

Study of interaction between longline and purse seine fisheries on yellowfin tuna, *Thunnus albacares* (Bonnaterre)

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Abstract

Interaction between longline and purse seine fisheries on yellowfin tuna remains ambiguous despite of high requirement on its information for fishery management of this commercially important species. The present study analyzed the interaction between the two fisheries on three stocks of yellowfin tuna in the eastern Pacific, western Pacific and eastern Atlantic Oceans up to 1983 since the commencement of the fisheries.

Detailed comparison was made for each stock in regard with the two fisheries on fishing grounds, fishing seasons, size and maturity of fish in the catch as well as trends of fishing effort, catch and CPUE. The present study covers roles of environmental factors affecting the success of the two fisheries, and possible effect of El Niño events on recruitment of yellowfin tuna through analysis of the longline data.

Several differences specific to each stock were observed during the comparative study. However, it was assumed that any factor did not hinder the revealing of the interaction between the two fisheries. The indications induced from the comparison coupled with results of stock assessments led to a conclusion that the purse seine fishery gave substantial adverse effects on the longline fishery for the eastern Pacific and the eastern Atlantic stocks, but not for the western Pacific stock until 1983.

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I . Introduction

Yellowfin tuna, *Thunnus albacares* (Bonmatere) is mainly distributed over the tropical and subtropical waters of the Pacific, Indian and Atlantic Oceans. Various fishing methods have been adopted to exploit the fish for a long time in different parts of the world. Major tuna fisheries have developed in the 1950s and aimed at yellowfin tuna, making it the most productive species of genus *Thunnus*.

It was Japanese longline fishery that started to harvest the yellowfin tuna in the distant waters, expanding the operations to almost the entire tropical regions of the three oceans. After the longline fishery, more efficient and labour saving purse seine fishery evolved from baitboat fishery in the eastern equatorial Pacific and the eastern equatorial Atlantic. The purse seine fishery has affected other gears due to its high fishing power. Therefore, it was often required to evaluate impact of the purse seining upon the precedently operated fisheries, especially upon the longline fishery which exploits larger yellowfin tuna than those taken by the purse seine fishery.

The Inter-American Tropical Tuna Commission (IATTC) was signed between Costa Rica and the United States and entered into force in 1950. The International Commission for the Conservation of Atlantic Tunas (ICCAT) started its activities in 1969. The major task taken by these commissions was establishment of management measures of yellowfin tuna. For the ICCAT, the task soon required understanding the interaction problem between the surface fishery aiming at small-sized fish and the longline fishery at large-sized fish. The IATTC has been leading studies of stock assessment and practical aspects of the fishery management for yellowfin tuna (SCHAEFER, 1957 ; JOSEPH and GREENOUGH, 1979).

Only limited knowledge was so far made available to comprehensively understand the impact of the purse seine fishery on the longline fishery for yellowfin tuna. Difficulties to analyze this subject stem mainly from lack of basic biological information. There are several possible factors which are considered to intervene revealing explicit interaction between the two fisheries such as difference in the fishing grounds, difference in the size of fish taken and ambiguity of stock structure. In addition, complexity of the fisheries such as multi-gear and multi-specific natures involved in the exploitation of yellowfin tuna stock also hindered the progress of the study. Therefore, only fragmental analyses have so far been attempted for this subject based on hypothetical calculations. Although the general background of this study is still not improved to a satisfactory level, there has been a significant increase of knowledge for yellowfin tuna on its basic biology in addition to improvement and accumulation of various fisheries statistics.

Yellowfin tuna fisheries are now experiencing enormous changes. French and Spanish purse seine boats moved from the eastern Atlantic Ocean to a new fishing ground in the western Indian Ocean. Eventually, the yellowfin tuna catch in the Indian Ocean was doubled in the mid 1980s just few years after the introduction of the purse seiners. Similar phenomenon occurred in the western Pacific from the early 1980s few years earlier than in the western Indian Ocean, and a significant number of the purse seiners made transoceanic cruise from the eastern Pacific to participate in the

internationalized purse seine fishery in the western Pacific.

The purpose of the present study is to provide the basic information of the interaction between the longline and the purse seine fisheries which forms the background of the rational conservation measures of the yellowfin tuna stocks on a global scale.

II . Review of literatures

Tunas of genus *Thunnus* could be classified into two general categories depending on geographical distribution. One is temperate species such as bluefin tuna, *Thunnus thynnus* (Linnaeus), southern bluefin tuna, *Thunnus maccoyii* (Castelnau) and albacore, *Thunnus alalunga* (Bonaterre) and the other is tropical species represented by yellowfin tuna. Bigeye tuna, *Thunnus obesus* (Lowe) has intermediate nature because it is widely distributed over the tropical and temperate waters. Therefore, this species has been arbitrary classified into either one of the two groups.

Gear interaction for exploiting yellowfin tuna has become concerned among the participating countries late in the 1960s when surface fishery for tropical species, first baitboats and then purse seiners started to develop in the Atlantic Ocean after the exploitation of the species by the longline fishery since 1956 (FAO, 1968). Since there were only slight overlap in the length compositions of yellowfin tuna taken by the longline and surface fisheries and limited biological information at that time, effects of introducing the purse seine fishery on the longline fishery and on yield from all fisheries as a whole were assessed briefly basing on several possible combinations of growth rate, natural and fishing mortality rates. It was anticipated from the study that the introduction of the purse seine fishery would reduce the longline catch but could increase total yield from the all fisheries combined.

This line of the study was succeeded by yield-per-recruit (Y/R) analysis (*e. g.*, HAYASI, HONMA and SUZUKI, 1972 ; LENARTZ and ZWEIFEL, 1979). LENARTZ and ZWEIFEL (*op. cit.*) suggested that the total yield from the yellowfin tuna stock was larger in the case of coexistence of the two fisheries than in the case of exploitation by either one of the two fisheries. On the other hand, a comparison in detailed time and area stratum of maturity of gonad and CPUE has been made for yellowfin tuna captured by longline and purse seine boats (SUZUKI, TOMLINSON and HONMA, 1978 ; YANEZ, 1979 ; YANEZ and BARBIERI B., 1980). YANEZ (1979) stated that longline catch decreased sharply due to increased catch by purse seine vessels in the eastern Atlantic. YANEZ and BARBIERI B. (1980) suggested possible relationship among thermocline structure, CPUE and gonad index in different seasons of a year.

FONTENEAU (1981), through his extensive works on Atlantic yellowfin tuna, proposed a hypothesis indicating a possibility that the longline and purse seine fisheries might not necessarily exploit the same stock. He hypothesized that the trend of the longline CPUE, especially in its early period of the exploitation did not reflect size of the adult population and inferred the complexity in studying the interaction between the two fisheries on yellowfin tuna. MARCILLE (1984) investigated

the relation between the MSY estimated from longline fishery before the introduction of purse seine fishery and the MSY estimated at the presence of the two fisheries aiming at the species in the Atlantic and Pacific Oceans.

The longline catch of yellowfin tuna decreased in contrast to the increase of the total catch, mainly due to the increase of the purse seine catch as theoretically anticipated. But the interaction between the two fisheries are hardly identified explicitly basing on analyses of the fisheries data due to later change in operational strategy of the longline fishery from tropical to temperate waters.

The fishery for yellowfin tuna is not an exception from effects of very complicated factors reflecting socio-economic activities and responses from the stock. Given these circumstances, it would be useful to assess the interaction problems by analyses of data obtained from the on-going fisheries in addition to analyses by conventional theoretical models workable under very limited conditions. Historical perspective analysis on general performance of the fisheries has been only lightly made or in most cases ignored in the past interaction studies.

In addition, the biological information on distribution, migration, spawning, mortality rates and effects of environmental condition is necessary to understand the interaction between the longline and purse seine fisheries on yellowfin tuna stock. However, the review pointed out that there were few works covering such information so as to form the base of analysis.

III . Materials and methods

1 . Materials

Fisheries statistics on catch and effort by detailed area-time stratum form one of two basic sources of the present study. The other data used extensively comprise measurement of the size of fish in the catch. In addition, the present analysis is based upon gonad maturation and oceanographic observations especially vertical thermal profile.

The two basic statistics were retrieved from data base stored at the headquarters of the IATTC, La Jolla, USA and the ICCAT, Madrid, Spain. Besides, comparable statistics for the Japanese data were obtained from the data base at the Far Seas Fisheries Research Laboratory (FSFRL). Taking into account the length of duration of data series and accuracy of logbooks, selected for the present analysis are the statistics mainly from Japanese longline fishery, and US, Japanese and French purse seine fisheries for the period up to 1983 since 1962 for the eastern Pacific Ocean, 1952 for the western Pacific Ocean and 1957 for the eastern Atlantic Ocean.

Japanese statistics cover the longliners over 20 gross tons for offshore and distant water longlining and the purse seiners about 500 gross tons. The French and US statistics also comprise the data from the distant water purse seiners mainly over 400 tons of carrying capacity. Fishing effort of the Japanese longline fishery was standardized by Honma method (HONMA, 1974) which takes into account heterogeneous spatio-temporal distribution of longline hook rates.

The length and weight of yellowfin tuna were mostly measured at unloading ports but a part

of the measurement was made on board of the longline boats. The gonad data were obtained from specimens caught by Japanese longline and purse seine boats in the western Pacific, and compiled by the FSFRL. These data were converted to gonad indices (GI: gonad weight in gram $\times 10^4$ / cube of fork length in centimeter). The comparable GI data were taken from publications of the IATTC and ICCAT.

The El Niño event provides an excellent opportunity to understand possible abiotic impact upon stocks of yellowfin tuna. The present study used bathythermograph (BT) observations in the Pacific conducted by Japanese research boats of scientific institutions and training boats of fisheries high schools. These data, compiled by the FSFRL (YUKINAWA and MIZUNO, MS), were used for the period from 1965 to 1983.

2 . Methods

In this study, the "interaction" is defined as mechanism of impacts of purse seine fishery exploiting mainly small-sized fish on longline fishery catching mostly large-sized fish. Namely, it reflects interrelationship between the activities of the two fisheries and resultant changes in the dynamics of the population.

Approach to the interaction in this study begins with historical perspective of the two fisheries. This part will be substantiated by detailed descriptions of such operational performances of the two fisheries as fishing grounds and seasons, size and maturity of fish in the catch, year-to-year trends of the catch, fishing effort and CPUE. Comparison of performance of the two fisheries materializes qualitative natures of the interaction. Quantitative analysis is attempted in the second part by referring the results of stock assessments with the indications induced from the comparisons between the two fisheries. The whole process of the analysis was conducted for each stock separately, because there are differences in the histories of the two fisheries among the stocks.

The present study covers three stocks of yellowfin tuna, in the eastern Pacific, western Pacific and eastern Atlantic Oceans. Overall discussion for the three stocks will be made in an attempt to deduce generalized common aspects in the interaction. Imminent interaction is anticipated for the yellowfin tuna stock in the western Indian Ocean where purse seine fishery started in the middle of the 1980s. However, since the purse seine fishery developed only in very recent years, basic data on the fishery for interaction study have not yet been available.

In addition to human intervention, environmental factors must affect the dynamics of fish populations. The El Niño phenomenon provides opportunity to assess effect of large-scale oceanographic changes upon the abundance and distribution of yellowfin tuna in the Pacific Ocean, although little is known about the possible relation between the environmental factors and either the fish stock or fisheries until now.

IV. Description of fisheries

1. Eastern Pacific Ocean

1-1. Types of fisheries

More or less industrialized tuna fishery in the eastern Pacific Ocean dates back to introduction of the US baitboats exploiting albacore along the California coast for canning plants in the early 1900s. Increasing demand for canned tuna accelerated shift of the target species from albacore to yellowfin tuna as well as skipjack, *Katsuwonus pelamis* (Linnaeus) by expanding fishing grounds to the tropical waters as far south as Ecuador in the late 1940s. Then, Latin American fishermen joined to the operation in addition to the US fleet. In order to manage the growing fishery, the IATTC was established and entered into force in 1950. In the 1950s, purse seiners were introduced to harvest the tropical tunas more effectively than baitboats.

Soon the purse seine fishery replaced the predecessor in the tropical waters, and made revolutionary expansion in the mid 1960s due to innovation of new technique. Namely, the dolphin-associated schools were found easily captured by use of speed boats. The operation is no longer

limited to the coastal waters but expanded to the entire Commission's Yellowfin Regulatory Areas (CYRA) in the eastern tropical Pacific (Fig. 1). Since 1968 the operation range moved farther offshore beyond the boundary of the CYRA, up to Long. 150° W along a line of Lat. 10° N.

The status of yellowfin tuna stock in the eastern Pacific has been monitored closely by the staff of the IATTC. The Commission adopted aquota system for the conservation of yellowfin tuna in the CYRA for the period from 1966 though 1979. The surface fleets operating in the CYRA were under regulated fishing for yellowfin tuna after a specific time of the year when the catch had become close to the quota. A maximum of 15 percent of yellowfin tuna in weight in total catch was allowed during the regulated fishing. Most of the fleets moved to outside the CYRA or pursued skipjack in the CYRA after the announcement of the end of unregulated fishing for yellowfin tuna.

Socio-economic factors appeared to have

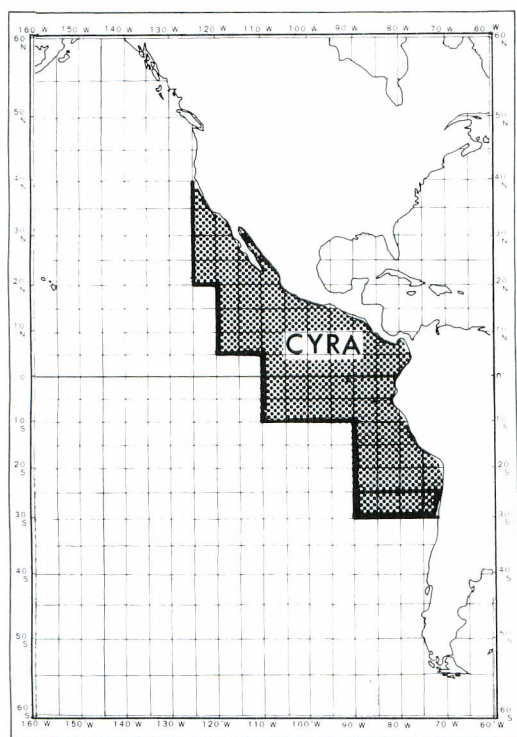


Fig. 1. The Inter-American Tropical Tuna Commission's yellowfin regulatory area (CYRA).

caused a drastic change of flag composition of the purse seine fleet. In the 1970s, the US boats comprised major part of the international fleet. Such Latin American countries such as Mexico, Ecuador and Venezuela developed the fishery and the combined fleet size is comparable to the US fleet since the 1980s. Another drastic change in the purse seine fishery of the eastern Pacific occurred in 1982 when significant members of the purse seine fleets moved to the western Pacific. This change was due to depressed catch rates in the eastern Pacific, and it drove the seiners to the more attractive fishing ground newly developed in the western Pacific.

Since the end of areal limitation in 1952, Japanese longline fishery expanded the fishing ground eastward and reached the CYRA by the end of the 1950s (Fig. 2). The fleet aimed at yellowfin

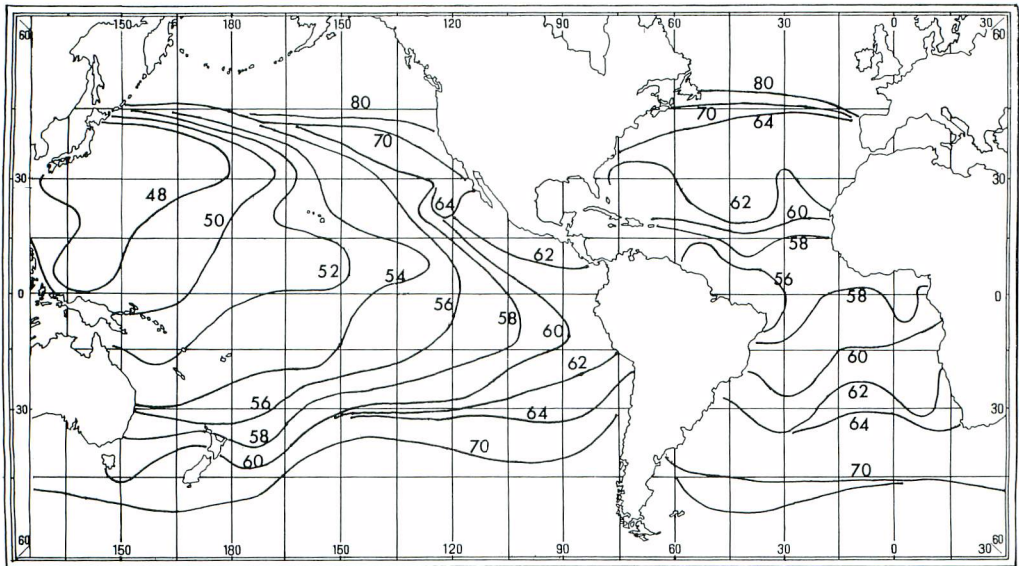


Fig. 2. Schematic map showing historical expansion of Japanese longline fishing grounds.

Numbers in the Figure denote last two digits of calendar year.

tuna for export until the mid 1960s, and then gradually shifted the target to bigeye tuna for domestic fresh fish market according to recovery of the Japanese economy. Profitableness of bigeye tuna fishery in the cold waters drove the longliners toward higher latitude along the American Continents up to Lat. 30° N and Lat. 30° S by 1970. Taking into account deep swimming layer of bigeye tuna, the fishermen have become to set the longline deeper than before in 1975, thus resulting in reduction of fishing power for yellowfin tuna (SUZUKI, WARASHINA and KISHIDA, 1977). After Japanese longliners, Taiwanese and Korean longliners came to the eastern Pacific Ocean. These fleets are interested in albacore and bigeye tuna rather than yellowfin tuna in offshore and southern areas, mainly west of Long. 120° W and south of the equator. They may be less affected by the surface fishery taking small-sized yellowfin tuna than the Japanese fleet that operates significantly within in the CYRA.

Since 1968, purse seiners produce 88-98 percent of yellowfin tuna caught in the CYRA. Share of baitboats, on the other hand, ranges between 1 and 7 percent, thus keeping the catch of the surface

Table 1. Catch of major tuna species caught by all fisheries in the purse seine fishing ground of the eastern Pacific Ocean, 1962, 1976 and 1983.

unit : 1000 tons			
Year	1962	1976	1983
Yellowfin tuna	79.1	237.1	94.5
Skipjack	71.0	127.1	58.0
Bigeye tuna	0.3	10.6	3.2
Bluefin tuna	11.3	10.6	0.7
Albacore	1.2	3.7	0.2
Total	162.9	389.1	156.6

Data from IATTC (1985).

fisheries at an overwhelmingly high level. Table 1 shows the catch of major tunas by all the fisheries from the eastern Pacific for three typical years of starting of Japanese longline in 1962, of the maximum catch made by the surface fleet in 1976, and the latest year 1983 (IATTC, 1985).

1 - 2 . Fishing grounds and fishing seasons

Longline fishery

In the eastern Pacific, east of Long. 140° W, two areas of the high hook rates (number of fish per 100 hooks) appear to the north of the equator during the first, second and fourth quarters and to the south of the equator during the third and fourth quarters of the year, respectively (Fig. 3). The

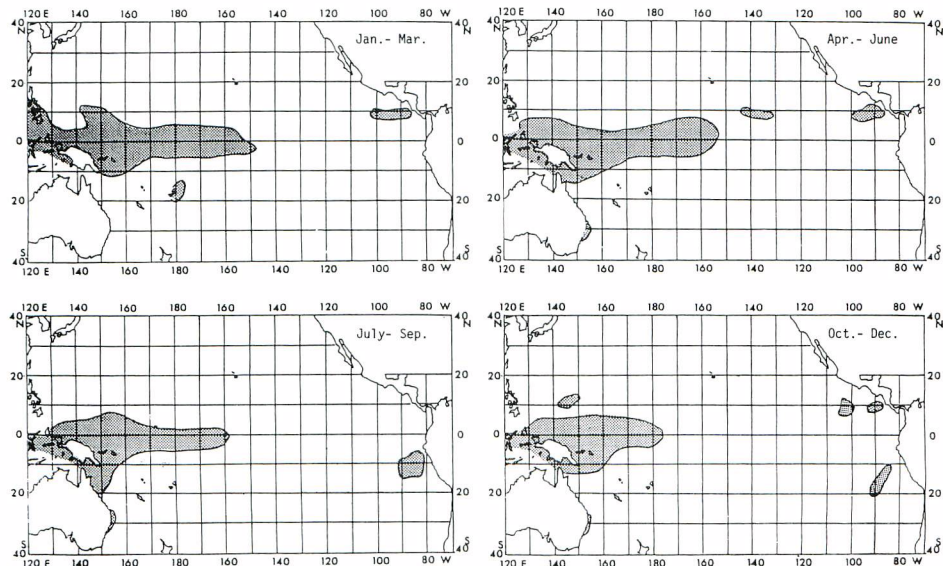


Fig. 3. Schematic presentation of major longline fishing ground for yellowfin tuna summarized from Appendix Figure.

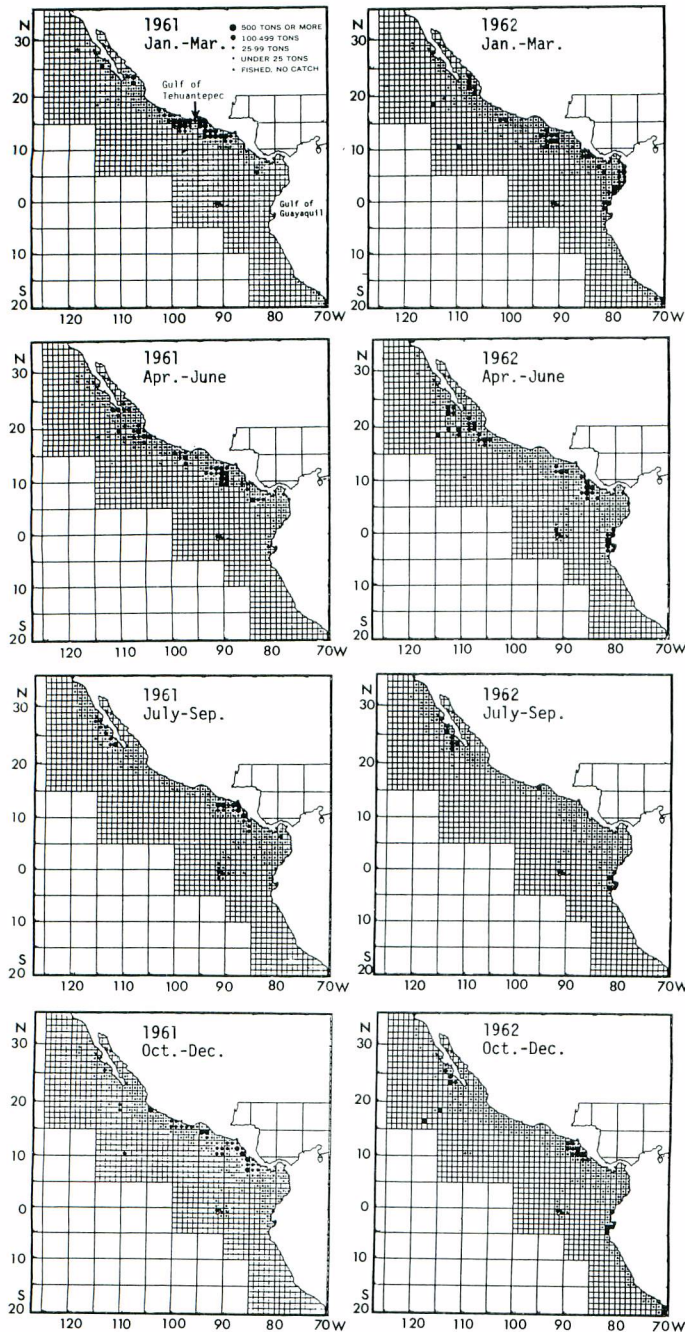


Fig. 4. Quarterly distribution of yellowfin tuna catch by purse seine boats for 1961 (left) and 1962 (right). After ALVERSON (1963).

high hook rates of the northern area in the fourth quarter appear actually from November to December (Appendix Figure). Catch rates in the coastal areas of the eastern Pacific are very low, except around Lat. 10° N from December to June (Appendix Figure).

In the northern area between Lat. 5° N and 10° N, there are two zones of high hook rates. The western area between Long. 130° W and 140° W, had high rates in the second quarter. On the other hand, the eastern area, which appears along Lat. 10° N and between Long. 85° W and 110° W, had high rates during the first, second and fourth quarters. However, the effort in this area was sparse during the third quarter (Appendix Figure). The area of high hook rates in the southern hemisphere between about Long. 85° W and Long. 95° W seems to shift its position southward from the third to fourth quarter.

Purse seine fishery

Fishing grounds and seasons of the purse seine fishery in the eastern Pacific changed due to such significant events as development of dolphin-associated fishery in the early 1960s, the introduction of quota system to regulate the yellowfin tuna fishery in 1966 and the 200

mile exclusive fisheries zones in 1977 declared by the countries participating in the purse seine fishery of this area. Detailed time and areal changes of the purse seine fishery have been reported by the IATTC.

Before the early 1960s, fishing grounds were confined within the coastal areas. During this period major catch of yellowfin tuna came from the areas around the Gulf of Guayaquil and Gulf of Tehuantepec throughout the year (Fig. 4). Other important fishing grounds were found in Baja California area during the second and third quarters of the year as well as around coastal areas of Mexico between Lat. 15° N and 20° N throughout the year except the third quarter. The fishing grounds expanded to offshore areas due mainly to dolphin-associated fishery and the quota regulation for yellowfin tuna was introduced from 1966.

Since the unregulated fishing ends somewhere between March and September (Table 2), the

Table 2. Catch and quota of yellowfin tuna and data of closing unregulated operations for surface fishery in the eastern Pacific Ocean, 1961-1983.

Unit : 1000 tons

Year	CYRA	Outside CYRA	Total	Quota	Closure data of unregulated fishing
1961	104.9	-	104.9	-	
1962	79.1	-	79.1	-	
1963	65.4	-	65.4	-	
1964	92.0	-	92.0	-	
1965	81.8	-	81.8	-	
1966	83.0	-	83.0	72	Sept. 15
1967	81.6	-	81.6	77	June 24
1968	103.9	1.1	104.9	84	June 18
1969	115.1	17.4	132.5	109	April 16
1970	129.3	27.8	157.0	109	March 23
1971	103.3	20.7	123.9	127+ (+9+9)	April 9
1972	138.3	40.6	179.0	109+ "	March 5
1973	161.3	44.9	206.2	118+ (+9+9+9)	March 8
1974	173.8	37.2	211.0	159+ (+9+9)	March 18
1975	160.0	43.1	203.1	159+ "	March 13
1976	191.1	46.0	237.1	159+ "	March 27
1977	184.1	16.2	200.3	159+ (+18+14)	July 7
1978	166.3	14.5	180.9	159+ "	May 6
1979	176.9	13.7	190.6	159+ "	July 21
1980	133.7	26.7	160.4	-	
1981	159.1	23.9	182.9	-	
1982	108.0	18.0	126.0	-	
1983	82.4	12.2	94.5	-	

Data from IATTC (1980, 1982, 1985).

Plus signs stand for possible additional stepwise increase of 9, 14 or 18 thousand tons of quota.

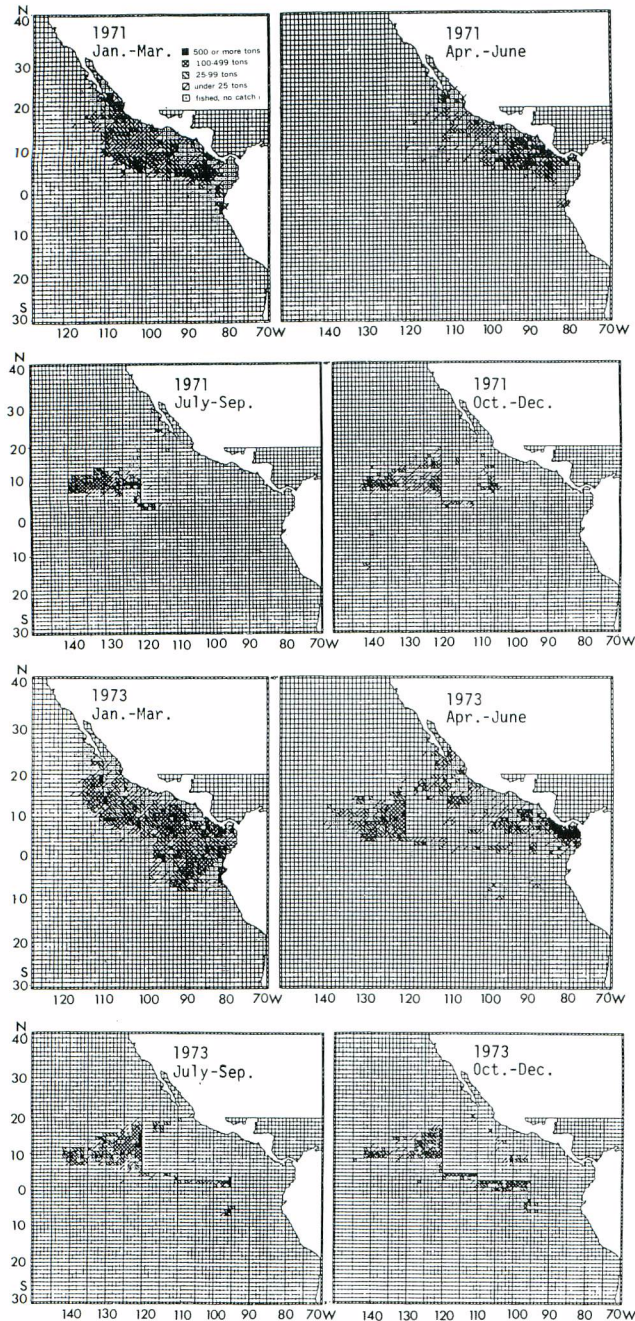


Fig. 5. Quarterly distribution of yellowfin tuna catch during unregulated trips by purse seine vessels for 1971 and 1973. After CALKINS (1975).

fishing activity in the CYRA decreased considerably in the third and fourth quarters while the outside CYRA areas were fished mostly in those periods by purse seine boats over the unregulated fishing period. There is no appreciable difference before and after regulation in the fishing pattern within the CYRA during the unregulated period except general expansion of the fishing grounds to offshore areas of the CYRA (Fig. 5). The quota regulation by the IATTC has not been implemented since 1980. The catches from the coastal areas, especially the US purse seine catch off Latin American countries has decreased as the 200 mile zone had become de facto even for the tuna stocks.

1-3. Factors affecting the success of fishing

Generally the purse seine fishing grounds appear to coincide with shallow thermocline areas in or above the bottom of the net hanging (IATTC, 1982), at most less than 100 m deep from the surface. Toward the higher latitude, north of Lat. 30° N or south of Lat. 20° S, the water temperature appears to affect formation of exploitable schools, reflecting migration of yellowfin tuna at surface temperature of 20° C or above.

Operation on dolphin-associated school characterizes the tuna purse seining in the eastern Pacific Ocean. Large-sized yellowfin tuna often follow herds of spotted dolphin, *Stenella attenuata* (Gray) and spinner dolphin, *S. longirostris* (Gray). It still remains open question why the fish associate very commonly with the dolphin herds only in the eastern Pacific Ocean. The extent of purse seine fishing grounds coincides more closely with the major distribution areas of spotted

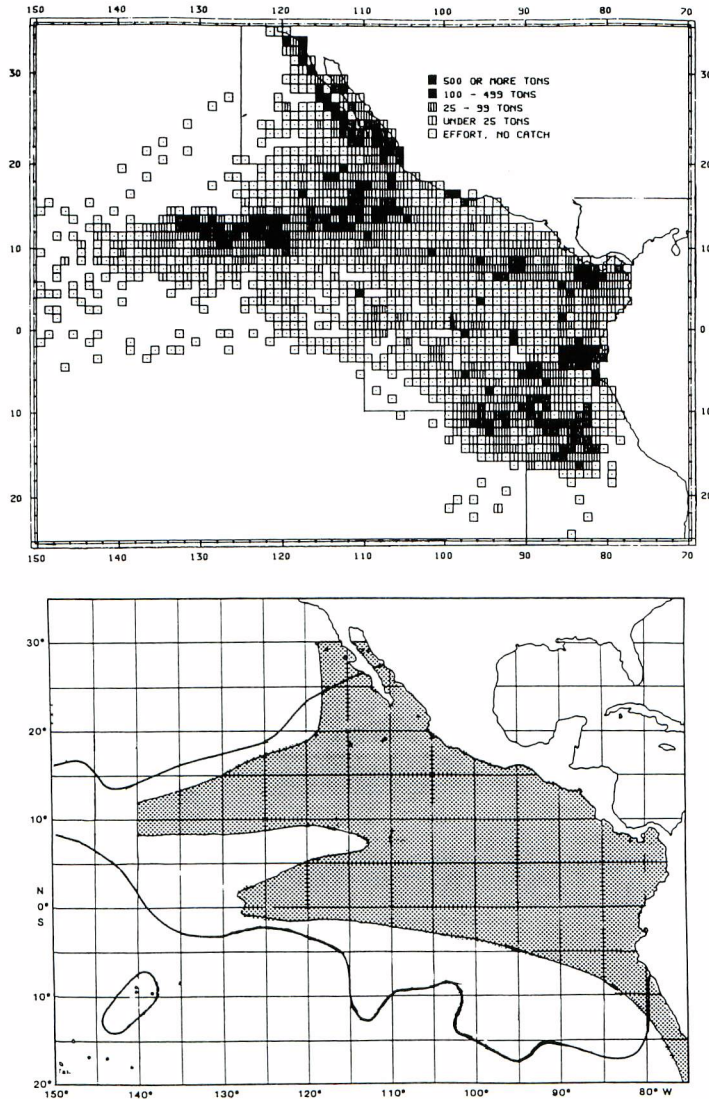


Fig. 6. Catch of yellowfin tuna by purse seine vessels in 1983 (upper panel, IATTC (1984)) and known distribution of spotted dolphin in the eastern Pacific (lower panel with heavy line, PERRIN *et al.* (1985)) and areas with thermocline shallower than 100 m (lower panel with shaded sign, WYRTKI (1964)).

dolphin than with the areas of the shallow thermocline less than 100 m from the sea surface (Fig. 6).

Thermocline located between 100 m and 150 m deep results in high efficiency of longlining for bigeye tuna in the tropical waters (SUDA, KUME and SHIOHAMA, 1969). This depth range of the thermocline is more widely appears in the eastern Pacific, thus makes bigeye tuna more vulnerable than yellowfin tuna to the longline.

It is summarized that major fishing grounds for the purse seine and longline boats do not necessarily overlap. However, there are major fishing grounds for both of the two fisheries in the areas along Lat. 10° N in and out of the CYRA.

1 - 4 . Size of fish in the catch

Majority of yellowfin tuna captured by the purse seine in the CYRA ranges between 40 cm and 70 cm in fork length, while the catch in the waters west of the CYRA but east of 150° W consists of two size groups, the fish from 40 cm to 70 cm and 100 cm to 150 cm, although the length composition changes to some extent from year to year (Fig. 7). Composition of the length data

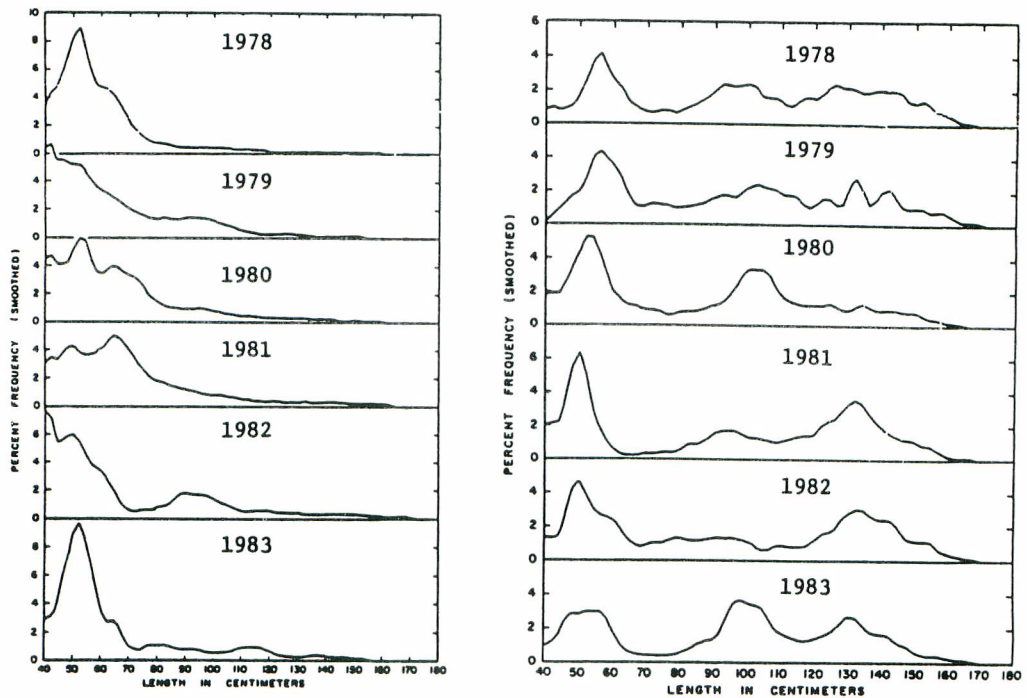


Fig. 7. Length frequency distributions of yellowfin tuna taken by purse seine vessels from the CYRA (left panel) and from outside the CYRA (right panel), 1978-1983.

After IATTC (1984).

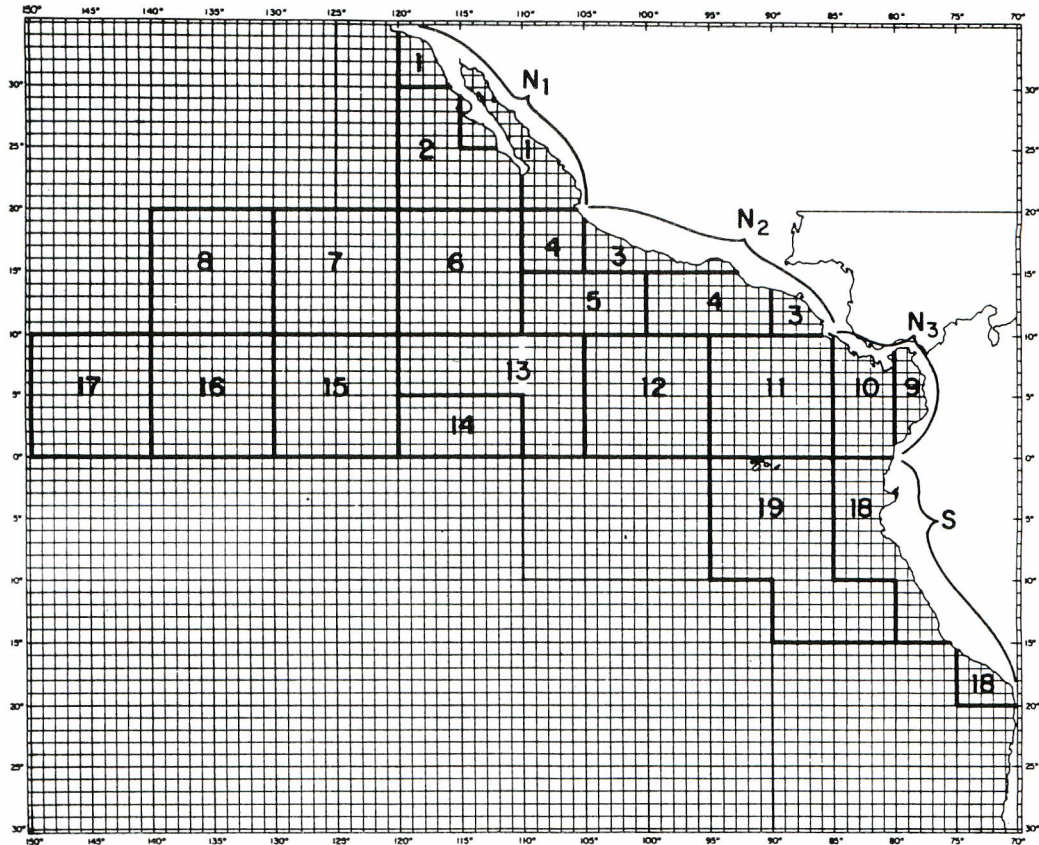


Fig. 8. Areas (bounded by heavy line) used in the computation of the length composition of yellowfin tuna caught by purse seine boats in the eastern Pacific. N1, N2, N3 and S designate major zonal (latitudinal) areas. After SUZUKI *et al.* (1978).

compiled by SUZUKI *et al.* (1978) for each of 19 subareas (Fig. 8) revealed appreciable geographical variations (Fig. 9). The data from 1966 to 1972 for the CYRA (areas 1-6, 9-14 and 18, 19) and from 1969 to 1974 for outside the CYRA (areas 7-8 and 15-17) were cumulated to obtain average year pattern of the length composition by areas. Large fish tends to dominate more remarkably with increase of the distance from the coast.

Longline gear is selective for large fish over 90 cm in fork length. Relatively small-sized fish below 100 cm dominate in the third quarter of the coastal waters, east of Long. 120° W, in the southern areas (Fig. 10).

SUZUKI *et al.* (1978) compared the size of fish captured by the two types of gears cumulated for the same months of the same years and in the same latitude 5° × longitude 10° area. The modal lengths above about 90 cm show similar values for the two gears, whereas there seems no accordance

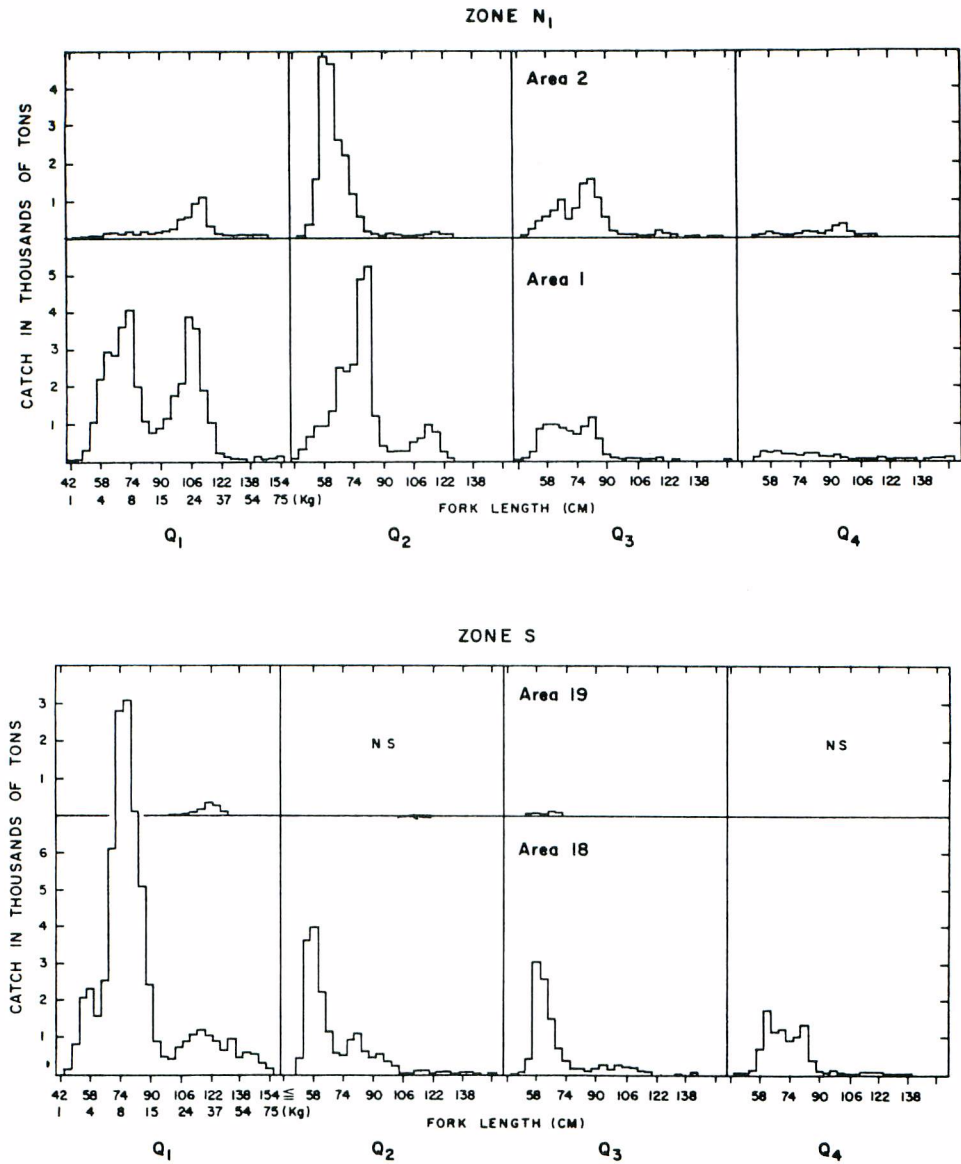


Fig. 9. Quarterly length composition of yellowfin tuna caught by purse seine boats in the CYRA (1966-1972 combined) and outside the CYRA (1969-1974 combined) by areas and major zones defined in Figure 8.

After SUZUKI *et al.* (1978).

NS denotes no samples.

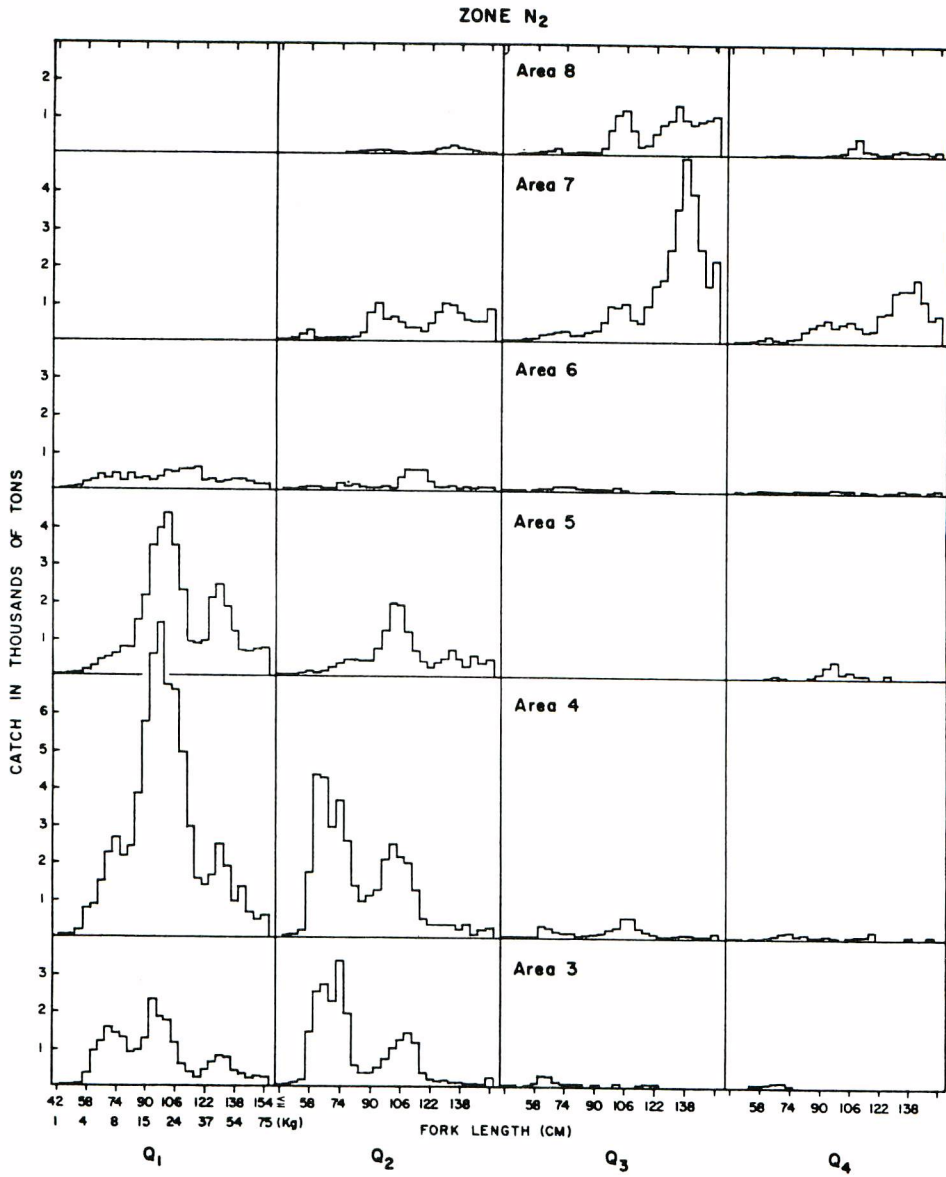


Fig. 9. Continued.

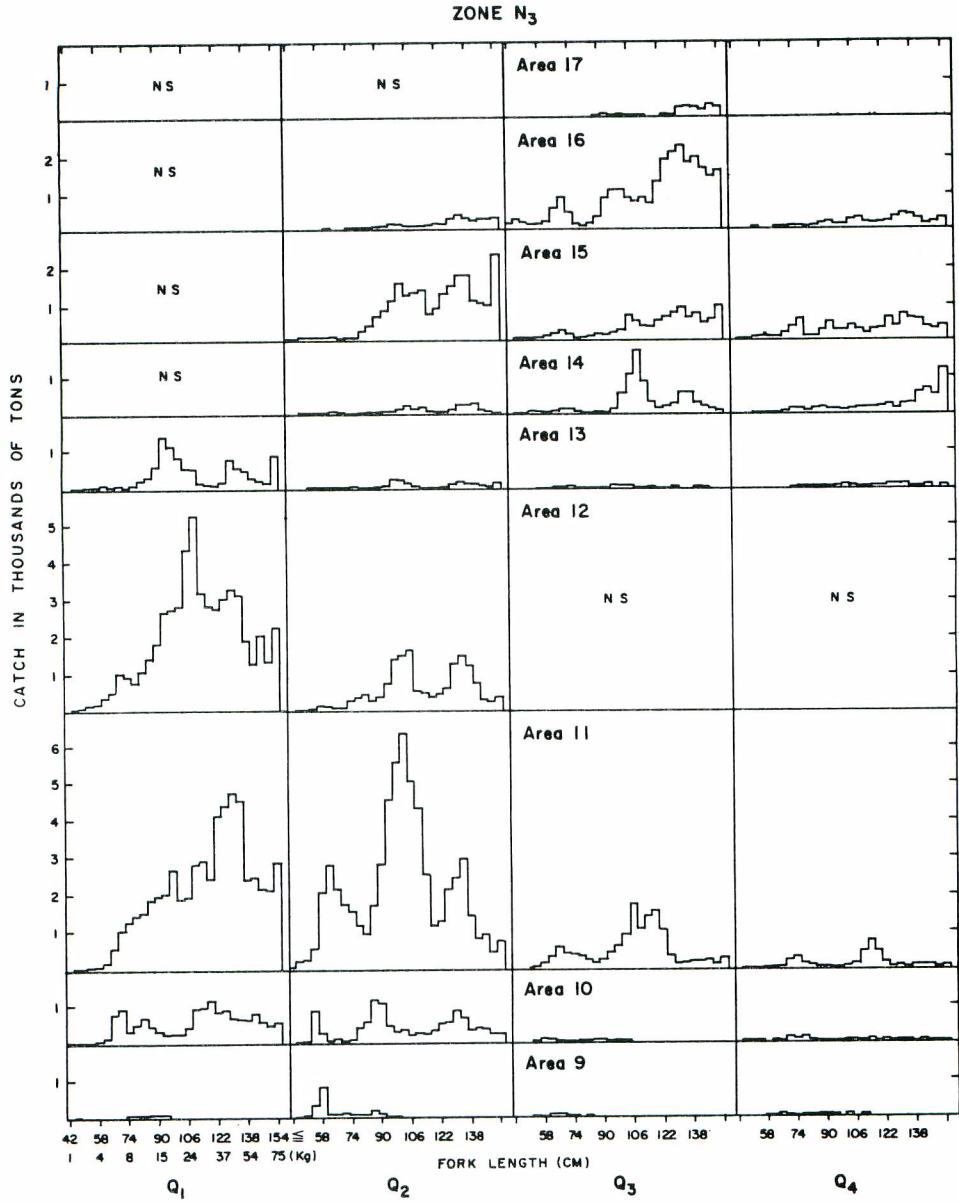


Fig. 9. Continued.

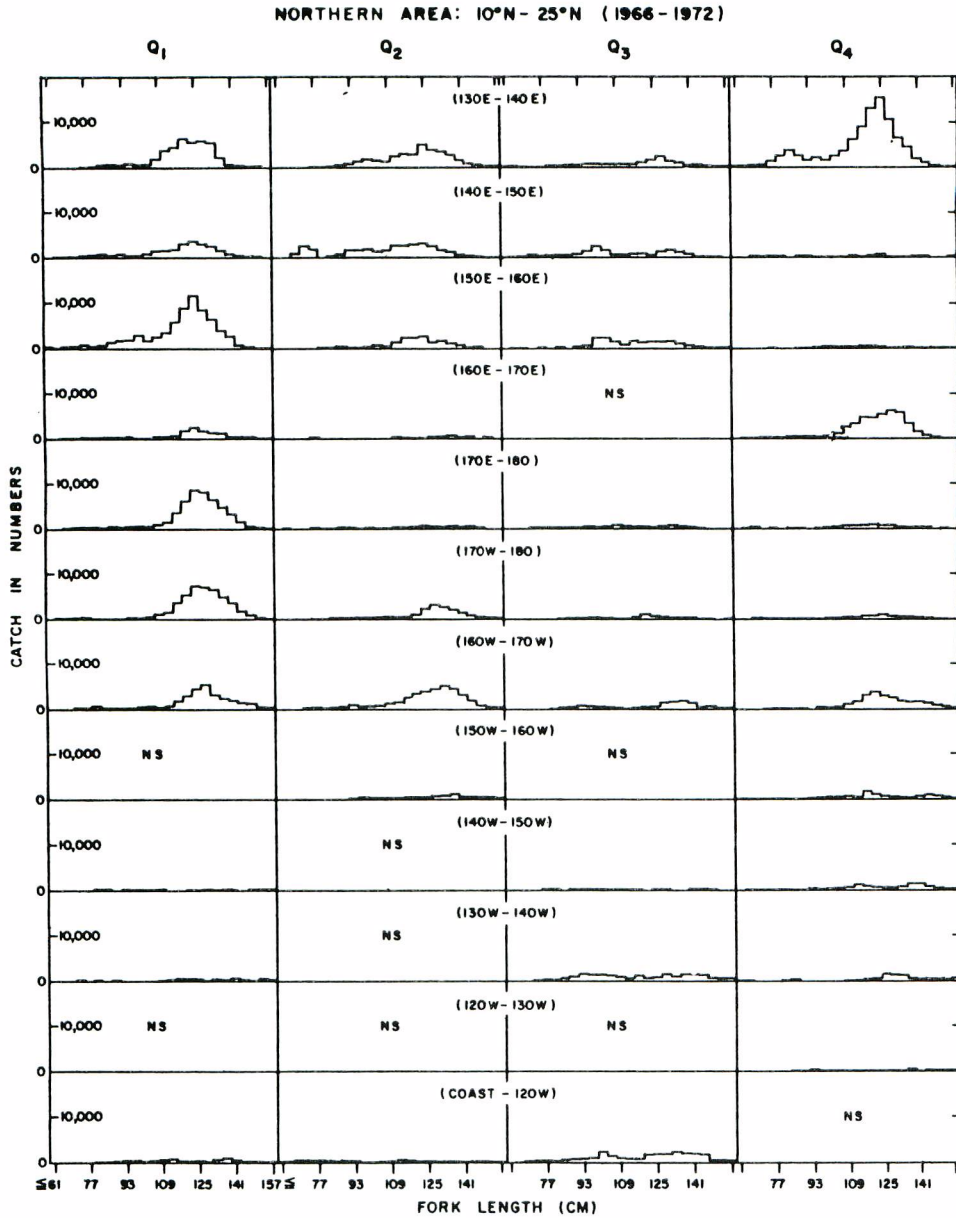


Fig. 10. Quarterly length composition of yellowfin tuna caught by Japanese longliners in three major areas of the Pacific (northern, middle and southern), 1966-1972 combined, by 10° longitudinal strips.

After SUZUKI *et al.* (1978).

NS denotes no samples.

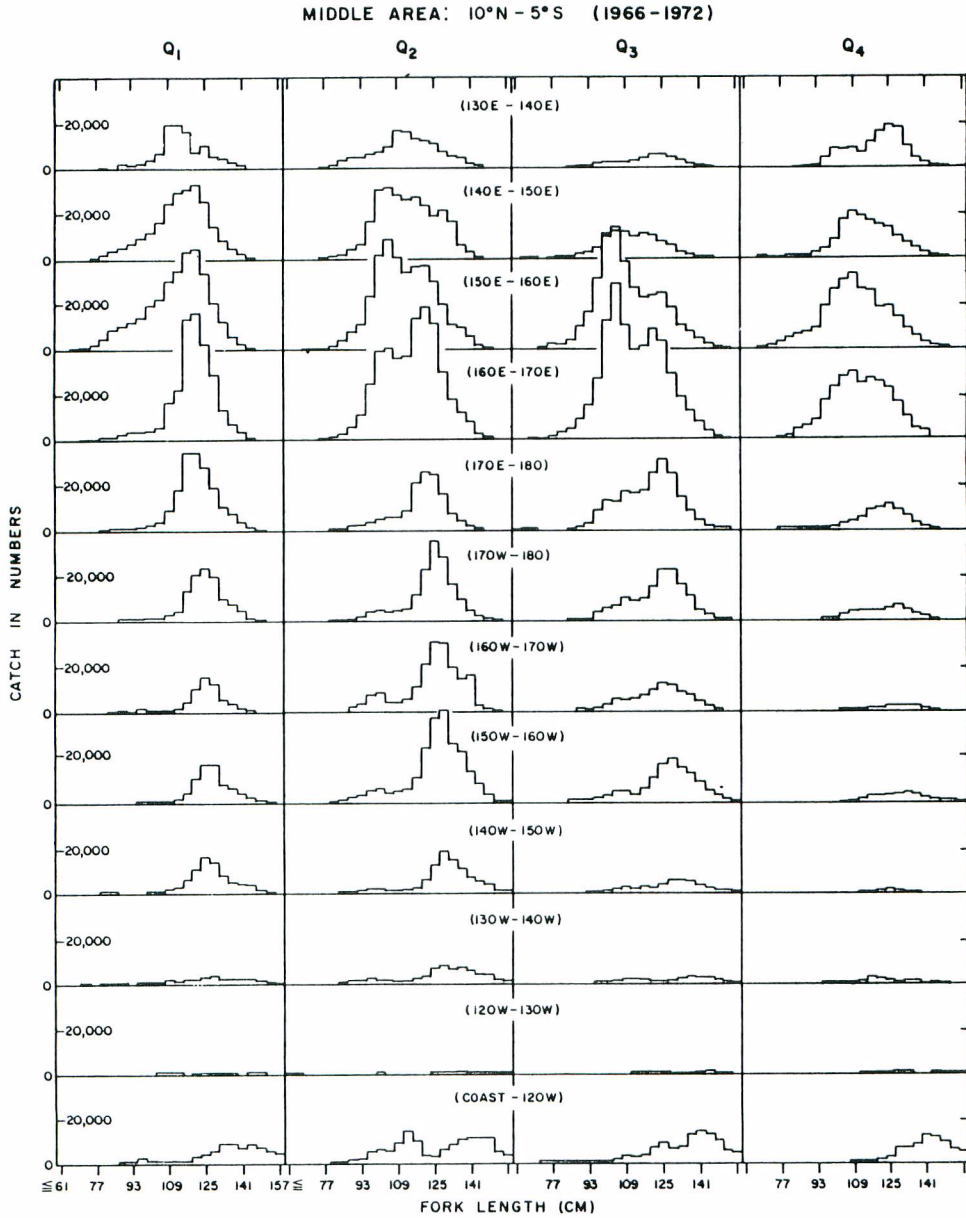


Fig. 10. Continued.

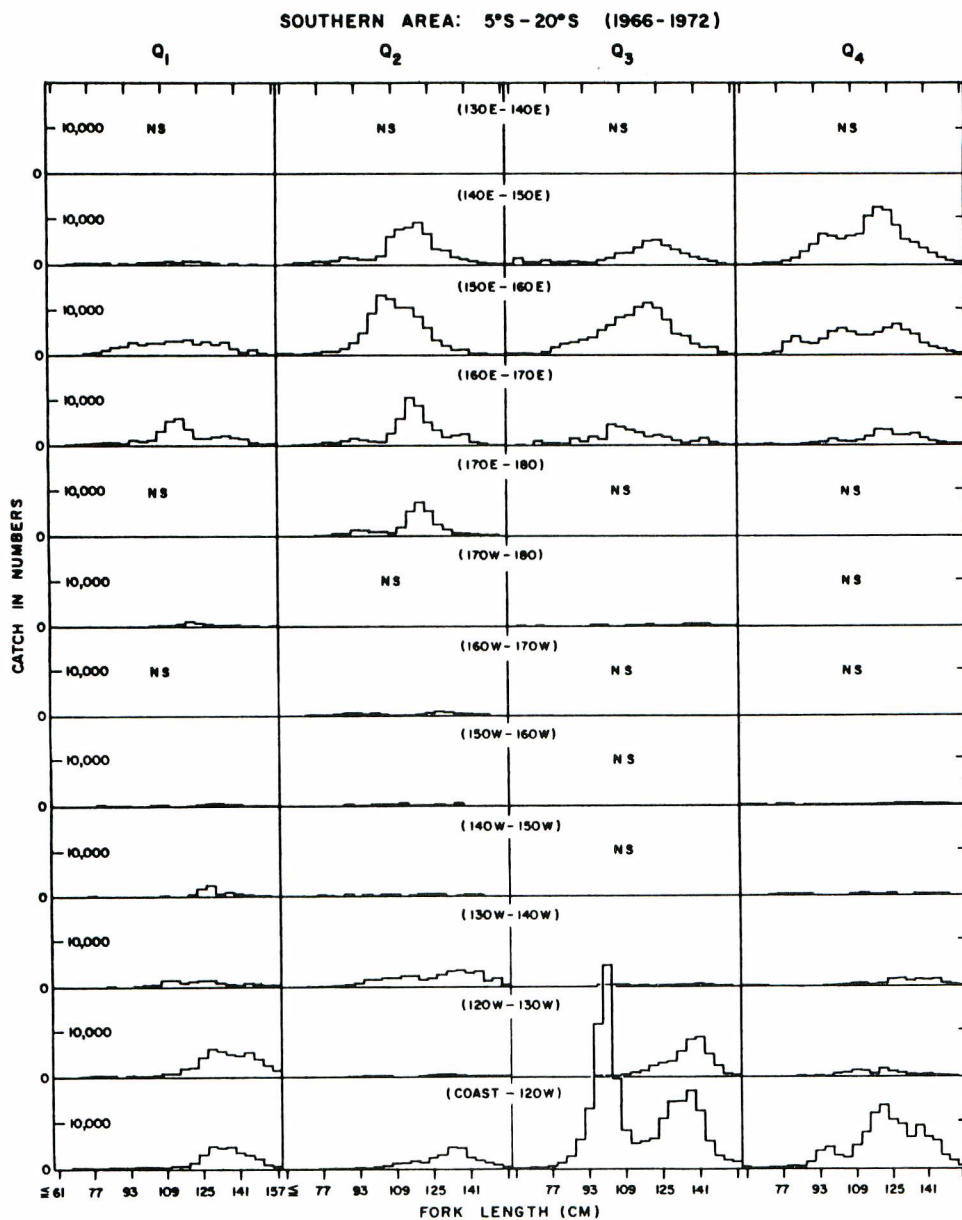


Fig. 10. Continued.

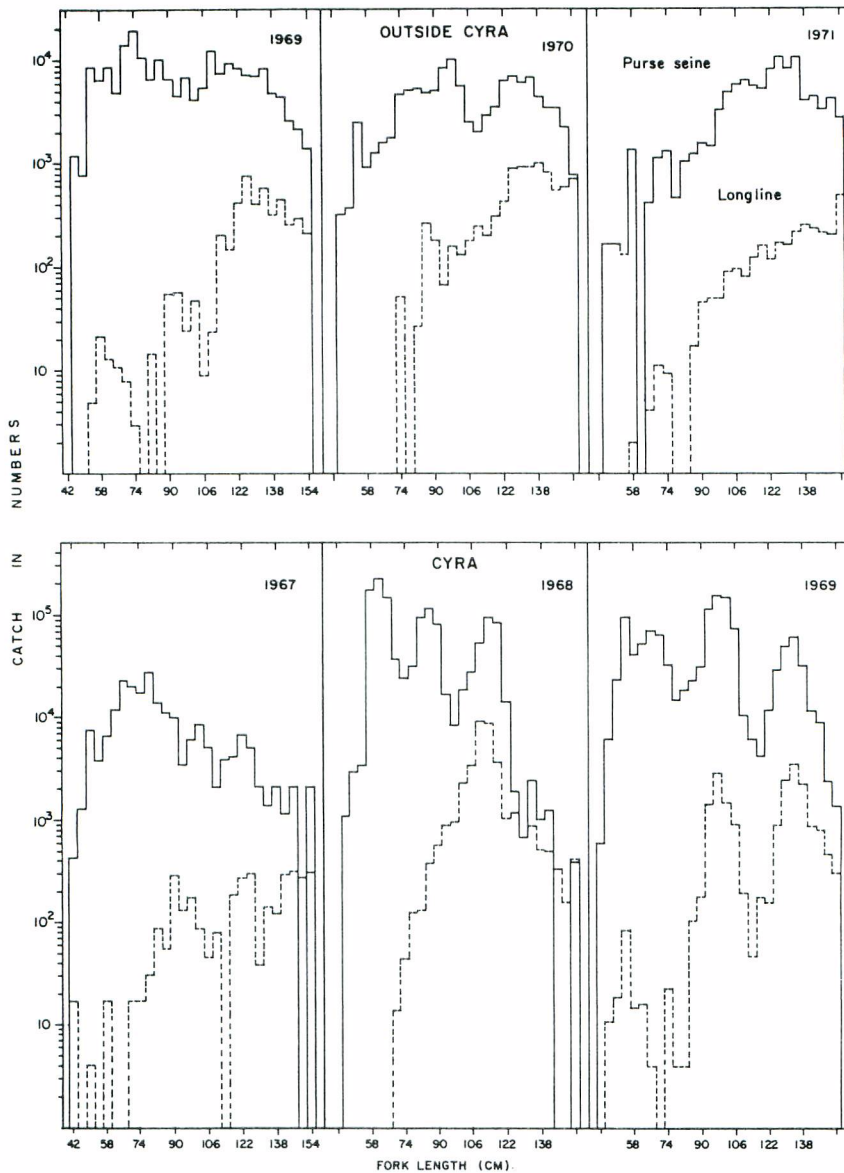


Fig. 11. Length composition of yellowfin tuna caught by purse seine (solid lines) and longline (dashed lines) boats in the same months of the same years and in the same $5^{\circ} \times 10^{\circ}$ area of the CYRA during 1967, 1968 and 1969, and outside the CYRA during 1969, 1970 and 1971.

After SUZUKI *et al.* (1978).

The data were available for 16 and 13 area-month strata in the CYRA and outside the CYRA, respectively.

in modal length for the smaller fish (Fig. 11). It is noted that the longline gear selectively catches larger fish above about 90 cm, while the purse seiner captures yellowfin tuna of much wider range from 40 to 150 cm. As purse seine fishery developed substantially in the 1970s, its catch of yellowfin

tuna has outnumbered the longline catch in any length classes in the recent years (MIYABE and BAYLIFF, 1987).

1 - 5 . Maturity of fish in the catch

KIKAWA (1962) describes that yellowfin tuna reach to adult stage at a fork length of 110 cm based on examination of gonad indices (GI) for the fish taken by longline in the whole Pacific Ocean. On the other hand, analysis of the GI by ORANGE (1961) indicates that 80 cm fish take significantly part in spawning in purse seine fishing ground of the eastern Pacific.

Since the longline and purse seine boats do not operate in exactly the same areas, SUZUKI *et al.* (1978) selected the area outside the CYRA bounded by 5° N-10° N and 120° W-145° W where both fisheries operated simultaneously. Female yellowfin tuna is considered ready to spawn with the GIs of 2.1 and over (KIKAWA, 1962). Although no data are available for purse seine-caught yellowfin tuna in the first quarter, it is obvious that the percentages with GIs of 2.1 and over in the same length class are considerably higher in the specimens caught by purse seine gear than those by longline gear in all months (Fig. 12). Both purse seine and longline specimens show high percentages of mature fish from April to September.

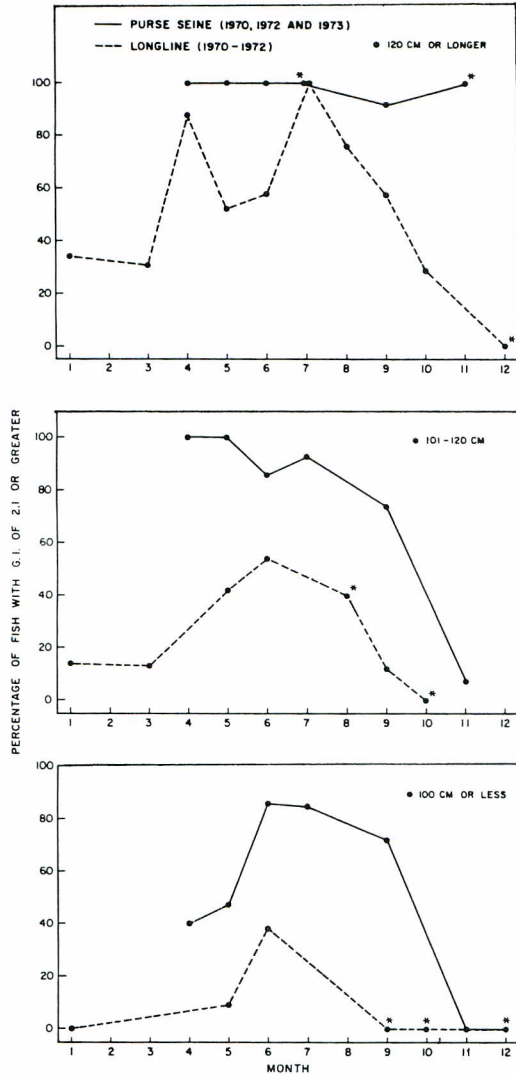


Fig. 12. Comparison of the percentages of female yellowfin tuna with GIs of 2.1 or greater caught by longline and purse seine boats in the area between 5° N and 10° N and between 120° and 145° W.

After SUZUKI *et al.* (1978).

Asterisks indicate the cases in which the rate of group maturity was calculated from less than ten specimens.

1 - 6 . Trends of fishing effort, catch and CPUE

Purse seine fishery

CYRA

Fishing effort of the purse seine fishery as such is not published. However, overall fishing effort by the surface fishery (IATTC, 1985) could be used as a measure to represent the magnitude and trend of effort by the purse seine, since the purse seine catch dominates overwhelmingly in the surface catch during the period of the study as mentioned before. Fishing effort of the surface fishery has been standardized in class 6 purse seine unit, the boats of 401 tons of carrying capacity and larger.

Fishing effort increased more than three times from about 10,000 standardized days fishing (SDF) in the 1960s to about 30,000 SDF around 1980 (Fig. 13, Table 3). In the 1980s, it decreased sharply. The purse seine fishery had been operating exclusively within the 200 mile zone by the early 1960s when the Japanese longliners started their operations in the CYRA.

The IATTC has routinely compiled number of fish caught by the surface fisheries by cohorts of X and Y each year. This data (provided by P. K. TOMLINSON, IATTC) was regarded here as those taken by the purse seine fishery by the same reason given in the previous effort section. The X and Y cohorts stand for two different segments of yellowfin tuna recruiting, about six months

Table 3. Fishing effort and CPUE for yellowfin tuna caught by surface fishery in the eastern Pacific Ocean, 1968-1983.

Year	Effort (SDF)		CPUE (tons/SDF)	
	Inside CYRA	Outside CYRA	Inside CYRA	Outside CYRA
1968	6335		16.4	
1969	7149	941	16.1	18.5
1970	8451	2623	15.3	10.6
1971	11607	2156	8.9	9.6
1972	8981	3593	15.4	11.3
1973	14149	3806	11.4	11.8
1974	19750	4000	8.8	9.3
1975	21622	3883	7.4	11.1
1976	23024	4000	8.3	11.5
1977	28323	1742	6.5	9.3
1978	27717	1648	6.0	8.8
1979	33377	1803	5.3	7.6
1980	31833	3296	4.2	8.1
1981	29463	3366	5.4	7.1
1982	24545	2250	4.4	8.0
1983	16480	1968	5.0	6.2

SDF denotes standardized days fishing in class 6 purse seine unit.

Data from IATTC (1985).

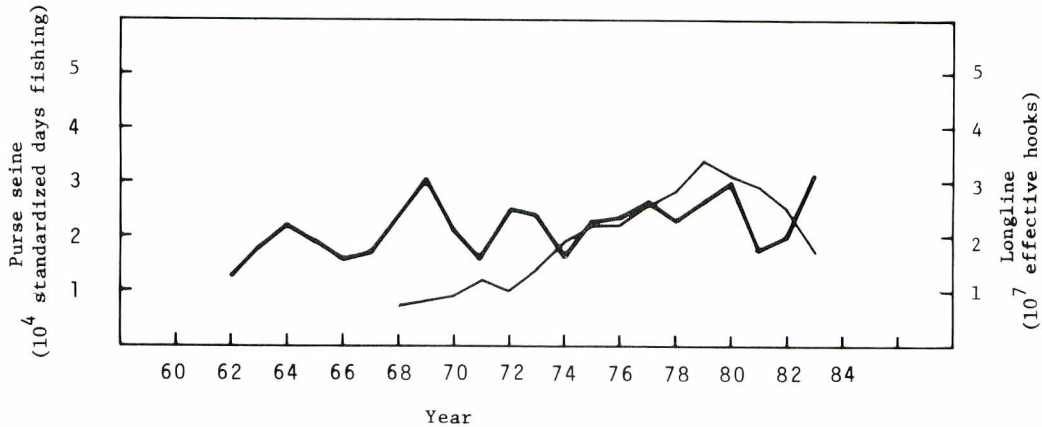


Fig. 13. Trends of fishing effort on yellowfin tuna by the Japanese longline (heavy line) and purse seine (thin line, IATTC 1985) boats in the CYRA.

apart each other, to the surface fishery. It is defined that a cohort consists of all the fish recruited to the fishery at the same time. For example, the X 70 cohort first enters the fishery in small numbers during the first half of 1970 and contributes to it significantly for the first time during the second half of that year. The Y 70 cohort enters the fishery in small numbers during the second half of 1969 and contributes to it significantly for the first time during the first half of 1970. For comparing with the longline fishery, the purse seine catch compiled by the cohorts was divided into small and large fish. Size of the large fish was set to accord roughly with that taken by longliners, larger than 90 cm and 110 cm which correspond to the Y and X cohorts recruited to the fishery 7th and 9th quarters after birth, respectively. The fish larger than 90 cm for the Y cohort and the fish larger than 110 cm for the X cohort were summed up each year for comparison with the longline catch.

From the latter half of the 1960s to the middle of the 1970s, the catch both for large and small fishes increased rapidly due to expansion of the fishing ground toward offshore areas and development of the dolphin-associated fishery. The catch, however, has been decreasing for both size classes afterward, especially in the turn of the 1980s reflecting shift of fishing effort from the eastern to the western Pacific (Fig. 14).

There appears no single series of CPUE common to 21 years from 1962 to 1983 due to the change of reference vessel size category used to standardize the fishing effort which reflects tremendous increase of the fishing efficiency during the period. CPUE shows consistent decreasing trend from 1968 up to 1980 (Fig. 15, Table 3).

Outside the CYRA

After the significant start of purse seining in 1969, fishing effort increased to a peak of 4,000 SDF in 1974 and 1976, and showed sharp decline, especially from 1976 to 1977 (Fig. 16, Table 3). Accordingly, amount of catch increased up to about 45,000 tons in 1976, and decreased since then (Table 2). Decline of catch occurred for the large-sized fish, while the small-sized fish did not show

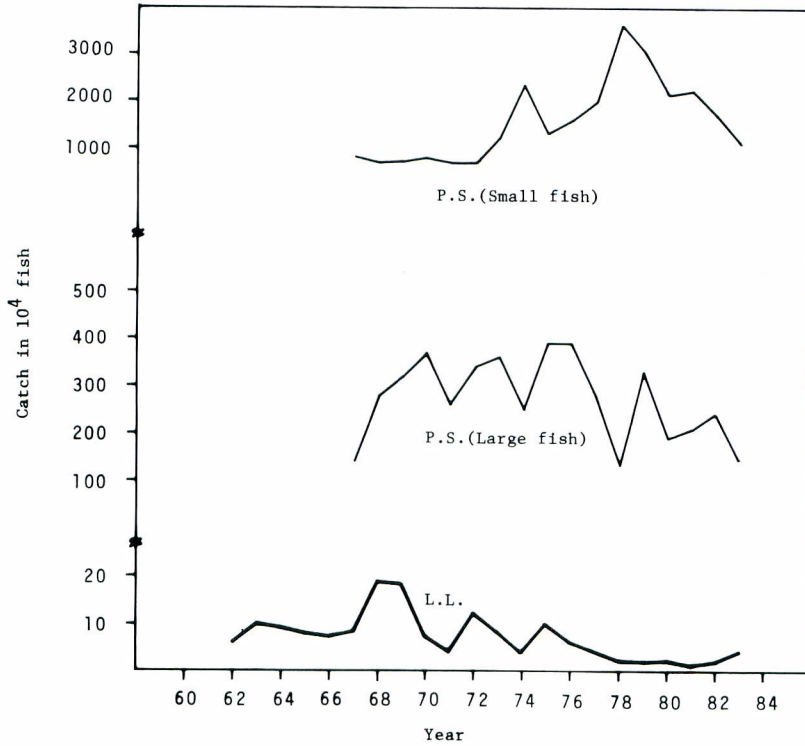


Fig. 14. Yellowfin tuna catch in number of fish by purse seine (P.S.) and longline (L.) vessels in the CYRA. Catch by purse seiners divided into smaller and larger fish. See text for definition of the small and large fishes.

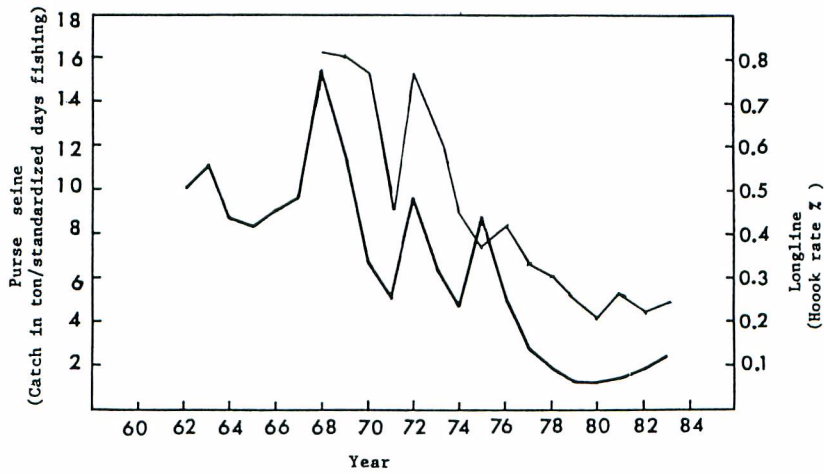


Fig. 15. Trend of longline (heavy line) and purse seine (thin line, IATTC 1985) CPUE for yellowfin tuna in the CYRA.

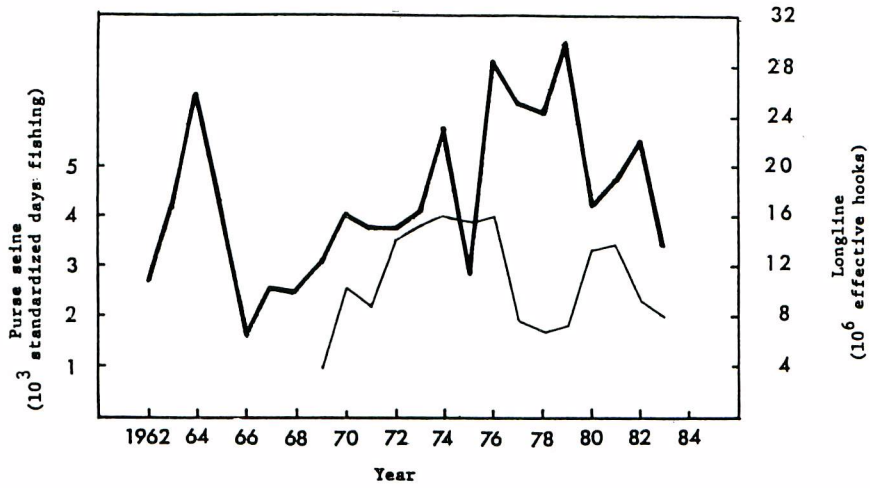


Fig. 16. Trends of fishing effort on yellowfin tuna by the Japanese longline (heavy line) and purse seine (thin line, IATTC 1985) outside the CYRA.

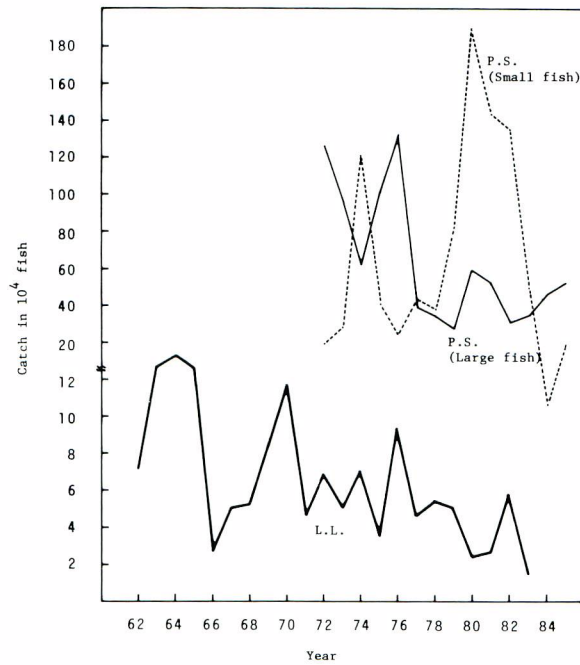


Fig. 17. Yellowfin tuna catch in number of fish by purse seine (P.S.) and longline (L.L.) vessels outside the CYRA.

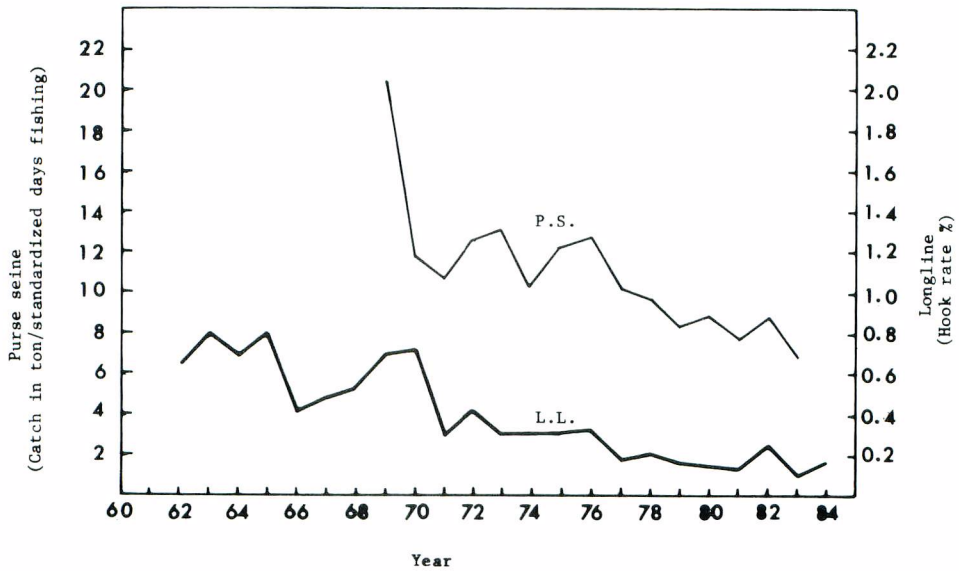


Fig. 18. Trends of purse seine (P.S., IATTC 1985) and longline (L.L.) CPUE for yellowfin tuna outside the CYRA.

any trend of catch from 1972 to 1983 (Fig. 17). A consistent decline of CPUE was observed during the period under study (Fig. 18).

Longline fishery

CYRA

The Japanese longline fleet operates widely over the whole eastern Pacific Ocean between Lat. 40° N and Lat. 40° S, while the purse seiners fished mainly north of Lat. 10° S. Therefore, here are selected the relevant longline data including fishing effort, catch and CPUE in the CYRA, north of Lat. 10° S, for comparison to those of purse seine fishery.

The standardized longline effort fluctuated between 10 and 30 million hooks from 1962 to 1983 without any consistent trend (Fig. 13). The longline catch peaked in 1968, about 200,000 fish, then showed decreasing trend to 1983 with temporal increases in 1972 and 1975. The catch in 1983 is only about 40,000 fish (Fig. 14). CPUE of the longline fleet in terms of hook rate showed a sharp decreasing trend, from about 0.5 fish per 100 hooks in 1962 to 0.1 in 1983 with some sparks in several years (Fig. 15).

Outside the CYRA

The area between Long. 120° W and Long. 150° W and between the equator and Lat. 20° N was chosen as outside the CYRA for the longline fishery taking into account its areal integrity of the fishing ground.

After a peak in 1964, the longline fishing effort decreased sharply to 1966, then showed increasing trend up to 1979 followed by decrease to 1983 (Fig. 16). The catch and CPUE showed a general decreasing trend throughout the period studied (Fig. 17 and Fig. 18). The CPUE decreased to

about one fourth from the period 1962-1965 to the period 1980-1983.

2 . Western Pacific Ocean

2 - 1 . Types of fisheries

The western Pacific Ocean is the most fertile area for yellowfin tuna. In fact, the FAO fisheries statistics show that the "Pacific, Central west", covering the waters under discussion, has

Table 4. World catch of yellowfin tuna by FAO fishing area, 1980-1983.

Year	unit : tons			
	1980	1981	1982	1983
Grand Total	529021	571844	524839	533629
Atlantic Total	117096	134921	124832	140959
Northwest	531	1405	359	417
Northeast	12	8	646	166
Central west	4976	6648	5943	23359
Central east	109467	123841	112889	111176
Medit. & Black Seas	-	-	-	5
Southwest	493	523	715	621
Southeast	1617	2496	4280	5215
Indian Total	35428	37607	45073	53618
Western	22405	29088	38062	45950
Eastern	13023	8519	7011	7668
Pacific Total	376420	399280	354934	339052
Northwest	42014	33330	32169	33327
Northeast	-	-	8	8
Central west	158843	180904	172855	181610
Central east	151905	167207	137177	116329
Southwest	10441	6117	6743	1793
Southeast	13217	11722	5982	5985

Data from FAO Fisheries Statistics vol. 56 (FAO 1984).

comprised the largest share of production of yellowfin tuna, at least during 1980-1983 period (Table 4). In the area, however, yellowfin tuna stays at the second rank of catch among tuna species after skipjack (Table 5). Before 1972, Japanese longline fishery produced the major part of tuna catches in the western Pacific (SUZUKI, 1986a). However, its share has been declining, due to development of other fisheries. A variety of local tuna fisheries also has long been existing.

The Japanese longline has a long history. The operation of longlining was confined to the northwestern Pacific and did not last throughout the year in and before the 1940s. In that old period, the fishing boats were used as skipjack baitboats in the warmer months and as longline boats in the

Table 5. Catch of tuna and tuna-like fishes by country in the central western Pacific area, 1983.

unit : tons

Country	Skipjack	Albacore	Yellowfin tuna	Bigeye tuna	Total
Fiji	3699	2515	1586	14	7814
Indonesia	56030	-	30390	-	86420
Japan	144454	7425	74818	21755	248452
Kiribati	2049	-	2135	-	4184
Korea, Rep.	15419	509	1156	319	17403
Pac. Is. Tri. Tr.	5388	-	-	-	5388
Philippines	59489	-	53074	-	112563
Singapore	7	-	-	-	7
Solomon Isls.	30904	9	2886	15	33814
U.S.A.	20972	1004	14507	4	36487
Others, n.e.i.	-	2535	1058	449	4042
Total	338411	13997	181610	22556	556574

Data from FAO Fisheries Statistics vol. 56 (FAO 1984).

colder months of the year. After 1952, the longline fishery developed remarkably equipping with advanced navigation and freezing techniques, and expanded the fishing ground, having covered most of the tropical waters by the mid 1950s (Fig. 2). In the late 1960s, the longline fishing grounds expanded toward the higher latitudes reflecting the shift of target species from yellowfin tuna and albacore to bigeye and southern bluefin tunas.

After Japanese, Taiwanese and Korean tuna fleets started distant water longlining in this area from 1954 and 1964, respectively. Their major fishing operations occur south of the equator. The Philippines and Indonesia produce significant amount of yellowfin tuna. The US catch increased in the recent years to a recognizable amount (Table 5).

Before the mid 1970s some Japanese purse seiners fished in the western equatorial Pacific Ocean only during northern winter, offseason for exploiting tuna in the Japanese waters. But there were no extensive operations there. In 1977 the Japanese fishermen discovered it easy to catch tunas associated with such materials as logs, and established year round operations in the western equatorial Pacific Ocean. The discovery resulted in sharp increase of amount of fishing effort and catch in the waters north of Papua New Guinea (HONMA and SUZUKI, 1978). Taiwanese and Korean fishermen followed the Japanese fleet in the late 1970s and fishing activity increased dramatically by introduction of super seiners from the eastern Pacific Ocean in the turn of the 1980s.

Besides, there has been coastal purse seining for tuna in the Philippines. This type of operation developed by the use of payao, a fish aggregating device. WHITE (1982) reported that the Philippino hand-lining captured about 40,000 tons of yellowfin tuna in the inshore area in 1980. Also Indonesia joined significantly in surface fishery aiming at tuna mainly with the use hand-lining and trolling gears. Furthermore, there are many artisanal fisheries in these two countries. Table 5 may

not comprise producer of a member of artisanal fisheries for yellowfin tuna in the South Pacific island countries.

In spite of existence of the active fishing industries in the western Pacific, the researches on tuna resources are mostly left to the national effort, especially in Japan and Taiwan. Recent international coordination covers relevant activities of the Food and Agriculture Organization (FAO) and the South Pacific Commission (SPC). The FAO held several international workshops and related meetings. The Indo-Pacific Tuna Development and Management Programme was established in 1981 for compiling catch and effort statistics of tunas and related species in the Indian Ocean and the western Pacific Ocean. The SPC conducted an extensive tagging programme of skipjack tuna during 1977 through 1980, and collected information on the regional fisheries in the South Pacific island countries. However, these international coordinating activities have not been effective to establish a comprehensive data base.

Lack of basic statistics for several major fisheries forms one of obstacles for conducting the study on gear interactions in the western Pacific Ocean. International arrangement might solve the data problem on the industrialized fisheries. But present unsatisfactory state requires more intensive work on data collection in the waters under discussion than in the other two areas, because of presence of small-scale but significant fishing activities in the coastal waters. Under these circumstances, interaction aspects between longline and purse seine fisheries were analyzed on the basis of the well monitored Japanese fishery.

2 - 2 . Fishing grounds and fishing seasons

Longline fishery

High hook rate occurs in the area between about Lat. 5° N and 10° S and west of Long. 140° W (Fig. 3). However, it narrows to an area between Lat. 5° N and 5° S in the east of the date line. There are few seasonal changes in the distribution of hook rates in this region, except that the high hook rate areas in the eastern part decrease in the third and fourth quarters. Moderately high hook rates extend from the western part of this region up along the Kuroshio Current and curving down along the East Australian Current in accordance with the seasonal strength of these currents, although local patches of high catch rates off Sydney, Australia, seem to persist nearly all year (Appendix Figure).

Purse seine fishery

Fishing ground is restricted to a limited area, mostly north of Papua New Guinea (Fig. 19). Like in the case of the longline operations, seasonal changes is not remarkable in the distribution of catch of the Japanese purse seine fleet. Only few data were made public on fishing activities of the US purse seine fleet, but the fleet seemingly operated in the waters farther southeast of the Japanese fishing grounds.

2 - 3 . Factors affecting the success of fishing

Fishing performance of longlining has been stable throughout the year in the western Pacific Ocean. However, purse seine boats often failed the operation before 1977, due to deep thermocline, about 100 to 150 m below the sea surface, beyond the hanging depth of about 100 m of nets, in addition to high transparency of the sea water. Technical advances, represented by pursing schools

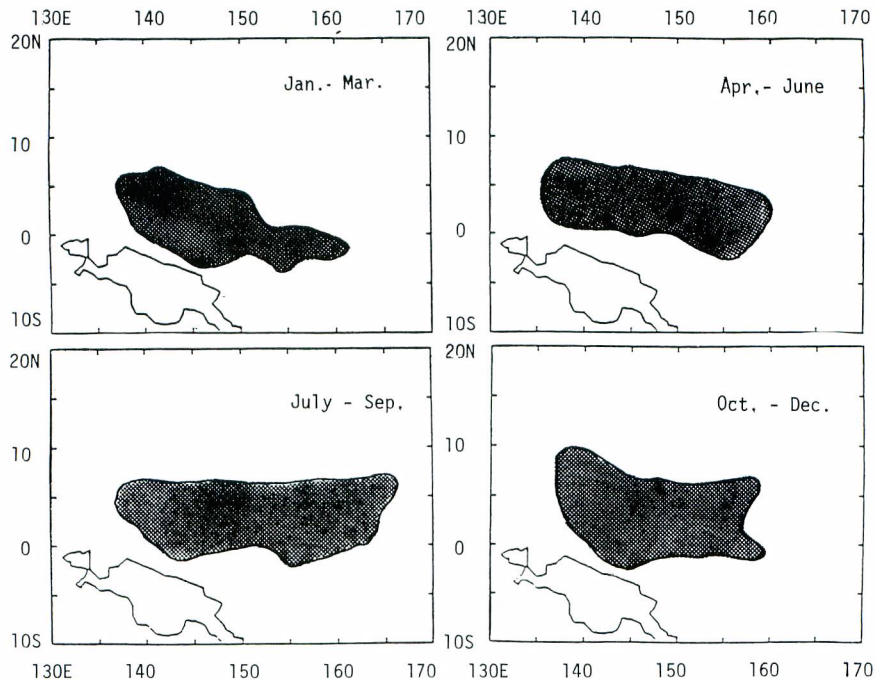


Fig. 19. Schematic presentation of quarterly extent of purse seine fishing ground for Japanese purse seine boats in the western Pacific during 1981 and 1982.

aggregated with drifting logs, assured stable operations.

No significant heterogeneity is observed in the distribution of CPUE for the purse seine fishery due probably to the limited extent of fishing ground, mainly around the North Equatorial Counter Current System, which corresponds to the range of abundant drifting logs. Artificial drifting objects or payaos have been adopted to attract small-sized yellowfin tuna and skipjack. However, the utility of this device is believed not to be high given relatively short duration of the devices and plenty of natural drifting objects in the area. The purse seine fishing is difficult to catch free swimming school fish in the western Pacific due to the unfavorable oceanographic conditions previously mentioned.

Thermocline topography also affects the success of longline fishery too. Namely, high hook rate areas for yellowfin tuna captured by the Japanese longliners, south of Lat. 5° N in the western Pacific, roughly correspond to deep thermocline waters. A detailed documentation for this subject could be found in the study of deep longlining (SUZUKI *et al.*, 1977).

2-4. Size of fish in the catch

Longline fishery

SUZUKI *et al.* (1978) compiled length composition of yellowfin tuna taken by the Japanese longline boats for the period 1966-1972, tabulated by quarters, areas of 5° latitude by 10° longitude and 2-cm length intervals. Although there are yearly variations in areal patterns of the length

composition, it can be noted that there is a consistent tendency for large individuals to become increasingly dominant from west to east in the three major areas (Fig. 10). Fish caught by the longline boats are smaller in the western Pacific than the counterparts from the central and eastern Pacific. Relatively small-sized fish ranging from 90 cm to 130 cm dominate in the former but not in the latter.

Purse seine fishery

Fig. 20 shows size of yellowfin tuna captured by the Japanese purse seine boats in 1981 and

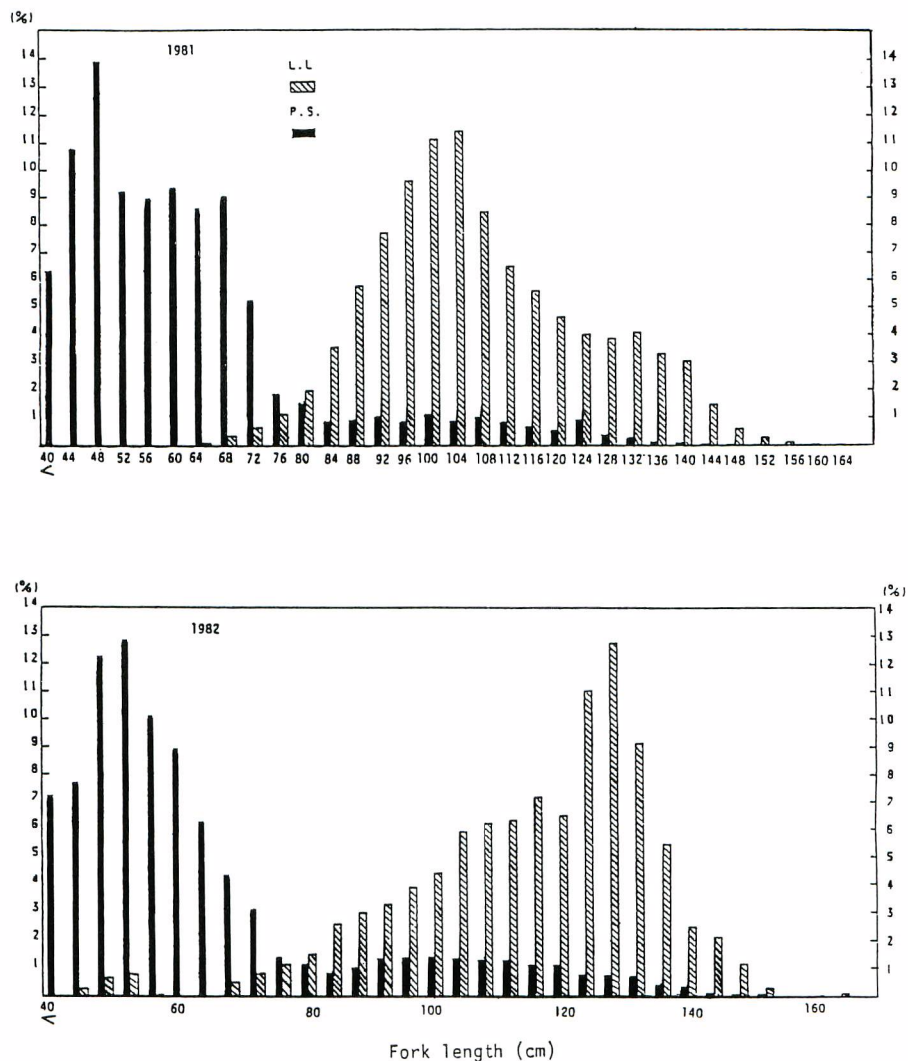


Fig. 20. Comparison of length composition of yellowfin tuna taken by Japanese purse seine (P.S.) and by Japanese longline boats (L.L.) in the main purse seine fishing ground (0-10° N, 140° E-160° E) for 1981 and 1982.

1982. The catch is dominated by fish less than 70 cm with minor catches of larger fish up 140 cm. The school type is a major factor determining the size of fish in the catch. Yellowfin tuna associated with logs is the smallest, mostly less than 70 cm, whereas large fish over 100 cm to about 150 cm dominates in free swimming school fish. The size of fish associated with whale and shark schools appears to be intermediate between the two school types.

Fig. 20 also compares the size of fish by the two gears, the length composition of the catches by the purse seine boats in the whole purse seine fishing ground and that by longline boats operating in roughly the same areas between 0-10° N and 140-160° E. Although the composition of the longline catch differs year by year, the longline fishery appears to catch larger fish than about 90 cm in fork length and the purse seine boats smaller fish than about 70 cm. According to age-length relation estimated by YABUTA, YUKINAWA and WARASHINA (1960), the two fisheries selectively catch the fish differing one to three ages.

2 - 5 . Maturity of fish in the catch

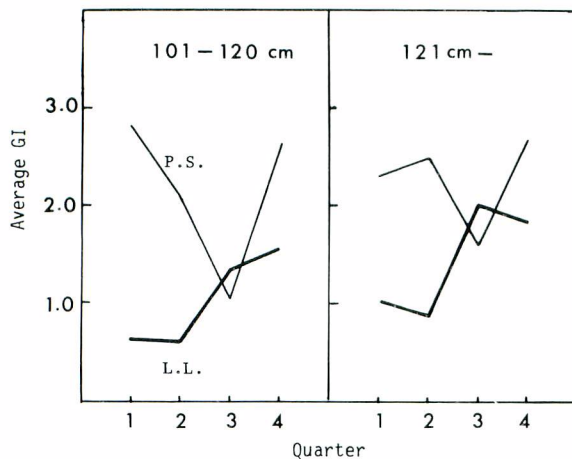


Fig. 21. Quarterly change of average gonad indices (GI) for yellowfin tuna caught by purse seine boats (P. S.) and longline boats (L.L.) in the equatorial western Pacific.

that of the longline samples (Fig. 21). This might be due to small sample size of yellowfin tuna caught by the purse seine. However, except for the third quarter, the females captured by the purse seiners appear to have higher maturity than those by the longliners.

2 - 6 . Trends of fishing effort, catch and CPUE

Fig. 22 shows annual trends of catch in number, effective effort and CPUE for yellowfin tuna caught by the Japanese longline boats operated in the western Pacific west of Long. 180°, south of Lat. 40° N and north of 40° S. Fishing effort showed first peak in the early 1960s, followed by temporal decrease, again turned to increase at the beginning of the 1970s and attained the highest level in the early 1980s. Yellowfin tuna catch showed similar trend with that of fishing effort. However, CPUE has decreased to about one half from 1960 to 1972 and then fluctuated without

Studies on reproductive biology of yellowfin tuna basing on the longline data in the western Pacific indicate the spawning activity increase in the third and fourth quarters (*e. g.*, Kikawa, 1962). To compare maturity of fish taken by the Japanese longline and the Japanese purse seine fisheries, GI was calculated from the fish taken in an area between Lat. 10° S and 10° N and between Long. 130° E and 160° E. The longline data consist of 3,027 females sampled from 1970 to 1972 and the purse seine data of 72 females in 1985. The seasonal trend of average GI from the longline samples corroborates the past works, whereas the trend of the purse seine samples seems different from

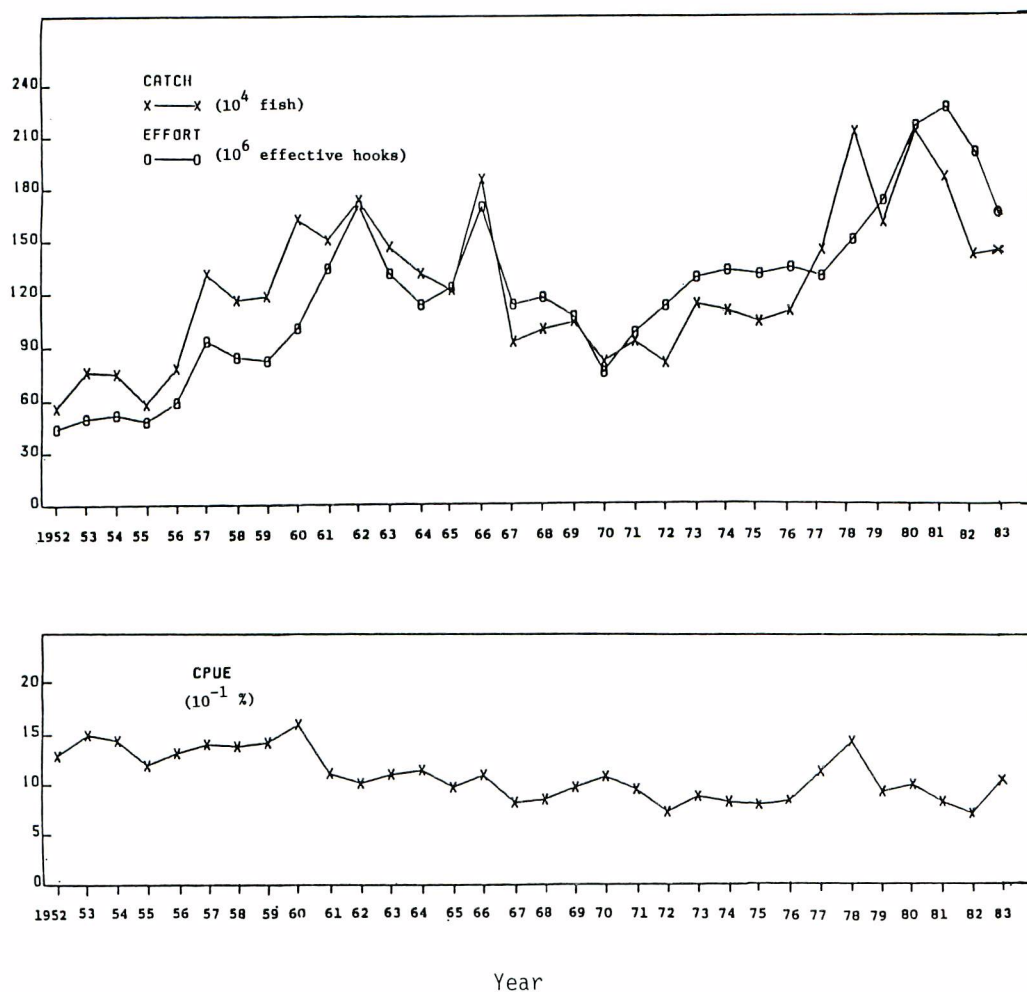


Fig. 22. Annual trends of catch in number and fishing effort in number of effective hooks (upper panel) and CPUE (lower panel) for yellowfin tuna caught by the Japanese longline fishery in the western Pacific.

trend up to 1983.

After establishment of year round operations since 1977 by the discovery of log school fishing, purse seine fishing effort and catch increased sharply especially in the 1980s (Fig. 23, upper panel). Since 1982, the number of the Japanese distant water seiners have been limited to 32 by the government for the purpose of managing domestic fisheries and no significant increase of catch was observed thereafter. The fishing effort shown in Fig. 23 is nominal value since it was not possible at present to calculate reasonable effective effort that takes account of unique operations

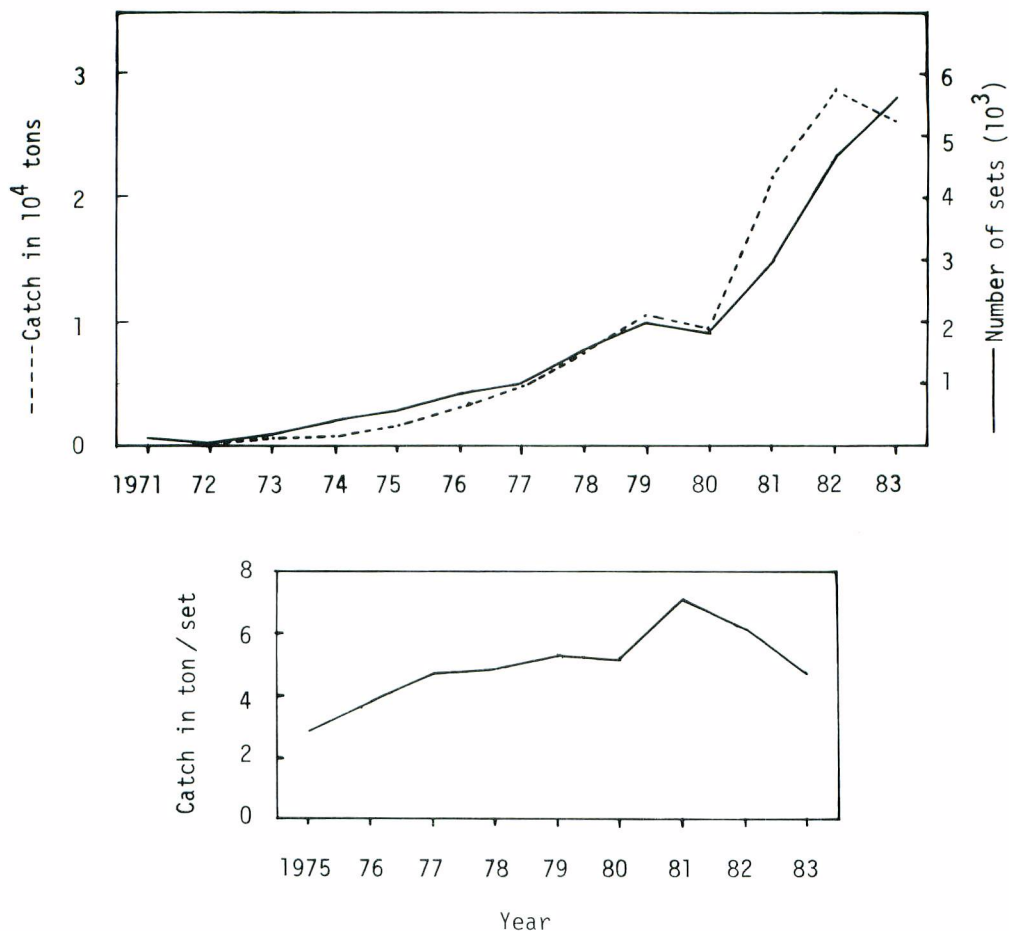


Fig. 23. Trend of number of sets, and yellowfin tuna catch (upper panel) and CPUE (lower panel) for Japanese purse seiners operating in the equatorial western Pacific.

by the purse seiners such as usage of radio buoys attached to the drifting logs and making successive sets for specific logs etc. CPUE increased, after 1977 when all year round operations were established, up to 1981 but some decrease was indicated in 1982 and 1983 (Fig. 23 lower panel).

3. Eastern Atlantic Ocean

3-1. Types of fisheries

In the Atlantic Ocean, tuna fisheries for temperate species have a long history especially among the European countries such as Spain and France. There is a variety of artisanal fisheries in African countries as well as in Iberian Peninsula. However, distant water fishery for tropical species, represented by yellowfin tuna and skipjack which dominate in the Atlantic tuna fisheries

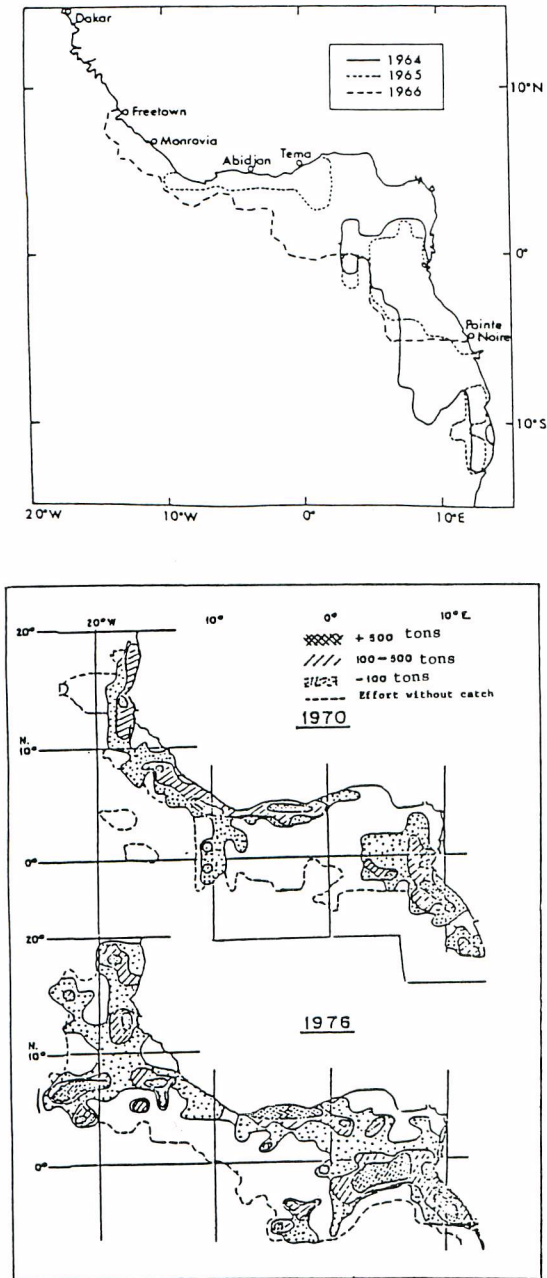


Fig. 24. Expansion of FISM purse seine fleet in the eastern Atlantic Ocean. After HONMA *et al.* (1969) and FONTENEAU and MARCILLE (1978) for upper and lower panels, respectively. See text for explanation of the FISM.

was initiated by Japanese longline boats. The Japanese longline boats started their operations in 1956 from the Caribbean Sea. They aimed at yellowfin tuna in the tropical waters at the beginning of the exploitation and covered the whole main distribution areas of yellowfin tuna by the turn of the 1960s. Then, as usual case in their history, they shifted the target to bigeye and bluefin tunas in the higher latitudes. Taiwan and Korea joined to the Atlantic longline fishery in 1962 and 1964, respectively.

The pure seine fishing replaced the longlining in exploitation of the tropical tunas due to high fishing efficiency. French fishermen started the purse seining in the water along the Gulf of Guinea in the early 1960, and expended their operations after construction of freezing facilities, first in Pointe-Noire, Congo (LE GUEN, POINSARD and TOADEC, 1965). Purse seine fishing grounds covered most of the coastal areas of the Gulf of Guinea from Freetown to the area off Angola by the end of the 1960s (Fig. 24).

The purse seining activity then dispersed among west African countries inclusive of Ivory Coast, Senegal and Morocco. Boats from the four nationalities behave closely cooperating each other, and are called FISM fleet. Spain and the USA joined in the purse seine fishery, the former developed into a comparable fleet size to the FISM fleet but the latter decreased and now consists

of only minor fraction.

Purse seine fishing ground expanded to the offshore areas in the late 1970s (Fig. 24). The fishing effort and catches of the purse seine fishery increased substantially. More than 80% of yellowfin tuna catch in the eastern Atlantic has been made by the purse seine fishery.

Table 6. Catch of major tunas in the Atlantic Ocean in 1950, 1961 and 1983.

Species	unit (1000 tons)			
	1950	1961	1983	Increment (1983/1950)
Yellowfin tuna	1.2	59.1	131.5	109.6
Skipjack	0.7	5.9	131.7	188.1
Bigeeye tuna	0.8	17.0	54.4	68.0
Bluefin tuna	19.9	22.4	10.8	0.5
Albacore	39.6	53.3	64.7	1.6
Blackfin tuna	0.3	0.4	1.5	5.0
Southern bluefin tuna	0	0	0.6	-
Total	62.5	158.1	395.2	6.3

Data from ICCAT (1982a, 1982b and 1984a).

Table 6 shows catch of Atlantic tunas by species in 1950, before introduction of Japanese longline fishery, in 1961 when the longline fishery was at its peak, and in 1983 the latest year in the study. The Atlantic tuna stocks are being managed by the ICCAT which entered into force in 1969. Fishing regulation for Atlantic yellowfin tuna now under way is minimum size regulation in which small fish less than 3.2kg (about 55 cm in fork length) can be taken within 15% allowance in the total yellowfin tuna catch in weight.

3 - 2 . Fishing grounds and fishing season.

Longline fishery

Fig. 25 shows distribution of average hook rates of yellowfin tuna for the Japanese longline fishery from 1967 to 1972. Equatorial eastern Atlantic centering on the Gulf of Guinea was chosen because both longline and purse seine fleets extensively operated in the area.

Major longline fishing grounds are located in the tropical areas between Lat. 10° N and 10° S throughout the year. However, the fishing ground shows some expansions to the north of Lat. 10° N in the period between August and November and to the south of Lat. 10° S from March to April. Although the operations in the inner part of the Gulf of Guinea are scarce from May to September, the hook rates of this area during that period somewhat decrease with respect to other seasons (HONMA and HISADA, 1971).

Purse seine fishery

Although purse seine fishing ground expanded to offshore areas, they are still confined to the coastal areas compared with those of the longline fishery. Distribution of average catch by month by the FISM purse seine fleet was computed for the years from 1978 to 1982 (Fig. 26). The purse seine fishing ground shows a remarkable seasonal change. Peaks of the fishing activity occur from May

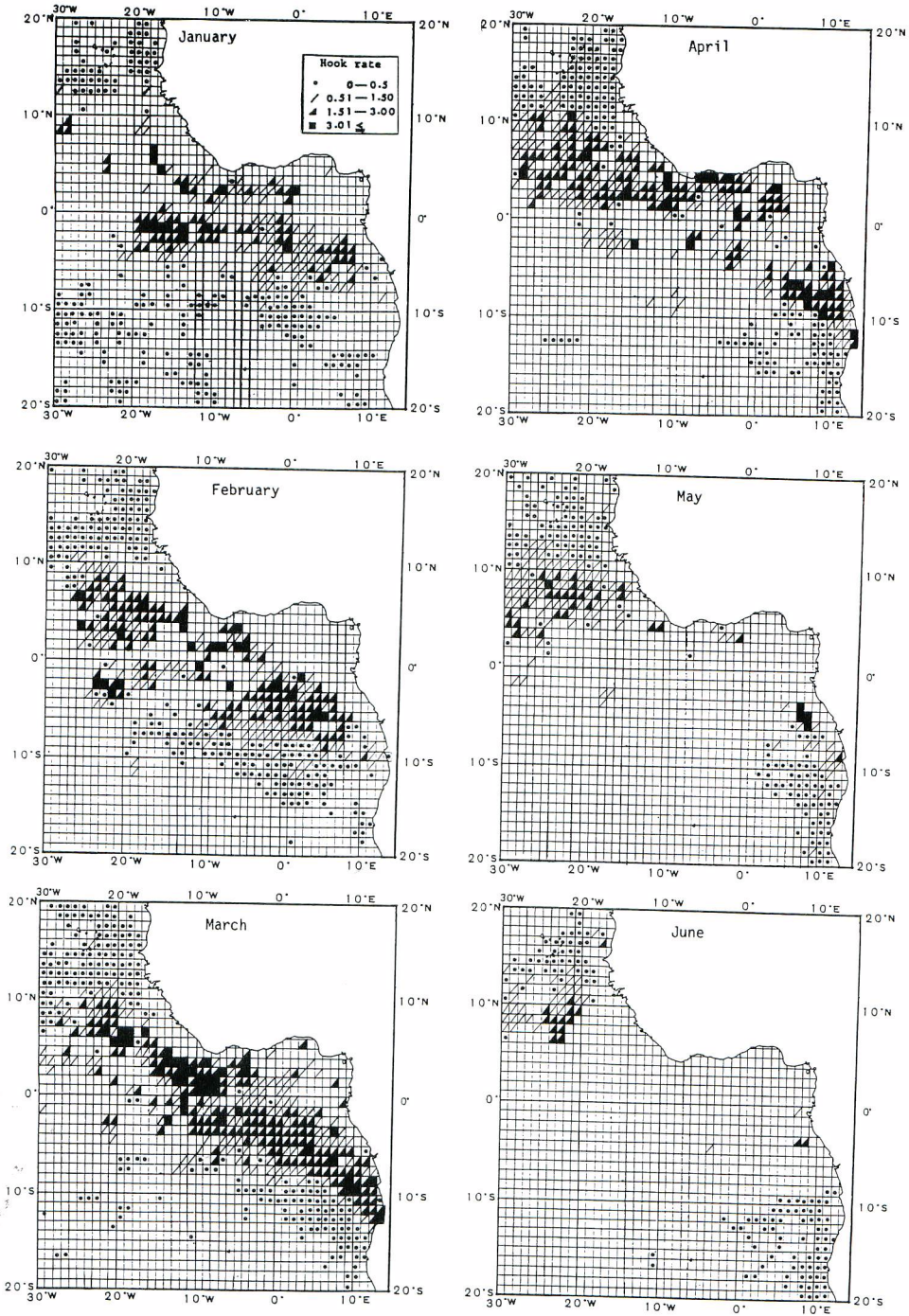


Fig. 25. Monthly distribution of average hook rates for yellowfin tuna caught by Japanese longline boats for the period 1967 through 1972.

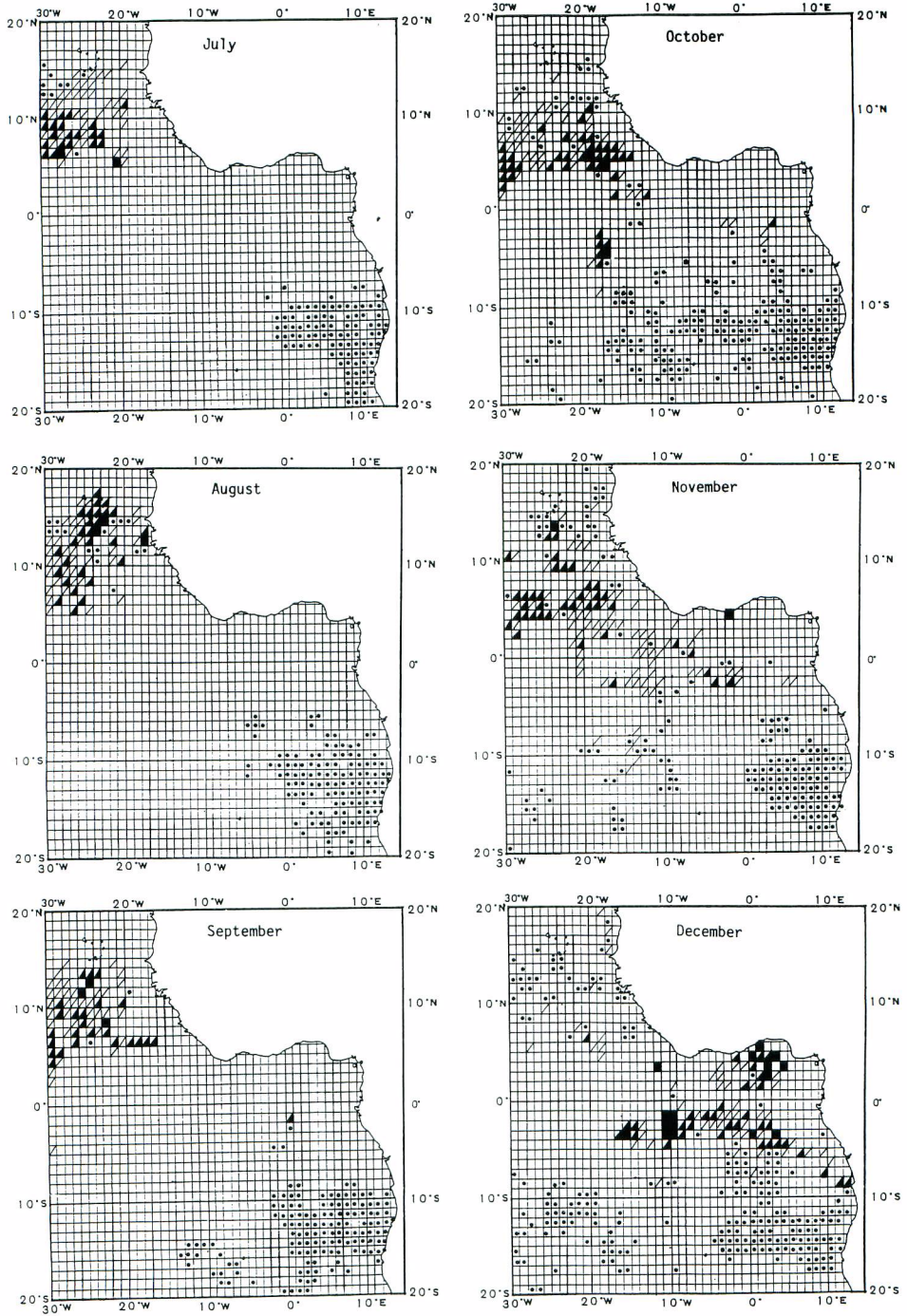


Fig. 25. Continued.

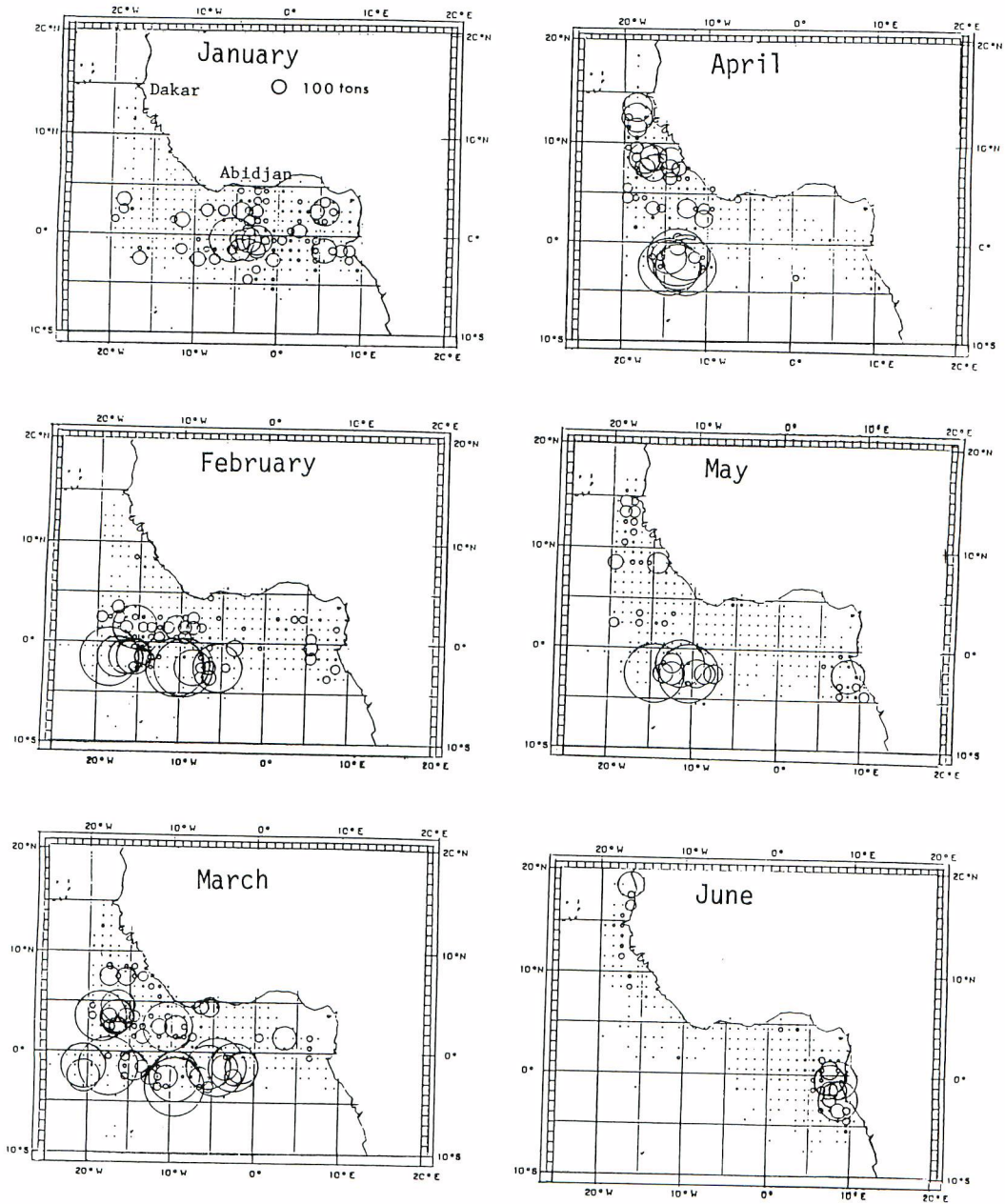


Fig. 26. Monthly distribution of average yellowfin tuna catch by the FISM purse seine fleet for the period 1978 through 1982.

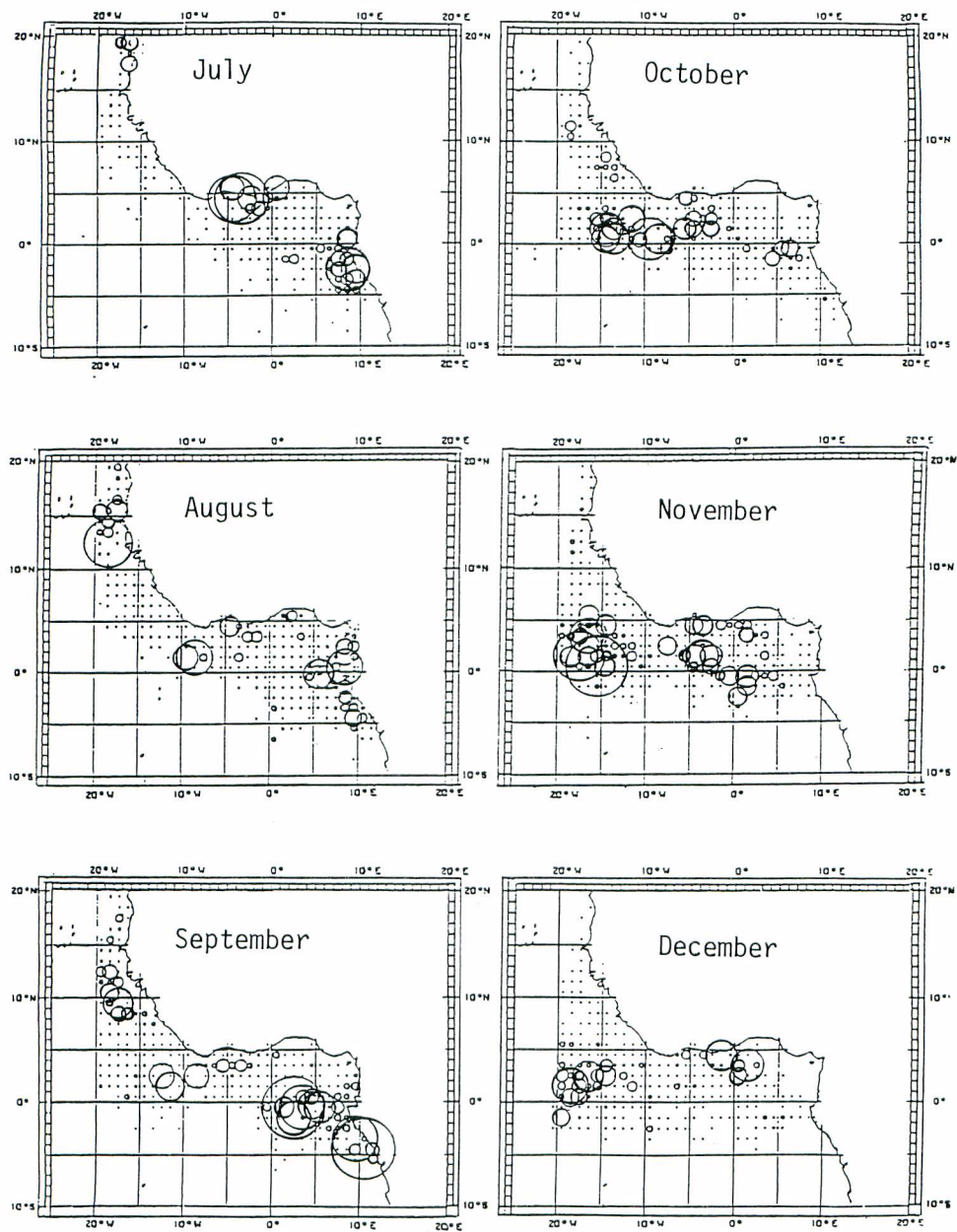


Fig. 26. Continued.

to September off Dakar, from January to May and from October to December off Abidjan and from June to September in the inner part of the Gulf of Guinea.

3 - 3 . Factors affecting the success of fishing

Generally longline boats set their hooks from 50 m to 250 m deep below the sea surface. Therefore, there will be a higher probability to encounter yellowfin tuna by the longline gear in the areas where vitally important factors such as water temperature, dissolved oxygen and salinity that define the habitat are favorable in addition to adequate food animals available to yellowfin tuna. On the other hand, the areas where yellowfin tuna tends to congregate near the sea surface could become fishing grounds of the purse seine fishery.

As mentioned previously, thermocline topography, which represents other factors than temperature as well to some extent is one of the most critical factors both for longline and purse seine fisheries. The surface temperature drops as low as 23° C in the Gulf of Guinea despite its location near the equator when the Benguela Current expands its influence northward during the southern winter from July through October. When thermocline becomes shallower, it forces the habitat of yellowfin tuna nearer to the surface, thus lets yellowfin tuna more vulnerable to surface fishing gears.

The depth of thermocline in the periods between February and May and between July and October is shown schematically in Fig. 27. Areas with shallow thermocline, not deeper than 50 m from the sea surface are shown shaded in the Figure taking into account the general facts that the longline hooks set deeper than 50 m on an average. The areas with shallow thermocline expand

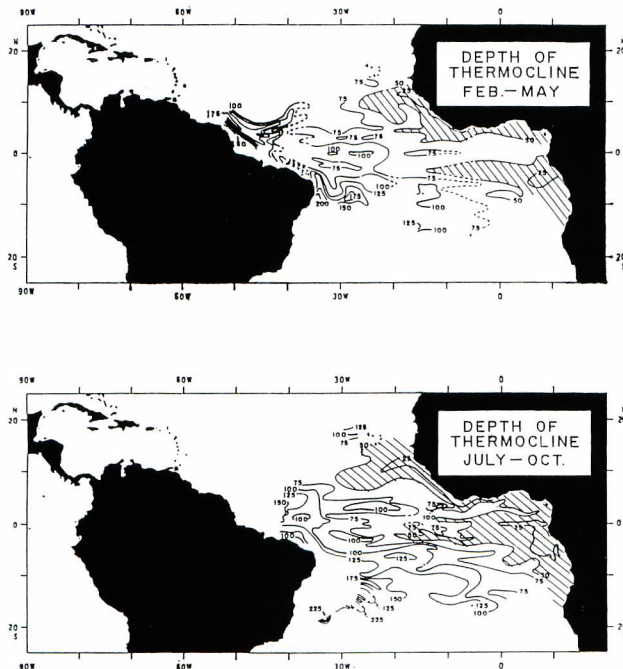


Fig. 27. Depth of thermocline for February to May (upper) and for July to October (lower).

After KAWAI (1969).

Numbers and shaded parts in the Figure denote thermocline depth in meter and shallow thermocline areas less than 50 meters from the sea surface, respectively.

from July to October. Seasonal changes of the depth of thermocline appears to explain the location of longline fishing ground in more offshore areas than that of purse seine and the reverse of peak fishing season in the inner part of the Gulf of Guinea from December to April for longliners and from June to September for purse seiners.

3 - 4 . Size of fish in the catch

FONTENEAU (1986) compared length composition of yellowfin tuna caught by purse seine and longline boats in the eastern Atlantic, east of Long. 30° W. As in the case of other oceans, the longline gear is selective for fish larger than about 90 cm (Fig. 28). Very large yellowfin tuna over

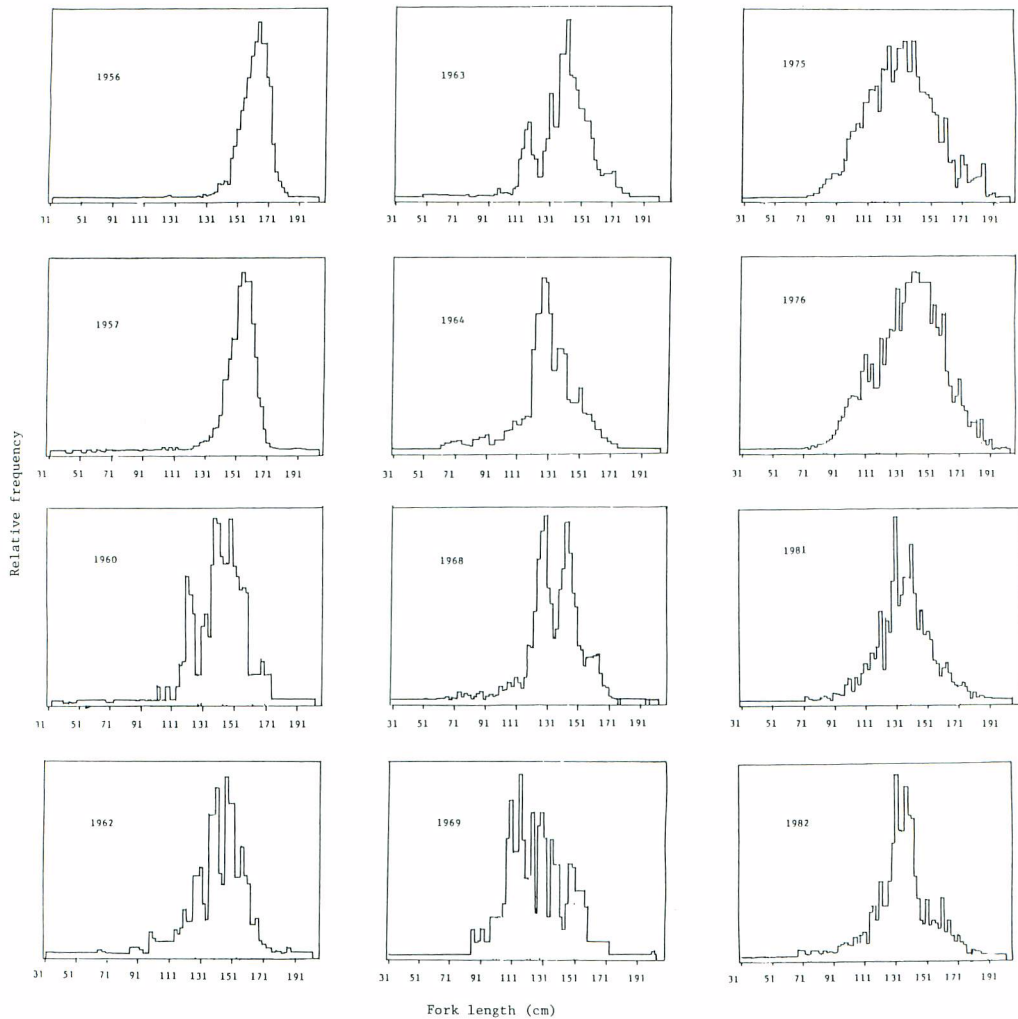
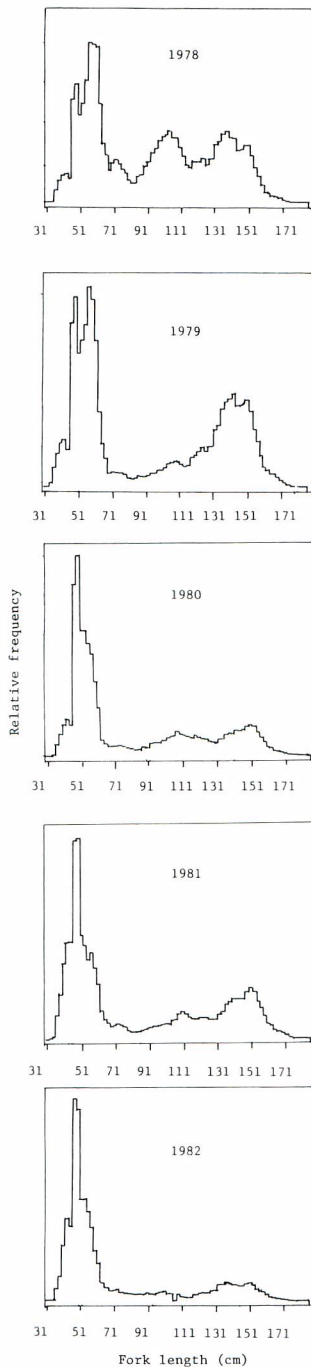


Fig. 28. Length composition of yellowfin tuna caught by longline boats operated in the eastern Atlantic (FONTENEAU 1986). Numbers in the Figure denote year.



150 cm dominated in the early period of the longline fishery operated in the tropical areas. The size of fish in the longline catch showed a clear trend of becoming smaller especially in the 1960s. This change partly reflects the expansion of the longline fishing grounds due to shift of target species distributed in the higher latitudes where smaller yellowfin tuna is usually caught.

The size of fish in the purse seine catch also shows significant change during the course of the development. Until the early 1960s, most of catch was composed of juvenile fish. However, since the late 1960s purse seine boats started to catch large-sized yellowfin tuna as well comparable to that taken by longline boats (Fig. 29). This change in the size of fish in purse seine catch is due to the expansion of the fishing grounds to offshore waters where larger fish are more commonly harvested than in the coastal areas. It should be noted that the size of fish from 70 cm to 90 cm is less represented even in the catch of purse seine fishery which has much wider gear selectivity for the fish size than that of longline gear.

3 - 5 . Maturity of fish in the catch

ALBARET (1977) reported that most of yellowfin tuna appear to start spawning in the Atlantic Ocean from a size of 120 cm in fork length, and at a GI value of 0.8 for males or 1.6 for females. Change of GI obtained from specimens by longline and purse seine boats in the Gulf of Guinea shows similar seasonality indicating the spawning activity becomes higher from November to May (YANEZ and BARBIERI B., 1980). It is obvious that yellowfin tuna caught by purse seine boats tends to have higher GI than that by longline boats in almost all months.

3 - 6 . Trends of fishing effort, catch and CPUE

Longline fishery

Overall effective fishing effort of longline fishery on yellowfin tuna in the eastern Atlantic east of 30° W was

Fig. 29. Length composition of yellowfin tuna caught by purse seine boats in the eastern Atlantic (FONTENEAU 1986). Numbers in the Figure denote year.

estimated multiplying the Japanese effective effort by a ratio of the total longline catch to the Japanese catch (Table 7). It showed an increasing trend to the early 1970s then decreased to 1979

Table 7. Catch of yellowfin tuna by major fishing gears in the eastern Atlantic Ocean, 1955-1983.

unit : 1000 tons

Year	Longline (A)	Purse seine	Baitboat	Others	Total	Japanese longline (B)	(A)/(B)
1955			0.2	4.1	4.3		
1956			5.7	0.1	5.8		
1957	10.3		9.2	0.3	19.9	10.3	1.00
1958	14.0		10.3		24.3	14.0	1.00
1959	32.8		5.8	0.1	38.6	32.8	1.00
1960	40.6		11.2	0.1	52.0	40.6	1.00
1961	40.9		9.8	0.2	51.0	40.9	1.00
1962	17.4		10.6	0.3	28.3	17.4	1.00
1963	23.2	1.3	17.8		42.3	23.1	1.00
1964	18.9	7.2	21.1		47.3	18.5	1.02
1965	27.6	8.3	18.5		54.4	26.5	1.04
1966	12.5	15.7	15.1		43.3	10.6	1.18
1967	17.1	18.7	16.8		52.6	10.1	1.69
1968	21.9	29.7	22.1		73.7	9.8	2.23
1969	20.4	45.1	15.9		81.5	6.4	3.19
1970	16.8	33.9	9.4	0.5	60.7	2.5	6.72
1971	13.2	32.6	10.4	1.4	57.7	1.6	8.25
1972	18.0	47.8	12.8		78.6	2.3	7.83
1973	19.2	44.9	14.3	1.2	79.7	1.3	14.77
1974	16.9	53.4	19.4	2.5	92.2	0.7	24.14
1975	13.6	83.4	9.3	1.9	108.1	1.7	8.00
1976	12.8	86.2	12.8		111.8	0.3	42.67
1977	15.6	87.6	11.0	0.3	114.5	0.1	156.00
1978	11.3	97.6	8.7	0.8	118.3	0.3	37.67
1979	6.8	91.6	12.8	1.2	112.4	0.3	22.67
1980	12.5	87.1	7.0	0.4	107.1	1.7	7.35
1981	7.9	108.6	9.4	0.8	126.7	1.2	6.58
1982	9.9	99.6	9.1	0.4	119.1	2.8	3.54
1983	10.0	82.1	7.9	0.4	100.4	1.2	8.33

Data from ICCAT (1982a, 1982b and 1984).

with temporal increase (Fig. 30, panel A). In the early 1980s, longline effort has increased again sharply and reached to 160 million hooks. This increase of the longline effort is mainly attributable to Japanese effort reconverted to the bigeye tuna in the tropical fishing grounds due to introduction of bluefin tuna catch regulation in the northwest Atlantic.

Yellowfin tuna catch by longline boats in the eastern Atlantic peaked in 1961 at about 40,000 tons (Fig. 30 panel B). Since that time, it showed a consistent decreasing trend up to 1983. Precipitous decline of CPUE for the yellowfin tuna caught by longline boats is observed from the

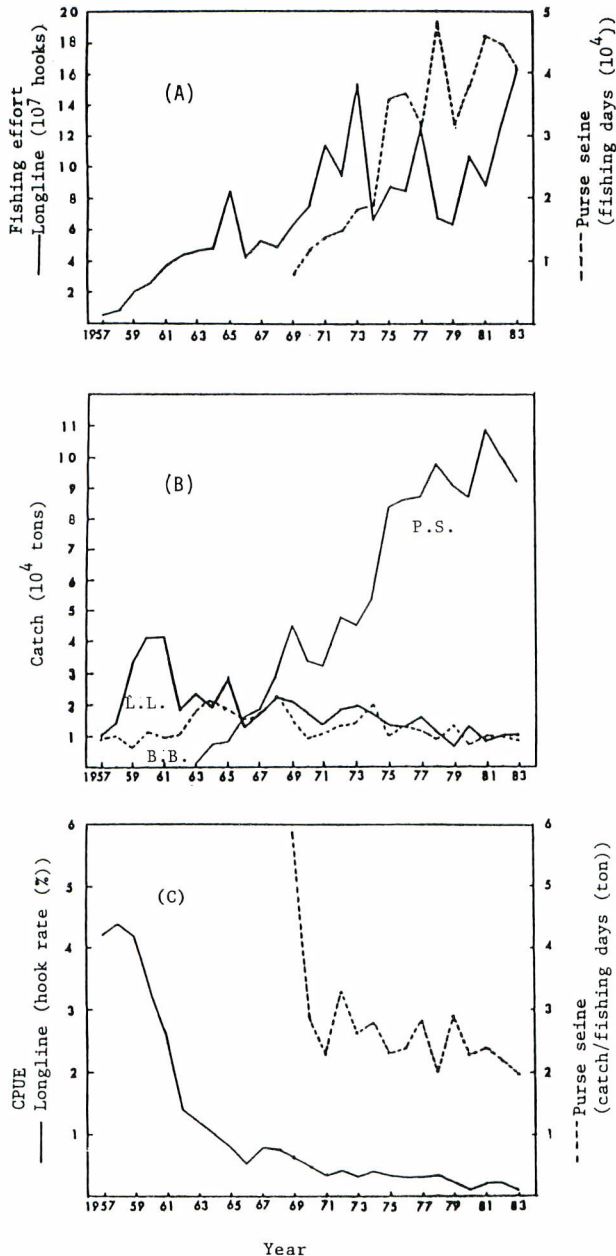


Fig. 30. Trends of fishing effort (A), catch (B) and CPUE (C) for yellowfin tuna caught by purse seine and longline fisheries in the eastern Atlantic. L.L., B.B. and P.S. in the panel (B) denote longline, baitboat and purse seine fisheries. Catch statistics after ICCAT (1982a, 1982b, 1984b) and fishing effort and CPUE for purse seine fishery after FONTENEAU (1986).

beginning of the fishery to about 1962 (Fig. 30, panel C). Then, the decreasing trend has been somewhat alleviated but still persistent to 1983. Longline CPUE decreased remarkably in three periods, first in the early 1960s to about one third, second in the early 1970s to about one half and the third from the late 1970s to the early 1980s to about one half.

Purse seine fishery

The purse seine fishery has expanded rather monotonously over the two decades since its start in the middle of the 1960s. Both fishing effort and catch have shown an increasing trend but faster in the former than the latter, resulting in moderate decline of the CPUE, a decline of about 80% from the period 1970-1973 to the period 1980-1983 (Fig. 30).

4. Possible effects of El Niño events on recruitment

El Niño events affect oceanographic features and the living resources in the eastern equatorial Pacific Ocean for every several years. Recently the effects are known widely also in the other parts of the Pacific Ocean. Such large scale oceanographic changes probably give significant impacts on the population of tunas and the fisheries.

The El Niño events are identified by changes of depth of the surface mixed layer (SML) in the western tropical Pacific Ocean. The

depths of the SML have a close relationship with the distribution of tunas. In the present study, the depth was calculated for 1965-1983 period based on BT observations made mainly by Japanese research and fisheries training vessels. The El Niño events were compared to the catches of yellowfin tuna taken by the Japanese longline boats from the western and eastern Pacific.

The deviation of the depth of the SML from average (1965-1983) was in the range of plus 60 m to minus 60 m (Fig. 31, YUKINAWA and MIZUNO, MS). However, the number of BT observations

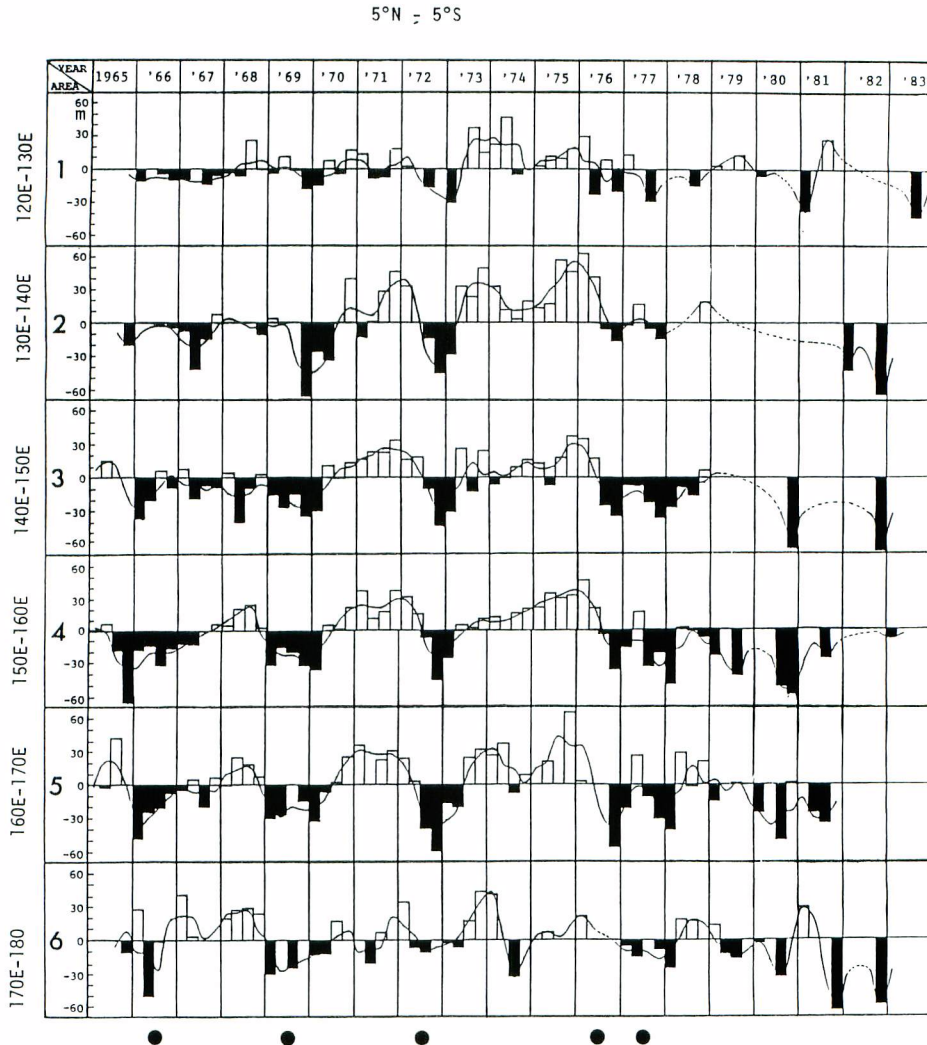


Fig. 31. Deviation of depth of surface mixed layer from average for the equatorial western Pacific by Lat. 10 and Long. 10 degree squares (YUKINAWA and MIZUNO MS).

Black and blank bars denote minus and plus deviations, respectively. Curves show smoothed trends of the deviation. Solid circles denote the El Niño years identified in the present study.

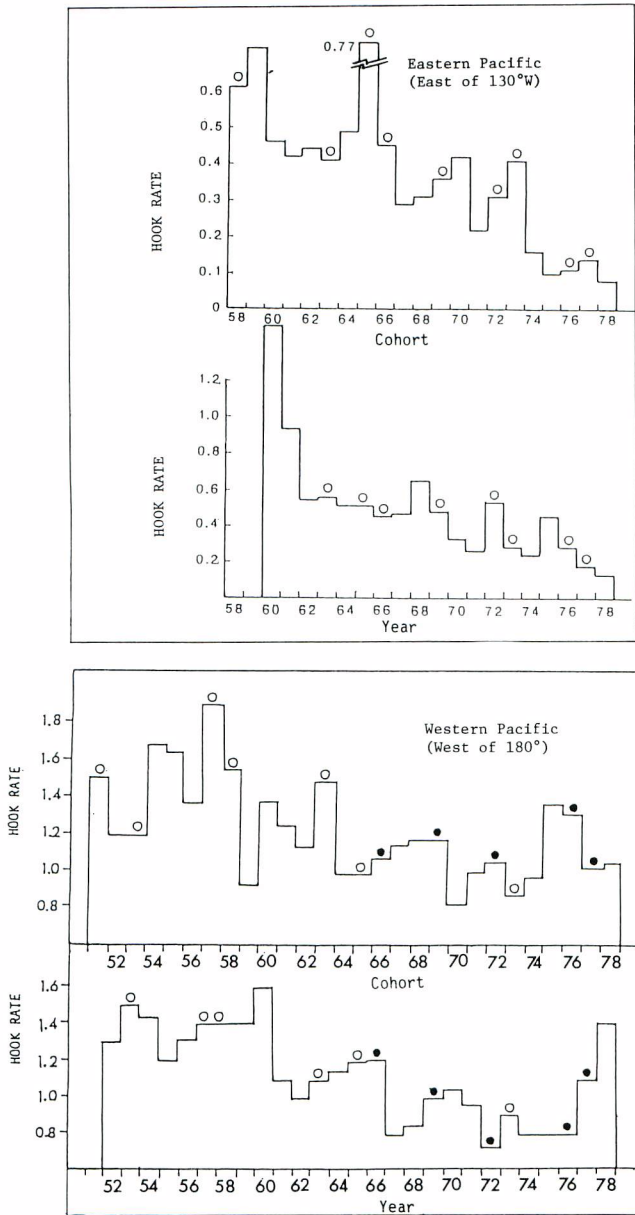


Fig. 32. Comparison of hook rates by year and cohort for yellowfin tuna caught by the Japanese longline boats in the eastern (upper panel) and western (lower panel) Pacific. Circles denote El Niño years. Solid circles indicate El Niño identified by the oceanographic studies in the western Pacific.

after 1977 is not enough to investigate the trend of deviation. The El Niño years reported in the past correspond fairly well with the years with minus deviations in the present study. The hook rate by cohort was calculated decomposing annual hook rate into age specific hook rates basing on age-length relation estimated by YABUTA *et al.* (1960). In the eastern Pacific, hook rate by cohort appears to indicate that cohorts which originated in or one year after the El Niño years tend to be larger than those around them which originated in non-El Niño years (Fig. 32). A similar relationship can be perceived from the analysis of yellowfin tuna data for the recent purse seine fishery of the eastern Pacific (IATTC 1984). However, there seems no apparent tendency for the hook rates in El Niño years to be greater or less than those in non-El Niño years. In the western Pacific, it appears difficult to point out any apparent correlation between El Niño events and either cohort strength or hook rate.

A major El Niño, perhaps the largest in this century, occurred from 1982 to 1983. If the relationship presently suggested holds, there should be good catches of yellowfin tuna by longline in 1985 or 1986 in the eastern

Pacific because the 1982 and 1983 cohorts would become available significantly to the longline gears at that time.

5 . Discussion

Several characteristics specific to each of the three stocks can be pointed out on historical process of fishery development, fishing performance and biological aspects of fish in the catch taken by the longline and purse seine fisheries, while there appears to be a common feature as well among them.

The longline fishery aims at bigger and rather solitary fish swimming in the subsurface layer, and the purse seine fishery pursues smaller fish forming schools near the sea surface. These two types of fishery support the different demand, the former for the raw fish market and the latter for the canned food market. Countries engaging in these fisheries and historical developmental process of the two fisheries have distinctive characteristics. Distant water longlining spreading over three oceans has been almost exclusively conducted by three Asian countries, *i.e.*, Japan, Taiwan and Korea, while the USA, Latin American and European countries have dominated in the purse seine fleets. The Japanese longline boats aimed at yellowfin tuna, albacore and bigeye tuna in the tropical areas in the early period of the fishery but later they shifted their target fish to southern bluefin, bigeye and bluefin tunas in the temperate areas. This pattern of the operational change is more or less common to the Japanese longline boats operating in three oceans while the Taiwanese and Korean fleets have remained in the tropical and subtropical fishing grounds.

Development of the tuna fisheries in the eastern and western Pacific stocks shows a sharp contrast (Fig. 33). In the eastern Pacific huge surface fishery had already existed before longline fishery have started to fishing. On the other hand, the reverse is true for the western Pacific although small amount of yellowfin tuna has been caught by baitboats from an old time. Catch by longline fishery could not be stabilized in the eastern Pacific in comparison to the case of the western Pacific. This would be due to shift of target species and probably to adverse effect of competing purse seine fishing on longline fishing.

Eastern Atlantic stock appears to be intermediate case from the view point of the development of the two fisheries. Both longline and surface fisheries started their operations almost simultaneously although the longline catch was dominant in the early period of the fisheries. Like in the eastern Pacific, longline catch could not be sustained. The same reasons for the eastern Pacific stock are pointed out.

The following could be summarized from the previous comparison. Fish larger than about 90 cm is usually taken by both purse seine and longline fisheries. Smaller fish ranging from 30 cm to 60 cm as well as larger fish over 90 cm are dominant in the catch of the purse seine fishery. Several biotic and abiotic factors affect the fishing success of the two fisheries. In general, shallow thermocline offers favorable condition for purse seining to capture yellowfin tuna whereas the reverse is true for longlining. Availability of floating objects or surface swimming dolphins, whales and sharks removes constraint of thermocline factor for purse seining. El Niño events may affect the year class strength of yellowfin tuna in the eastern Pacific.

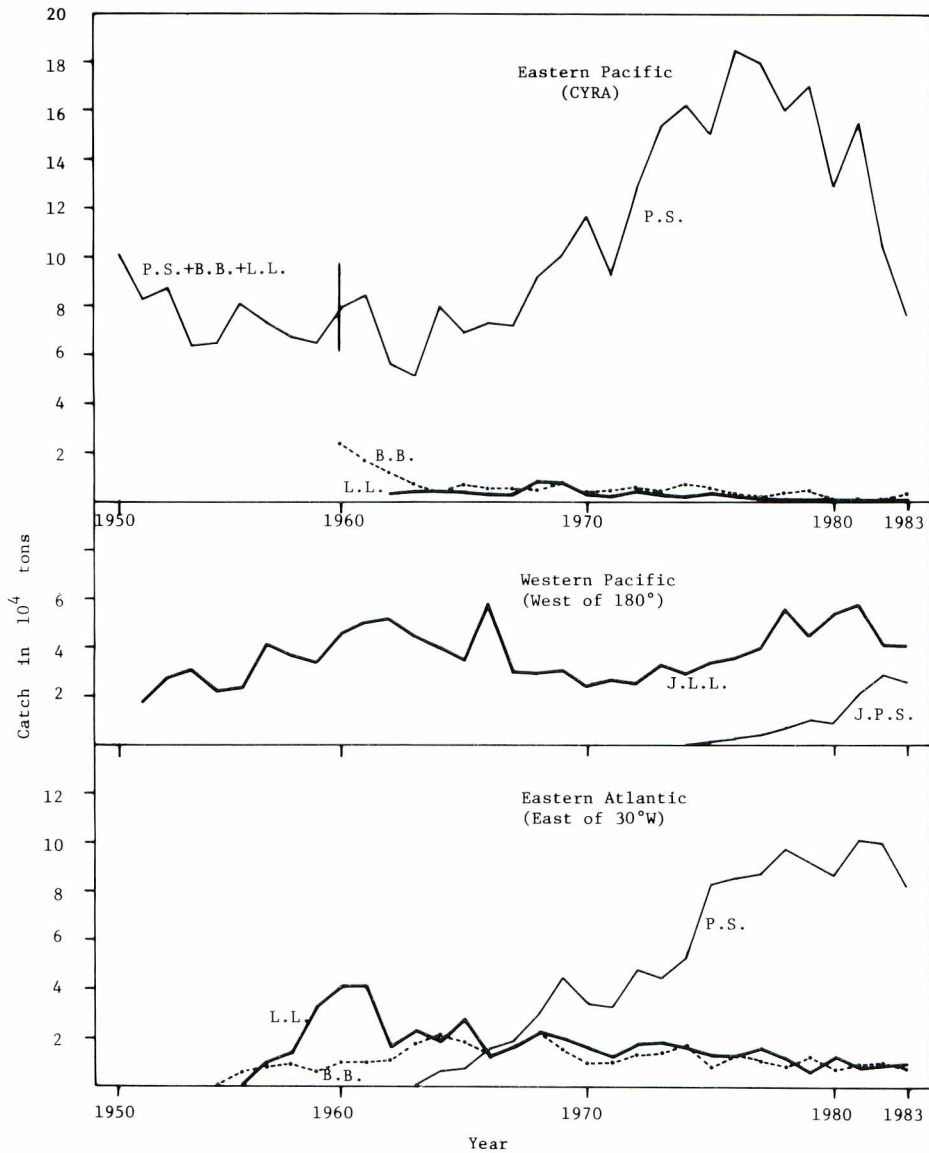


Fig. 33. Trends of yellowfin tuna catch by purse seine and longline fisheries for the eastern Pacific (upper panel), western Pacific (middle panel) and eastern Atlantic (lower panel).

P.S., B.B., L.L., J.L.L. and J.P.S. denote purse seine, baitboat, longline, Japanese longline and Japanese purse seine fisheries, respectively. Combined catch by P.S., B.B and L.L for the eastern Pacific before 1961.

Fragmental information of vertical movement of yellowfin tuna by sonic tagging experiments indicates that the juvenile ranging from 50 cm to 80 cm shows a considerable movement (CAREY and OLSON, 1982 ; SUZUKI, 1984). They tended to stay deeper in the day and shallower at night with frequent intrusions to the cooler water below thermocline. Since adult yellowfin tuna has higher tolerance to lower temperature (SHARP and DIZON, 1978), adult yellowfin tuna probably shows an even wider vertical movement. Occurrences of deep water preys in stomach contents of yellowfin tuna suggest this possibility (WATANABE, 1961).

Consistent presence of the fish with more matured gonad in the purse seine catch than in the longline catch shows a possible differential vulnerability to the two gears by maturation stage of the species. This phenomenon could be explained basing on vertical gear selectivity and spawning behavior of yellowfin tuna as suggested by HISADA (1973). HISADA (*op. cit.*) hypothesized that the yellowfin tuna prefers to warmer surface waters higher than 26° C when they become sexually matured and this makes them more vulnerable to the surface fishing than the longline fishing (Fig. 34).

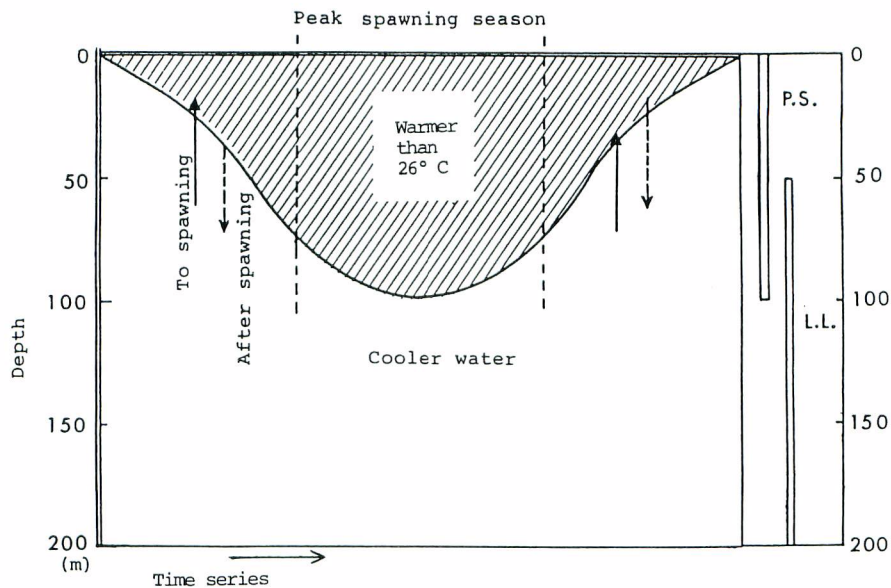


Fig. 34. Hypothetical diagram showing vertical movement of yellowfin tuna toward warmer surface waters for spawning.

Blank bars with P.S. and L.L. denote depth range of purse seine nets and longline hooks. Hatched area shows warmer waters preferred to spawning.

There is areal and seasonal difference for the fishing grounds of the purse seiners and the longliners for the eastern Pacific (Figs 3 and 5) and eastern Atlantic (Figs 25 and 26) stocks. However, the difference does not appear so large as to hinder the mixture of yellowfin tuna aimed at by the two fisheries significantly given the highly migratory nature of this species, if not so

remarkable to show transoceanic movements such as in the case of albacore and bluefin tuna. Also, vertical movement demonstrated for juvenile fish suggests there will not be significant differential vulnerability for adult fish for the two gears in vertical direction. The difference in maturation stage of the fish by the two gears appears only temporal, the same fish is equally vulnerable to the two gears basing on the hypothesis previously mentioned.

From the previous comparison, it is reasonable to conclude that only the size of fish taken by the two fisheries differs significantly, *i.e.*, longline boats fish for yellowfin tuna larger than about 90 cm while purse seiners capture small fish ranging from about 30 cm to 60 cm and larger fish over 90 cm.

V . Impact of purse seine fishery on longline fishery

As summarized in the previous section, if the only significant difference in the yellowfin tuna caught by the two gears is the size of fish and the fish population exploited by the two fisheries has reasonably high mixing, the impact of purse seine fishery on longline fishery may be assessed as conventional problem between small-fish-fishery and large-fish-fishery typically seen in southern bluefin tuna (KONO, 1985). However, in the case of yellowfin tuna large fish taken by longline boats is also an important object to the surface fishery and the fishery is much more diversified with complex history as mentioned previously. Taking these into account, the impact of purse seine fishery on longline fishery is analysed basing on the changes of basic vital statistics in the historical time series with additional information obtained from results of stock assessments.

1 . Eastern Pacific Ocean

Since the fishery in the CYRA is much more substantial and the fishing performance in general by the two fisheries outside the CYRA appears similar to that in the CYRA, here the analysis deals only with the fishery in the CYRA.

Longline fishing effort has been stable from the beginning of the fishery in 1962 to 1983 (Fig. 13), whereas the catch and the CPUE have been on a consistent decline (Figs 14 and 15). On the other hand, purse seine catch and effort increased by the end of the 1970s (Figs 13 and 14). The steep decline of longline CPUE from the early 1970s through 1980 corresponds fairly well with the remarkable increase of purse seine fishing effort and resultant increase of its catch. Therefore, the decline of longline catch and CPUE should be interpreted as caused by the development of the purse seine fishery.

To verify this interpretation, more analytical information is obtained from the stock assessment of the eastern Pacific yellowfin tuna (IATTC 1985). Cohort analysis made for the stock shows the standing population number by quarter of the year, for X and Y cohorts. Although the nature of the two cohorts has not yet been made clear, those two groups have been used combined to estimate overall stock size. This population estimates may be used to compare with the longline CPUE data.

As shown previously in Figure 14, disproportionately large amount of small and large yellowfin tuna has been captured by the purse seine fishery compared with that by longline fishery. Therefore, impact of purse seine catch can be identified by examining whether or not the trend of population size for large-sized fish calculated by cohort analysis is in accord with that by the longline CPUE. The population size of the adult fish calculated by cohort analysis (IATTC 1985) shows a similar trend with that of the longline CPUE (Fig. 35). Since there have been no indications of a

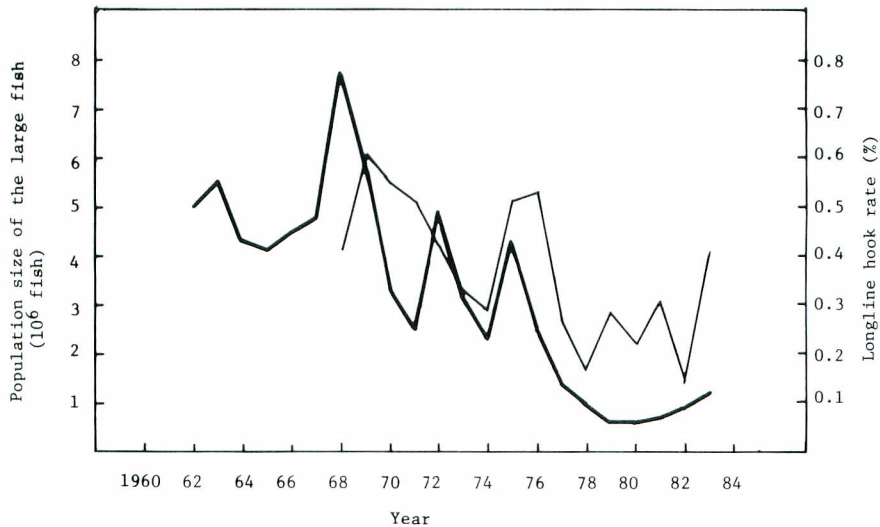


Fig. 35. Trends of population size for the large yellowfin tuna calculated from the purse seine data by cohort analysis (thin line, IATTC 1985) and longline CPUE (heavy line) in the CYRA.

consistent changing trend in the level of recruit to the surface fishery, the decline of stock size of the larger fish is an evidence for adverse effect of the purse seine catch on longline fishery.

A series of comparisons given in the previous section could be summarized by production curves of the longline fishery (Fig. 36). Plots of catch and effort relationship with progress of time series should behave clock-wise around an equilibrium production curve as explained by production model and if the fishing efforts were fixed to a certain level, the catches approach to a corresponding level of equilibrium curve. However, the locus of the relationship in Figure 36 differs from that expected by the model. The catch has not been sustained at any levels of the fishing effort, especially after the mid 1970s. This period corresponds to that of increased catch of yellowfin tuna by the purse seine fishery. Therefore, it is concluded that the purse seine fishery has given a substantial adverse effect to the longline fishery.

2. Western Pacific Ocean

Purse seine fishery in the western Pacific significantly developed quite late in the early 1980s

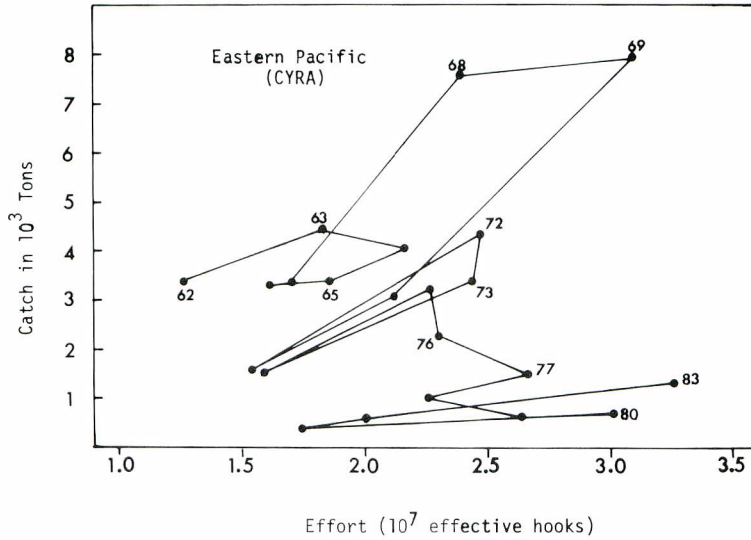


Fig. 36. Catch and effort relationship for yellowfin tuna taken by the Japanese longline fishery in the CYRA. Numbers in the Figure denote last two digits of calendar year.

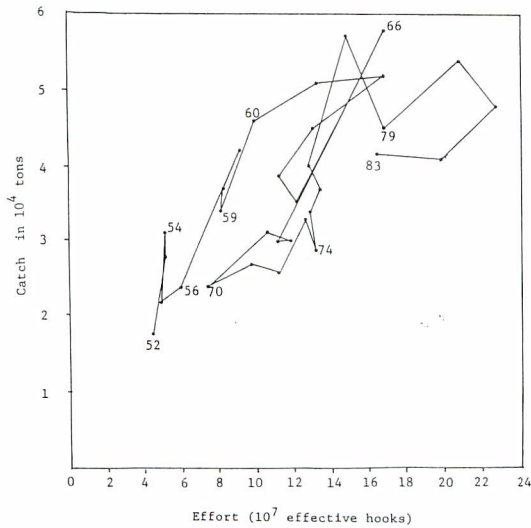


Fig. 37. Catch and effort relationship for yellowfin tuna caught by the Japanese longline boats in the western Pacific. Numbers in the Figure denote last two digits of calendar year.

compared with the eastern Pacific and eastern Atlantic counterparts. Among several distinctive features of the purse seine fishery in this region, predominant catch of smaller fish less than 70cm with respect to larger fish could be pointed out although some amount of the larger fish even bigger than longline caught yellowfin tuna has been taken by the seiners operated with free swimming schools. Since the purse seine boats capture younger fish, one to three ages younger than that taken by the longliners, it is anticipated that there might not yet be observed a clear-cut interaction between two fisheries in this areas. In fact, SUZUKI (1986a) and POLACHEK (1985) could not show evidence that the catch of yellowfin tuna by the purse seine fishery decreased the longline CPUE for yellowfin tuna.

Fig. 37 shows the catch and effort relationship for yellowfin tuna taken by the Japanese longline fishery in the western Pacific. Three periods could be recognized, *i.e.*, early period from 1952 to 1962, middle period from 1963 to 1978 and recent period after 1978. In the early period, the catch and effort increased rapidly with decrease of CPUE. The catch appears leveled off despite of increased effort at the end of the early period. This implies decrease of the adult yellowfin tuna population. The fishing effort during the middle period did not exceed the level in the early period. Although the CPUE showed some decline, it recovered at the end of the middle period and the catch and effort relationship returned to the similar position with that at the end of the early period. Therefore, the adult yellowfin tuna population is considered to have been stable during the middle period. The fishing effort attained the highest level in the recent period but the catch did not increase, thus resulting in the decrease of CPUE. The fishery in this period might start to operate in the right hand rim of the production curve. During this period the purse seine catch has also substantially increased (Fig. 23). Therefore, it was anticipated that the longline CPUE would more remarkably decrease in the recent period after 1978 than in the previous periods due to intensified fishing pressure from the longline and purse seine fisheries because a gradual decreasing trend of CPUE was already shown from 1952 to the middle of the 1970s (Fig. 22). Nevertheless, CPUE for the Japanese longline in the recent years remained close to or above the lowest level of the past.

It is not certain why the longline CPUE could remain without an apparent further declining trend in the recent period. However, some inference for it may be possible. As mentioned previously, effect of increased purse seine catch has not yet been reflected on the longline CPUE due to time lag caused by difference in age of the yellowfin tuna caught by the two fisheries. In addition, there might be an increase of the population size in the recent years independent of the fishery. In this regard, intensive studies on environmental conditions including El Niño events as well as on vital biological characteristics should be encouraged. At any rate, it is certain that exploitation of the yellowfin tuna stock in the western Pacific has increased to the highest level in the recent period. This necessitates more careful monitoring of the fisheries than the past.

3 . Eastern Atlantic Ocean

Although starting years for the surface and longline fisheries were very close and the catch by the longline gears dominated over the whole production until the early 1960s, like in the case of eastern Pacific stock, the catch by the purse seiners has been overwhelmingly high for all age classes of the catch than that by the longliners from the middle of the 1970s (FONTENEAU 1986). Fishing effort of the longline fishery showed an increasing trend to the early 1970s but since that time except for 1983, it did not increase beyond the 1973 level (Fig. 30). On the other hand, purse seine effort and catch increased drastically since the start of the fishery. Therefore, it is inferred that the development of the purse seine fishery is of major responsibility for the decline of catch and CPUE of yellowfin tuna captured by the longliners.

FONTENEAU (1986) estimated, from cohort analysis of the eastern Atlantic stock, the trend of adult population size which roughly corresponds to the fish over 90cm, *i.e.*, the size taken by the longline boats. This trend was compared with that of the longline CPUE (Fig. 38). A steep decrease

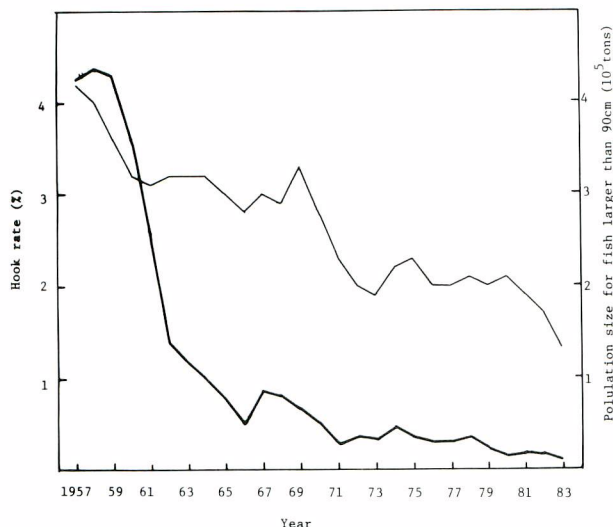


Fig. 38. Trends of population size for fish larger than 90 cm (thin line, after FONTENEAU (1986)) and longline CPUE (heavy line) for yellowfin tuna in the eastern Atlantic.

of longline CPUE is observed in the early period up to the mid 1960s while adult population size shows much slow decline during the same period. The declining trend of these two estimates accords fairly well each other since the middle of the 1960s when the purse seine fishery began to develop. On the other hand, SUZUKI (1979) mentioned a good accordance in the CPUE trend since the middle of the 1960s between the surface and longline fisheries in the eastern Atlantic stock which led him to infer existence of highly mixing yellowfin tuna stock exploited by the longline fishery and purse seine fishery as well. Both longline CPUE and adult stock size decreased sharply

ly from the late 1960s to the early 1970s followed by rather stable period during the middle of the 1970s and again showed significant decline from the late 1970s to the early 1980s. These changes appear in accordance with the increasing trend of purse seine fishing effort and catch fairly well (Fig. 30) and further indicate the decline of the longline CPUE reflects a real decrease of the population size of large fish, at least from the late 1960s.

SUZUKI (1986b) compared the relationships between catch and effort for yellowfin tuna taken by the longline fishery in the eastern and western Atlantic Ocean (Fig. 39). Dotted lines for the longline fishery indicate the early period of the exploitation by 1964. During the period, most of the longline boats operated in the central equatorial Atlantic (Fig. 2) crossing somewhat arbitrarily drawn line of Long. 30° W which separated the eastern stock from the western stock. Therefore, it may be pertinent to see the years after 1964 as characterizing the situation specific to the eastern stock. It should be noted that virtually no purse seine fisheries for yellowfin tuna existed in the western Atlantic during the period under study.

The catch and effort relationship shown in the two panels appears similar at first glance. However, there observed an important difference in the plots after 1970 when the purse seine fishery showed sharp increase in its catch. While the catch appears to be sustained over a range of fishing effort after 1970 in the western stock, the catch and effort relationship for the eastern Atlantic has been moving toward catastrophic lower right direction. This denotes the fishing pressure by longline alone cannot explain the deteriorating relationship of the eastern yellowfin tuna stock and further implies adverse effect of the purse seine fishery on the longline fishery.

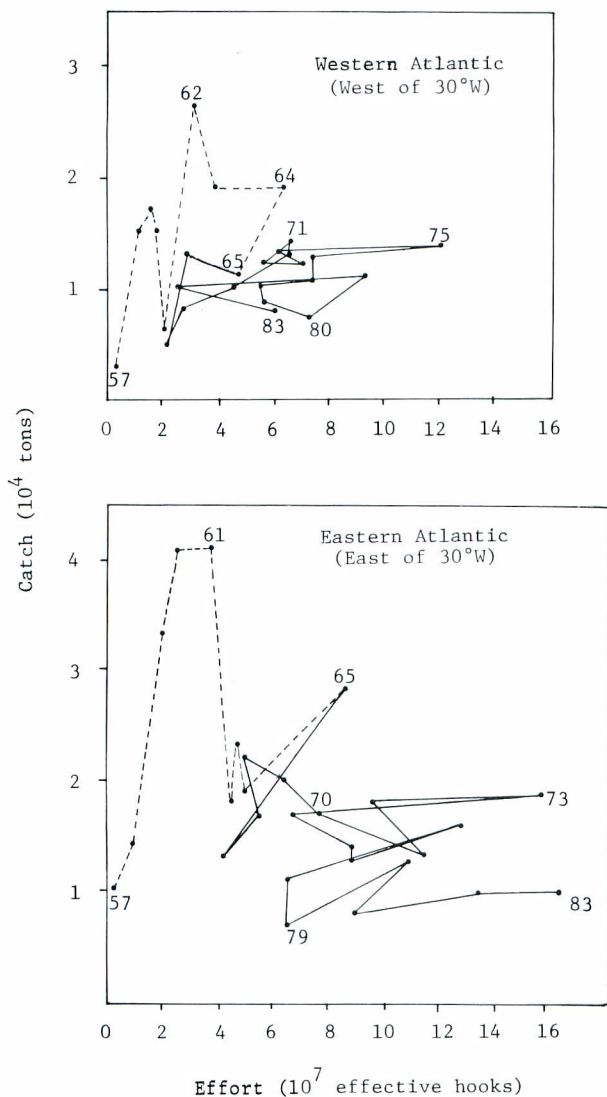


Fig. 39. Comparison of catch and effort relationship for yellowfin tuna caught by longline fishery in the western (upper panel) and eastern (lower panel) Atlantic. See text for dotted lines. Numbers in the Figure denote last two digit of calendar year.

4 . Discussion

4 - 1 . Yellowfin tuna population exploited by the longline and the purse seine fisheries

It was assumed in this study that the whole population of yellowfin tuna greater than at least about 90cm is vulnerable both to the longline and purse seine fisheries. On the other hand, there have been studies, as previously mentioned in the review section, that the two fisheries might not exploit the same part of the large fish population. If there exists differential exploitation with the large yellowfin tuna taken by the longline and purse seine fisheries, the interaction between the two fisheries may not be perceived straightforward. However, if they mix well in space both horizontally and vertically within relatively short time, this will neither hinder to reveal the interaction nor be indicative of different stocks exploited by the two fisheries.

LENARTZ and ZWEIFEL (1979) and FONTENEAU (1981) both compared the tag return rates from the longline and the surface fisheries, the former for the eastern Pacific and the latter from the eastern Atlantic. They inclined to hypothesize that not a whole stock of the large fish is available to the longline fishery because all tag returns were from the surface fishery (mainly purse seiners) but no reports of tag returns from the longline boats operating in those two areas despite substantial catch of the large yellowfin

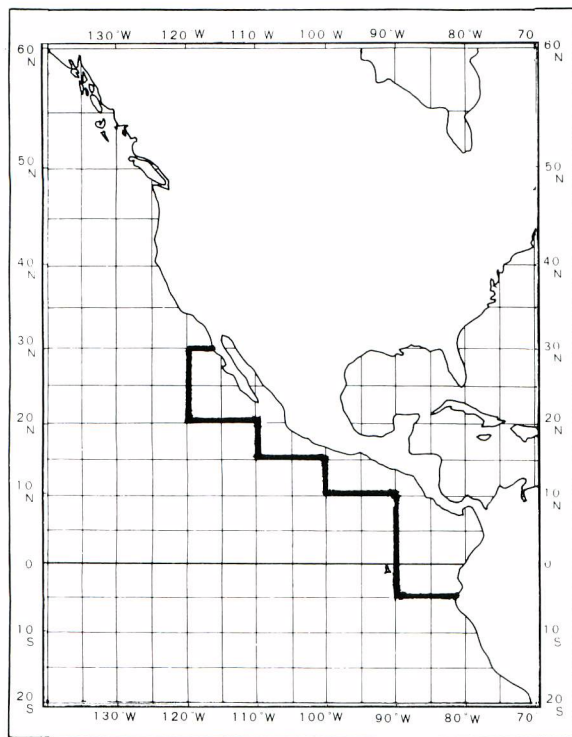


Fig. 40. An extent of surface fishing ground of the eastern Pacific during 1963 and 1966.

the result. The number of catch by the purse seine boats is far more dominant than the longline catch for any size class. Thus, it is not unreasonable to expect that no tags were returned from the longline boats during the period in question. As for the eastern Atlantic case, most of the fish recapture were made within several months from release although FONTENEAU (*op. cit.*) excluded the data with very short period of liberty at sea shorter than two months. Unless more recapture data of the tags and general knowledge of migration become available it would be difficult to use tagging data as indication of possible differential exploitation of the adult yellowfin tuna stock by the two fisheries.

4 - 2 . Interpretation of the longline CPUE

As previously mentioned, the trend of population size for large fish estimated by FONTENEAU (1986) has been in good accordance with the declining trend of the longline CPUE since the late 1960s (Fig. 30). However, there was a remarkable difference in the degree of decline between the two variables for the early period from the late 1950s to the early 1960s, the period before beginning of the purse seine fishery. The adult stock size decreased to about only 75 percent whereas the longline CPUE declined to nearly 25 percent during the period.

FONTENEAU (*op. cit.*) hypothesized several possible explanations such as differential ex-

tuna taken by the two fisheries.

However, the result of the tagging experiments requires a considerable amount of cautions to interpret. For example, the comparison made by LENARTZ and ZWEIFEL (*op. cit.*) was for the fish caught by the Japanese longline boats operated in the east of Long. 130° W. During the period of the tagging experiments from 1963 to 1966 for which the comparison was made, the distribution of yellowfin tuna catch by the Japanese longline fishery had centered on the southeast Pacific far away from the area of the surface fishing ground in very coastal areas (Fig. 4). Besides, all the fish were released within the coastal surface fishing ground. Therefore, a comparison of return rates of the tags with respect to rate of catch by the two fisheries was made for the coastal area where the surface and longline fisheries had been operating simultaneously during 1963 and 1966 (Fig. 40). Table 8 shows

Table 8. Catch by surface (S) and longline (L) fisheries by size class and number of tag returns (R) for yellowfin tuna in the eastern Pacific Ocean, 1963-1966.

unit : 100 fish for S and L

Size interval (cm)	1963			1964		
	S	L	R	S	L	R
101—110	653	336 (0)	2	4082	173 (14)	16
111—120	473	455 (0)	1	2245	465 (36)	7
121—130	508	390 (3)	2	720	1078 (52)	0
131—140	237	751 (4)	0	448	804 (20)	0
141—150	240	541 (5)	0	320	469 (16)	0
151—160	212	144 (5)	0	102	104 (11)	0
	1965			1966		
	S	L	R	S	L	R
101—110	3386	30 (4)	3	2926	54 (21)	3
111—120	2211	93 (10)	1	2044	116 (20)	1
121—130	1895	444 (10)	2	1312	304 (39)	0
131—140	905	758 (24)	0	718	515 (32)	1
141—150	498	466 (22)	0	536	575 (38)	0
151—160	194	205 (11)	1	204	200 (3)	0

All tag returns came from surface fisheries. Numbers in parentheses were calculated in the present study for the area shown in Figure 40. All other numerals were cited from LENARZ and ZWEIFEL (1979).

exploitation of the stock by the two fisheries in terms of vertical and horizontal directions as well as maturation stages of the fish, shift of the longline fishing grounds from very high density areas to low density areas and possible existence of two stocks, a "stupid" one taken by the passive longline gears, the other, an "intelligent" one taken by the active purse seiners. AU (1986) proposed a possibility basing on theoretical study that change of schooling habit, schools becoming more clumped with decrease of the population size, plays an important role to bias the decline of the longline CPUE toward overestimation. At present, there seems to be no single promising hypothesis which explains the phenomenon to a satisfactory degree.

It was mentioned previously that the size of yellowfin tuna caught by the longline boats was extremely large in the eastern Atlantic at the beginning of the fishery, mostly larger than 150cm. Therefore, the comparison of declining trend of the fish population over 90cm with that of the longline made by FONTENEAU (*op. cit.*) may not be pertinent, especially for the period in question due to a big gap in length.

Unfortunately, cohort analysis does not provide reliable estimates of the change of the population size for the early period because of lack of information on starting value of the fishing mortality coefficient and difficulties in assigning ages to the older fish due partly to poor size measurement data. Yet, it may be worth to make a simple simulation to see how the adult population size decreased in the early period. Several assumptions were made in the simulation, 1)

the population was in an equilibrium condition at the beginning of the Japanese longline fishery, 2) annual natural mortality coefficient (M) is 0.6 or 0.8 throughout all ages of the fish, 3) constant recruit (R) of 20 or 30 millions at the beginning of age 1 was adopted regardless of cohorts (after FONTENEAU, 1984).

Under these assumptions and basing on the catch at age data compiled by FONTENEAU (1986), trend of total population number was computed for the fish age 5 and older which correspond to the size of yellowfin tuna caught by longline boats in the early period. For each cohort, starting from a constant recruit and removing the catch by age and the death due to natural mortality, the number of survived fish at the beginning of next year was computed by generalized method for solving the catch equation (TOMLINSON, 1970). Ratio of population size in 1962 to that in 1957 were calculated for four combinations of M=0.6 and 0.8 and R=20 and 30 millions. The ratio ranged from 0.60 (M=0.8 and R=20 millions) to 0.84 (M=0.6 and R=30 millions). This indicates the precipitous decline of the longline CPUE in the early period probably overestimates the real decline of the stock available to the longline. Among the various possible explanations for the overestimation previously mentioned, rapid shift of the longline fishing grounds from high to low density areas should be studied further.

4 - 3 . Comment on the Y/R analysis

The interaction between the longline and purse seine fisheries on yellowfin tuna, more specifically adverse effect of purse seine catch on longline fishing in the present study, has not necessarily been recognized explicitly in the past works as mentioned in the introductory part. Probably, one of the major reasons of this ambiguity arises from a gap between the result by hypothetical Y/R analysis and real fishing performance. According to the Y/R analysis, it seems to be a common indication that the Y/R by the longline fishery alone is higher than or roughly the same with that by the purse seine fishery alone within a reasonable range of parameter values (HAYASI *et al.*, 1972; LENERTZ and ZWEIFEL, 1979). On the other hand, the actual yellowfin tuna catch by the longline fishery has been much smaller than that by the purse seiners in the eastern Atlantic and eastern Pacific stocks.

However, the apparent gap observed is not contradictory if the historical changes of the two fisheries are taken into account. FONTENEAU (1986) stated after Y/R calculations of the eastern Atlantic with the two fisheries that without surface fishery, increased fishing mortalities of longliners should provide a substantial increase of yield, reaching 120 thousand tons with effort multiplied by 7 and the same expectation was also obtained in his previous analysis conducted on the 1970 data.

As the longline and the purse seine fisheries have been operating simultaneously, it is appropriate to see the breakdown of Y/R by fishery in the presence of the other fishery. The Y/R of individual fishery as well as the total of the two fisheries was calculated using the conventional Beverton-Holt model programed by HONMA (1978). Annual natural mortality coefficient was assumed to be 0.8 and the growth parameter estimated by YABUTA *et al.* (*op. cit.*) was used. The fishing and natural mortality coefficients were set to be constant regardless of ages. The longline and the purse seine fisheries were assumed to fish the yellowfin tuna between ages 3 and 8 and between ages 1 and 8, respectively. The result is shown in Fig. 41.

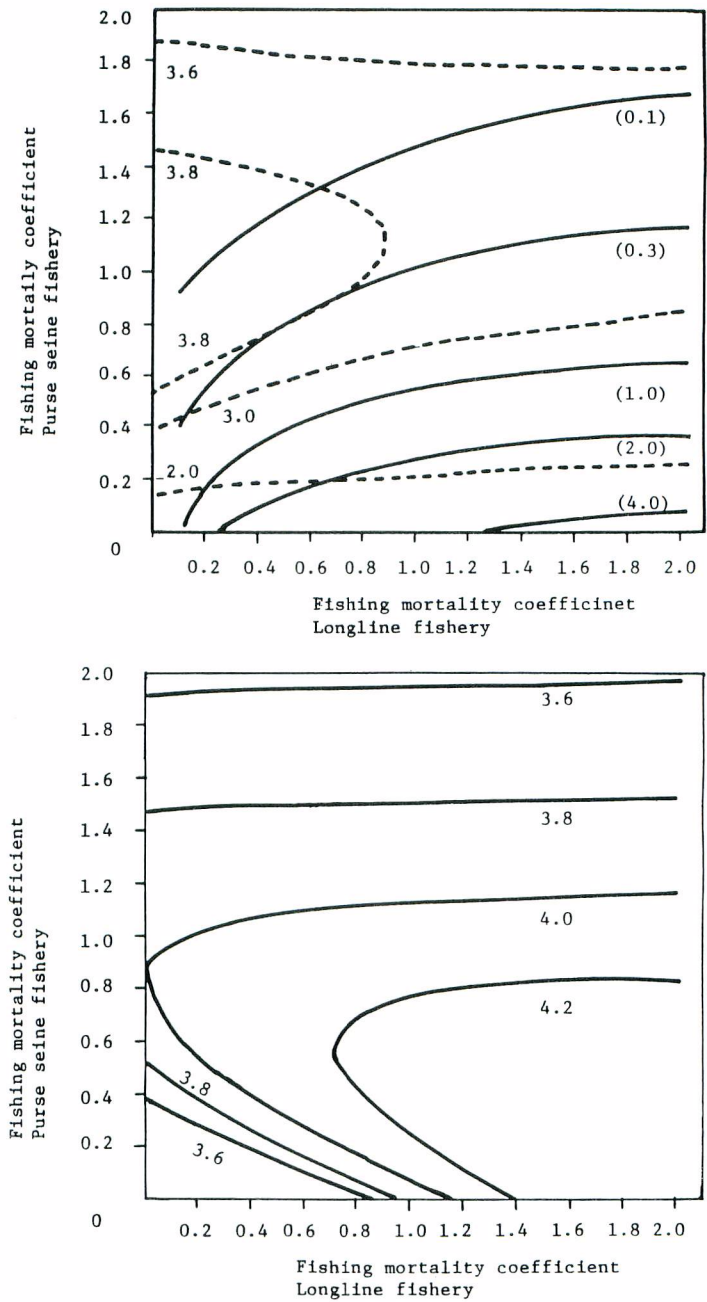


Fig. 41. Isopleth diagrams of yield-per-recruit (Y/R) in kg against fishing mortality coefficient of purse seine and longline fisheries. Panel A shows the Y/R by the purse seine fishery (dotted line and number without parentheses) and by the longline fishery (solid line and number with parentheses). Panel B shows the total Y/R by the two fisheries.

The Y/R by the longline fishery decreases rapidly with the increase of the purse seine fishing mortality whereas the effect of the longline fishing mortality on the purse seine Y/R is much more small (Fig. 41, panel A). Change of total Y/R is rather small with a wide range of the fishing mortality by the two fisheries except very small fishing mortality (Fig. 41, panel B). The result of Y/R calculation in the present study indicates that the longline fishery is sensitively affected by the surface fishery.

The performance of the two fisheries in the eastern Atlantic fishery seems to corroborate the result of the Y/R calculation. First, the longline fishing effort has not increased since the early 1970s (Fig. 30 Panel A) in such a way of sevenfold mentioned by FONTENEAU (*op. cit.*). Second, after the early 1970s purse seine fleet has continuously captured a huge amount of small-sized fish before recruiting to the longline as well as large fish comparable to the size aimed by longline fleet. Therefore, it is concluded that the increase of the purse seine catch and the total catch could be attained in exchange for reduction of the longline catch.

4 - 4 . Consideration on management of yellowfin tuna stock in the western Pacific

In the eastern Pacific and eastern Atlantic Oceans, purse seine fishery could increase almost exclusively the catch of yellowfin tuna without serious opposition from longline fishery due to change of target species by the latter fishery. However, yellowfin tuna is still one of the target species with a significant catch for longline fishery in the western Pacific, especially for the Japanese fleet. Adverse effect of newly developing purse seine fishery on the longline fishery has not been observed for this stock. However, it seems probable that the effect becomes apparent sooner or later if the purse seine fishery further developed judging from various analyses made previously. Besides, although the stock status of yellowfin tuna in the western Pacific is only poorly studied, SUZUKI (1986a) suggested that the stock has become exploited heavily and the exploitation was approaching close to the MSY level. Under these circumstances, there are several problems to be considered in the management of the yellowfin tuna stock in the western Pacific.

The catch of the purse seine fishery consists of predominantly smaller yellowfin tuna than that taken by purse seine boats in the eastern Atlantic where minimum size (3.2 kg, about 55 cm in fork length) regulation has been implemented. The purse seine fishery, along with artisanal fisheries of the Philippines that take a fish as small as 20 cm, should make an effort to increase minimum size of yellowfin tuna entering to its fishery since it could bring a gain of about 20% to the total catch of yellowfin tuna by all fisheries if it is increased to about 75 cm (SUZUKI 1986a). The decrease of the catch in the Philippines artisanal fisheries by the increase of minimum size may be offset by higher commercial value of the larger yellowfin tuna.

It should be recognized that the catch of skipjack dominates in the purse seine fishery of the western Pacific. Since yellowfin tuna and skipjack are captured mixed in most cases and skipjack stock in this area is considered to be underexploited (KLEIBER, ARGUE and KEARNEY, 1983), a management scheme is required which will not hamper the exploitation of skipjack and simultaneously with effective measures to reduce fishing pressures to yellowfin tuna.

In the case more direct fishing regulation either reduction of the catch or the fishing effort becomes necessary, there will be a considerable difficulty in mediation between longline and purse

seine fisheries over the yellowfin tuna stock in the western Pacific. Several limits were already mentioned in conducting the study on gear interaction in this region. In addition, domestic as well as international mediation between the two types of fishery must be considered simultaneously for some country like Japan.

No individual country can solve these problems, thus international cooperation is prerequisite. Tunas are classified into highly migratory species in the new Law of the Sea and the existing international treaties for tunas are still functioning in a satisfactory condition at least for research activities. Formulation of an international management body in the western Pacific, therefore, has enough rationale and should be pursued for.

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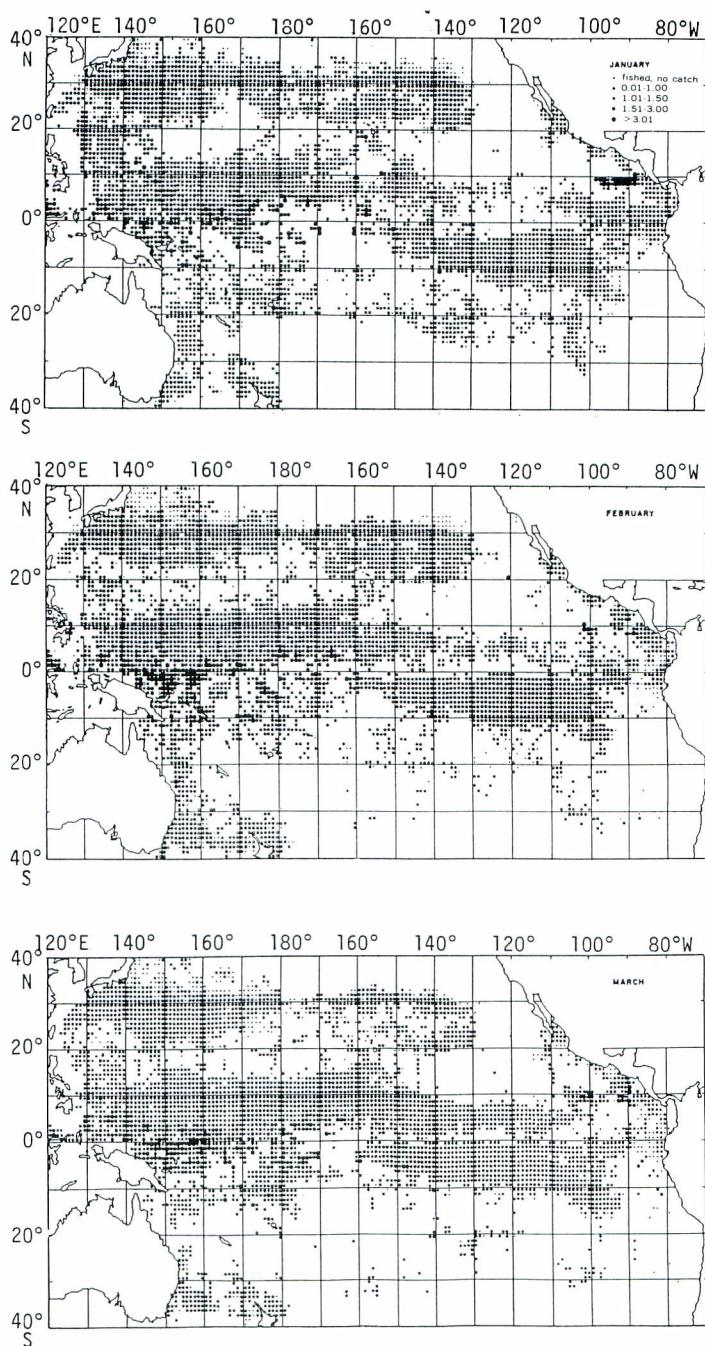
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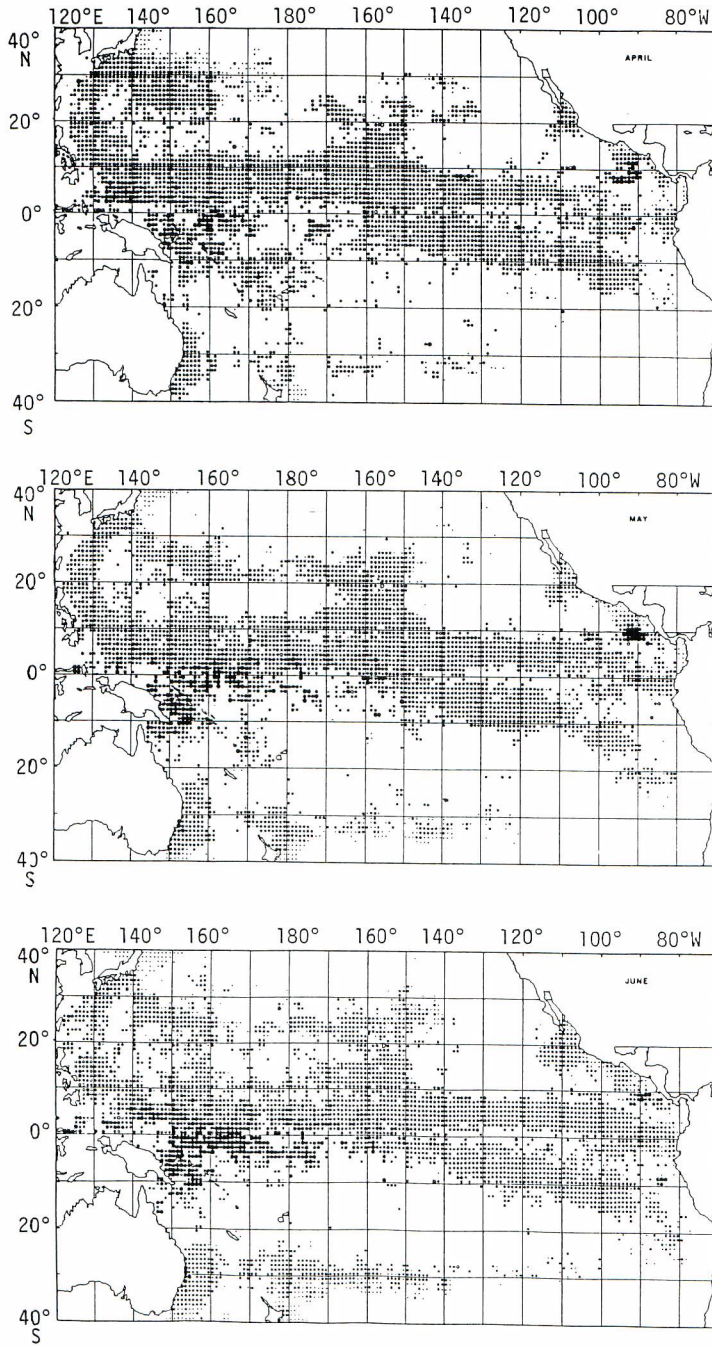
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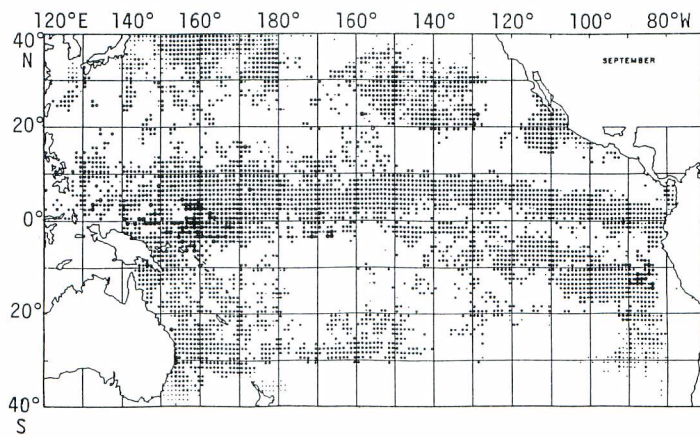
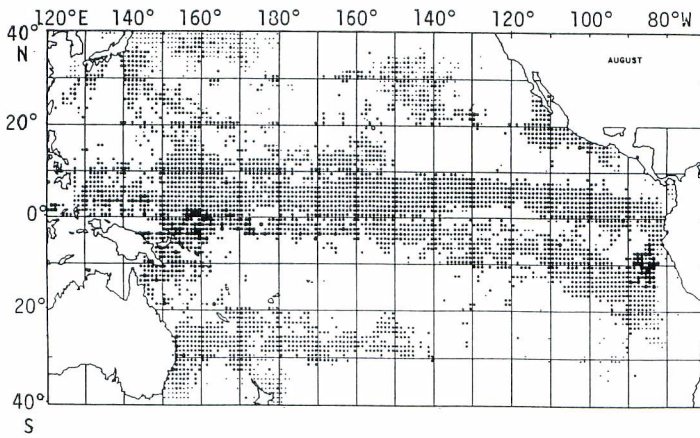
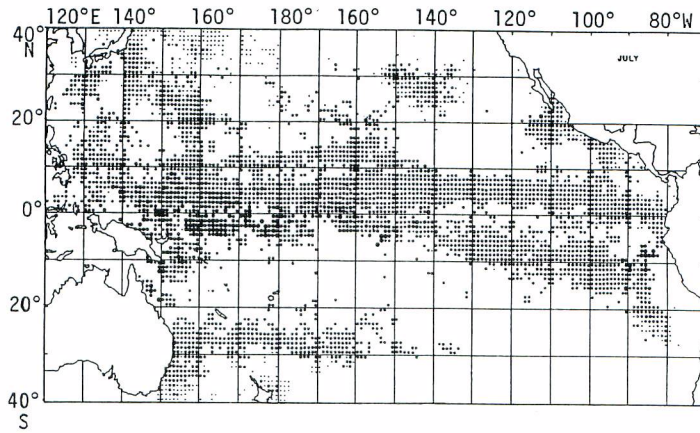


Appendix Figure Monthly distribution of average hook rates for yellowfin tuna caught by Japanese longline boats, for the period 1967 through 1972.

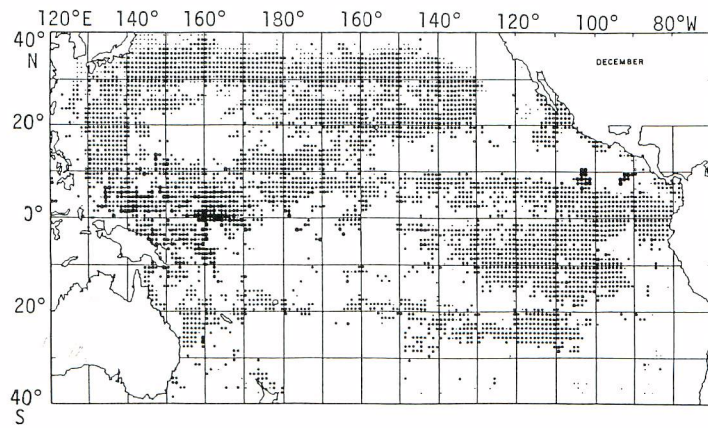
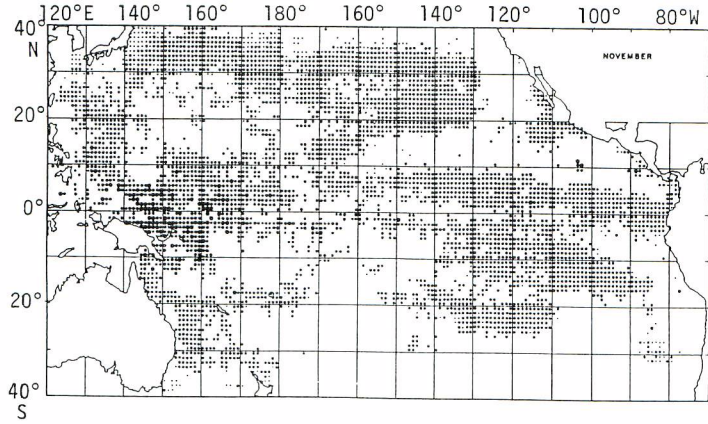
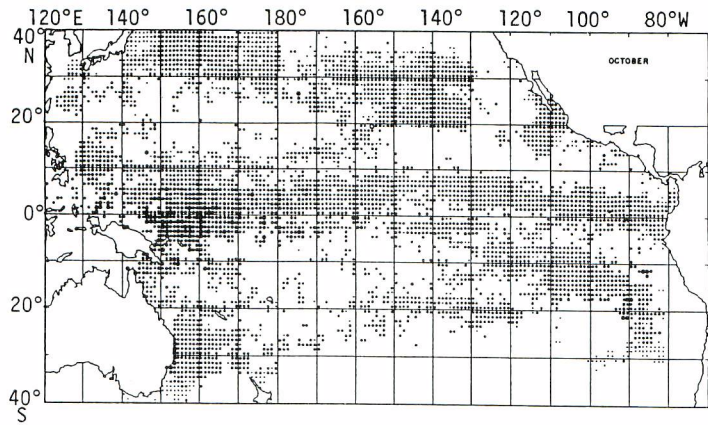
After SUZUKI *et al.* (1978).



Appendix Figure Continued.



Appendix Figure Continued.



Appendix Figure Continued.

キハダ資源に関するはえなわ漁業とまき網漁業の相互作用の研究

鈴木 治 郎

摘 要

キハダ, *Thunnus albacares* (Bonnaterre) はマグロ属の中で、漁獲量が著しく大きく、商業的に最も重要な魚種の一つである。主分布域を熱帯のほぼ全域に持つ本種は、古くから種々の漁法で多数の国によって漁獲されており、現存するマグロ類の国際的な資源管理機構は本種の管理を主目的として設立された。

はえなわ漁業に比べ小型のキハダを主体に漁獲するまき網漁業が、はえなわ漁業に与える影響や、これら2種の漁業がキハダ資源の持続生産量や個体群変動に及ぼす影響は、一般に相互作用と呼ばれている。キハダ資源に関する2種の漁業の相互作用の研究は、これまで理論的な計算に基づく断片的なものしかなく、相互作用そのものの存在を含めて一致した見解は得られていない。

本研究では、世界の主要なキハダ系群である東部太平洋、西部太平洋及び東部大西洋の3系群をとりあげ、まず、従来の研究で欠落していたはえなわ漁業とまき網漁業に関する漁場、漁期、漁獲されるキハダの大きさ及び性成熟状態を具体的に比較した。また2種の漁業の存立に及ぼす環境条件の役割を考察し、エル・ニーニョが本種の加入に与える影響の可能性をはえなわの資料を通して検討した。次に漁獲量、漁獲努力量、CPUE等の歴史的な変動傾向を漁業ごとに把握するとともに、それらを諸手法による資源評価結果と関連づけることにより、両漁業の相互作用の実態を分析した。

前半における2種の漁業に関する諸項目の詳細な記述の比較により、各系群に特有な差異がみられる場合もあるが、いずれの項目に関する漁業間の差異も、キハダの生物学的特性を考慮すれば、2種の漁業間における相互作用の発現を妨げる程大きくはないと判断された。この知見に基づき、2種の漁業に関する漁獲量、漁獲努力量、CPUE等の歴史的な変動傾向を検討した。その結果、東部太平洋及び東部大西洋系群については、まき網漁業がはえなわ漁業に対して先獲りによる悪影響を与えていることが指摘され、資源評価の諸結果の包括的な検討により、その相互作用が確認された。西部太平洋系群では、まき網の漁獲によるはえなわ漁業に対する悪影響はまだ認められないが、まき網漁業がさらに発展する可能性が高く、近い将来に相互作用が発現すると思われる。現在、西部太平洋は実質的なマグロ漁業管理機構を持たない唯一の海域となつて残されており、早急な国際的漁業管理機構の設立が望まれる。