccoyii* (Castlenau)): Australian, Japanese and New Zealand systems for collecting, processing and assessing catch, fishing effort, aircraft observation and tag release/recapture data. CSIRO, Mar. Lab., Rep., 179: 95 pp.

13. Bayliff, William H., and Yoshio Ishizuka. 1990. Growth, movement, and attrition of bluefin tuna in the north Pacific Ocean, as determined by tagging. manuscript.

14. Kirkwood, G., J. Majkowski, W. Hearn, and N. Klaer. 1989. Assessment of the southern bluefin tuna stock using virtual population analysis. Eighth Trilateral Meeting, Shimizu, 1989.

15. Kono, H., and Y. Ishizuka. 1989. Assessment of the southern bluefin tuna stock. manuscript.