# TUNA FISHERIES AND THEIR RESOURCES IN THE PACIFIC OCEAN

by

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ABSTRACT

The recent status of the tuna fisheries and resources in the Pacific is reviewed. This report extends material provided in Suda's report which was submitted to the IPFC 14th Session held in 1970. Two principal tuna fishing countries, Japan and United States, harvest nearly two-thirds of the total "tuna" production. Longline fishing holds a leading position, taking approximately 60 percent of the Pacific catch of large-size tunas and nearly all of the billfish. Catches by the purse seine and bait boat fisheries are predominated by yellowfin and skipjack.

Biological and ecological information relating to large-size tunas and to some extent, billfish, are provided in this report. Information on yellowfin from the eastern Pacific is excluded. Most of the species of the large-size tunas appear to be utilised, at or near full exploitation; any increase in fishing effort will probably not result in a corresponding increase in catch. Voluntary regulatory measures taken by the Japanese tuna industry on southern bluefin are briefly mentioned.

## 1. INTRODUCTION

The importance of tunas in commercial fisheries of the world has been generally recognised. In the Pacific Ocean there have been various kinds of tuna fisheries; many have long histories. The major tuna fisheries prevailing today include the longline, purse seine and live bait fisheries. The longline fishery harvests the large, deep-swimming tunas and billfish; while the surface fisheries, represented by purse seining, pole-and-lining with live bait and trolling, are aiming at the smaller size tunas.

According to the FAO Report on tuna stock assessment (FAO 1968), the exploitation of tunas in recent years by various countries has been at such levels that some of the stocks of tunas may have reached the stage of full utilisation.

International activities for tuna fisheries management are expanding in the world's ocean. Since 1952, the Inter-American Tropical Tuna Commission (IATTC) has been active in the management programme for tropical tunas in the eastern Pacific. The Commission, which currently has six member nations, has implemented a yellowfin regulation since 1966. Although not a regulatory agency, the Indo-Pacific Fisheries Council (IPFC), considers the fisheries management of tunas in the Western Pacific as one of the important subject areas for review. The Asian Tuna Fishermen's Roundtable Conference has held annual sessions for the discussion on the rational development of tuna industries since 1967. A scientific meeting has been held in conjunction with this annual conference since 1970.

Biology, ecology and stock assessment of tuna species in the western Pacific have been summarised by Suda (1971); the information was presented to the 14th Session of the IPFC Meeting held at Bangkok, Thailand in 1970. The present paper updates the information given by Suda.

## 2. TUNA FISHERIES IN THE PACIFIC

Tunas are distributed throughout the tropical and temperate waters of the Pacific Ocean. Currently the activities of tuna fisheries cover nearly the entire ocean area.

### 2.1 Recent catch statistics of tuna fisheries

Recent catches of tunas, billfish and tuna-like species have averaged approximately one million metric tons. The annual average Pacific Ocean catches by species and countries are summarised in Table I; basically the information is based on data published by FAO (1972). The major fishing nations in the Pacific include Japan, the United States of America (US), Peru, Taiwan, Philippines and Korea. The total annual catch of large-size tunas is approximately 400,000 tons. Japan and the US are responsible for taking approximately 50 percent and 25 percent of the catch, respectively. The Japanese catch of billfish accounts for almost 80 percent of the total billfish caught in the Pacific. Additionally, Japan also lands a substantial proportion of the catch of small-size tunas, including the tuna-like species. Japan is followed by such countries as Peru, US, Philippines and Taiwan.

### 2.2 Review on major tuna fisheries

Several fishing methods are employed in the tuna fisheries in the Pacific. Longlining, pole-and-lining with live bait (bait boat fishing), trolling and purse seining are principal fisheries. Table II shows the estimates of the recent average catches of the major species by fishing method and country. The longline fishery contributes about 60 percent (nearly 230,000 tons) of the large-size tuna catch. Billfish are caught exclusively by longline, while skipjack are caught by surface fishing methods, e.g., pole-and-line and purse seine.

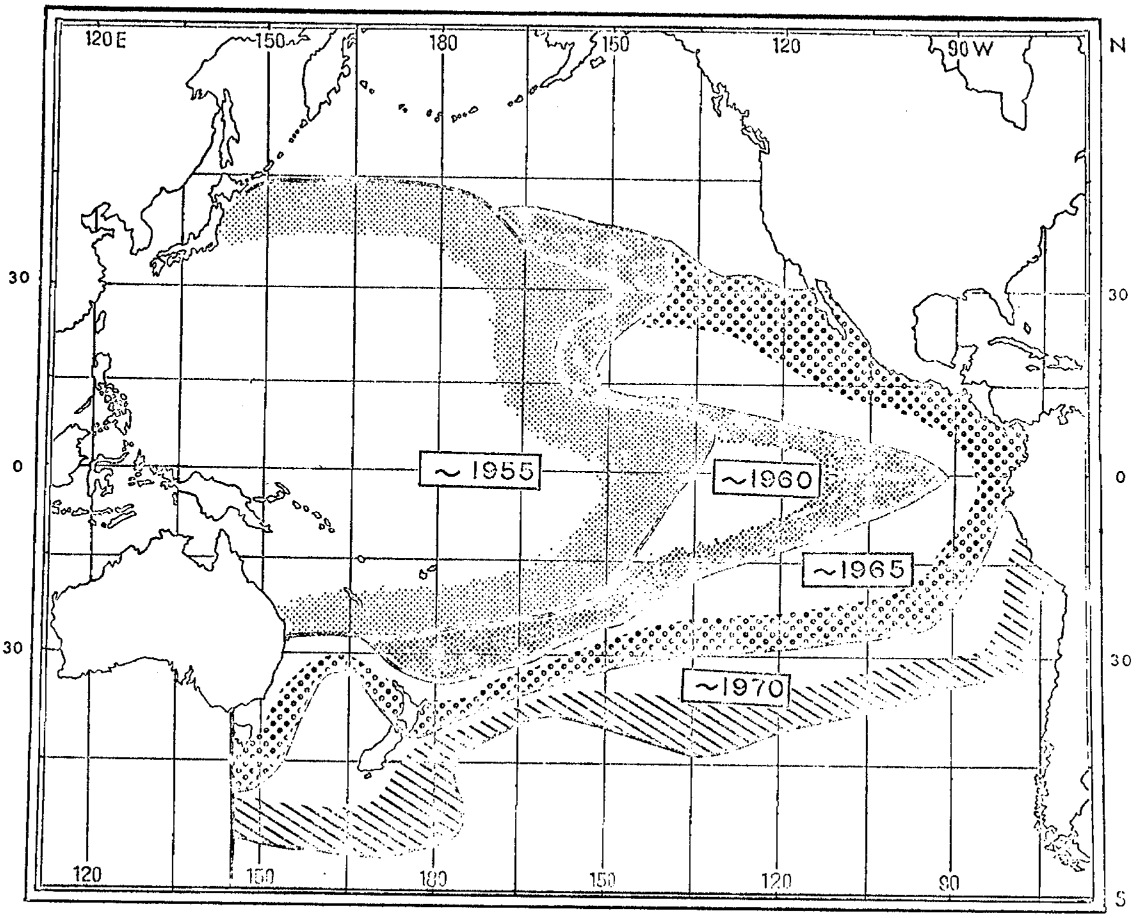


Fig. 1 Expansion of the Japanese longline fishing ground at five-year intervals

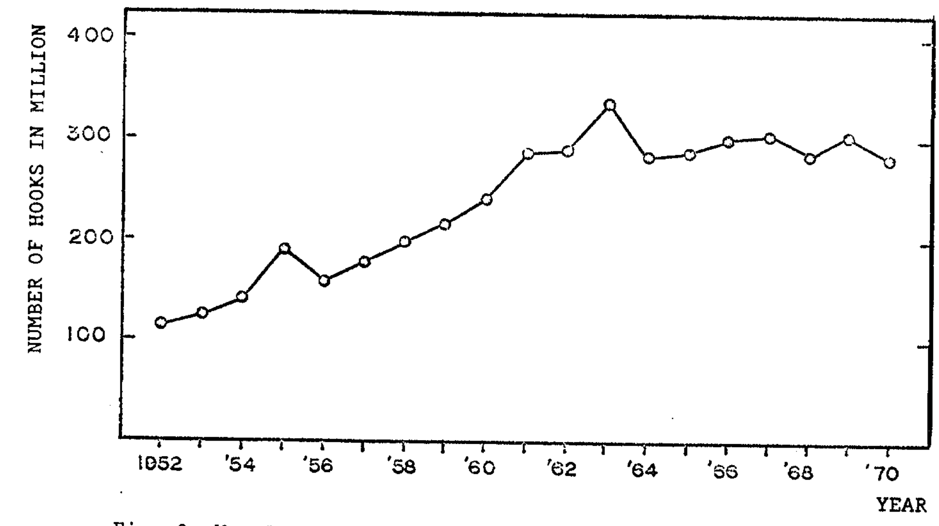


Fig. 2 Yearly number of hooks invested by the Japanese longliners in the Pacific Ocean

### 2.2.1 Longline fishery

As noted previously, the longline fishery holds the leading position in the tuna fisheries af the Pacific. The gear is capable of taking a wide variety of commercially important fish species, and also fish of various sizes. Thus, in the event poor fishing is encountered in one area, fishing strategy can be switched readily and the entire operation moved to a new ground. This feature of the gear makes it possible for the longline fishery to operate over a vast and far-distant area.

The three major longline fishing countries are Japan, Taiwan, and Korea.

#### 2.2.1.1 Japan

Since the restriction of Japanese vessels from the distant water tuna fishing grounds was removed in 1952, the Japanese longline fleet has expanded rapidly. The expansion of the fishing ground in the Pacific Ocean is shown in Fig. 1. The current fishing ground covers nearly the entire Pacific, extending from latitude 40°N to latitude 35°S in the eastern Pacific, and in the western Pacific as far south as latitude 55°S. The fishing effort has also increased as the area of fishing has expanded (Fig. 2). The effort increased steadily until 1963, then levelled off. It should be noted that Japan established a fisheries policy in 1963, wherein a special licence system was used to control the number of fishing vessels operating in the major fisheries. This was done to maintain sound condition of the fishing industry and to avoid an irrational utilisation of the resources. As for the tuna longline and bait boat fisheries, the fishing boats larger than 20 gross tons came under the system; thus the tuna fishing effort has been held substantially steady since 1963.

Currently there are three types of operations of the longline fishery in the Pacific. The annual changes in effort by type of operation and size of vessel are shown in Fig. 3. The largest type of operation is the Japan-based fleet of individually operated vessels. The fishing grounds differ for the various sizes of fishing vessels (Fig. 4). Generally, the larger vessels operate in the more distant fishing grounds. Although not indicated in Fig. 4, the foreign-based operation in the South Pacific has decreased noticeably in recent years. Also, although the mothership-type fleet operation was discontinued in 1965 (Fig. 3), the mothership carrying loaded skiffs are still operating on a small scale in the eastern tropical Pacific.

#### 2.2.1.2 Taiwan and Korea

The longline fleets of Taiwan and Korea are based at a number of foreign ports, e.g., Samoa, Santo and Fiji in the South Pacific. The extent of Taiwanese longline fishing activities is shown in Fig. 5. The Korean fleet also operates in the same general area. The longline fisheries of Taiwan and Korea have assumed substantial proportions of the longline fishing effort in the South Pacific since 1965. The longline fleet of each country currently consists of more than 100 vessels. The Taiwanese small (less than 50 gross tons) longliners presently are operating in the South China Sea and the westernmost equatorial Pacific; billfish predominate the catch of these boats.

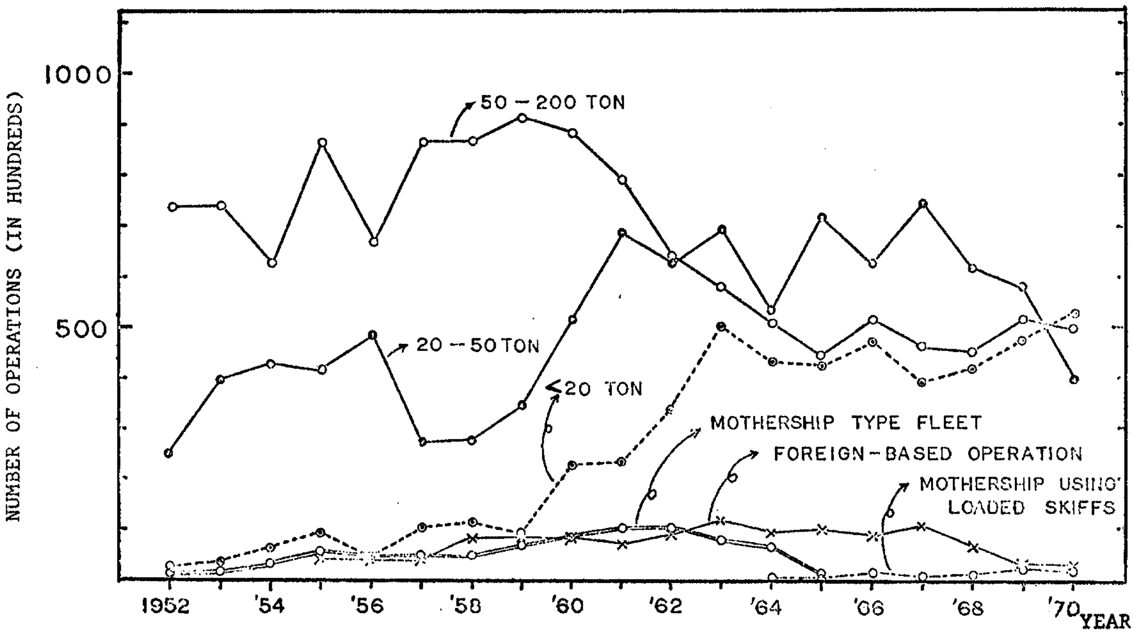


Fig. 3 Annual change in fishing effort (expressed in number of operations by types of operation and size of boats) of the Japanese longline fishery

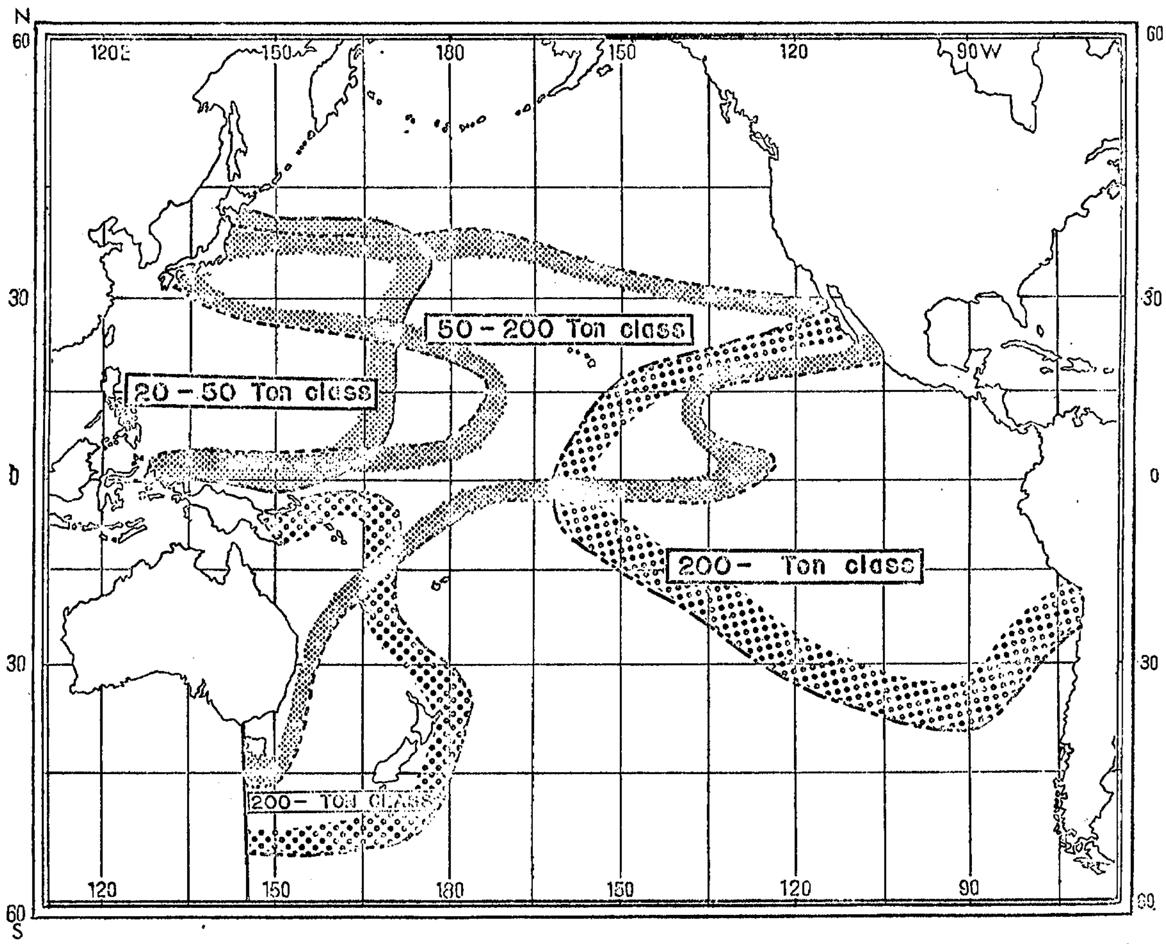


Fig. 4 Schematic fishing grounds of Japan-based longline fleet by boat-size categories

2.2.2 Bait-boat fishery

This fishery depends on the aggregation of tunas at the sea surface. In order to attract the tuna school close to the vessel, small amounts of small sardines and anchovies are chummed into the midst of the school; fishing is by hook and line. The range of the fishery is restricted to the longevity of the baitfish; dead baitfish have not been used with any measure of success. In Japan, baitfish are taken by several specialised fisheries for bait which operate solely to supply the tuna boats; in the US the tuna clippers catch their own supply of baitfish. It should be noted that the pole-and-line method has been largely displaced by the purse seine method of fishing for tunas in the eastern tropical Pacific.

2.2.2.1 Japan

The Japanese bait-boat fishery catches mainly skipjack and albacore tuna. In recent years the average annual catch of skipjack tuna has been 150,000 metric tons, while the albacore has averaged 25.000 tons. The size of the fishery was fairly stable during 1952-1960 period; and geographically, the area fished was restricted to the area north of latitude 15°N. Since 1964 the number of large vessels operating in the baitfish fishery has increased; concomitantly, there has been an expansion of the fishing grounds. The recent fishing ground is shown in Fig. 6—the localities of good albacore catches are noted to extend as far east as longitude 180°. The recent improvements developed to hold live bait for a longer period has made it possible to extend the fishery to grounds as far south as the equatorial waters of the western Pacific. The expansion has extended the pole-and-line fishing season to a year-round operation.

2.2.2.2 The United States

The US bait-boat fishery has developed in the coastal area of the Americas since the early 1930's. Until the late 1950's the bait-boat fleet enjoyed good fishing. Since then the fleet has decreased in size due to the conversion of bait-boats to purse seiners and the construction of new purse seiners. The recent catch of the bait-boat fleet has been less than 16,500 tons, the catch consisting of primarily skipjack and yellowfin tuna. Some small boats are reported to fish for albacore in the North Pacific in the summer.

In Hawaii, a small pole-and-line fishery for skipjack tuna has been in operation since the early 1900's. The current annual catch averages around 5,000 tons.

..2.3 Purse seine fishery

The purse seine is the most mechanised and intensive fishing method for catching tunas. The success of purse seining for tunas is reported to be associated with a shallow thermocline; thus the most important purse seine fishing ground is located in the eastern tropical Pacific where the depth of thermocline is shallow. The catch of the US purse seine fleet consists mostly of yellowfin and skipjack tuna. Some bluefin are also taken by purse seiners operating off southern and Baja California during the summer months. In the western Pacific, purse seining has not been successful, principally because of the deeper thermocline found in the fishing grounds. Some success has been achieved by the two-boats-type purse seining developed in the Tohoku area off north-eastern Japan. In this area the presence of a frontal zone between the two large currents, the Kuroshio and the Oyashio, provides favourable conditions for the aggregation of tunas especially bluefin.

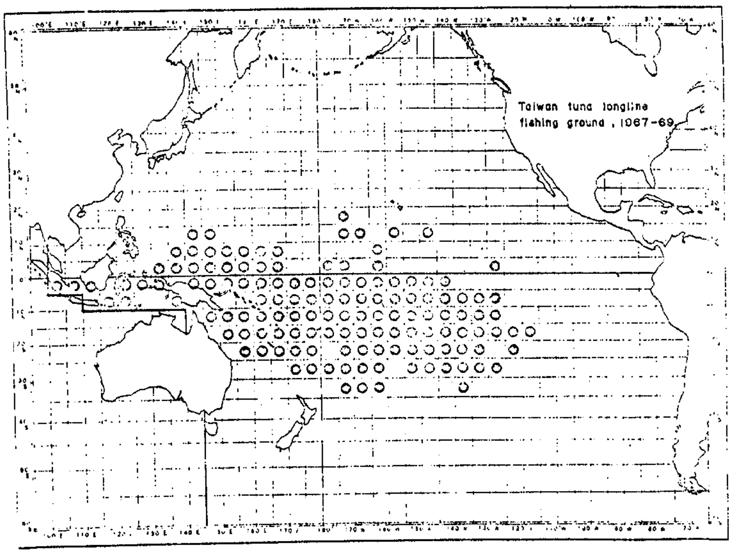


Fig. 5 Taiwanese South Pacific longline fishing grounds 1967-1969

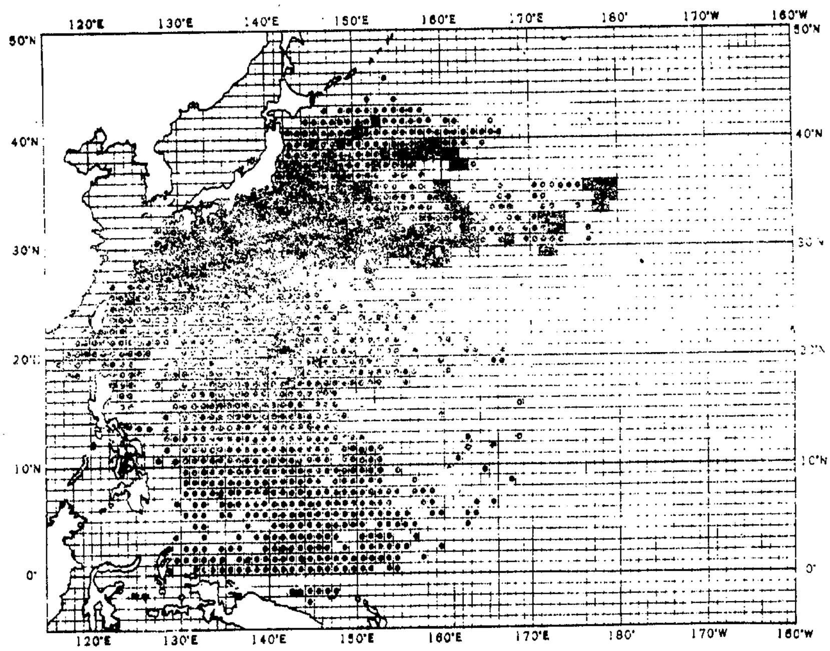


Fig. 6 Japanese bait-boat fishing ground in 1968.
Shaded areas indicate the albacore catch recorded.

2.2.4 Trolling

Trolling is the only effective method used to catch albacore off the northern coast of North America. Jig boats which are usually small in size, troll several lines from the stern and from outriggers. The fishing season reaches a peak during the northern summer months.

3. RESOURCES OF LARGE-SIZE TUNA

The five large-size tuna species discussed in this section include the albacore (Thunnus alalunga), bluefin (Thunnus thynnus), southern bluefin (Thunnus maccoyii), yellowfin (Thunnus albacores), and bigeye (Thunnus obesus). For yellowfin and bigeye, an emphasis will be placed on stock assessment studies. Voluntary measures adopted by the Japanese Fishermen's Association have been introduced for the southern bluefin (Thunnus maccoyii) longline fishery since October 1971.

3.1 Albacore

Fig. 7 indicates that there are two abundant areas of albacore in the Pacific, one in the northern hemisphere and the other in the southern hemisphere. The relation between these two groups has been studied by Otsu (1963) and Suda (1962). On the basis of biological and ecological information and the results of tagging experiments the albacore in the North Pacific appear to consist of a unit stock; one that is different from the albacore found in the South Pacific. Albacore in the South Pacific are considered most likely to be a unit stock. However, complete explanatory information is not available yet.

Albacore has been taken throughout the Pacific by the longline fishery and by the surface fisheries off Japan and the northern portion of North America. Small local surface fisheries for albacore have been reported to occur in the waters off northern New Zealand, south-eastern Australia and off Chile.

Under this section, the northern and southern albacore will be described separately.

3.1.1 Albacore in the North Pacific

The albacore stock of the north Pacific Ocean has been harvested historically by the Japanese longline fishery in winter, and by surface fisheries off Japan, the United States and Canada in the spring and summer months.

3.1.1.1 Distribution and migration

It is distinctive that the realm of northern albacore can be seen in the range of Sub-tropical Gyre. The geographical range of the distribution extends over the entire North Pacific from latitude 10°N to 45°N. Judging from the hook rate (catch in number per 100 hooks) for longline-caught albacore (Suda, 1962) and the location of fishing grounds of surface fisheries in the eastern and western portions of the Pacific, the main centres of distribution of albacore available to the fishery lie between latitude 25°N and 40°N.

The size composition of albacore differs with the method of fishing and the area of capture. In the eastern Pacific, the main constituents of the catch are small in size. The size frequency distribution of the albacore taken by the US trolling and bait-boat fisheries (Fig. 8) show a pronounced mode between 60 and 70 cm (3 years old). In the north-western Pacific, recent studies of the size composition of albacore caught by the bait-boat fishery during the spring season show prominent modes at 83 cm (age 5) and 95 cm (age 6) in the northern and southern

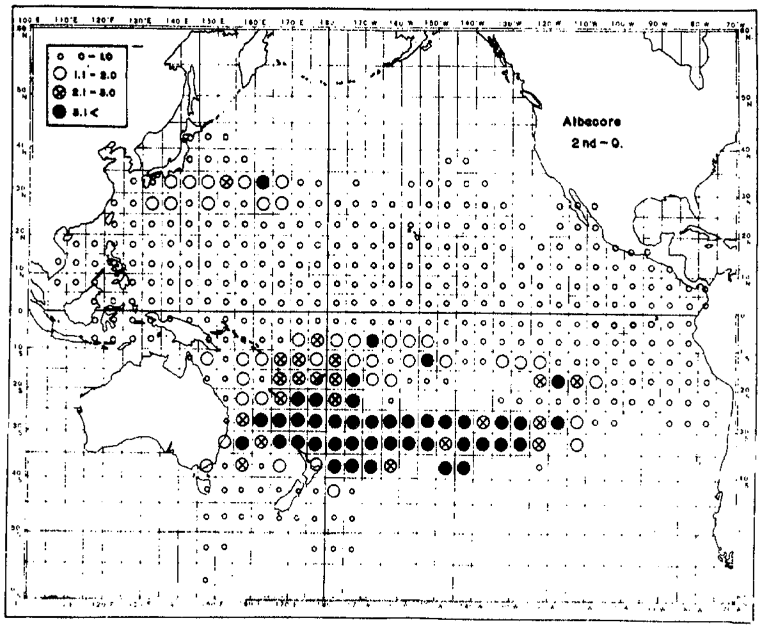


Fig. 7 Geographical distribution of hook rate of the long-line albacore, as an average of 1966-1970: 2nd quarter

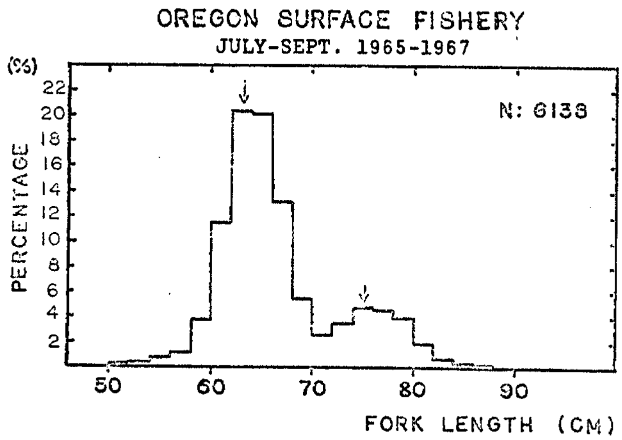


Fig. 8 Size composition of the U.S. surface albacore (after Meehan and Hreha, 1969)

grounds, respectively (Fig. 9). For the winter longline fishery, the modal sizes are located at 80 and 90 cm (ages 4 and 5). Fig. 10 shows the size frequency distribution of albacore caught by the Japanese longline fishery in January-March 1968.

Latitudinal segregation of the distributional pattern by size, which is explained as the relation of the size difference to surface temperature (Suda and Shiohama 1962), is apparent from the data shown in Figs 9 and 10 on size of surface and longline catches and in the size differences of albacore caught in the different ocean currents (Suda, 1956).

Tagging experiments have indicated that the albacore is a trans-Pacific migrant. These experiments were carried out in the 1950's principally by the Nankai Regional Fisheries Research Laboratory, The Honolulu Laboratory of the Southwest Fisheries Centre (formerly known as the Pacific Oceanic Fisheries Investigation), and the California Department of Fish and Game. The results of these studies showed clearly that the albacore migrates from the eastern to the western Pacific and appears in the Japanese fishery from one-half to one year after its occurrence in the eastern Pacific. The data of these tagging experiments were summarised by Clemens (1961) and Otsu and Uchida (1963).

3.1.1.2 Maturity and growth

The maturation and spawning activities of albacore in the northern hemisphere have been reported by Ueyanagi (1957) and Otsu and Uchida (1959a) on the basis of the examination of the developmental stages of the gonads. According to these studies, the minimum size for first spawning is estimated at about 90 cm in length for females. In addition, Yabe et al. (1958) and Yoshida (1965 and 1969) examined the occurrence of young and juvenile albacore found in the stomach contents of tunas and billfish in order to add to the knowledge of the early life history of this species as well as of the spawning.

Ueyanagi (1969), in a summary of spawning, indicated that the spawning area of the albacore was located in the sub-tropical area centring around latitude 20°N; principally in the inner waters surrounded by the Sub-tropical Gyre. The oceanographic characteristics of the spawning area inferred from the occurrence of the larvae and females with ripe ovaries, indicated that the surface water temperature was about 24°C and the surface mixing layer was as deep as 250 m. Ueyanagi (1969) also noted that the spawning season of the albacore extends throughout the year in waters south of 20°N. However, a peak in the summer season is indicated.

There have been a number of studies of the growth of albacore based on hard parts (especially scale), size frequency distributions of catches, and tagging recovery data. The principal works include Aikawa and Kate (1938), Nose et al. (1955), Partlo (1955), Otsu and Uchida (1959b), Clemens (1961), Bell (1962), Yabuta and Yukinawa (1963) and Yoshida (1969). Most of the recent studies have shown relatively similar growth equations. The relationship between age and growth, estimated by Yabuta and Yukinawa (1963), who utilised scale reading method as a main technique, is expressed in the following von Bertalanffy's equation:

$$L_t = 146.46 \quad (1 - e^{-0.15(t + 0.86)})$$

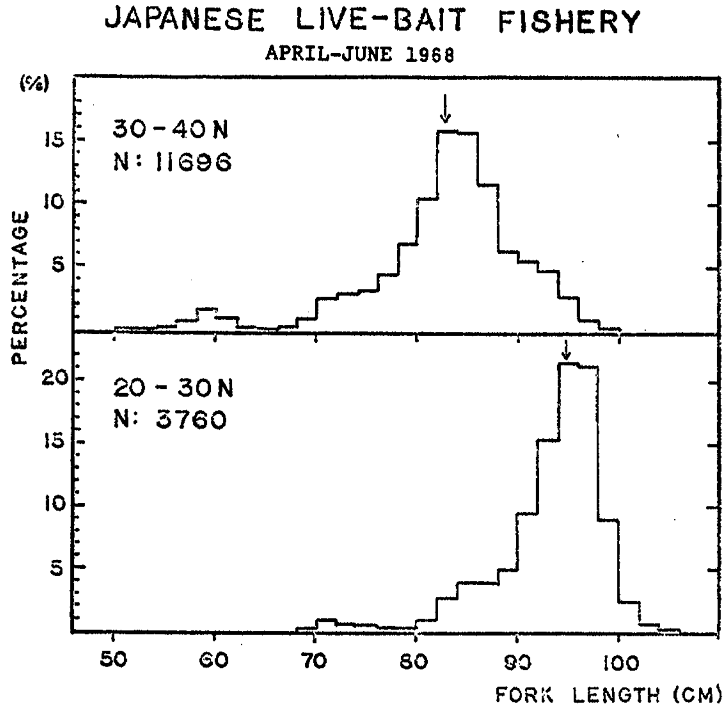


Fig. 9 Size composition of the Japanese surface-caught albacore in the north-western Pacific

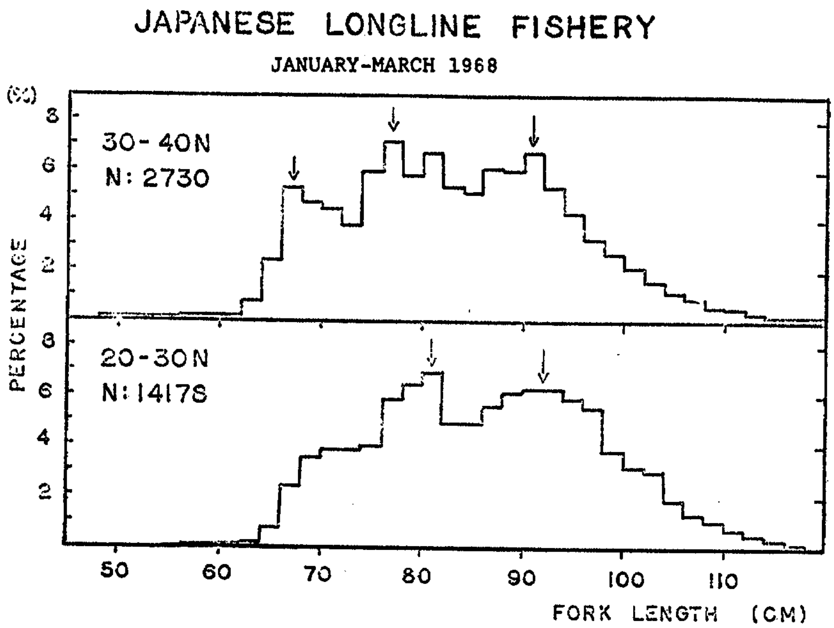


Fig. 10 Size composition of the Japanese longline-caught albacore in the north-western Pacific

The equation is based on the assumption that the fish is 6 months of age at the time of first ring formation.

3.1.1.3 Stock structure

Fig. 11 diagrams a hypotheses developed by Suda (1962) to show the complete life cycle of the North Pacific albacore. Another model of the migration of this species was developed by Otsu and Uchida (1963) and is illustrated in Fig. 12. These two hypotheses are based on tagging recovery data, age, growth, and maturity information, and distribution and size frequency data collected from the various fisheries. As indicated in Figs. 11 and 12, an underlying feature of the hypotheses is that the albacore in the North Pacific is composed of a unit population.

3.1.1.4 Stock assessment

The annual fluctuation of the albacore catch is fairly large. This fluctuation is dependent upon the abundance of the fishable stock entering the fishery and the year class strength; the latter varying to the extent that the coefficient of variance has been estimated to be 45 percent (Suda 1962). During the recent decade the annual albacore catch in the North Pacific has varied from 12,000 to 23,000 tons (average of 18,000 tons) for the longline fishery, from 9,000 to 41,000 tons (average of 25,000 tons) for the Japanese bait-boat fishery, and from 13,000 to 27,000 tons (average of 20,000 tons) for the US surface fishery.

Mainly utilising the Japanese data on catch and effort of longline and bait-boat fisheries during the 1950's and early 1960's, estimates of the parameters for mathematical models in population dynamics are as follows: the mortality coefficient is 0.4 (Suda, 1963) and the average age of the fish entering the fishery is 3.8 (Suda, 1966). Using these and other parameters, Suda (1966) estimated the relationship between effort and sustainable yield. The calculated yield curve indicated that the fishing intensity had been below the level of the maximum sustainable yield (MSY) before the early 1960's.

From their study of the longline-caught albacore in the North Pacific, Rothschild and Uchida (1968) commented that the albacore in the North Pacific appeared to be overfished rather than underfished. However, as indicated in Fig. 13, the relative abundance of the longline-caught albacore in terms of hook rate during the peak fishing months (January and February) does not show a decreasing trend during the recent decade. Preliminary information obtained to date indicates that the Japanese bait-boat fishery experienced its best fishing season in history in 1971, thus it appears that the stock might not have been overfished as suggested by Rothschild and Uchida (1968).

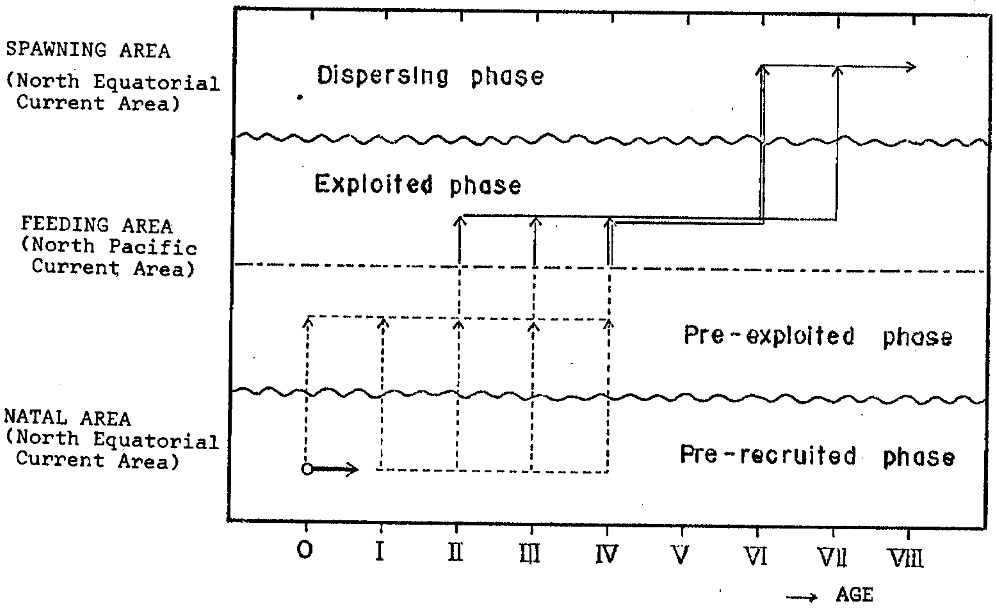


Fig. 11 Diagrammatic presentation of the life cycle of the northern albacore (after Suda, 1962a)

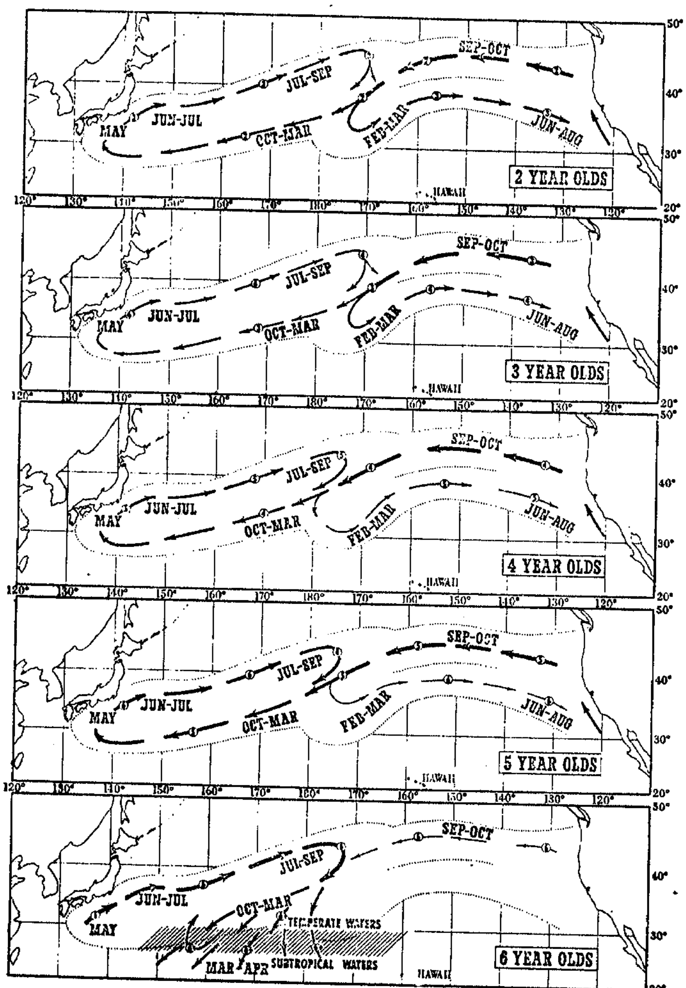


Fig. 12 Model of albacore migration in the North Pacific Ocean, by age groups (age encircled) (after Otsu and Uchida, 1963)

### 3.1.2 Albacore in the South Pacific

As indicated previously, albacore in the southern hemisphere are considered to be a separate stock from the albacore found in the North Pacific. Unlike the North Pacific, where albacore have been taken in commercial quantities with surface fishing gear, the southern albacore has been captured exclusively by the longline fishing gear. It is notable that the southern albacore fishery exploits mainly the spawning individuals, whereas in the North Pacific mature fish make up only a small fraction of the total albacore catch.

The longline fishery for albacore in the South Pacific was initiated in 1954, commencing with the operations by the Japanese mothership fleet and the Samoa-based longliners. Since 1954 the albacore fishing ground has expanded widely to the east and to the south (Fig. 1). Recently, the principal countries fishing for albacore in the South Pacific have been Japan, Taiwan, and Korea. The longline fleets of the latter two countries are primarily based in ports located at Samoa, Fiji, and Santo.

In addition to the longline fishery, commercial fishing for albacore on a small scale has been carried out by Chile (Yoshida and Otsu (1963)) and New Zealand (Slack, 1969 and 1972). Albacore fishing off Chile and New Zealand is currently restricted to their coastal waters.

#### 3.1.2.1 Distribution and migration

The past studies on the geographical distribution of albacore in the South Pacific showed that there is a marked concentration of albacore in an east-west zonal band located between latitude 10°S-20°S and extending from the western margin of the South Pacific to as far east as longitude 100°W (Honma and Kamimura (1957), Koto (1966) and Otsu and Sumida (1968)). Recent longline data (Fig. 7) revealed that the area of abundance extends toward the vicinity of the coastal waters of Chile. On the basis of longline data, the albacore concentration changes seasonally: in the southern hemisphere summer the albacore fishing ground is located in lower latitudes, and in the winter in higher latitudes. In New Zealand, albacore are taken by trolling gear in the nearshore waters in the southern summer months with a peak reached in February (Slack, 1969 and 1972).

The size composition of the albacore in the South Pacific by area is similar with that of the northern albacore. The size of the albacore taken in the area north of latitude 30°S, where spawning of this species takes place, is represented by individuals larger than 80 cm; while most of the albacore captured in the area south of latitude 30°S is composed of individuals smaller than 80 cm (Honma and Kamimura, 1957 , Koto and Hisada, 1967 and Otsu and Sumida, 1968).

The seasonal change in size by area is not as pronounced as the area difference. Examining the seasonal change of the relative abundance and size composition of albacore by area, Koto and Hisada (1967) suggested that recruitment of the fish to the area north of latitude 30°S might come from the southern areas from April through September. The size frequency data for the easternmost area indicate that the smaller size group is encountered in relatively greater abundance in the northern area in the southern winter (Fig. 14 ). This shift relates probably to the northward intrusion of cold water of the Peru Current to the north. The size difference by water temperature is consistent with that observed in the north Pacific

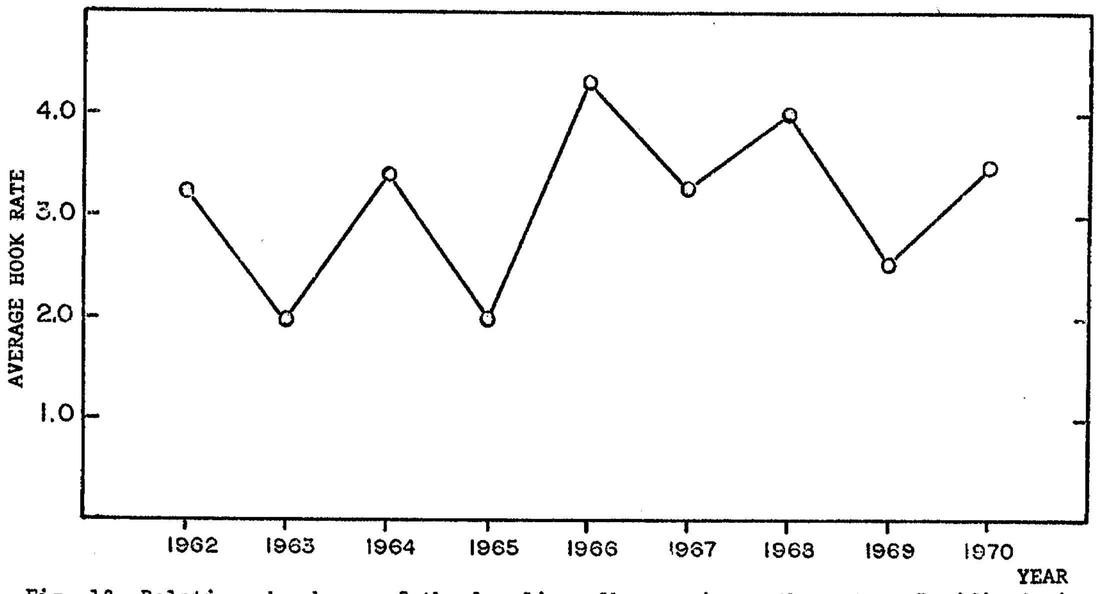


Fig. 13 Relative abundance of the longline albacore in north-western Pacific during the months of January and February 1962-1970, expressed in average hook rate

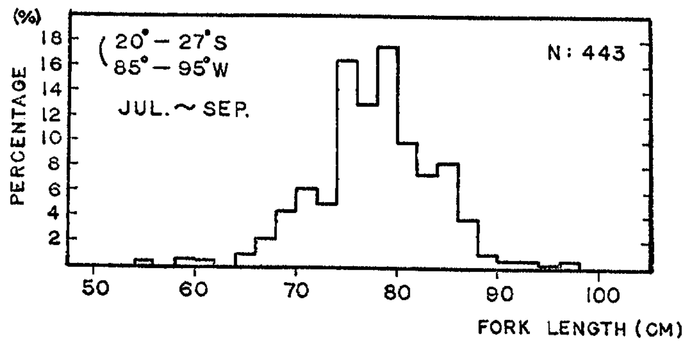


Fig. 14 Size composition of albacore caught by longline in the south-eastern Pacific in 1967

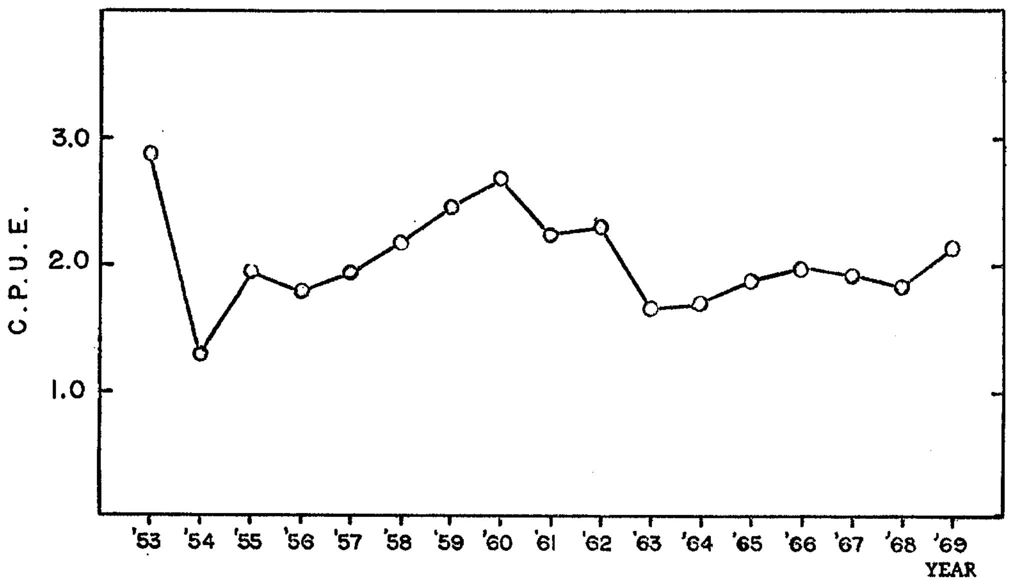


Fig. 15 Yearly fluctuation of c.p.u.e. of the southern albacore, expressed in catch by number per 100 effective hooks

The length composition of the southern albacore shows clearly a dominance of males in the larger size groups (Otsu and Sumida, 1968). This difference in size-sex distribution was also observed in the case of northern albacore (Otsu and Uchida, 1959). To date the cause of this dominance of males in the larger size classes has not been determined.

The size of albacore caught by the New Zealand surface fishery ranged from 36 to 105 cm, with prominent modes at 51 cm (2+ age) and 61 cm (3+ age) (Slack, 1969 and 1972).

Tagging experiments for the albacore in the South Pacific have not been extensive enough to provide direct information on the migration of the southern albacore. Considering the biological and ecological characteristics of this species, the migration of the southern albacore may follow the same pattern of that of the northern albacore.

3.1.2.2 Maturity and growth

The biological features concerning maturation of the albacore in the South Pacific is essentially the same as noted for the northern albacore. On the basis of the occurrence of larvae and the locality of the catch of ripe adults, Ueyanagi (1969) reported that the spawning area of the albacore probably lies in the waters surrounded by Sub-tropical Gyre in the southern hemisphere, and that the most active spawning season is likely to be the southern summer. This deduction is also supported by the maturation study of Otsu and Hansen (1962) and on the occurrence of juvenile albacore found in the stomach of billfish (Yoshida, 1971). Otsu and Hansen (1962) estimated the minimum size of first spawning at about 86 cm; this is smaller than the 90 cm minimum size reported for the northern albacore

Growth data of the southern albacore are not available yet.

3.1.2.3 Stock assessment

The annual catch of southern albacore exceeded 20,000 tons in 1958 and reached the best years in 1962 and 1967 when 43,500 and 45,800 tons were landed, respectively. The combined catch of Taiwanese and Korean fleets began to increase substantially from 1962, exceeded the Japanese catch in 1967, and reached more than 5 times the Japanese catch in 1969.

The catch (in numbers) of albacore per 100 effective hooks for the period 1953 to 1969 does not show an increasing or decreasing trend (Fig. 15). An estimate of the overall annual longline effort invested by the Taiwanese and Korean fleets was determined by using conversion factors computed from the catch effort data obtained from the Japanese South Pacific based fleet. Fig. 16 shows the relation between catch in weight and effective effort for the fishing season (April-March) for the period 1953-1969. The catch in terms of weight increased proportionally with the increase in corresponding effort until 1962. This was followed by a sharp decline despite the increase in effort in 1963. Since 1963, the trend of catch on effective effort suggests that the stock has stabilised at a lower level. This may be reflected partly by the increase in catch of smaller individuals, since the CPUE expressed in terms of number has not changed to a measurable degree. The above relation suggests that a further increase in yield on a sustainable basis is possible. However, the magnitude of this increment in yield has not been determined.

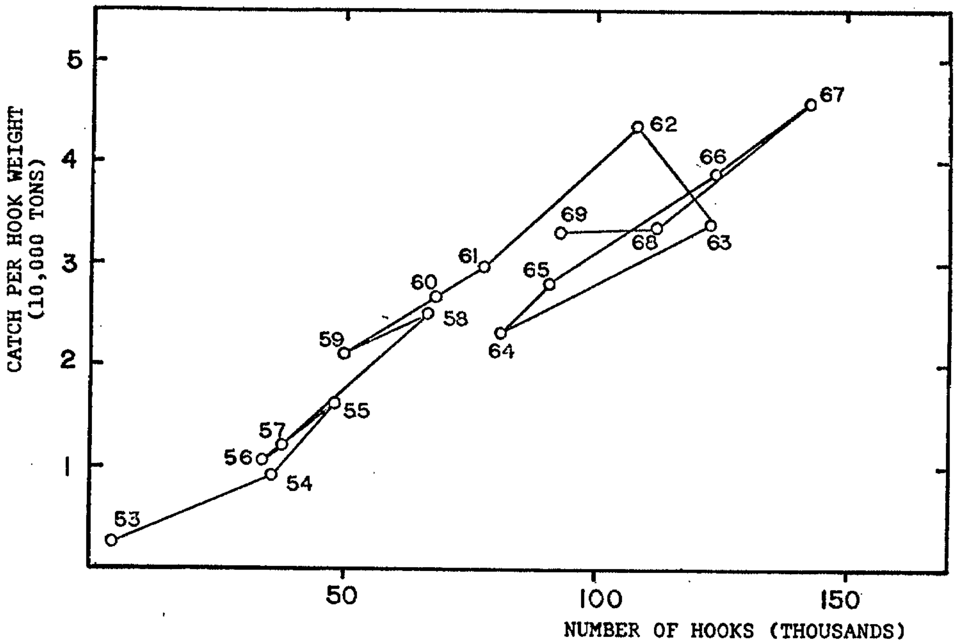


Fig. 16 Relation between catch by weight and effort in effective hooks for the whole South Pacific albacore, 1952-69 fishing season (April-March)

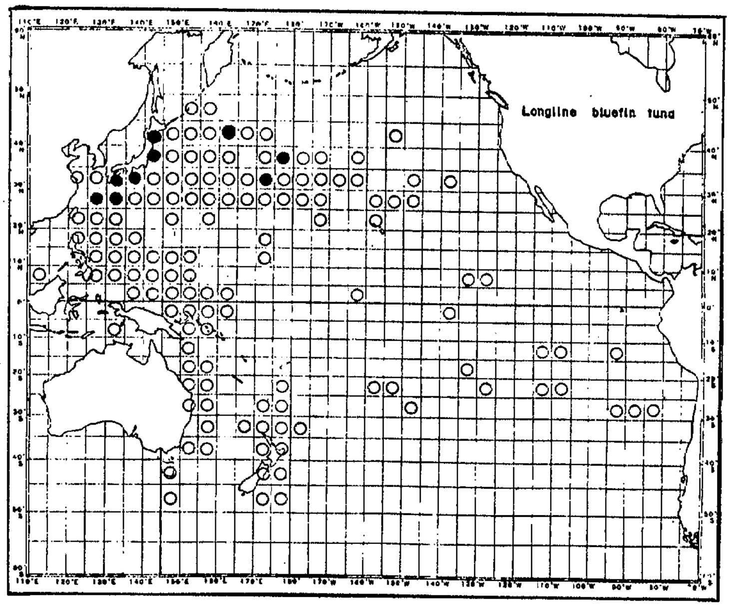


Fig. 17 Distribution of longline-caught bluefin in the Pacific, 1968-70. (Shaded circles show number number of catch of more than 100 in one year)

Bluefin tuna

This species is distributed mainly in the North Pacific. Approximately 70 percent of the total bluefin catch is taken by the purse seine method of fishing. In the western Pacific, some bluefin are also taken by the longline, trolling, set-net and bait-boat fisheries.

3.2.1 Distribution and migration

On the basis of the purse seine fishing, bluefin occur in heavy concentrations in the near shore waters of western and eastern North Pacific Ocean, off the Sanriku area (northern Japan) in the western Pacific, and off southern and Baja California in the eastern Pacific. The coastal distribution of this species is further evidenced by the bluefin catches made by the other fisheries operating near Japan, e.g., longline and set-net. Bluefin, however, are distributed over a wide area of the Pacific, even extending to the waters of the South Pacific as shown in Figure 17.

A comparison of the size composition of the albacore catch by the various fisheries shows the distributional segregation by size (Fig. 18). The longline catch east of Taiwan consists of fish larger than 60 kg in weight while the purse seine catch off Sanriku area ranges from small (20 kg) to larger size fish. The catch of the Japanese set-net fishery in the northern part of the Japan Sea also consists of fish larger than 20 kg. Bell (1963) reported that although the size composition of the US purse seine bluefin catch varies from year to year, the main constituents range from 10 to 40 pounders (4.5 to 18 kg), additionally, the smallest size group of 62 to 66 cm fish (about 5 kg) also appears each year. For the trolling and bait-boat fisheries operating in the near shore waters off southern Japan, Tatsuki et al. (1963) reported fish ranging in length from 45 to 65 cm or approximately 2-5 kg in weight. The size of the longline-caught bluefin south of 15°N is reportedly large (Shingu et al. MS), which suggests that some large individuals disperse widely to the south and south-eastern area of the Pacific (Fig. 17).

A trans-Pacific migration of bluefin was established by the recovery of tagged fish from both sides of the Pacific Ocean (Orange and Fink, 1963 and Clemens and Flittner, 1969).

3.2.2 Maturity and growth

On the basis of the occurrence of larvae and the gonad examination of bluefin, Yabe et al. (1966) postulated that spawning took place from April through June, in the area north of latitude 20°N in waters extending from Taiwan to as far east as longitude 150°E. The spawning season and spawning ground have been confirmed with recent research on larval occurrence; the spawning ground east of Taiwan is believed to be the only reproductive area for the bluefin stock in the North Pacific (Ueyanagi, 1969).

Yukinawa and Yabuta (1967) computed the von Bertalanffy's growth equation for the stock as $L_t = 320.5\ (1 - e^{-0.15(t + 0.86)})$. The authors felt that their estimates of the younger ages have been confirmed by the tagging results. However, confirmation of the growth for the advanced ages was left for further studies.

3.2.3 Stock assessment

The stock assessment of the bluefin in the Pacific has remained at a very preliminary level, principally because of the difficulty encountered in quantitatively evaluating the overall amount of fishing effort. This difficulty

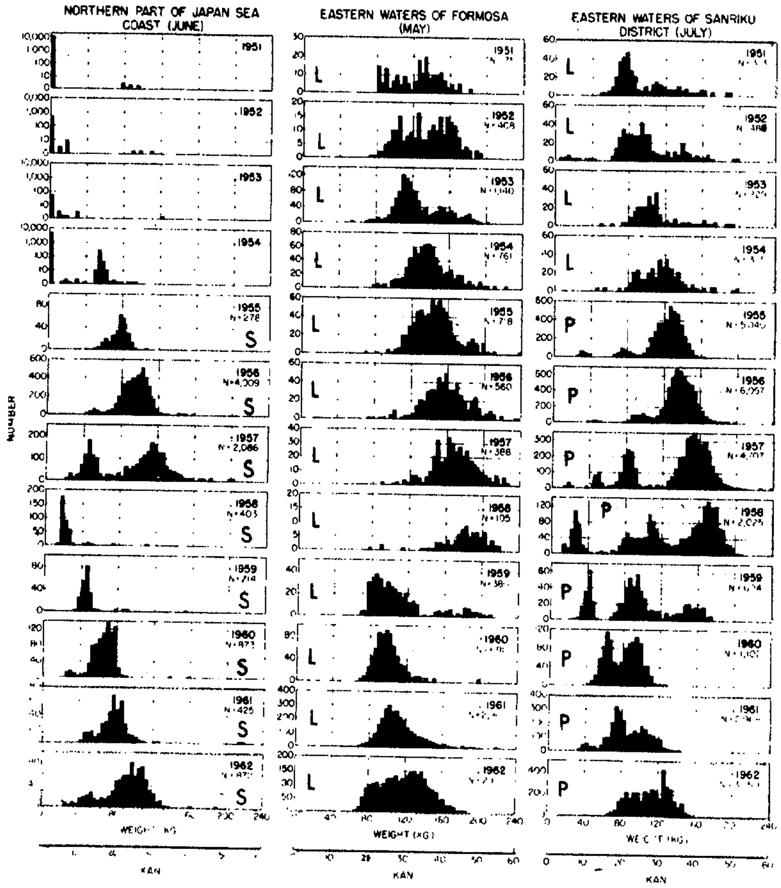


Fig. 18 Size composition of bluefin by areas and gears. N, S, L and P denote number of fish, set net, longline and purse seine, respectively (after Nakamura, 1965)

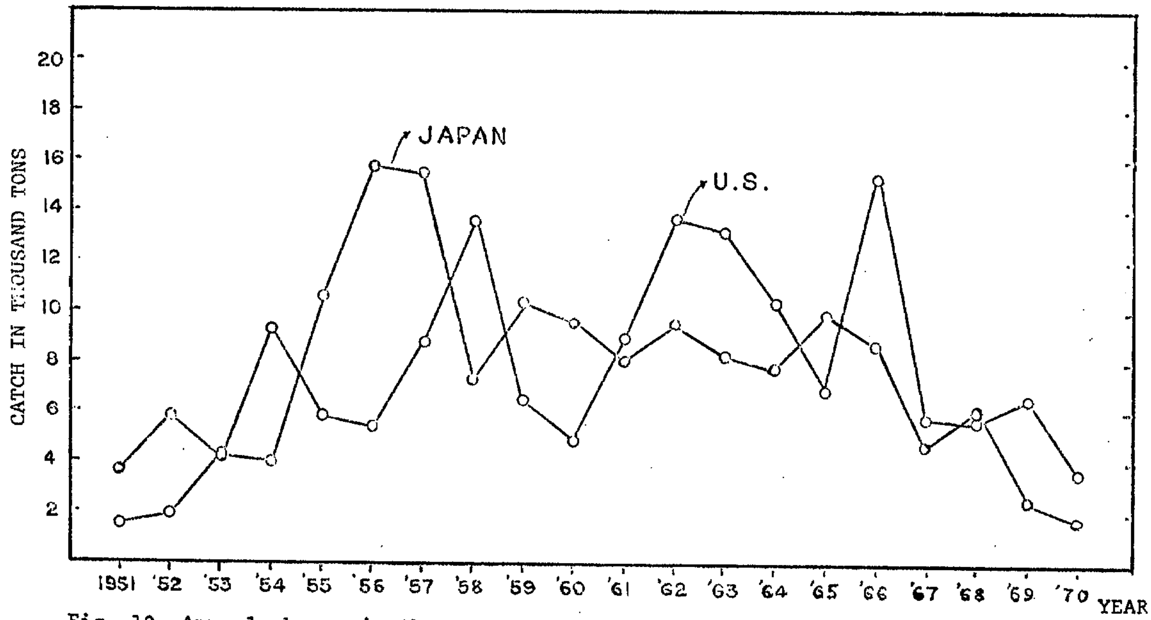


Fig. 19 Annual change in the catch of bluefin caught by purse seining in both sides of the North Pacific, 1951-1970

has been directly attributed to the nature of the various types of gear used to capture bluefin.

Insofar as the catch record is concerned, long-term trends in catch fluctuation have been observed. During the past two decades the catches of the purse seine fisheries from both sides of the Pacific Ocean have shown a similar trend of increasing and decreasing phases (Fig. 19). This trend was also observed in the catch statistics for the earlier years (Yamanaka, 1959). Whether this trend reflects an actual change in stock abundance has not been ascertained.

Nakamura (1965) suggested that the good bluefin fishing era is ascribable to the appearance of dominant year class; Watanabe (1968) also stated the same opinion for the set-net bluefin fishery. Yamanaka (1959) pointed out that good bluefin fishing was followed by the abundant occurrence of young individuals of the 0-age group. To clarify the dependences of the fishery on dominant year class will require a detailed examination of the US catch and size composition data.

As to the effect of fishing effort on bluefin, Yamanaka (1959) pointed out the fact that although very little effort was directed toward the capture of bluefin during the 1940's, primarily because of the Second World War, the stock appeared to be at a low level. This may suggest that the fluctuation of the bluefin stock is under the control of natural causes and that fluctuations are not ascribable to fishing intensity.

## 3.3 Yellowfin tuna

There are areas of concentrations of yellowfin in the western and eastern Pacific (Fig. 20). As shown in Table I, yellowfin are taken principally by two countries: the US with surface fishing methods and Japan with the longline gear. Yellowfin in the eastern tropical Pacific is the only species in the Pacific that is regulated by a catch quota system established by the IATTC.

Studies of the distribution, size composition, maturation, spawning and growth of longline-caught yellowfin have been already described by Suda (1971). Regarding biological and ecological features and the fishery management programme in the eastern Pacific, reference is made to the excellent series of the IATTC bulletins.

### 3.3.1 Stock structure

In the study of the population structure of the yellowfin in the Pacific, there have been several suppositions on the relation between stocks fished by the different fisheries. To date no conclusive results have been obtained, partly because of the local or semi-independent nature of this species.

As to the longline-caught yellowfin, Kamimura and Honma (1963) on the basis of distribution, size composition, morphometrics and tagging experiments stated that the small individuals which are concentrated in the western area gradually migrate eastward as they grow. They concluded that the stock might consist of not more than two independent populations nor of a completely homogeneous one, but probably represent a case in between the above two situations. The possible relation of the yellowfin in the western Pacific to that of the eastern Indian Ocean has been discussed by Suda (1971).

On the basis of information concerning tagging, morphometrics, vital statistics, catch statistics and spawning, Joseph <u>et al</u>. (1964) suggested that an empirical break exists between the stocks caught by the surface fisheries in the eastern

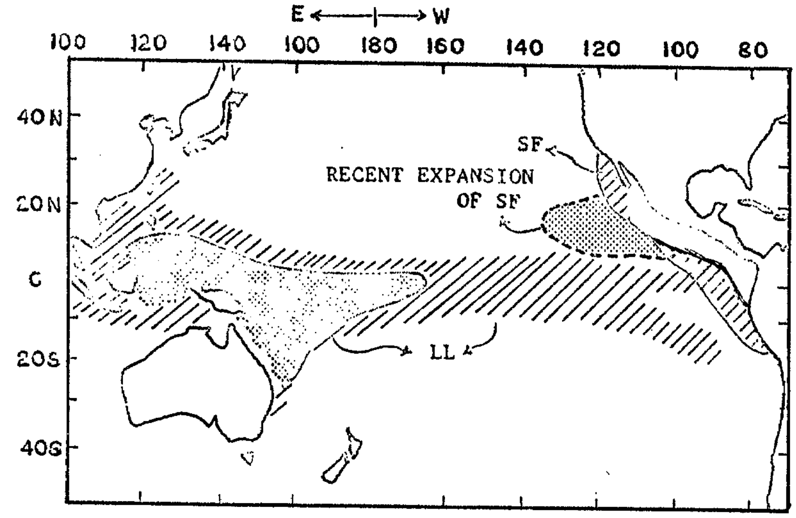


Fig. 20 Schematic illustration of yellowfin fishing grounds in the Pacific. SF and LL represent surface fishery and longline fishing grounds, respectively.

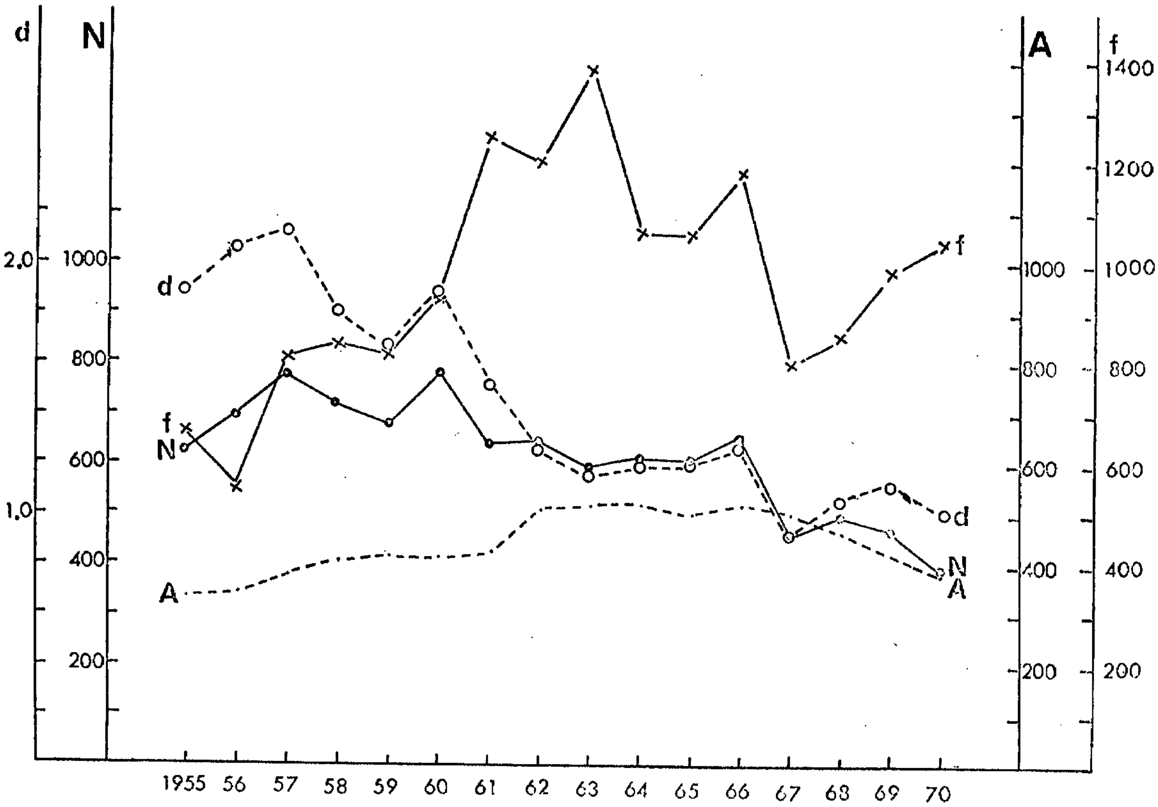


Fig. 21 Annual changes in index of abundance (N), index of density (d), fishing intensity (f) and extent of fishing area (A) of longline yellowfin in the western and central Pacific

Pacific and those to the westward. In addition, they considered from a management point of view that the yellowfin of the eastern Pacific as a management unit (as applies to Schaefer's (1957) population model) was separate from the yellowfin stocks to those to the west. The recent expansion of the conventional surface fishing ground to waters as far west as longitude 140°W, has raised a new question on the above consideration. Tagging experiments, biochemical studies, analysis of size composition and other research activities have been undertaken to clarify the structure of the stock (IATTC, 1971).

### 3.3.2 Stock assessment of the longline-caught yellowfin

The annual fluctuation of the relative abundance, the relative extension of the yellowfin fishing grounds, and fishing intensity of yellowfin caught by the Japanese longline fishery in the western and central tropical Pacific from 1955 to 1970 are shown in Fig. 21. The index of abundance indicates a decreasing trend in the 16-year period. Together with the expansion of the fishing area the average density from 1967 to 1970 declined to about one half of the level noted for the 1957 to 1960 period. The fishing intensity increased to a maximum in 1963 and declined sharply in 1967. Since 1967 there has been a gradual increasing trend.

Almost all of the longline-caught yellowfin are taken by Japan, Taiwan and Korea. The yellowfin catch and effort data for the Taiwanese and Korean fleets were estimated and combined with the Japanese catch and effort. Fig. 22 shows the relation between longline fishing intensity and the catch of yellowfin for the entire Pacific. Until 1960, the catch increased almost proportionally with the increase in fishing effort. After 1960, however, the increase in fishing intensity did not result in a corresponding increase in catch. It seems that, empirically, the expected catch with a further increase in effort would be around 60,000 tons. This would, however, be surely accompanied by an increasing decline in catch per unit of effort.

## 3.4 Bigeye tuna

Bigeye tuna in the Pacific are caught exclusively by the longline fishing method. This species is distributed in the temperate and tropical waters. The value of this species in the Japanese domestic market is as high as those noted for the bluefin group, especially for those fish caught in temperate waters. The geographical distribution of the bigeye in the Pacific is shown in Fig. 23. The distribution of bigeye shows a seasonal separation by size and ecological stage of individuals. In the temperate waters of the high latitudes, aggregations of this species occur in the winter seasons of both hemispheres. In these waters the fish are smaller in size and are sexually dormant adults. In equatorial waters, the spawning group dominates the catch throughout the year. Further biological and ecological features and some of the characteristics of the population dynamics of bigeye are provided by Suda (1971).

### 3.4.1 Stock assessment

Fig. 24 shows the annual changes in the relative abundance of Pacific bigeye by three size categories. Comparison of the average relative abundance of the total Pacific bigeye between 1955-1960 and 1964-1970 indicates that in the recent period the level of the stock is about one-half of the level noted in the earlier period. The decline in the index of abundance is apparently ascribable to a large extent to the decrease in large individuals and to a lesser extent to the medium-size fish. As previously stated, the rapid eastward expansion of the longline fishery ground in the early 1960's and the increased effort seems to have resulted in the decline of the relative abundance of larger individuals. This was especially observed in the eastern tropical Pacific (Kume and Joseph, 1969a). Insofar as the recruitment as measured by the index of abundance of the small-size group is

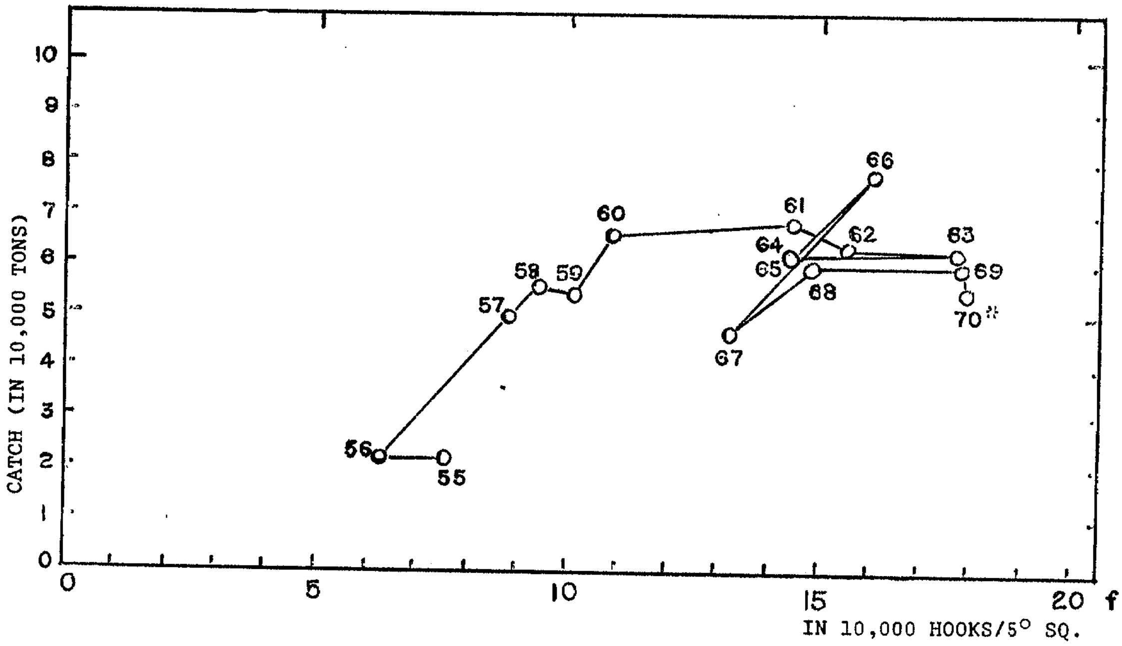


Fig. 22 Relation of catch of the longline yellowfin to the fishing intensity in the whole Pacific, 1955-1970. Korean yellowfin catch not included.

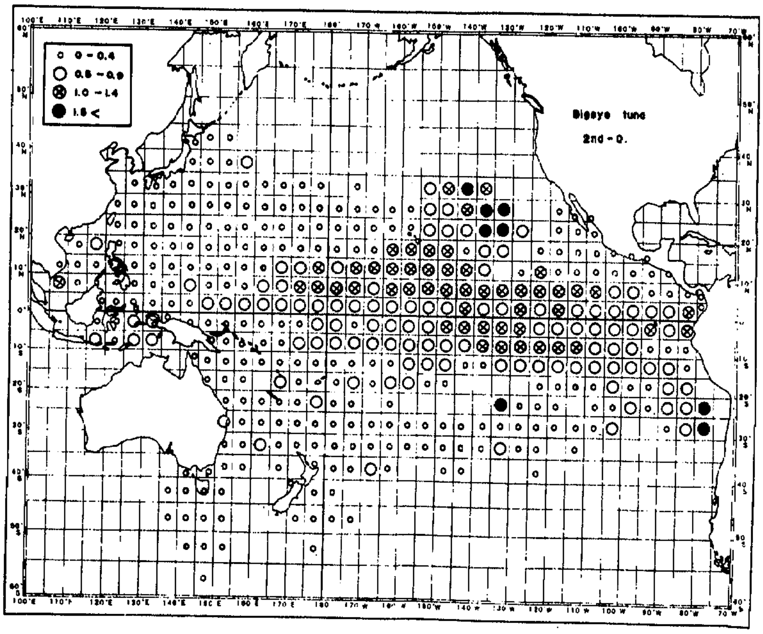


Fig. 23 Geographical distribution of hook rate of longline bigeye as an average of 1966-1970. 2nd quarter.

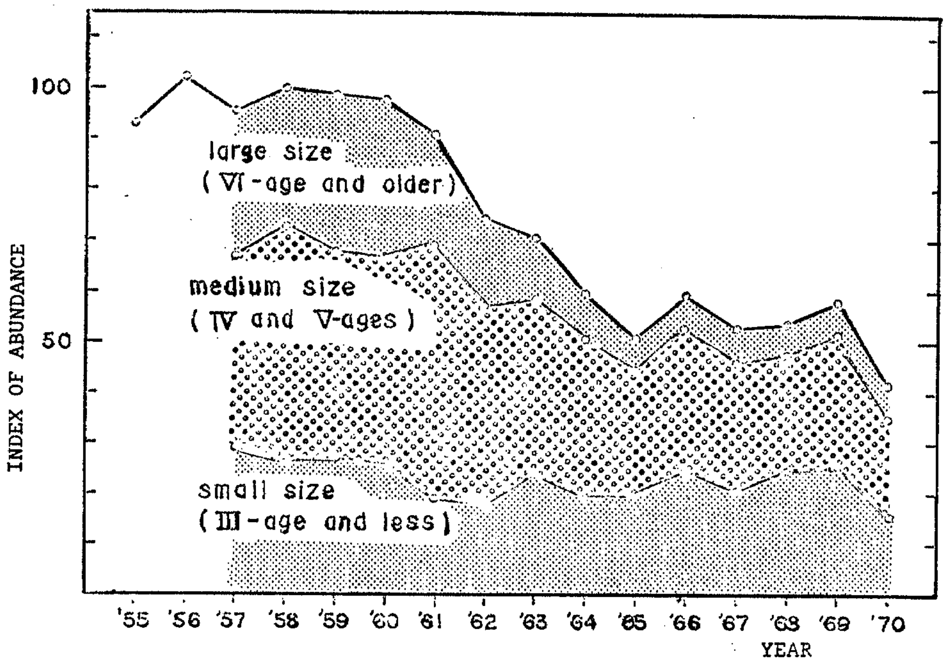


Fig. 24 Annual change in index of abundance of bigeye in the whole Pacific

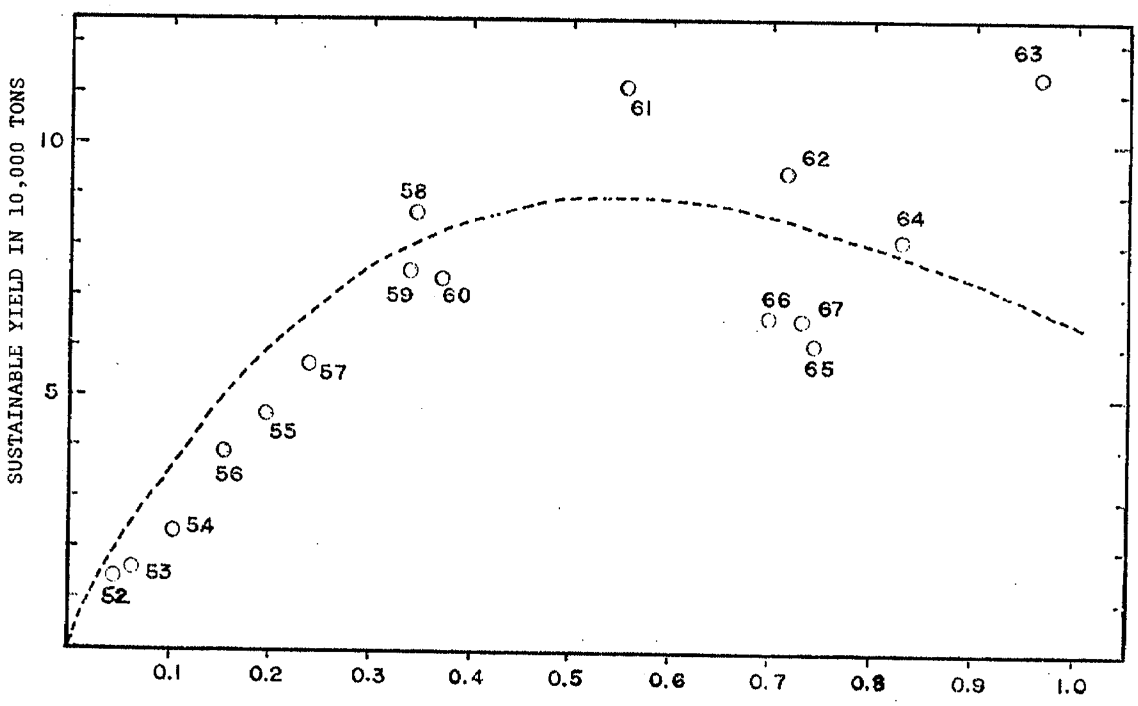


Fig. 25 The calculated sustainable yield (dotted line) and the observed yearly catches of the Pacific bigeye (after Suda, 1970)

concerned, it is suggested that the reproduction capacity of the stock has been maintained at a stable level.

The study concerning the relationship between CPUE and the fishing mortality coefficient of the Pacific bigeye (Suda, 1970) showed that the population decreased rather rapidly even under light fishing pressure. This may be interpreted as a case of a virgin stock, which consists of a cumulative supply of many advanced age groups, being fished sufficiently to be depressed effectively to lower level. In the same study, Suda noted that, after being decreased to a lower level, the population persists in moderate reproductive potentiality even under rather intensive fishing mortalities. Suda explained this situation by stating that some individuals younger than 4 years old, the average age of first entry to the fishable stock, participate in spawning. This may be one of the reasons indicating the persistent potentiality of reproduction of the stock.

Rothschild and Uchida (1968) analysed the Japanese longline bigeye catch data up to 1965 and stated that "it appears that the opportunity for increased catch of bigeye tuna is limited." Although preliminary, the observed values of the catch and corresponding coefficients of fishing mortality in the recent years (Fig. 25) appear to fall around the values of 1965-1967 (Suda, 1970). This suggests that the level of fishing intensity is still on the side of heavy exploitation; consequently, a further increase in effort on the Pacific bigeye over the recent level will not be desirable.

### 3.5 Southern bluefin tuna

The southern bluefin is one of the most valuable species of the Japanese domestic fresh fish market. The southern bluefin consists of a single population distributed in the higher latitudes of the southern hemisphere of the Atlantic, Indian, and Pacific Oceans (Shingu, 1970). The southern bluefin fishery has been carried out exclusively by the Japanese longliners on the high seas and by the Australian surface fishery for young individuals in the coastal waters of southern Australia. The catch of the southern bluefin in the Pacific area, which is taken almost exclusively in the western side of the Ocean, is estimated to be equivalent to approximately one-half of the total production. The total includes the catch of the Australian surface fishery. Details of the biological and ecological features and the stock assessment of this fish stock were described by Suda (1971).

As already reported by Suda (1971), the conservation measures proposed by the Far Seas Fisheries Research Laboratory for this species have been under discussion by the organisations of research, fishery administration and industries. After due considerations for the results of the overall studies and the rational utilisation of the resources, the Federation of Japanese Tuna Fishermen's Cooperative Associations which represented the tuna industry decided in October 1971 to adopt voluntary regulatory measures on the Japanese southern bluefin fishery. The regulatory plan adopted is based fundamentally on the combination of closed seasons and areas, for the purpose of controlling the effort on small-size individuals and spawning adults (Fig. 26).

## 4. RESOURCES OF BILLFISH

Six species of billfish are known to be caught in the Pacific. In terms of production, swordfish (Xiphias gladius), striped marlin (Tetrapturus audax), blue marlin (Makaira mazara) and sailfish (Istiophorus platypterus) are considered nearly equally important in the Pacific longline fishery. Only a small amount of black marlin (Makaira indica) and shortbill spearfish (Tetrapturus angustirstris) is caught in the Pacific.

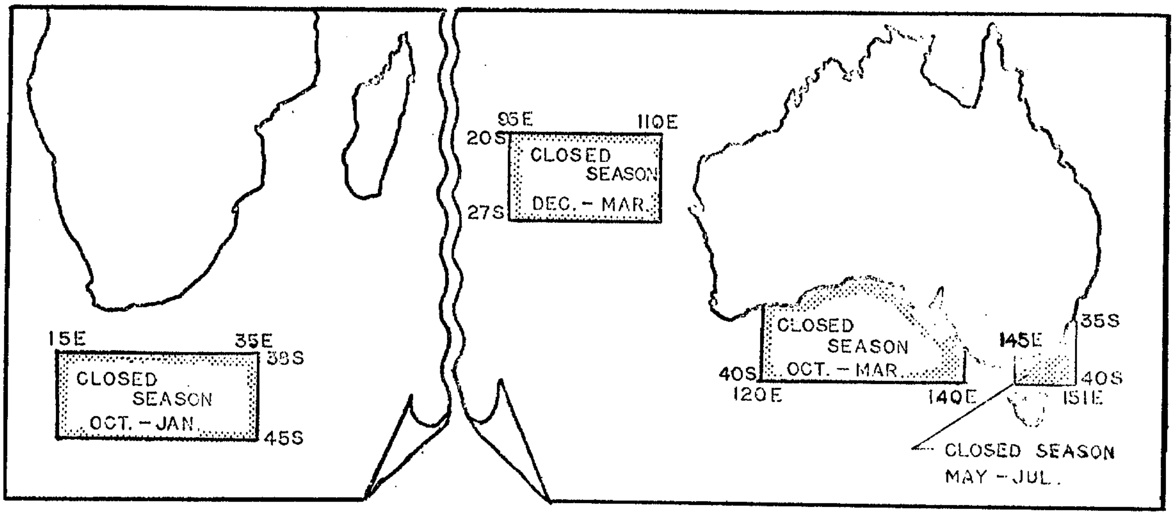


Fig. 26 Voluntary regulatory measures on southern bluefin fishery adopted by the Japanese longline industry

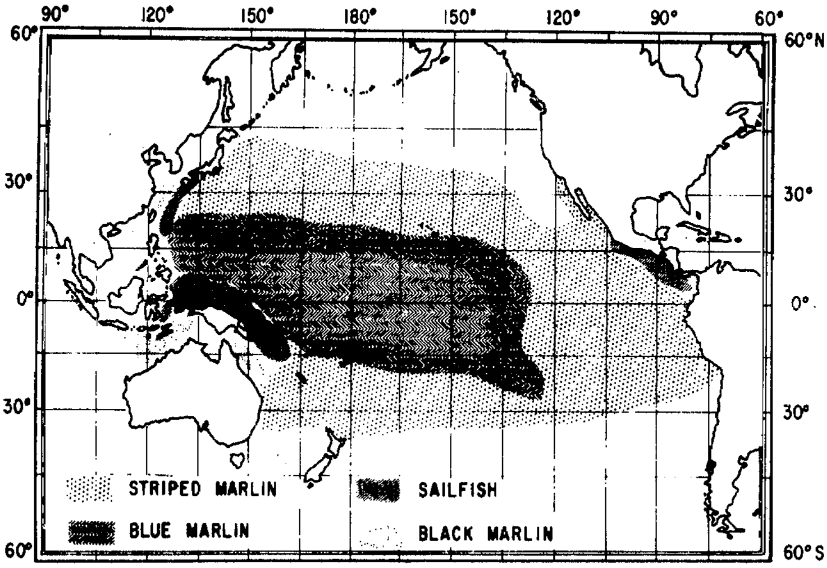


Fig. 27 Dominant distribution pattern of Istiophoridae in the Pacific Ocean (excluding shortbill spearfish) (after Howard and Ueyanagi, 1965)

The abovementioned species are caught almost entirely by the longline fisheries of Japan, Taiwan, Korea, and Ryukyu. It should be noted that the Korean billfish catch is not shown in the FAO catch statistics (Table II). An annual average catch of all billfish species combined amounts to a little more than 60,000 tons in the Pacific; this accounts for about 20 percent of the total longline production. The harpoon and set-net fisheries also harvest some of the billfish from coastal waters. However, these fisheries account for less than 10 percent of the total longline catch of billfish. Catches by other fisheries than the abovementioned are considered to be negligible.

Although localised and seasonal in distribution, some species of billfish are sometimes sought as the primary objective of the longline fishery. For instance, references have been made to the striped marlin fishery in the middle latitudes of the North Pacific in spring, the swordfish fishery in the North Pacific in winter and off Baja California in summer, and the striped marlin and sailfish fishery in the eastern Pacific. As a general rule, however, billfish are generally regarded to be by-products of the longline fishery. It is noted that there is a specialised type of longline operation for swordfish, called the "night-time longline". This is a different operation from the general longline operation with respect to bait, gear construction, and the setting time of the gear (Yabe et al., 1959) and Kume and Morita, 1966).

Billfish have been utilised commonly as one of the indispensable ingredients of fish sausages. Striped marlin are preferred for fresh consumption, and the recent demand for SASHIMI of billfish has been reported to be increasing in Japan.

From the standpoint of fishery science, the biological and ecological studies of billfish are still in the early stages as compared with current knowledge of tuna species. Studies of the stock structure of billfish, as well as knowledge of stock assessment, are in the same early stages. Although several contributions have been made to the studies on billfish, the author feels that the following publications are useful for general biological information on billfish: Howard and Ueyanagi (1965), Kume and Joseph (1969b) and Strasburg (1970). In this section the description is therefore rather fragmentary.

### 4.1 General distribution

The general distributions of the four species of Istiophoridae in the Pacific are illustrated in Fig. 27. Striped marlin are distributed in a horseshoe-shaped pattern; blue marlin is the most tropical species; and the abundant areas of sailfish and black marlin are confined to coastal waters. The recent development of the striped marlin fishery revealed a high abundance of this species in the eastern Pacific (Fig. 28). Swordfish are known to be abundant in the North Pacific area, north of sub-tropical convergence (Yabe et al., 1959) and off Baja California (Kume and Joseph, 1969a). The density of the shortbill spearfish is likely to be high in areas where the distributions of striped and blue marlin overlap (Howard and Ueyanagi, 1965), which suggests an oceanic habitat for this species.

### 4.2 Annual fluctuation in catch

Annual changes of catch by number of the four major species are shown in Fig. 29, by three areas: North Pacific Region (NPR), South Pacific Region (SPR) and Eastern Pacific Region (EPR). Although the number of sailfish caught includes that of shortbill spearfish, the catch of the latter is believed to be negligible. This figure, however, does not indicate the change in relative abundance. Swordfish are caught mainly in NPR, where the "night-time longline" operation is carried out. Recently the catch in EPR showed an increase; this supposedly reflected an increase in the swordfish catch from the grounds located off Baja California and off Ecuador (Kume and Joseph, 1969a). The importance of the EPR area for striped marlin began to be reflected in the increased catch since 1963, and the poleward expansion of the

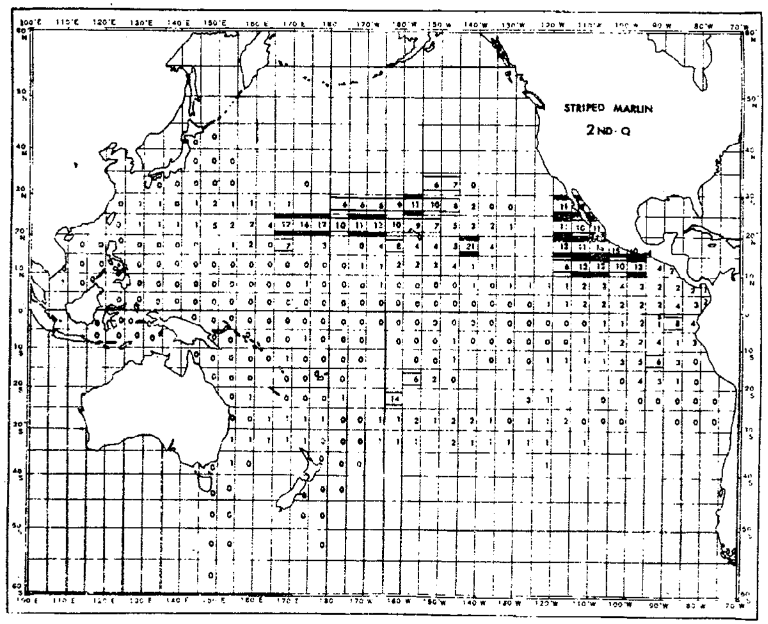


Fig. 28 Georgraphical distribution of hook rate of striped marlin caught by longline as an average of 1966-70 - 2nd quarter

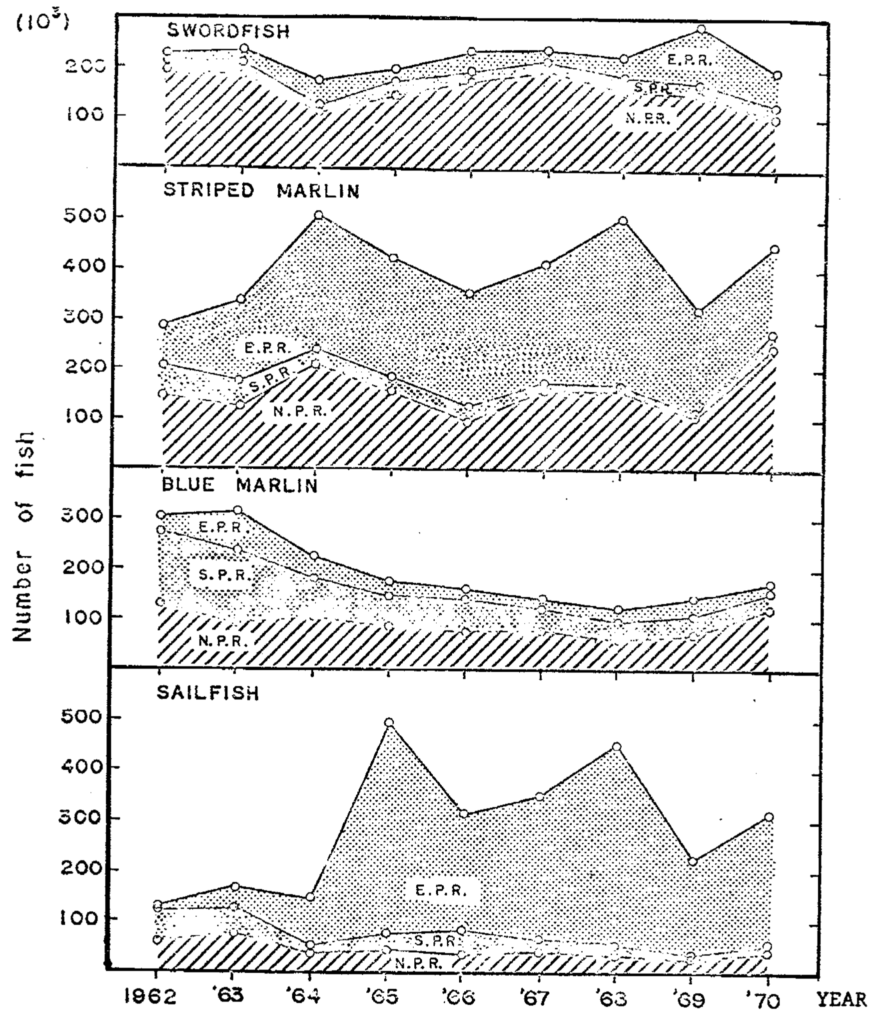


Fig. 29 Annual changes in catch of four major species of billfish, 1962-1970

E.P.R. : Eastern Pacific Region (east of 130°W)

S.P.R. : South Pacific Region (south of 5°S and west of 130°W)

N.P.R. : North Pacific Region (north of 5°S and west of 130°W) longline ground (Kume and Joseph, 1969a). The decline in production of the blue marlin is pronounced in SPR. The blue marlin fishing ground between latitude 10-20°S and longitude 130-160°W in the southern summer (Kamimura and Honma, 1959) has not shown high catch rates in the area in recent years. This species appears to be the most severely exploited billfish resource in the Pacific. For sailfish a remarkable increase in catch was noted in EPR in 1965. An extremely good sailfish fishing ground was encountered in the coastal waters off Central America in 1965 (Kume and Joseph, 1969a).

In order to observe the change in the relative abundance of the stock from catch and effort statistics, dividing catch by effort to obtain a CPUE value may be misleading in the case of longline fishery, especially since the longlining is multi-species fishery and the fleet tends to shift the concentration of effort from one species to another rather frequently. Therefore, a standardisation of the stock is necessary for a proper evaluation of the effort. At this time, such research results are not available for the billfish; research of this nature should be carried out in the near future.

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TABLE I Average annual catch of tunas, billfish and tuna-like species in the Pacific Ocean 1967-1969. Unless otherwise noted data are cited from the Yearbook of Fishery Statistics published by FAO.

| Country | Large-size tunas | | | | | | Billfish | |
|---|---|---|---|---|---|---|---|---|
| | Bluefin | Southern bluefin | Albacore | Bigeye | Yellowfin | Tunas sub-total | Swordfish | Black and blue marlin |
| Canada | | | 1.3 | | | 1.3 | | |
| USA | 6.6 | | 23.0 | | 75.7 | 105.3 | 0.2 | 0.2[7/] |
| Colombia | | | | | | | | |
| Ecuador | | | | | 3.2 | 3.2 | | |
| Peru | | | | | 3.6 | 3.6 | 1.1 | |
| Chile | | | 0.1 | | 0.2[6/] | 0.3 | 0.2 | |
| Puerto Rico[1/] | 0.1 | | | | 13.7 | 13.8 | | |
| Japan | 8.9 | 17.5 | 57.0 | 70.1 | 56.7 | 210.2 | 16.3 | 12.3 |
| Korea | | | 15.3 | 1.9 | 5.4 | 22.6 | | |
| Taiwan | | | 11.7 | 3.9 | 9.6 | 25.2 | 0.9 | 4.7 |
| Ryukyu | | | | | | 12.3[5/] | | |
| Philippines | | | 0.9[2/] | | | 0.9 | | |
| Malaysia | | | | | | | | |
| Australia | | 7.5[3/] | | | | 7.5 | | |
| French Polynesia | | | | | 0.1 | 0.1 | | |
| New Hebrides | | | | | | | | |

TABLE I - Continued

| Country | Billfish | | | Small-sized tunas | | Grand Total |
|---|---|---|---|---|---|---|
| | Striped marlin | Sailfish | Billfish sub-total | Skipjack | Tuna-like species | |
| Canada | | | | | | 1.3 |
| USA | | | 0.4 | 36.3 | 8.1 | 150.1 |
| Mexico | | | | 2.8 | 7.0 | 9.8 |
| Colombia | | | | | 0.9 | 0.9 |
| Ecuador | | | | 16.3 | | 19.5 |
| Peru | | | 1.1 | 10.7 | 59.6 | 75.0 |
| Chile | | | 0.2 | 0.2 | 6.2 | 6.9 |
| Puerto Rico[1/] | | | | 24.0 | | 37.8 |
| Japan | 17.7 | 8.6 | 54.9 | 172.0 | 52.2 | 489.3 |
| Korea | | | | | 9.3 | 31.9 |
| Taiwan | 0.7 | 3.8 | 10.1 | 22.6[4/] | 6.5 | 64.4 |
| Ryukyu | | | 2.1[5/] | 4.8[5/] | 0.1 | 19.3 |
| Philippines | | | | 1.0 | 36.8 | 38.7 |
| Malaysia | | | | | 4.6 | 4.6 |
| Australia | | | | | 4.5 | 12.0 |
| French Polynesia | | | | 1.5 | | 1.6 |
| New Hebrides | | | | | 6.1 | 969.2 |

Notes:

1/ May include quantities caught in other areas.

2/ Could possibly be yellowfin tuna.

3/ Data from a series of Fisheries Field Bulletins, CSIRO, Australia.

4/ According to Fisheries Yearbook, Taiwan Area; tuna-like species other than skipjack.

5/ National or local equivalent not ascertainable.

6/ Data for 1967 only.

7/ Includes striped marlin.

TABLE II Annual catch as an average of three years, 1967-1969, of major tunas and billfish by different fishing methods of main fishing countries (in 1,000 tons).

| Fishing Method | Country | Bluefin | Southern bluefin | Albacore | Bigeye | Yellowfin | Billfish | Skipjack |
|---|---|---|---|---|---|---|---|---|
| Longline | Japan | | 17.5 | 30.0 | 67.8 | 51.0 | 51.5 | |
| | Taiwan | | | 11.7 | 3.9 | 9.6 | 8.1 | |
| | Korea | | | 15.3 | 1.9 | 5.4 | ? | |
| | Ryukyu | | 12.7 | | | | | |
| Bait-boat | Japan | | | 26.6 | 2.3 | 2.7 | | 159.5 |
| | US | | | | | 6.5 | | 9.8 |
| Bait-boat and trolling | US | | | 23.0 | | | | |
| | Australia | | 7.5 | | | | | |
| Purse seine | Japan | 4.5 | | | | 3.0 | | 9.5 |
| | US | 6.6 | | | | 69.2 | | 26.5 |