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SYNOPSIS OF BIOLOGICAL DATA ON YELLOWFIN TUNA *Neothunnus macropterus* Temminck and Schlegel 1842 (INDIAN OCEAN)

Exposé synoptique sur la biologie du thon à nageoires jaunes *Neothunnus macropterus* Temminck et Schlegel 1842 (Océan Indien)

Sinopsis sobre la biología del atún de aleta amarilla *Neothunnus macropterus* Temminck y Schlegel 1842 (Océano Indico)

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1 IDENTITY

1.1 Taxonomy

1.1.1. Definition[1]

Phylum VERTEBRATA
Superclass Gnathostomata
Class Osteichthyes
Subclass Teleostomi
Superorder Teleostei
Order Percida
Suborder Scombrina
Family Scombridae
Subfamily Thunninae
Genus Neothunnus Kishinouye 1923[2]
Species Neothunnus macropterus (Temminck and Schlegel) 1842[3]

1.1.2 Description

- Genus Neothunnus Kishinouye 1923

Cutaneous blood vessels are found from the segment of the seventh vertebra. Posterior cardinal vein is united to the right Cuvierian duct, and the former vein is connected with a plexus of blood vessels in the haemal canal, so the haemal arch is remarkably wide. The first haemal arch is found in the eleventh vertebra. On the exterior surface of the liver we find no minute veins. Caudal vertebrae elongated, and accordingly the caudal portion long. (Kishinouye 1923)

- Species Thynnus macropterus Temminck and Schlegel 1942 is described by the authors as follows:

"Cette espèce inédite se reconnaît facilement a la forme de son anale et de sa deuxième dorsale, ces nageoires étant en faux et beaucoup plus allongées que d'ordinaire. Quant aux pectorales, cette espèce est intermédiaire entre les germons ou thons à longues pectorales et les autres thons; car les pectorales occupent, dans ce poisson, un peu plus du quart de la longueur totale du corps. Le corselet est encore moins distinct que dans le Sibi, mais il parait offrir une forme tout à fait semblable. La première dorsale est assez basse vers les parties postérieures. La deuxième dorsale est presque de deux tiers, l'anale du double plus longue que les premiers rayons de la première dorsale. Les fausses nageoires sont au nombre de neuf, mais la première d'en bas est contiguë à l'anale. — D. 14 et 14 + 9 fausses nageoires libres; A. 12 + 1 fausse nageoire + 8 fausses nageoire libres.

"A l'état frais, les parties supérieures de ce poisson sont d'un bleu d'acier noirâtre, qui passe au blanc bleuâtre clair sur les flancs, et à l'argenté, sur le ventre. L'iris de l'oeil est blanc bleuâtre. Les pectorales sont d'un bleuâtre sale, mélangé de rougeâtre à la base, mais passant au noir à l'extrémité et sur le bord postérieur de cette nageoire. La caudale est d'un bleu-noirâtre pâle réfléchissant le pourpre, mais mêlé de jaune, vers le bord postérieur de cette nageoire. Les fausses nageoires sont d'un jaune citron. Les autres nageoires offrent un gris noirâtre pâle, qui passe cependant au jaune sur la partie inférieure des ventrales ainsi que vers le bord postérieur de l'anale et de la seconde dorsale.

"Ce poisson atteint une longueur de huit à dix pieds. C'est le Hirenaga des Japonais. On ne le prend que pendant les mois d'été, en compagnie d'autres espéces de thons, à l'entrée des baies

1/ after Matsubara (1955) except species name

2/ The generic name Neothunnus has been treated with doubt (Rivas 1961), and the issue is still in confusion. The present report will adopt the name used most often.

3/ Although a number of workers agree the yellowfin tuna is a species of worldwide distribution, the agreement is not final. The specific name given to the yellowfin tuna varies with author and sea. In the Indian Ocean it was called N. argentivittatus Cuvier by Schaefer and Walford (1959) but Rivas (1961) does not agree. The name T. macropterus was given to the specimens collected in the Pacific Ocean. But the fish in the Pacific and Indian Ocean show continous distribution and morphometry of the fish from the two seas does not warrant specific distinction. Kishinouye (1923) states that yellowfin tuna, being called N. macropterus, ranges widely in the Indo-Pacific region. Under such circumstances, the present report will adopt the specific name macropterus given by Temminck and Schlegel (1842).

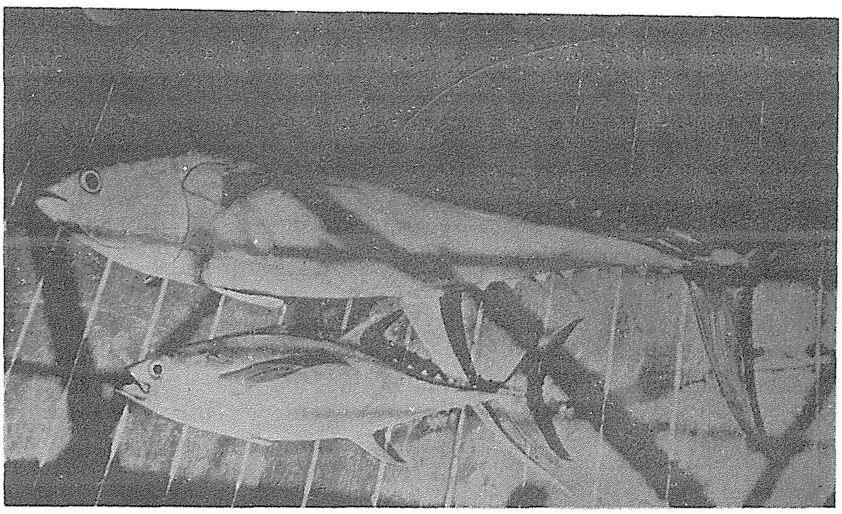


Fig. 1 Neothunnus macropterus (Temminck and Schlegel). After Nakamura (1939 b)

qui se trouvent à la côte sud-ouest du Japon. On en mange la chair, soit séchée, soit crue. Il offre un article considérable pour le commerce intérieur de cet empire. Les Japonais prétendent que ce poisson, autrefois commun dans les mers de leur pays, y est devenu beaucoup plus rare depuis une trentaine d'années."

- Species Neothunnus macropterus (Temminck and Schlegel) 1842. D. 13, 14, 9. A. 14 to 15, 8 to 9. Gill rakers 9 + 21. Scales ca. 270.

Body fusiform, elongated, head small, and the caudal portion long. Scale minute. Pectorals long, pass beyond the origin of the second dorsal, their dorsal and ventral outline nearly parallel each other, and are connected by a short oblique side near the distal end. The second dorsal and the anal are much elongated. No venules on the surface of the liver, the left lobe of which is sometimes divided into two, and the right lobe is longer than the other. Pyloric coeca as a mass is shorter than the stomach. Intestine rather short, the third bend scarcely reaching the middle between the first and the second. The rectum is also short. Air-bladder narrow and long not divided at the anterior end. Thick strong connective tissue protects the ventral part of the air-bladder.

Venules to the cutaneous vein are arranged in one row on the side towards the lateral median line. These venules run over the external side of the cutaneous artery, after uniting many fine venules. Arterioles forming the cutaneous artery are arranged in one or two alternate rows from the side near the lateral median line. Cutaneous blood vessels are found at the surface of the lateral muscle behind the origin of the first dorsal. A cutaneous vein on each side of the body pours separately to the Cuvierian duct of the respective side, or is united to the cardinal vein below the ninth vertebra, and in the kidneys. The cardinal vein joins the right Cuvierian duct. In the haemal canal the cardinal vein is united with a plexus of short transverse venules forming a dark red rod of plexus with similar arterioles from the dorsal aorta. It is remarkable that this rod of vascular plexus is found in the tunas which lack the conical vascular plexus on the inner side of the liver. Kidneys are much elongated posteriorly, reaching to the segment of about the fifteenth vertebra. Ureters are united, forming an acute angle under the thirteenth vertebra, and the common ureter is found behind the vertebra. Thus the ureters are shaped like the letter Y. Vertebral column rather slender, and the second vertebra is nearly as high as high as broad. The posterior caudal vertebrae are remarkably elongated. Parapophyses long and flattened. They become more or less vertical in the eighth vertebra, turned downwards in the ninth vertebra, and an arch from the eleventh vertebra. Haemal canal wide, especially in the precaudal region, where the breadth of the cavity is nearly equal to that of the middle part of the respective vertebra. In one specimen, the author found the dorsal and ventral spine of the thirty-sixth vertebra short and nearly horizontal, instead of long and covering those of the next vertebra.

The color is nearly black at the back; side greyish with oblique transverse line and series of dots of silvery-white in alternation. Iris greenish yellow; first dorsal greyish tinged with yellow; tips of the second dorsal and dorsal finlets bright yellow; pectorals black on the inner side, greyish or sometimes yellowing on the outside; ventrals greyish, tinged with yellow; anal and anal finlets bright yellow. (Kishinouye 1923) See Fig. 1.

1.2 Nomenclature

1.2.1 Valid scientific name

Neothunnus macropterus (Temminck and Schlegel)

1.2.2 Synonym[1/]

Thynnus macropterus Temminck and Schlegel 1842 (original description); Day 1876-1878, 1889

Germo albacora (not of Lowe) Molteno 1948; Smith 1949

Germo itosibi (?) Smith 1949

Germo macropterus Jordan and Seale 1906; Jordan and Evermann 1906; Jordan and Snyder 1907; Jordan and Jordan 1922; Fowler 1923, 1928

Neothunnus albacora macropterus La Monte 1945

1/ Taken from Rosa (1950). It is held that the species in the Pacific and Indian Ocean is identical. See foot-note, 1.1.

Neothunnus catalinae (?) Jordan and Evermann 1926; Nichols and La Monte 1941; Jordan, Evermann and Clark 1930

Neothunnus itosibi (?) Jordan and Evermann 1926; Molteno 1948

Neothynnus macropterus Fowler 1936

Orcynus macropterus Kitahara 1897

Semathunnus guildi Fowler 1934

Semathunnus itosibi (?) Tinker 1944

Thunnus macropterus Kishinouye 1915; Hildebrand 1946

Thunnus (Germo) macropterus Deraniyaala 1933

Thunnus nicolsoni (?) Whitley 1936

1.2.3 Standard common names, vernacular names[1/] (see Table I)

1.3 General variability

1.3.1 Subspecific fragmentation (races, varieties, hybrids)

Apparently no agreement has been reached on whether the ocean yellowfin tuna is monospecific. A number of studies on morphometry of the fish have suggested that the yellowfin is specifically identical but the possible existence of regional races has not been discarded. Royce (1961) reports that many yellowfin tuna stay within several hundred miles of the water where they have originated. Royce endorses the racial formation of the species.

Kurogane and Hiyama (1958) and Kurogane (1960) find some morphological differences among fish taken in the western and eastern Indian Ocean equatorial region around the Lesser Sunda Islands and in the Banda Sea. Tsuruta and Tsunoda (1960) find that fish collected in the mid-Indian Ocean along the equator and in the Arabian Sea and Javanese seas are morphologically distinguishable. Tsuruta (1955) reports that the yellowfin tuna in the western seas of Greater Sunda Islands are morphologically similar to specimens collected in Hawaiian and Costa Rican waters. Hirano and Tagawa (1956) find also that the fish in mid-Indian Ocean are similar to those of Angola, Hawaii and Costa Rica. Kurogane (1960) found similar fish in the Banda Sea and the equatorial west Pacific. All these reports affirm the worldwide range of the species, but with apparent raciation by regions.

Regional raciation of the species is not fully supported if criteria other than morphometry were considered. For instance, Mimura (1958) finds that, since the start of the Indian Ocean longline operation, the hooked rates became lower and the size of fish grew smaller, but this tendency does not shift to neighboring waters. Kamimura and Honma (1961), on the other hand, report in the analysis on the variability of size classes by waters; "It is highly probable that this fish show a large scale migration from west to east along with their growth". These two concepts, one supporting and the other negating the regional raciation of the fish, clearly indicate the species' complex population structure.

Since Hiyama and Kurogane (1961) have noted the yearly change in morphometry of the north Pacific bigeye tuna, the morphological analysis on tuna is to be accompanied by consideration on year-to-year variability.

1/ Taken from Rosa (1950) with some additional vernacular names heard in Japan. For the species concept, see 1.1.2.

Table I

Common and vernacular names

Country	Standard common name	Vernacular name (s)
Australia	Yellowfin tuna	
Ceylon	Yellowfin albacore	Kelavalla, Asgedi kelavalla, Pihatu kelavalla, Horealla (Sinhalese dialect); Kelavalai (Tamil dialect)
Chile	Atun de aleta amarilla	Atun
Hawaiian Islands	Yellowfin tuna	Yellowfin albacore, Pacific albacore, Thread tuna; Haranaga, Hirenaga, Kihata, Kiwada, Itosibi, Gesunaga (Japanese); Ahi (Hawaiian)
India		Socca (Madras Province); Kannalimas (Minicoy Island)
Indonesia		Genlang kadawoeng, Genlang kawoeng, Geelvin; Toniji (Dutch)
Japan	Kihada	Kiwa, Itosibi, Sibi, Masibi, Gesunaga, Kinhire, Hatsu, Honbatsu, Binkiri, Meji, Kimeji, Hashibi, Hirenaga
Mexico	Atun de aleta amarilla	Atun
New Guinea		Madidihang
Peru	Atun	Albacora (Northern coast); Tuno (Port of Callao)
Philippines	Yellowfin tuna	Albacora, Badla-an, Buyo, Tambakol (Tagalog); Buyo (Bikol); Malaguno (Kuyans and Tagbanwa); Badla-an, Balarito, Painit, Panit, Tambakol (Visayan-Benton dialect); Yellowfin tuna medium - Malalag (Visayan)
Saudi Arabia		Gaithir
South Africa	Yellowfin tuna	Yellowfin tunny, Itoshibi tuna, Itoshibi tunny, Japanese tuna
United States	Pacific yellowfin	Yellowfin tuna, Yellowfin albacore, Tuna, Allison tuna, Allison's tunny, Autumn albacore

2 DISTRIBUTION

2.1 Delimitation of the total area of distribution and ecological characterization of this area.

Yellowfin tuna is fished in a vast area of the Indian Ocean north of 30°S where longline fishing is done. The fish range from temperate to tropical water in this area (Fig. 2). According to Suda (1960), the fish do not occur in the south Australian waters which are affected by Antarctic water mass.

2.2 Differential distribution

2.2.1 Areas occupied by eggs, larvae and other junior stages: annual variations in these patterns, and seasonal variations for stages persisting over two or more seasons. Areas occupied by adult stages: seasonal and annual variations of these.

- Larvae

On the seasonal change in distribution of the larval fish in the Indian and Pacific Oceans, Yabe and Ueyanagi (1961) conclude: "Most of the material was obtained from equatorial (tropical) areas, and several were found in the subtropical areas. In the latter area, the positions where larvae occurred are located in areas which are under the influence of the warm current. In the equatorial region, larvae occur throughout nearly the whole year but there is a seasonal change of occurrence in the subtropical region". Jones (1959) also reports larval yellowfin from the waters of Laccadive Archipelago and the Minicoy Islands.

As to vertical range of larvae and young of tuna species, Yabe and Ueyanagi (1961) state: "During the daytime, tuna larvae seem to occur rarely in the surface layer but distribute abundantly in the middle layers sounding over 20 m. During the night, tuna larvae seem to have the tendency to distribute uniformly in the upper 50 m layer."

The vertical range and diurnal movement of Pacific tuna larvae were studied by Matsumoto (1958) and Strasberg (1960). Both recognised nearly identical phenomena. Strasberg reports: "The larval fish are found most abundantly 0 to 60 m deep; 20 to 25 percent in the layer 70 to 130 m; and none at 140 m".

- Young

On the study of the young (130 to 195 mm in forklength) found in stomachs of adult tuna and marlin, Yabe and others (1958) tell: "... the young of albacore frequent the Pacific and Indian Ocean at 20°N and 20°S, while the young of yellowfin and bigeye tuna are seen in the waters of low latitudes (10°N to 10°S)". Yabe and Ueyanagi (1961) find that the distribution of the young closely resembles that of larval fish.

- Adult

Nakamura (1951) reports on the distribution of yellowfin tuna: "It is an oceanic fish but often they approach to shore and by seasons enter inner seas".

Mimura and Nakamura (1959) and Mimura (1962), based on data accumulated by longline operations for Indian Ocean yellowfin tuna, conclude: 1) the species occurs widely north 30°S, 2) the population is thick from 10°N to 10°S but thin south of 10°S, 3) distribution details are not known for waters north of 10°N where fishing is done only from March to June, 4) between 10°N and 10°S, fish density is high in the west and low in the east, 5) in the western part of the ocean the population is thick from January to June and thin during the rest of the year, and 6) slight geographical and seasonal distribution changes are found south of 10°S. (Fig. 3)

The yellowfin tuna is believed to go down fairly deep. Usually longlines, operated mostly in the midlayer, hook larger fish than pole-and-line and trolling methods aimed at hooking the surface school. (Yabe, Anraku and Mori 1950. Tester and Nakamura 1957 and Murphy and Shomura 1953a) (see 5.2.3.)

2.3 Behavioristic and ecological determinants of the general limits of distribution and of the variations of these limits and of differential distribution.

Kishinouye (1923) says: "The fish live at 15° to 25°C and prefer 20°". But Nakamura (1951), showing the fish accepts a wider temperature range, says: "It is true that tuna distribution and migration are highly dependent on wate temperature. Temperature becomes a limiting

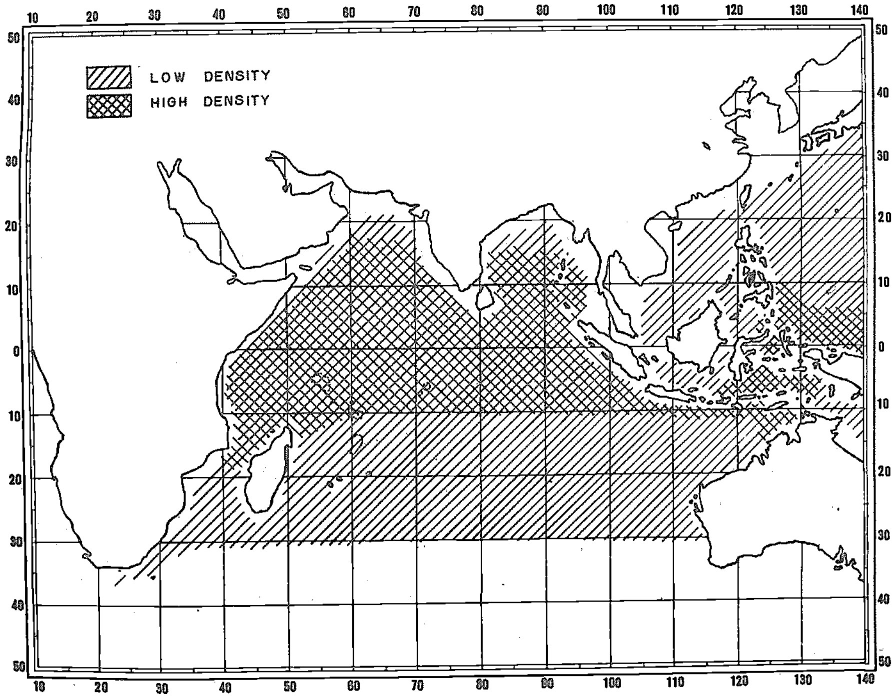


Fig. 2 Distribution of yellowfin tuna in Indian Ocean based on the data of longline catch up to the end of 1960

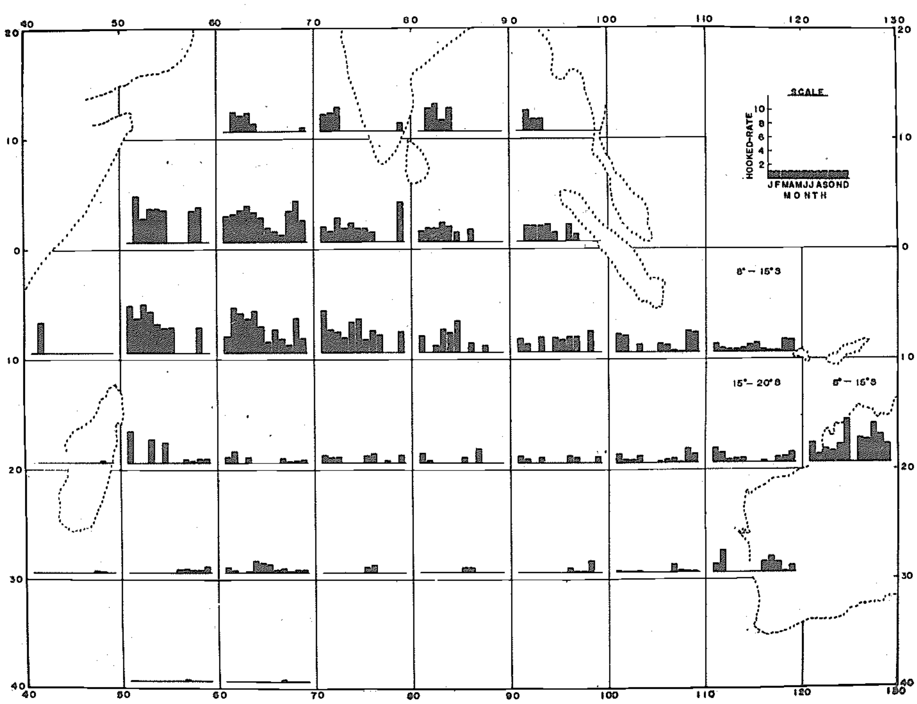


Fig. 3 Hooked rates in longline operation of yellowfin tuna in Indian Ocean by months and areas, 1959. After Mimura (1962)

factor determining fishing season and ground where temperature is critical for tuna. But in their usual habitat, where temperature is optimum, temperature does not determine fishing ground and season." Further, Nakamura (1951 and 1959), by observing that each species of tuna finds its center of distribution in a particular ocean current system, believes: "Each current system presents a specific biosphere to the species of tuna" (current system is interpreted as water mass by Nakamura and Yamanaka 1959).

Mimura and Nakamura (1959) point out that the population density of fish by regions in the Indian Ocean has been observed to correspond well to ocean currents; also that a dense population of yellowfin is seen in the waters where the Equatorial Counter Current and North Equatorial Current prevail. Yamanaka and Anraku (1959 and 1961) find each species of tuna showing dense population in specific water masses and support Nakamura's belief.

The larvae and young of yellowfin are found more abundantly, same as in adult, in equatorial and adjacent waters but the details of their occurrence by developmental stages are not known in this region.

3 BIONOMICS AND LIFE HISTORY

3.1 Reproduction

3.1.1 Sexuality (hermaphroditism, heterosexuality, intersexuality)

Yellowfin tuna is heterosexual. No external observable characteristics are known to distinguish male from female.

3.1.2 Maturity (age and size)

No information is available on the fishes of the Indian Ocean. Schaefer and Marr (1948), Schaefer and Orange (1956), Yuen and June (1957) and Kikawa (1959) all arrived at nearly the same generalization on Pacific yellowfin tuna, though there was some difference in water or gear used for these studies. These authors agreed that fishes smaller than 70 cm are always in non-spawning condition, some individuals over 70 cm show maturation of gonads and all fishes participating in sexual activity are 120 cm or larger. Nakamura believed sexual development was related to the elongation of the second dorsal and anal fin which started in fish about 1 m in standard length. (Nakamura 1939a). This finding was confirmed by the authors mentioned immediately above.

Comparing sexual development with size or age of fish (3.4.3), fishes at 0-age are immature, some individuals at 1-age show sexual maturity and fishes at 2-age join sexual activity. The belief that the fishes late in the first year may not be sexually mature (Tester and Nakamura 1957) thus corresponds to the generalization introduced above.

3.1.3 Mating (monogamous, polygamous, promiscuous)

No observation has been made but mating will be promiscuous. Well-developed gonads are often found in many yellowfin tuna but individuals with fully mature gonads are very rare (Schaefer 1948; June 1953; Schaefer and Orange 1956; and Kikawa 1959). Schaefer and Orange (ibid) present three possible explanations for this particular phenomenon on sexual development of yellowfin tuna: 1) it may be due to the fish moving off-shore into deep water to spawn, 2) or it may be due to the school breaking up, 3) or ceasing to feed.

3.1.4 Fertilization (internal, external)

Fertilization is external.

3.1.5 Fecundity

- Relation of gonad size and egg number to body size and to age.

No report is available on fish from the Indian Ocean.

June (1953) reports on the Pacific yellowfin tuna: "An individual will spawn more than twice within a season, and the number of eggs carried by a female, corresponding to the size of fish, will be expressed by regression Y = 125,000 X - 2,853,000, where X denotes the weight of fish by kg and Y the number of maturing ova". Table II, taken from June (ibid), shows the weight of fish and the number of eggs.

Table II

Fecundity of yellowfin tuna

(June 1953)

Body weight (kg)	47	53	56	57	59	59	61	62	69	80	88
Number of ova (1,000)	2,370	3,390	4,340	5,170	3,230	6,510	3,580	5,610	6,380	6,000	8,590

- Coefficient of fecundity

Nakamura (1959), referring to tuna in general, points out the extremely high number of eggs carried by a fish, hence the variability of the fecundity in a large magnitude. Present knowledge in this respect is fragmentary.

3.1.6 Spawning

- Spawning season.

Based on accumulated information Nakamura (1949 and 1959) states: "The spawning will take place within a definable period in some species of tuna but it may be generally said that the fish as a spawning mass or shoal will conduct sexual activity in an extended period, and those in the waters of low latitudes will continue the activity throughout the year, but with different peaks".

Among yellowfin caught by longline in the Timor Sea in February 1953, Ueyanagi and Yukinawa (1953) found many fish weighing 52.5 to 56.3 kg with gonads which were well developed in size and maturity. Yukinawa and Watanabe (1956), in a study of fish caught in Sunda Channel, February 1956, report that the fish carry eggs in advanced stage and mature, and fish taken at 10°S, 95°E are also sexually mature. Yabuta (MS) found yellowfin with well-developed ovaries in western tropical waters of the Indian Ocean and collected two females which were believed fully ready to spawn. These findings, though restricted to a narrow area and a short period, will show that yellowfin tuna in western Indian Ocean spawn about February and the fish in the Sunda Sea spawn in February or shortly after.

Kikawa (unpublished), by examining the gonad index of fish collected in a wide area north of 10°S, finds that the value is generally high throughout the year and is higher from January to June, especially in April and after, than from July to December.

- Number of spawnings per year, frequency.

This is not well know for fish in the Indian Ocean.

June (1953) examined the frequency distribution of egg diameter for Hawaiian yellowfin. He found that the modal group which suggests spawning may be continuous. He also found that there are recognizable remnants of ova in individuals believed to have already spawned. The author concluded: "An individual fish will spawn more than twice during a season".

- Induction of spawning, artificial fertilization

No work has been done. The scarcity of fully mature fish make artificial insemination studies extremely difficult.

3.1.7 Spawning ground

Nakamura (1959) states: "Spawning waters are defined often by species, but in general the spawning of tuna takes place in a wide ocean area. There is evidence to suggest that each species finds a different current system for its spawning ground".

According to the studies by Ueyanagi and Yukinawa (1953), Yukinawa and Watanabe (1956) and Yabuta and Yukinawa (1961) (see 3.1.6), it is clearly understood that yellowfin in the Indian Ocean enter sexual activity in the western tropical water and seas around Sunda Islands. On the other hand, Kikawa (MS) shows that, on the basis of gonad index, the vast area of the Indian Ocean north of 10°S will provide spawning grounds for yellowfin and the index values grow higher toward the north of the region.

The water layers where fish discharge eggs are not defined at present.

3.1.8 Egg; structure size hatching type, parasites predators

No information is available on fish from the Indian Ocean.

The eggs of Pacific yellowfin have been studied by several authors. Nakamura (1949) reports that yellowfin ova are identical with bluefin tuna ova, which are nearly colorless and transparent, with an oil globule in dark yellow surrounded by cloudy marking; spherical ova, the membrane of which is not particularly characterized. June (1953), examining ovarian eggs and ova in different growth stages, describes as follows:

"Maturing eggs: As the ova advance towards maturity, the group becomes opaque and exhibits a characteristic yellowish color in formalin. The yolk granules appear as highly refractive, spherical bodies in the cytoplasm. Ripe eggs: On reaching the stage at which the ova are about to be spawned, distinct morphological changes occur in them, and they lose their opacity and assume a translucent, greyish color in formalin. Embedded in the yolk is a single, conspicuous, golden-yellow oil globule, which averages about 0.26 mm in diameter."

Various authors have measured the egg size of Pacific yellowfin tuna. Schaefer and Marr (1948) report the eggs filled with yolk and believed to be at maximum size when 0.6 mm in diameter. Nakamura (1949) records 0.85 mm for fully mature eggs. June (1953) finds immature eggs 0.01 to 0.18 mm; intermediate, 0.18 to 0.40 mm; maturing, 0.40 to 0.70 mm; and ripe, 0.76 to 1.23 mm. Kikawa (1959) reports: "Most eggs of tuna caught by longline measure 0.40 to 0.64 mm. Segregation of ova in the mature egg mass starts when the eggs measure about 0.6mm, and full gonad maturation is believed to be reached at the complete segregation. Hence, eggs 0.40 to 0.64 mm in diameter appear to be in the stage immediate to full maturation. The mature eggs, measuring 0.8 mm or larger, are detached from the ovarian epithelium into the abdominal cavity."

Schaefer and Orange (1956) give a measurement of 0.9 to 1.2 mm for mature eggs.

3.2 Larval history

3.2.1 Account of embryonic and juvenile life (pre-larva, larva, post larva, juvenile)

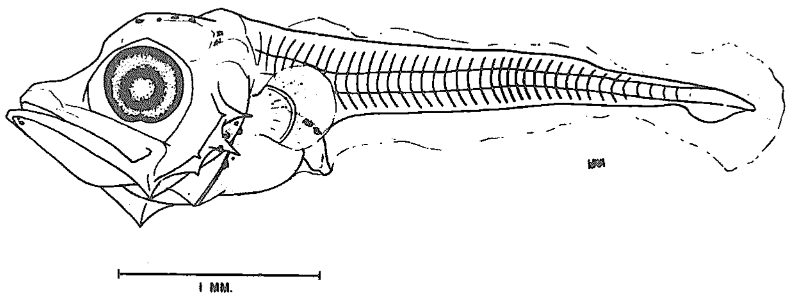
The larval forms of yellowfin tuna were described by Schaefer and Marr (1948), Wade (1950), Mead (1951) and Matsumoto (1958). Matsumoto (ibid) distinguishes the larvae of yellowfin from others, thus: "In general, tuna larvae are characterized by a complete, triangular visceral mass with a short intestine that is directed ventrally at its posterior end. The entire visceral mass is located well forward in the body, the preanal distance being less than one-half the total body length on specimens up to about nine mm. A continuous median fin membrane starts at the nape and extends completely around the caudal region to the anal opening. The myomeres, when distinct, number between 38 and 42. The head, mouth, teeth and eyes are well developed, and prominent preopercular spines are noticeable. Pigmentation is rather sparse, most of it being concentrated over the abdominal sac, over the brain, and in the caudal region, depending upon the species."

The same author identifies the larvae of yellowfin tuna by, a) complete lack of chromatophores on the trunk, except over visceral mass, until the larvae approaches 14 mm total length; b) no chromatophores over the forebrain; c) heavy pigmentation on the first dorsal fin in specimens of more than 7 mm. (Fig. 4)

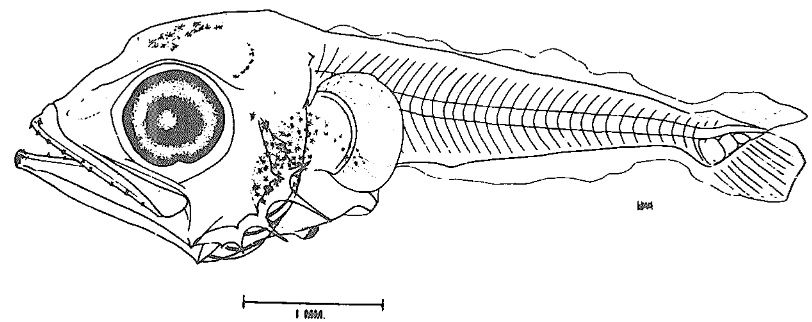
In the study of juvenile tuna (106.8 to 195.0 mm) collected from the stomachs of adult tunas and marlins in the Pacific and Indian Oceans, Yabe and others (1958) describe the juvenile yellowfin: "A series of minute teeth on both upper and lower jaw; villiform teeth on vomer and palatines; pectoral fin short and located anterior to the first dorsal base or on the tenth or thirteenth verterbra; second dorsal and anal fin show no sign of elongation; left lobe of liver short and broad, but the right, long; intestinal bending measuring 0.29 in the length of body cavity". (Fig. 5).

- Feeding

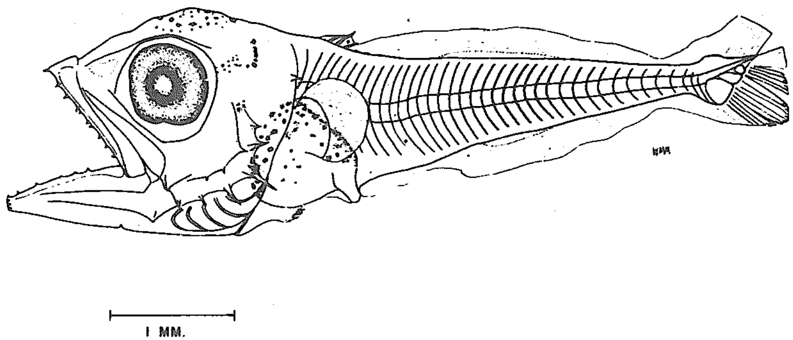
Yabe and others (ibid) conclude: "The food items so far examined do not vary by species of tunas or the size of fish. Cuttle-fish and isospondyli fishes are the major food found in the stomach of albacore, bigeye and yellowfin tuna and young tuna 10 to 30 cm long. Due to advanced digestion, the identification of food fishes is rarely possible. However, it may be said that carangoid fish and chaetodontid fish are often identified as miscellaneous food fish of bigeye and yellowfin tuna, respectively." (Table III)



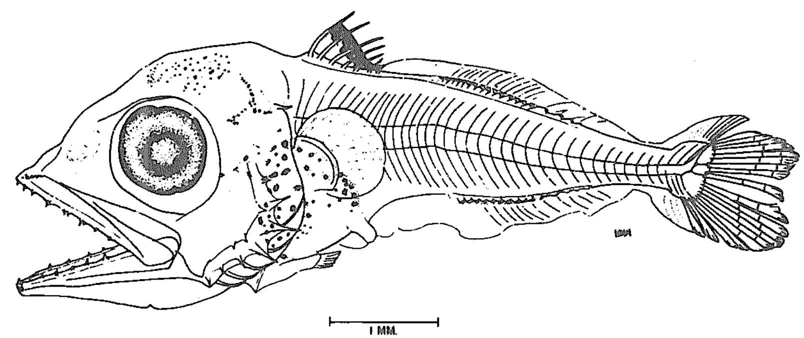
(a) Neothunnus macropterus, 3.9 mm. total length



(b) Neothunnus macropterus, 5.5 mm. total length



(c) Neothunnus macropterus, 6.4 mm. total length



(d) Neothunnus macropterus, 7.15 mm. total length

Fig. 4 Larvae of Neothunnus macropterus. After Matsumoto (1958)

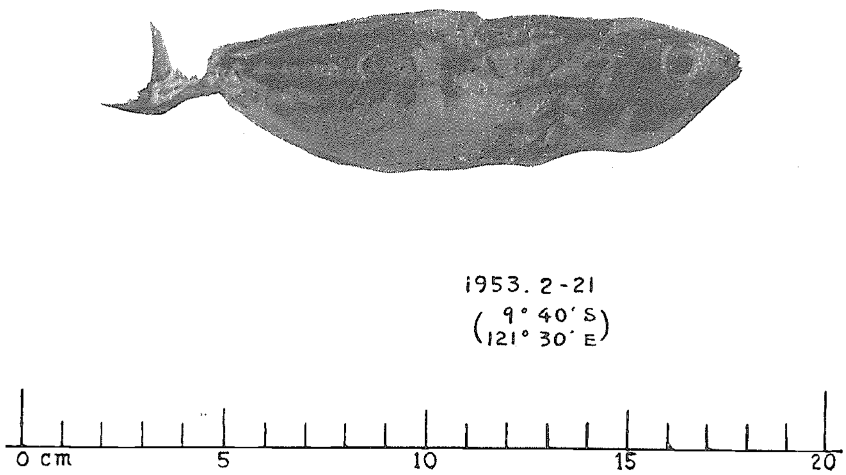


Fig. 5 Juvenile of Neothunnus macropterus. After Yabe and others (1958)

Table III

STOMACH CONTENTS OF JUVENILE YELLOWFIN TUNA
(Yabe and others 1958)

Standard length (mm)	Contents
106.8	Parts of fish larvae
146.5	One squid
157	3 pairs of squid jaws and part of fish vertebra
195 1/	1 upper jaw and 2 lower jaws of squid; 2 chaetodontids
195	10 pairs of squid jaw, part of crustacean; 1 octopus 10 mm long in mantle

1/ Vertebral length.

- Parental care

No information is available but the existence of any form of parental care is unlikely.

- Parasites and predators

There are no appreciable studies dealing with predators on young tuna but apparently they are devoured by the adults, as reported by Kishinouye (1917), Suda (1953), Yabuta (1953), Watanabe (1958) and Yabe *et al* (1958).

3.3 Adult history

3.3.1 Longevity

The longevity of yellowfin tuna is not known. It has been reported it takes about 5 years for fish to reach 150 cm. Large fish grow to more than 190 cm (3.3.6) but present knowledge cannot determine the age of such fish.

3.3.3 Competitors

Nakamura (1949) writes: "It may be generally stated that tuna feed on other animals which are abundant and available in the water and no selection of food items is sought by species". Koga (1958) finds that yellowfin, albacore and bigeye depend on nearly the same items of food in the western Indian Ocean. Watanabe (1960) working on the stomach contents of tunas and marlins in the Pacific and Indian Oceans, finds no particular difference between these two groups. The same feeling has been expressed by Juel (1955), King and Ikehara (1956), Watanabe (1958) and Koga (1958 and 1960) in the Pacific. It is thus conceivable that the species of tunas and marlins compete with each other. There must be other animals in the water which compete with tuna but no information is available on such animals at present.

3.3.4 Predators

As is well known, sharks and killer whales devour tunas hooked by longline. Sato (1955) reports a positive correlation between the number of cases of shark attack and the number of sharks caught by longline in eastern Indian Ocean. The similar phenomenon was also observed in the Pacific (Shomura and Murphy 1955 and Murphy and Shomura 1955).

Table IV shows the rate of attack (number of tuna attacked against number of total catch) by sharks and killer whales. It is apparent on the table that the rate of tuna attacked is high north of 10°S, especially west of 80°E, and around Banda and Flores. Tuna attacked by these predators are those which were weak or dead after escaping longline hooks. Then it must be true that the attack of these animals on free (or alive) tuna is much less than that shown in the table. It is also noted that the attacks by sharks are experienced evenly on each operation of the gear, while killer whale attacks are sporadic, severely damaging the tuna catch. Fisherman say tuna chased by killer whales often congregate into a big shoal, also that there is often a large tuna catch before the attack. Such claims by fishermen indicate the killer whale plays an important role as a tuna predator.

3.3.5 Parasites and diseases

Arai and Matsumoto (1952) isolated a sporozoan parasitized on abnormal muscle of tuna known as jelly-meat; this led to the discovery of the disease in yellowfin tuna from Banda Sea. The authors state: "They were the cnidosporidium spores, which seem to be new to science, and are described here under the name of <u>Hexacapsula neothuni</u> gen. et sp. nov., after the number of polar capsules and the generic name of the host fish". Asakawa and Suda (1957), working on the occurrence of jelly-meat tunas in the Solomon Sea, say: "It occurs most frequently on fish of 30 to 45 kg from June to August. One jelly-meat fish was found in every 200. The jelly-meat is found on red muscle (chiai) as well as white muscle, and the abnormality in white muscle is always followed by red muscle".

Yuen and June (1957) find a nematod worm 0.5 to 4 cm long in the ovary of yellowfin tuna collected from the central equatorial Pacific. The worms were found in 22 of 25 fishes examined. In most instances, it seemed there were not enough nematodes to seriously affect egg production.

3.3.6 Greatest size

Nankai Regional Fisheries Research Laboratory Field records show the largest yellowfin tuna taken from the Indian Ocean was 171 cm long. Market surveys at Tokyo, Misaki and Yaizu conducted by Nankai Laboratory record the largest fish at 195 cm. Records indicate fish over 170 cm are not common.

In the study of scale reading of yellowfin collected in the waters of Pacific and Indian Ocean Yabuta, Yukinawa and Warashina (1960) calculated the largest fish to be 190.1 cm. In the same way Moore (1951) proposed 190.0 cm and 294.9 lb (134 kg) for Hawaiian yellowfin.

3.4 <u>Nutrition and growth</u>

3.4.1 Feeding (time, place, manner, season).

From his study on the yellowfin tuna taken from Pacific Ocean, Watanabe (1958) concludes: "The facts that myctophid fish are not commonly found in stomach, that daytime operations catch three times as much as night operations and that many fish hauled on board alive in daytime lead one to believe daytime feeding is more active than night feeding". Fishermen of yellowfin tuna aim to catch fish in their daytime feeding activity. Nevertheless, no sound evidence has been obtained to flatly deny that yellowfin tuna feed at night.

3.4.2 Food (type, volume)

Based on information gathered in the southwest Pacific, Nakamura (1949) says: "It is most reasonable to believe that tunas feed on animals which are abundant and available in the water". Watanabe (1958) and Koga (1958) report that tuna are not highly selective and food choice is not basically different for various species.

Koga (1958), by the examination of stomach contentsof yellowfin in the western Indian Ocean, finds: "The fish take other fish such as alepisaurids, sphyraenids, polypinus and young skipjack as well as decapods and cephalopods." Watanabe (1960) reports: "Yellowfin of 10°S feed on squid and such fish as alepisaurids, sternoptychids, palalepids, lepidotids, and

Table IV

RECORD OF ATTACKS BY SHARKS AND KILLER WHALES ON TUNAS CAUGHT BY LONGLINE IN INDIAN OCEAN 1/

Area 2/	Months	Rate of attacks 3/	Hooked rate of attacked tuna 4/	Hooked rate of shark 5/
A	Apr. - June	0.09	0.63	0.60
	July - Sept.	0.18	0.83	0.46
-	Oct. - Dec.	0.17	1.46	0.71
-	Jan. - Mar.	0.15	1.46	0.73
B	Apr. - June	0.07	0.33	0.48
-	July - Sept.	0.09	0.52	0.38
-	Jan. - Mar.	0.07	0.30	0.65
C	Apr - June	0.14	0.89	0.58
-	Jan. - Mar.	0.16	0.88	0.59
D	Oct. - Dec.	0.04	0.41	0.28
-	Jan. - Mar.	0.06	0.62	0.41
E	Oct. - Dec.	0.04	0.21	0.50
-	Jan. - Mar.	0.06	0.35	0.26

1/ Data from the surveys made by Prefecture Fisheries Station Boats and Training Vessels of Fisheries High Schools of Japan from April 1958 to March 1960 totaling 43 cruises.

2/ A-- north of 10°S and west of 80°E: B-- north of 10°S and east of 80°E: C-- Banda and Flores Seas: D-- south of 10°S and west of 80°E: E-- south of 10°S and east of 80°E.

3/ Number of tuna attacked divided by number of tuna hooked.

4/ Number of attacked tuna per 100 hooks.

5/ Number of shark caught per 100 hooks.

similar species. Moving southwards, the food items are characterized by the decrease of amphipods, sternoptychids and chiasmodontids, abundant occurrence (30 percent) of pteraclids and the appearance of ocean sunfish. The food items identified in Sau Sea are not qualitatively different from those in the eastern Indian Ocean, though the occurrence in number is different between the two waters. In the former, a marked decrease of megalopa larvae, lepidontids and chiasmodontids is noted." (Table V)

The food organisms taken by Pacific yellowfin were studied by Kishinouye (1917), Nakamura (1936), Reintjes and King (1953), Juel (1955), King and Ikehara (1956), Tester and Nakamura (1957), Watanabe (1958 and 1960), Koga (1960) and others. The results reached by these authors, with some local variations, show that yellowfin tuna are euryphagous, depending on animals which are available and abundant in the water.

On the food preference by the fish in different waters of Pacific and Indian Ocean Watanabe (1960) concludes: "In the waters out side 30°N and 30°S, there are few kinds of food items compared with those in the seas of lower latitudes; they are heterogeneous in the waters around the equator and in low latitudes. Food fish taken by yellowfin tuna in shore waters are frequently represented by chaetodontids, balistids, auxiinean bonito and others not found in oceanic waters." Thus, it is very clear that the fish fauna of the sea is well represented in the diet of yellowfin tuna.

3.4.3 Relative and absolute growth patterns and rates

In reading scales of Pacific and Indian Ocean yellowfin Yabuta, Yukinawa and Warashina (1960) compared the growth rate of the fish in two oceans finding almost no variation. The estimation of growth by ages of fish are given on Table VI in which results reached by different authors are tabulated.

Talbot and Penrith (1960) conclude the growth of yellowfin in the waters of Cape and Zanzibar about 40 cm a year from their study on size composition of fish.

Age determination of Pacific yellowfin has been attempted by a number of authors, including Kimura (1932), Aikawa and Kato (1938), Yabuta and Yukinawa (1957 and 1959), Nose, Kawatsu and Hiyama (1957), Schaefer (1948) and Moore (1951). The sizes of fish referred to ages determined by these authors are given in Table VI.

The growth estimation based on tagging experiments shows a wide individual range averaging 20 to 40 cm a year (Blunt and Messersmith 1960 and Yabuta and Yukinawa 1961).

3.5 Behavior

3.5.1 Migration and local movement

Nakamura (1959) treats the migration of tunas under two categories - migration within the same current system and migration between different current systems. He states: "In the first type the migration of fish takes place under a similar ecological factor and precedes the migration of the second type. In the first type the migration is usually affected by seasonal fluctuation of the current. The other type is seen as the result of active fish movements which demand changes of ecological factors. The latter migration is often observed in a shorter period with the peaks of activity in March and September." The migration of yellowfin tuna contaminated by radioactivity of nuclear bombing (Nakamura and others 1955) may have also taken place under the same migration category.

Kamimura and Honma (1961), by studying size frequency in shoals of Pacific yellowfin, found: "In the waters west of 100°W, fish tend to grow smaller toward the west. In eastern seas, there are fewer small fish than big fish." The authors, then, believe that the fish migrate eastward as they grow.

Nakamura's second type of migration has not been recognized for Indian Ocean yellowfin due to demand on environmental changes by fish since the larvae, the young and the adults of the species are all evenly distributed in the vast area north of 10°S. South of 10°S, where the fish are large but have gonads of low maturity (4.1.3 and 3.1.7), it might be possible to see the second type migration.

In the Indian Ocean there seems no evidence to show migration is accompanied by growth. But a suspicion of such migration might be

Table V

THE COMPOSITION OF THE FOOD ORGANISMS FOUND IN THE STOMACH OF TUNA CAPTURED IN INDIAN OCEAN

Area	Sau Sea		East Indian Oc., around 10°S		East Indian Oc., around 20°S	
n	57		71		63	
Food organisms	%	N	%	N	%	N
CRUSTACEA						
Decapoda						
Macrura	8.71	8	12.1	103	6.35	11
Megalopa	40.3	680	6.60	-		
Euphausiacea			26.4	419	1.59	12
Amphipoda	8.78	10	17.6	25	28.6	137
Stomatopoda	1.75	1	6.60	7		
Alima	8.78	14	4.40	6		
Unidentified Crustaceans	8.78	161	9.90	13	1.59	18
MOLLUSCA						
Heteropoda			29.7	153	1.59	1
Cephalopoda						
Octopoda	5.27	2	46.1	86	15.9	18
Decapoda	49.1	103	75.8	377	80.9	305
TUNICATA						
Salpa	1.75	30	17.6	86	6.35	11
PISCES						
Sternoptychidae	1.75	2	20.9	269	1.59	1
Synodontidae					1.59	4
Myctophidae	10.5	11	16.5	127		
Paralepidae	12.3	15	37.4	128	3.18	2
Alepisauridae	1.75	1	46.1	57	19.0	14
Omosudidae			19.8	29		
Plotosidae	1.75	37				
Nemichthydae			1.10	1		
Exocoetidae					11.1	16
Fistulariidae	1.75	1				
Syngnathydae	8.78	5	1.10	1		
Trachichyidae	5.27	7				

Table V (Continued)

Directmidae			3.30	8		
Holocentridae	3.51	2				
Caristiidae	1.75	1				
Caulolepidae	3.51	2	9.90	20	6.35	4
(Berycidae)			7.70	15		
Trachipteridae			4.30	6		
Lophotidae					3.18	2
Scombridae						
Thunninae					1.59	1
Katsuwoninae			9.90	9	1.59	1
Auxiinae	31.6	38				
Acinacedae	31.6	55′	30.8	53	23.8	22
Lepidopidae					1.59	1
Coryphaenidae	5.27	4				
Lepidotidae	15.8	14	39.6	129	36.5	61
Pteraclidae	1.75	1			31.8	30
Carangidae	1.75	1				
(Stromateina)			13.2	21	7.94	14
Apogonidae (?)			11.0	19		
Priacanthidae	1.75	5				
Chiasmodontidae	15.8	25	68.2	520	23.8	40
Blenniidae	3.51	2				
Chaetodontidae	36.9	167	1.10	1		
Acanthuridae					1.59	1
Triacanthodidae			3.30	5		
Balistidae	68.4	351	5.50	2		
Aluteridae	3.51	4				
Ostraciontidae	5.27	3	1.10	1		
Tetra dontidae	15.8	17	13.2	12		
Diodontidae	1.75	1				
Molidae	1.75	1			3.18	2
Scorpaenidae			1.10	2		
Peristediidae	1.75	1	1.10	1		
Cephalacanthidae	1.75	1				
Echeneidae			1.10	1	6.35	4
Lophiidae			1.10	1		

After Watanabe (1960)

$^{o}/_{o}$ - Percentage of stomachs in which occurred
N - Number of food organisms found in the stomachs
n - Number of stomachs examined.

Table VI

GROWTH BY AGES OF YELLOWFIN TUNA ESTIMATED BY DIFFERENT AUTHORS

(Nose and others 1957)

Authors	0	I	II	III	IV	V	VI	VII	VIII	Remarks
Kimura (1932)		62	81	106	120	134				Weight frequency
Aikawa and Kato (1938)	38	54	70	85	100	115	130	145	160	Vertebrae
Schaefer (1948)	60	85	115							Length frequency
Moore (1951)	54	103	136	155	168					Weight frequency
Nose and others (1957)	52.4 ±21.5	64.3 ±18.0	76.3 ±14.7	87.6 ±11.7	98.9 ±8.6	109.0 ±6.3	119.3 ±4.9	127.1 ±4.9	135.1 ±5.9	Scale
Yabuta and Yukinawa (1957)	51	100	133	146						Length frequency
——— (1959)	51	100	125	137	145					
Yabuta, Yukinawa & Warashina (1960)	54.3	92.3	120.1	139.9	154.1					Scale

Note: Three bottom data added by the present authors.

allowed because, as shown by Mimura and Nakamura (1959), smaller fish seasonally frequent the waters of western Sumatra, southern Java and east Africa.

These facts suggest the migration of yellowfin tuna over wide areas. But there is contrary evidence to suggest localization of stock. Mimura (1958), tracing the yearly fluctuation of size and the hooked rate since longline operations began in the Indian Ocean, believes that fish large enough to be caught by the gear are fairly well characterized by localization in different waters. Also, morphometry studies conducted by Kurogane (1960), Kurogane and Hiyama (1958), Tsuruta (1955), Hirano and Tagawa (1956), and Tsuruta and Tsunoda (1960) point out the existence of semi-independent populations within the Indian Ocean.

On the migration following seasonal changes of water currents, Mimura and Nakamura (1959) find a high fish density in southern equatorial water from October to March but that fish appear north of 5°S from April to September, suggesting a north-south migration by season, and the authors comment that such a latitudinal movement corresponds to environmental changes. The same authors call attention to the observation of the north-south migration, particularly from Ceylon to the Andaman and Nicobar islands, the species' northern limit of distribution. The authors add that the fishing ground in the south-eastern Indian Ocean extends in vast area from the waters of Java, the Lesser Sunda islands, and Timor Sea eastward to Australia from November to February, when the South Equatorial Current changes direction. The fishing ground concentrates in the restricted waters of Java and Lesser Sunda islands from May to August.

No information is available concerning vertical movements of fish in the Indian Ocean. In the Pacific, according to Watanabe (1958), who analyzed stomach contents of fish, the occurrence of myctophid fish as food fish would suggest tuna approach surface at night. For behavior of larval fish, see 2.2.1.

3.5.2 Schooling

Referring to surface fish caught by pole-and-line and trolling, Nakamura (1949) writes that yellowfin tuna often congregate in shoals mixed with skipjack but they also form shoals of their own.

Broadhead and Orange (1960) have this to say about the surface shoal: "Even when the skipjack and yellowfin populations overlap, they tend to segregate into their own shoals. The fish in the shoals are larger and more uniform in size than those picked at random from entire population. The individual yellowfin in mixed shoals is smaller than those in non-mixed shoals, and the size variation is less significant in the former." Yabe and Mori (1953) report that the surface shoals often follow driftwood.

Concerning yellowfin tuna caught by longline in the Indian Ocean Hirayama (1957) writes, "The shoal expands from 1,400 to 4,500 m in width. The fishes in such a large school are not believed to behave in the same pattern. Thus, it may be logical to interpret that such a large school is composed of groups of individuals distinguished by different behavior."

The longline catch would suggest that the fish in the midlayers will not form schools of high density.

It may be reasonably concluded that small fish in surface water tend to congregate and larger fish in the midlayers tend to scatter.

3.5.3 Reproductive habits

See sections 3.1.1, 3.1.3, 3.1.4, 3.1.6, 3.1.7

4. POPULATION

4.1 Structure

4.1.1 Sex ratio

The study of the sex ratio of Indian Ocean yellowfin tuna is all based on the longline catch. Hirano and Tagawa (1956) find in the middle equatorial Indian Ocean that the ratio is 1:1 among the fishes smaller than 140 cm but larger fish were 51.6 percent male and 42.5 percent female. In the same water Kataoka (1957) finds 57.6 percent male and 42.5 percent female. Tsuruta and Tsunoda (1960) report male fish are 80 percent of the catch in the Arabian and Javanese Seas dropping to 60 percent in middle equatorial waters.

Mimura (unpublished) recognises a sex ratio varying by latitudes and states: "The male dominates north of 10°S, especially north of 10°N. The two sexes appear equal from 10°S to 15°S, but females dominate south of 15°S. South of 10°N fish smaller than 120 cm show an even sex ratio; larger than 150 cm have more males, and fish 120 to 150 cm show a sex ratio varying with latutude, male predominance increasing toward the north." (Fig. 6). This tendency is recognized in the whole Indian Ocean but not restricted to the water (60° to 80°E), illustrated in Fig. 6. As pointed out before (2.2.1), the fish population is particularly thick north of 10°S where males dominate females. Therefore, despite female dominance in southern areas, the yellowfin population in the Indian Ocean, represented by fishes about 120 cm, may be said to show male dominance.

The sex ratio of Pacific yellowfin has been studied by a number of authors including Nakamura (1949), Murphy and Shomura (1953 a and b and 1955), Otsu (1954), Shomura and Murphy (1955), Schaefer and Orange (1956), Iversen and Yoshida (1956 and 1957), Tester and Nakamura (1957), Yabuta and Yukinawa (1959) and Koga (1959).

In these studies, the ratio is even in the population of smaller fish but more males are seen as fish grow larger. The relation of fish size and sex ratio changes when fish reach 120 cm in the eastern Philippines (Nakamura) and 147 cm (Murphy and Shomura) or 120 cm (Schaefer and Orange) in the eastern Pacific. In the south Pacific Ocean, Koga (1959) finds a 1:1 ratio in fish below 130 cm long, female predominance in fish 130 to 150 cm, and male predominance in the largest fish over 150 cm.

It is thus clear that more female fish are counted than male south of mid-latitude in the southern hemisphere, whether in the Pacific or Indian Ocean.

4.1.2 Age composition

The studies on age (3.4.3) and size composition (4.1.3) will indicate the principal population of yellowfin taken by longline in Indian Ocean is represented by fishes of 2, 3 and 4 age.

4.1.3 Size composition

In their analysis of size composition data accumulated to 1956, Mimura and Nakamura (1959) report: "In the southern boundary of thickly populated water, fish are larger than in northern waters. The population in waters near islands or surrounded by islands has more small individuals than the open-water population." The variability of size composition by latitudes was studied by Mimura (MS) based on 1958 to 1960 data. He says: "North of 5°N, fish size ranges from 110 to 140 cm, with peaks of 120 to 130 cm. From the equator to 5°N, fewer fish of 110 to 120 cm are found. There is a considerable increase in larger size fish (140 to 150 cm) from 5°S to 10°S. From 10°S to 25°S, size ranges mainly from 130 to 150 cm but there is an increase to 140 to 150 cm from 15°S to 20°S. From 25°S to 30°S, size ranges mainly from 130 to 140 cm, slightly smaller than from 18°S to 25°S." (Fig. 6). The tendency for size to decrease toward the north is recognized throughout the Indian Ocean but is not restricted to the particular area, (as Fig. 6 shows), except near islands.

Since the Indian Ocean yellowfin tuna population is concentrated north of 10°S, it may be concluded that the yellowfin fished by longline is 110 to 140 cm long, and most likely 120 to 130 cm.

Mimura (1958), analyzing catch data from early years of longlining, reports: "In the beginning the catch showed larger fish but these have decreased in following years".

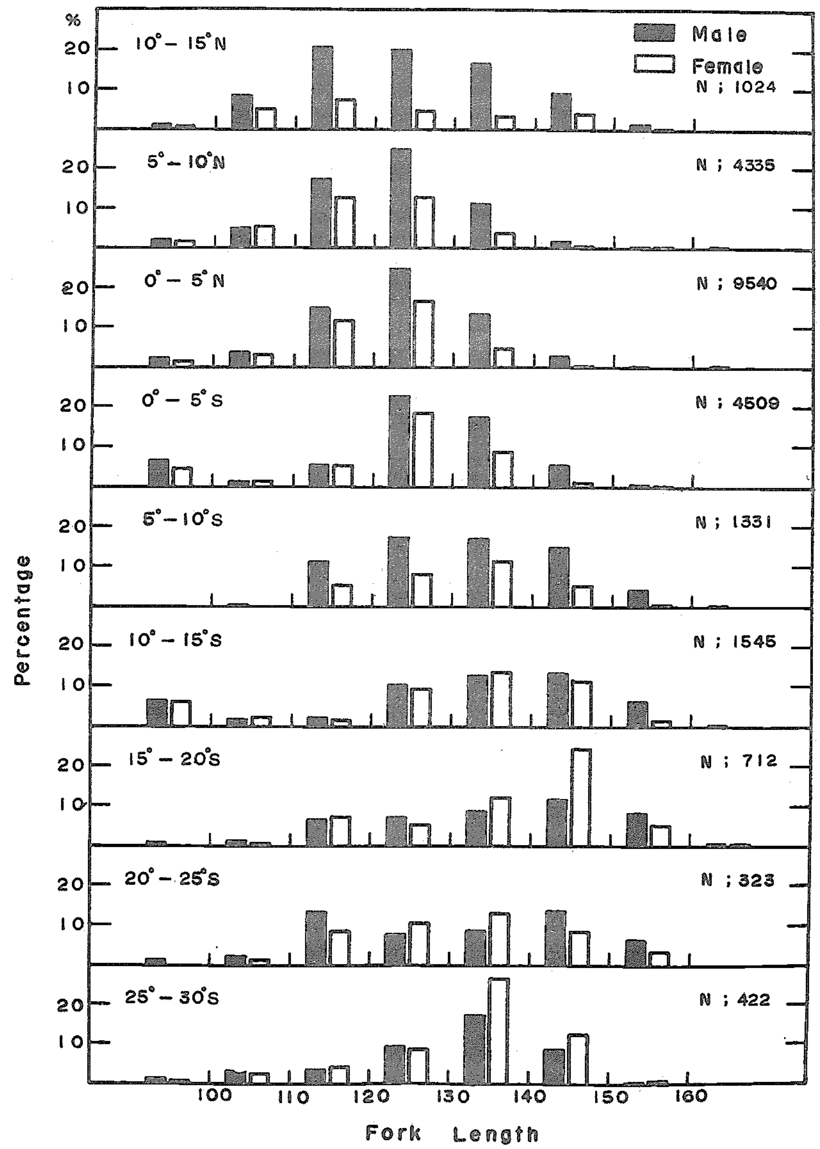


Fig. 6 Histograms to show sex ratio by size class of yellowfin tuna in Indian Ocean based on 23,741 fishes taken in 1958-1960. Shown for each 5° of latitude from 60° - 80° E. N indicates total number of fishes examined in respective latitudinal range. After Mimura (MS)

Extending his study, Mimura (MS) says that the major population fished by longline does not show much variation in size composition in consecutive years (except for the second and third) but it is apparent that the larger fish caught in the first year are not found in later years.

4.2 Size and density

4.2.3 Average density

See section 4.2.4

4.2.4 Change in density

Based on data on hooked rates, Mimura (1958 and 1962) and Nakamura (1959) report on the density changes due to water, season and year. Density changes in different waters and seasons were given (2.2.1). Yearly density changes may be summarized thus: "The fishing ground in Indian Ocean was exploited from east to west, and in all the regions the hooked rates were high during the first year and lower in the second and third. The hooked rates, however, stabilized in the fourth year and after. It seems highly probable that the decrease of larger fish in the population is responsible to the lowering of the hooked rates in the early years of operation."

Mimura and Nakamura (1959) say there is not enough information to judge whether fishing pressure or natural variation is responsible for the phenomena of the early years. The present status is based on analysis of data up to 1956 and Mimura (unpublished) admits a stabilized condition since 1957. He also points out that larger fish caught in the earliest year of operation were mostly male.

4.4 Mortality, morbidity

4.4.1 Rates of mortality

No study has shown mortality rates of Indian Ocean fish.

Of the Pacific yellowfin tuna caught by pole-and-line and purse-seine operations, Schaefer (1960) estimated mortality at 86 to 89 percent on the basis of year classes, and 95.7 percent on the basis of marking experiments. The higher mortality derived from marking experiments was explained by the author as due to the loss of tags and the escape of tagged fish from the water surveyed.

4.5 Dynamics of population

The study has not yet been made but the hooked rates and size composition (4.1.3 and 4.2.4) have been directed toward understanding the dynamics.

4.6 Relation of population to community and ecosystem, biological production

Nakamura (1954) and Nakamura and Yamamura (1959) conclude: 1) the species of tuna and marlin have different centers of distribution in particular ocean current systems or water masses, 2) the same species of tuna and marlin dwelling in different current systems or water masses shows marked differences in size composition, a fact suggesting the ecological adaptation of the fish to the water mass, 3) thus, each water mass presents a different biosphere to the fish. This fact is well demonstrated in the Indian Ocean.

The food preference of tunas and marlins is not much different (Watanabe 1960 and Koga 1958) and it is clear they are potential competitors. Thence, an interpretation may be allowed that tuna, distributed in a given water mass under specific pattern by species or ecological requirements of the species, are not severely exposed to intra-specific or inter-specific competition.

Murphy and Shomura (1953 a and b and 1955), King and Demond (1953) and King and Hida (1957) report that the habitat of Pacific yellowfin in equatorial region corresponds well to water where equatorial upwelling causes heavy concentration of plankton organisms. Contradictory facts are reported in the Pacific. Murphy and Otsu (1954) find that where equatorial upwelling is weakened in the western Pacific there is a similar distribution pattern, as in the central Pacific. Shomura and Murphy (1955) and King and Ikehara (1956) reported that bigeye tuna, though having similar food preferences as yellowfin, are highly concentrated in the Equatorial Counter Current and not necessarily in enriched water.

Murphy and Shomura (1955) report that the surface schools of yellowfin in the Pacific equatorial region frequent island waters rather than semi-oceanic or oceanic seas, a fact attributed to the abundance of plankton in the island seas. The authors further note that the occurrence of surface schools in oceanic waters does not necessarily correspond to the abundance of plankton.

The relation between the appearance of the fish schools and the plankton growth in the water has not been yet clarified for the Indian Ocean.

5 EXPLOITATION

5.1 Fishing equipment

5.1.1 Fishing gear

The gear employed in tuna fishing include set net, purse seine, handline, pole-and-line (live-bait), trolling, longline and others. In the Indian Ocean the major fishing operation has been by Japanese longliners. Other operations, on a smaller scale, are trolling in African coastal waters (Talbot and Penrith 1960) and live-bait fishing off the Minicoy Islands (Jones 1958).

A typical longline gear adopted by Japanese fishermen is illustrated in Fig. 7. One set of longline is called "one basket", the term commonly used to express the single unit of the gear. A longline unit is composed of float, float line, main line, branch lines and hooks. The float is a glass sphere (30 cm in diameter), to which a flag is attached as marking. The float line and main line are made of strands of synthetic fiber and on the main line four or five (usually five) branch lines are tied. Each branch line has three parts (from the nearest end): rope, sekiyama (wires coiled by cotton strands) and wire snood, ending with a hook.

Longline fishermen often use frozen Pacific-saurey, *Cololabis saira*, for bait.

The number of baskets carried on board varies with boat size, larger vessels carrying more baskets. Frequently one longliner has 350 to 400 baskets. The longline is hauled on board by electric line hauler at about 5 knots. Gear setting usually starts early in the morning and lasts three to four hours. Two to three hours after lines are set, hauling starts from the end of line last thrown into the water. Sometimes line-hauling starts before the completion of setting. Time required for hauling lines depends on catch and weather, but the operation usually ends in the late evening.

5.1.2 Fishing boat

Japanese tuna longliners range from 20 to 1,000 tons, and their model is quite variable. The tuna longline boats now operating in the Indian Ocean are always larger than 150 tons, the size required to navigate to and from fishing grounds. Boats this size are equipped by line-haulers and large fish holds. Recently-built large boats also have quick-freezing systems. (Fig. 8) The largest longliners in 1,000 tons class carry on board a catcher boat, the latter operating fishing independently upon arriving at the ground.

5.2 Fishing areas

5.2.1 General geographical distribution

The yellowfin tuna is caught in the extended area north of 30°S where the longline is used, but fishing specifically for yellowfin is limited to north of 10°S. Outside this area, yellowfin is caught as a subsidiary catch whether south of 10°S (where albacore is fished)or west and north of Australia (where Indomaguro, southern bluefin, is sought). (Mimura 1962)

5.2.2 General ranges (latitude, distance from coast, etc.)

See section 5.2.1

5.2.3 Depth range

Yabuta and Ueyanagi (1953) estimated the depth reached by longline hooks at 80 to 140 m, based on a calculation of shortening the line. Murphy and Shomura (1953 b) estimated the maximum depth at 165 m. The depth where longline hooks stay varies depending with gear structure, current, line tension and other factors, and is believed highly variable.

Nakamura (1943), by means of specially-designed gear (each branch line provided with a float), discovered that hooked rates increase with depth within the layer of 100 m deep (the deepest that hooks can reach), also that hooks lowered as deep as 160 m catch a considerable number of fish.

In the analysis of the hooked rates in Pacific equatorial water, Shomura and Murphy (1955), Murphy and Shomura (1953 b and 1955) and Watanabe (1958) concluded that rates increase proportionally with hook depth for both yellowfin and bigeye tuna, especially for bigeye.

Nakagome (1958 and 1959), in the study of catches around the Marshall Islands, reports that the depth where high hooked rates are experienced changes by season, also that the season when fish are in shallower waters is the season of high hooked rates.

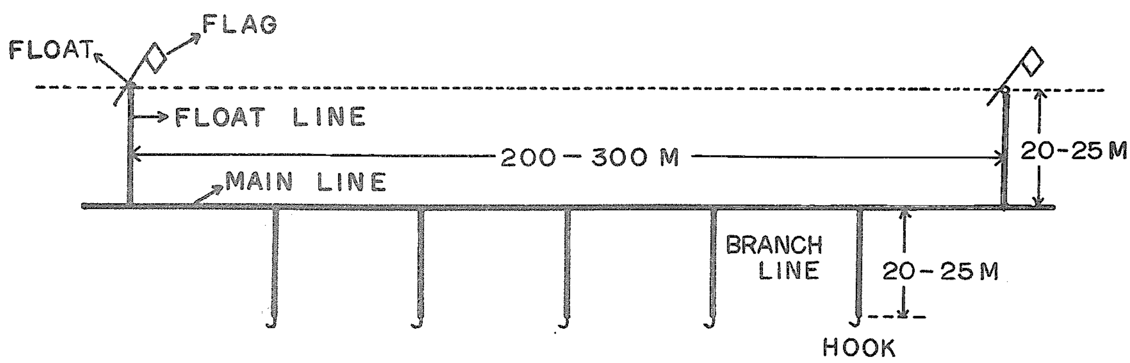


Fig. 7 Illustration of a typical tuna longline used by Japanese fishing boats

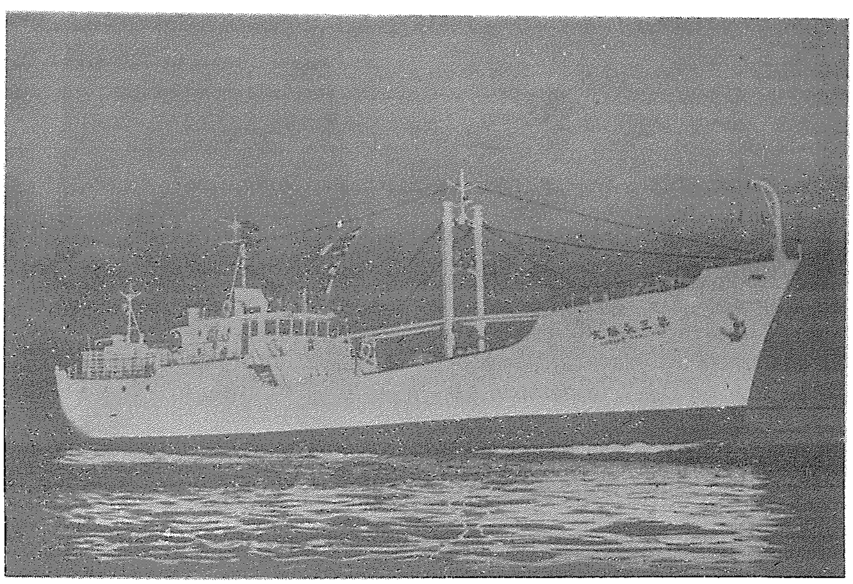


Fig. 8 A type of Japanese tuna longliner: tonnage 339.93 tons, and length 43.21 m with engine 750 HP

Watanabe (1961) finds, through depth recorder, that yellowfin tuna bite hooks more frequently when gear is set and hauled, when the hooks are believed to move up and down in the water, and the fishing depth is from 0 to 60 m.

5.3 Fishing season

5.3.1 General pattern of fishing season

Around the equator, the fishing season extends throughout the year but in the peripherial waters of northern and eastern grounds the season is determined by ocean conditions (Mimura and Nakamura 1959 and Mimura 1962).

5.3.2 Duration of fishing season

See section 5.3.3

5.3.3 Dates of beginning, peak and end of season

Fishing continues throughout the year in equatorial water but it is more frequently conducted in earlier half of the year because there is a higher rate of catch in this period. In the northern Indian Ocean, the fishing season is from March to July and the peak activity moves toward the north from south of Ceylon. Off the Lesser Sunda Islands the peak is seen from November to January (Mimura and Nakamura 1959 and Mimura 1962).

5.3.4 Variation in time or duration of fishing season

The fishing season does not show much variation from year to year but there are some changes in starting date and period.

5.3.5 Factors affecting fishing season

The factors will involve the size, density and distribution of fish population and oceanographical conditions which affect those biological factors. Information available at this time is not sufficient to discuss the problem more critically.

The weather is also a determining factor. The selection of fishing ground by boats is also concerned; fishermen take the fishing condition into account in various waters as well as the price of fish.

5.4 Fishing operation and results

5.4.1 Efforts and intensity

The fishery statistics issued in Japan cover the total tuna catch landed by Japanese vessels but figures are not broken down by region. The market surveys, conducted by the Nankai Regional Fisheries Research Laboratory (Mimura, part 1961), will show the longline operation in Indian Ocean as presented in Table VII. The figures in the table present a partial (50 to 70 percent) status of the actual operation; they will show accurately the changes of activity from year to year. Operations by months and waters are illustrated in Fig. 9 cited from Mimura (1962).

5.4.2 Selectivity

The longline catch in Indian Ocean is represented by the fish 110 to 140 cm long and individuals 120 to 130 cm constitute the bulk. Fish smaller than 110 cm are by no means rare. Experience shows that the bulk of albacore catch by longline is represented by fish 90 to 110 cm long (Mimura 1957) and that yellow fin in surface water and subjected to trolling, purse seine and pole-and-line are smaller than those hooked by longline. These facts will explain that the factors responsible for the catch of small fish by longline involve not only some mechanical hindrance of the gear but also maladjustment between the operation of gear (depth and fishing water) and the habitat of smaller fish (water layers and distribution).

5.4.3 Catches

For the same reason as in 5.4.1, the actual figure for the Indian Ocean catch is not available. Mimura (MS) presents Table VIII to show yearly fluctuation in the relative number of yellowfin caught in the ocean based on source data from market surveys conducted by the Nankai Regional Fisheries Research Laboratory.

5.5 Fishery management and regulation

At present there are no Japanese regulations on yellowfin tuna fishing either on size limit or season and ground restrictions. The longline operation in the Indian Ocean is at present conducted exclusively by Japanese boats. The boats require licenses issued by the Japanese Government; since 1960 new longline fishing licenses have been suspended for the vessels

Table VII

NUMBER OF OPERATIONS OF LONGLINE FISHING

Year	1952	1953	1954	1955	1956	1957	1958	1959	1960
A	107	861	2,998	6,194	8,096	6,820	7,740	9,759	12,872
B		5	1,674	4,430	4,783	4,128	4,382	3,289	4,125

A. Figures for all Indian Ocean; B. Figures for north of 10°S and west of 110°E. Data from market surveys by the Nankai Regional Fisheries Research Laboratory. Figures are believed to present 50 to 70 percent of total operations by Japanese boats.

Table VIII

RELATIVE NUMBER OF YELLOWFIN TUNA CAUGHT

Year	1952	1953	1954	1955	1956	1957	1958	1959	1960
A	920	3,020	11,380	38,630	34,100	18,200	17,830	15,570	21,940
B		10	8,670	32,860	27,080	14,980	13,090	11,540	14,650

A. Figures for all Indian Ocean; B. Figures for north of 10°S and west of 110°E. Figures are obtained by adding products of mean hooked rate and operation numbers in each of one degree square; data source same as for Table VII.

over 40 tons to control the increase of boats.

The Inter-American Tropical Tuna Commission declares that in eastern tropical equatorial water yellowfin tuna fishing by pole-and-line and purse seine reached the maximum sustainable yield in 1961, and recommends curtailing the catch to 8,300 tons in 1962 and that this figure be adjusted every year.

5.6 Fish farming, transplanting and other investigations

None so far.

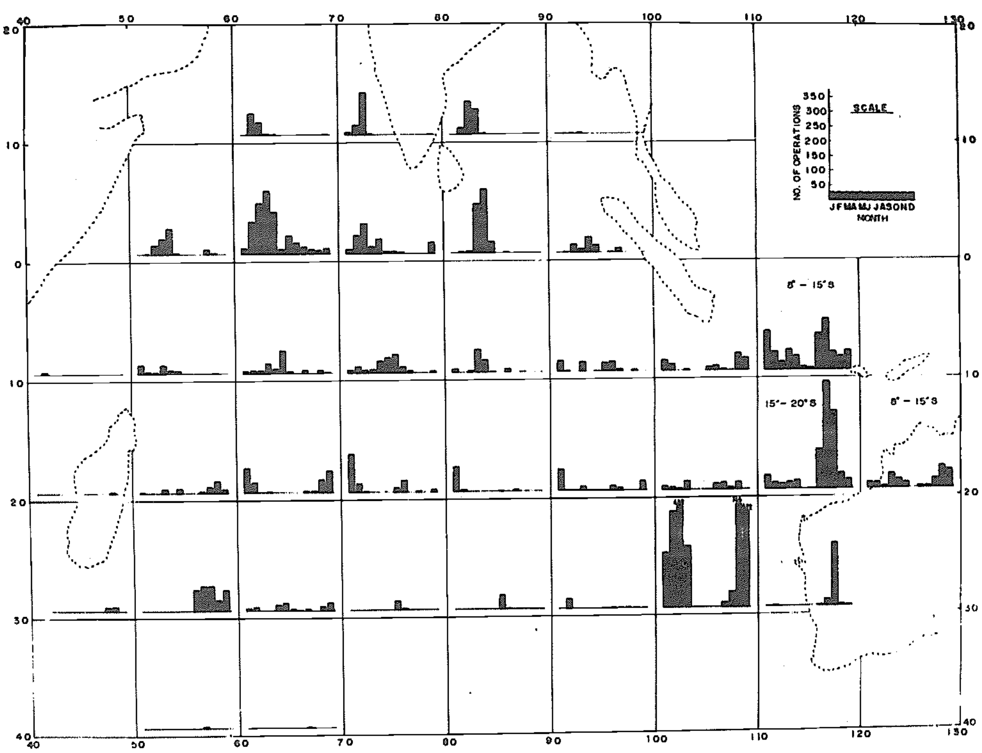


Fig. 9 Longline operation by Japanese boats in 1959. The number of operations checked by the Nankai Regional Fisheries Research Laboratory totalling 9,759 is shown in 10^{o} square S. After Mimura (1962)