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SYNOPSIS OF BIOLOGICAL DATA ON ALBACORE *Thunnus germo* (Lacépède), 1800 (PACIFIC AND INDIAN OCEANS)

Exposé synoptique sur la biologie du germon *Thunnus germo* (Lacépède), 1800 (Océans Pacifique et Indien)

Sinopsis sobre la biología de la albacora *Thunnus germo* (Lacépède), 1800 (Oceanos Pacífico e Indico)

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1 IDENTITY

1.1 Taxonomy

1.1.1 Definition

Classification down to family after Schultz, et al 1960.

Phylum CHORDATA
Subphylum Craniata
Superclass Gnathostomata
Class Osteichthys
Subclass Teostomi
Superorder Teleosteica
Order Percomorphida
Suborder Scombrina
Family Scombridae
Genus *Thunnus* South 1845
Species *Thunnus* germo (Lacépède), 1880

1.1.2 Description

- Genus *Thunnus* South 1845

"Body moderately robust; snout pointed, not very long; mouth rather large; maxillary not concealed by preorbital; teeth in jaws small, those on vomer and palatines in villiform patches; gill rakers long, moderately slender; scales covering entire body, enlarged, and forming a corselet in region of pectorals; interval between dorsal fins slight; first dorsal with 12 to 15 rather slender spines, the fin high anteriorly; second dorsal and anal each followed by 8 or 9 finlets; ventral fins rather small, less than half length of head; pectoral short or long, with about 32 to 35 rays." (Hildebrand, 1946).

- *Thunnus germo* (Lacépède) 1800

"Body elongate, fusiform; caudal peduncle slender, keel on each side. Head conical; mouth terminal, moderate; gill rakers below angle of first gill arch, 19 to 21. Fins: dorsal (2), XIII or XIV - II, 13 or 14, interspace very short, spinous fin long, high anteriorly, finlets 7 or 8; anal, II, 12 or 13, origin below insertion of rayed dorsals, finlets, 7 or 8; pelvic I, 5, thoracic; pectoral very long, longer than head, reaching behind insertion of anal fin, sabre-shaped; caudal lunate. Lateral line: decurved anteriorly, nearly straight for greater part of length. Scales: cycloid, moderate, covering body; corselet small, indistinct. Color: metallic steely blue on dorsal surface and sides; silvery on ventral surface." (Clemens and Wilby, 1946). (Fig. 1).

The internal anatomy of the albacore has been studied in great detail by Godsil and Byers (1944) and Kishinouye (1923). Excerpts from these studies are presented below.

"The view of the viscera *in situ* is strikingly different from that of any other tuna investigated. The course of the intestine from right side to left across the abdominal cavity, the location of the spleen on the left side, and relatively conspicuous position of the gall-bladder serve to distinguish this tuna from any other.

"The center lobe [of the liver] is always the longest, and the outline of all lobes is quite irregular, due to extensive lobulation. The ventral surface of all lobes is always marked with characteristic radiating striations, and large conical vascular cones are invariably present on the dorsal face of each lobe. There are generally two moderate cones beneath the right lobe, one large one beneath the center lobe, and four or five small ones beneath the left lobe.

"In the albacore the straight intestine, in ventral view, appears anteriorly upon the right side of the fish, but in the anterior half of the abdominal cavity it crosses to the left side. Both anterior and posterior bend, and in consequence the fold of the intestine, are located on the left side of the abdominal cavity, and the descending portion of the intestine runs to the vent against the left wall of the body cavity.

"In shape and location the spleen of the albacore differs from that of the remaining tunas. This is the only species in which the spleen appears on the left side of the abdominal cavity.

"Due to its location, the gall-bladder is a conspicuous and distinctive character in the albacore. It follows closely the course of the straight intestine from its apparent origin anteriorly on the right side. Crossing with this to the left side of the fish it continues posteriorly beyond the posterior bend of the intestine. It lies on the median side of the intestine as a tubular, green structure and can rarely be overlooked. A short distance beyond the posterior bend of the intestine, the gall-bladder doubles anteriorly upon itself and, reaching the bend of the intestine, terminates here or occasionally again doubles back upon itself." (Godsil and Byers, 1944)

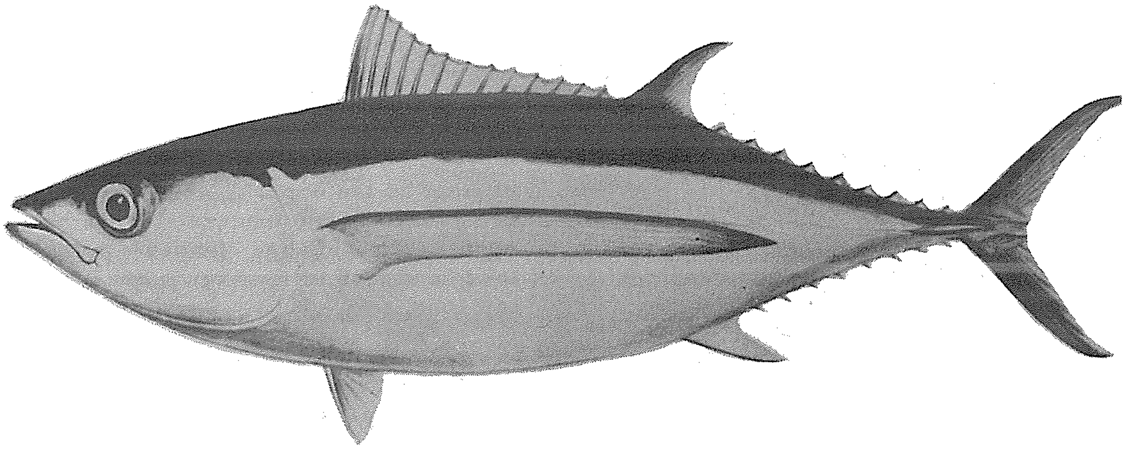

Fig. 1 Thunnus germo (Lacépède) (reproduced from Walford, 1937)

"Skull rather narrow. Vertebral column more or less slender. Height of the vertebrae nearly uniform. Parapophyses well developed. Parapophyses of the ninth vertebra are almost horizontal as in the preceding vertebrae; but in the tenth vertebra the haemal arch is formed and is turned forward leaving only a little space between the centrum and the arch. In each of the following precaudal vertebrae the haemal spine is formed, and it is remarkable that it is nearly uniformly elongated. These precaudal haemal spines are remarkably longer than in other tunnies. The head of the second and third ribs is very thick, and the distal portion of these ribs is broad, thin, and gradually narrow. The part between the head and the broad distal portion is very narrow to admit the passage of the cutaneous blood vessels." (Kishinouye, 1923)

1.2 Nomenclature

1.2.1 Valid scientific name(s)

Thunnus germo (Lacépède)

It should be mentioned here, without delving into the details, that the validity of this name has not been verified. Collette (MS) and Roedel and Fitch (MS) have discussed the problems concerned with the taxonomy and nomenclature of the tunas in some detail.

1.2.2 Synonyms

Collette (MS) has compiled a list of synonyms of the albacore. The names that have been applied to the albacore in the Pacific and Indian Oceans are listed below.

Scomber germo Lacépède 1800
Thynnus pacificus Cuvier in Cuvier and Valenciennes 1831
Thunnus pacificus South 1845
Orcynus pacificus Cooper 1863
Orcynus germo Lütken 1880
Germo alalunga Jordan and Everman 1896
Germo germo Jordan and Seale 1906
Thunnus alalunga Jordan, Tanaka and Snyder 1913
Thunnus germo Kishinouye 1923

1.2.3 Standard common names, vernacular names

The common and vernacular names listed in Table I were drawn primarily from the list compiled by Rosa (1950).

1.3 General variability

1.3.1 Subspecific fragmentation (races, varieties, hybrids) (see also section 1.3.2)

- Meristic counts

Meristic counts on albacore from various localities are presented in Table II.

- Varieties

Godsil (1948) compared albacore from California and Japan and noted that "the Japanese albacore are characterized by a relatively shorter head and caudal region and a longer abdominal or central trunk."

Kurogane and Hiyama (1959) compared albacore taken from several different localities. They found that the albacore from the Indian Ocean had larger heads and much posteriorly positioned fins than albacore from the northwest Pacific. Also, they concluded that albacore from the Indian Ocean and the southwest Pacific Ocean did not form a homogeneous population because of the rather great differences between them. However, the difference was not as great as that between the albacore in the Indian Ocean and the northwest Pacific. Therefore, they further concluded that there existed a possibility of intercourse between the populations in the Indian Ocean and the southwest Pacific Ocean.

Table I

Common and vernacular names

Country	Standard common name	Vernacular name(s)
Australia	Albacore	
Canada	Albacore	Longfin albacore, Longfin tuna
Chile	Atun de aleta larga	Atun
Hawaii	Albacore	Longfin albacore, Ahipalaha
Japan	Binnaga	Bincho, Tomboshibi, Kantaro
Mexico	Albacora	
New Zealand	Longfin albacore	
Peru	Alalonga	
Philippines	Albacore	Albakora (Tagalog), Kiyawon (Bikol)
Union of South Africa	Albacore	Longfin albacore, Longfin tunny Longfin tuna
United States	Albacore	Longfin albacore, Longfin tuna, Albacora, Alilonghi, Germon, Abrego

Table II

Meristic counts of albacore

Locality	Gill Raker Counts																
	Upper limb				Lower limb					Upper and lower limbs combined							
	7	8	9	10	18	19	20	21	22	25	26	27	28	29	30	31	32
Japan	-	3	5	-	-	1	5	2	-	-	-	1	1	5	1	-	-
Hawaii	-	1	2	-	-	-	3	-	-	-	-	-	1	2	-	-	-
California	-	2	8	1	-	1	7	3	-	-	-	-	2	6	3	-	-
Indian Ocean	1	12	25	-	-	7	20	10	1	-	-	5	9	15	8	1	-
Northwest Pacific	2	38	58	4	4	14	59	24	1	1	1	8	32	44	12	3	1
Southwest Pacific	5	52	66	4	1	23	71	29	3	-	2	14	41	45	23	2	-

Locality	1st dorsal fin		2nd dorsal fin		Dorsal finlets		2nd dorsal fin plus dorsal finlets		Anal fin		Anal finlets		Anal fin plus Anal finlets	
	13	14	15	16	7	8	22	23	14	15	7	8	21	22
Japan	-	9	2	5	6	3	1	6	2	7	8	1	1	8
Hawaii	1	2	-	3	3	-	-	3	-	3	3	-	-	3
California	3	8	3	7	8	3	-	10	1	10	10	1	-	11

Locality	1st dorsal spine			
	12	13	14	15
Indian Ocean	-	39	84	-
Northwest Pacific	3	74	206	1
Southwest Pacific	-	53	127	-

Note: Japan, Hawaii, and California data from Godsil and Byers (1944); Indian Ocean, Northwest Pacific, and Southwest Pacific data from Kurogane and Hiyama (1959).

1.3.2 Genetic data (chromosome number, protein specificity)

Suzuki, Morio and Mimoto (1959) discovered a blood group system designated Tg1 - Tg2 - 0 in the albacore. Sprague (MS) discovered another blood group system designated the G-system. Other systems that have been recognized in the albacore are the A-system and C-system (Sprague and Nakashima, MS).

The blood group characteristics have been utilized in studying the problem of sub-populations of albacore. Suzuki, et al (1959) compared the blood group frequency of albacore from the North Pacific and Indian Oceans and found striking differences between the two. Marr and Sprague (MS) subjected the data from Suzuki, et al to another analysis and concluded that the Pacific Ocean samples were drawn from a single inter-breeding population, but that the Indian Ocean samples were drawn from a mixture of two or more inter-breeding populations.

Sprague (MS) noted that the difference in the relative proportions of pheno-types of C-positive albacore from Samoa and North America was highly significant and concluded that the albacore from the two areas are representative of genetically isolated stocks.

2 DISTRIBUTION

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

The distribution of albacore in the Pacific and Indian Oceans is shown in Fig. 2, which was adapted from Fig. 11 of Brock (1959a). It can be seen from this chart that albacore is quite cosmopolitan in distribution. On the eastern side of the North Pacific, albacore has been recorded from Baja California to the Gulf of Alaska. In the western North Pacific albacore is distributed from the Equator to approximately 45° N latitude. Centered approximately along 35° N latitude, albacore has a continuous distribution across the North Pacific Ocean.

In the South Pacific, albacore has been recorded from the Equator to 45° S latitude and from the east coast of Australia to the coast of Chile. However, the occurrence of albacore from about 135° W longitude to the coast of Chile is quite spotty.

The range of distribution of albacore in the Indian Ocean is from approximately 10° N to 30° S latitude and from Australia to the east coast of Africa.

The major oceanographic features of these areas were described in a general way by Brock (1959a). Figs. 3, 4, 5, 6, and 7 were adapted from Brock and show the ocean current systems, summer average surface temperature and depth of thermocline, winter average surface temperature and depth of thermocline, respectively.

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

- Larval stages

There is very little information on the distribution of larval albacore. Table III lists some records of the occurrence of larval albacore, based on the tentative identification of Matsumoto (MS).

Table III

Occurrence of larval albacore[1/]

Date	Position		No. of Albacore larvae
May 1929	20°04' N	123°59' E	1
May 1929	25°30' N	125°28' E	259
June 1929	14°37' N	119°52' E	1
July 1929	00°50' S	134°15' E	1
September 1929	01°29' S	100°07' E	2
October 1929	02°57' S	99°36' E	1
November 1929	04°20' N	98°47' E	1
January 1952	01°54' N	155°03' W	1
May 1952	01°57' N	140°03' W	1
May 1952	03°09' N	139°53' W	1
November 1957	09°13' S	141°35' W	1
February 1958	02°10' S	144°08' W	1
February 1958	07°12' S	142°10' W	4
March 1958	06°20' S	139°39' W	1
May 1958	09°12' S	143°08' W	1
May 1958	09°14' S	142°20' W	5
July 1960	09°05' N	168°20' E	1

[1/] Data from files of U. S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii.

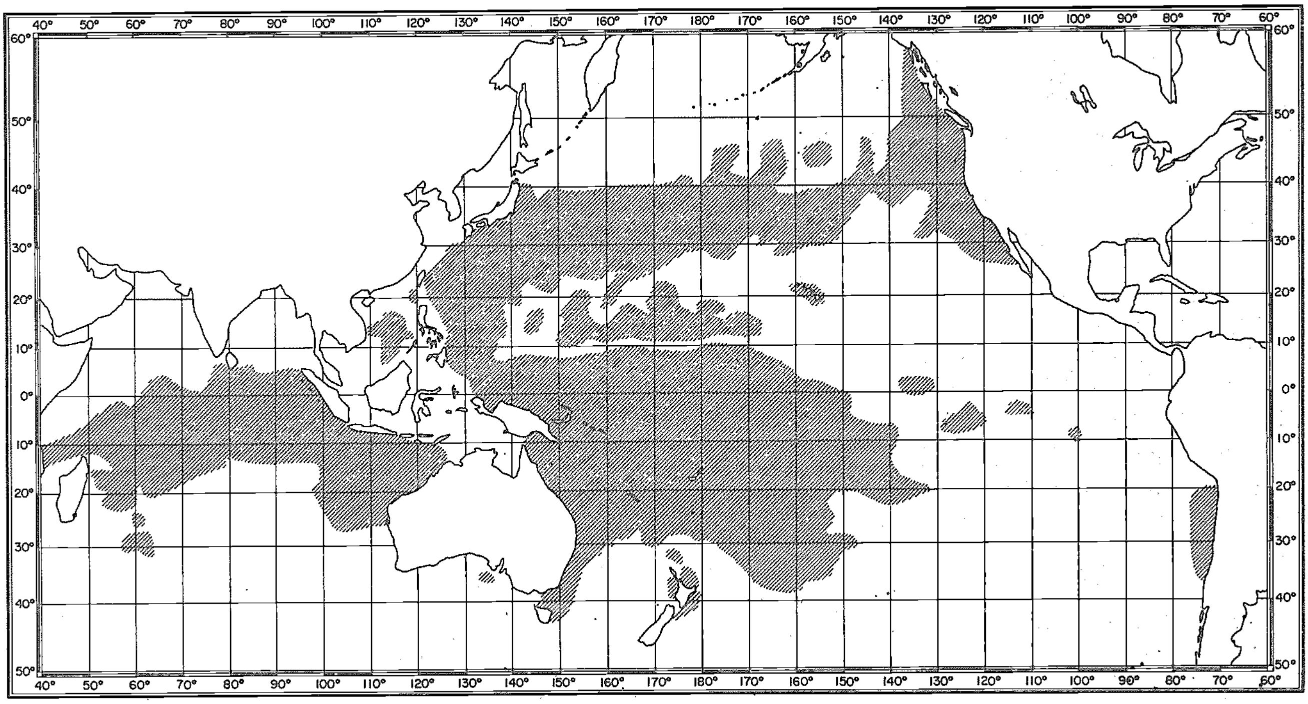

Fig. 2 Distribution of albacore in the Pacific and Indian Oceans (Brock, 1959a)

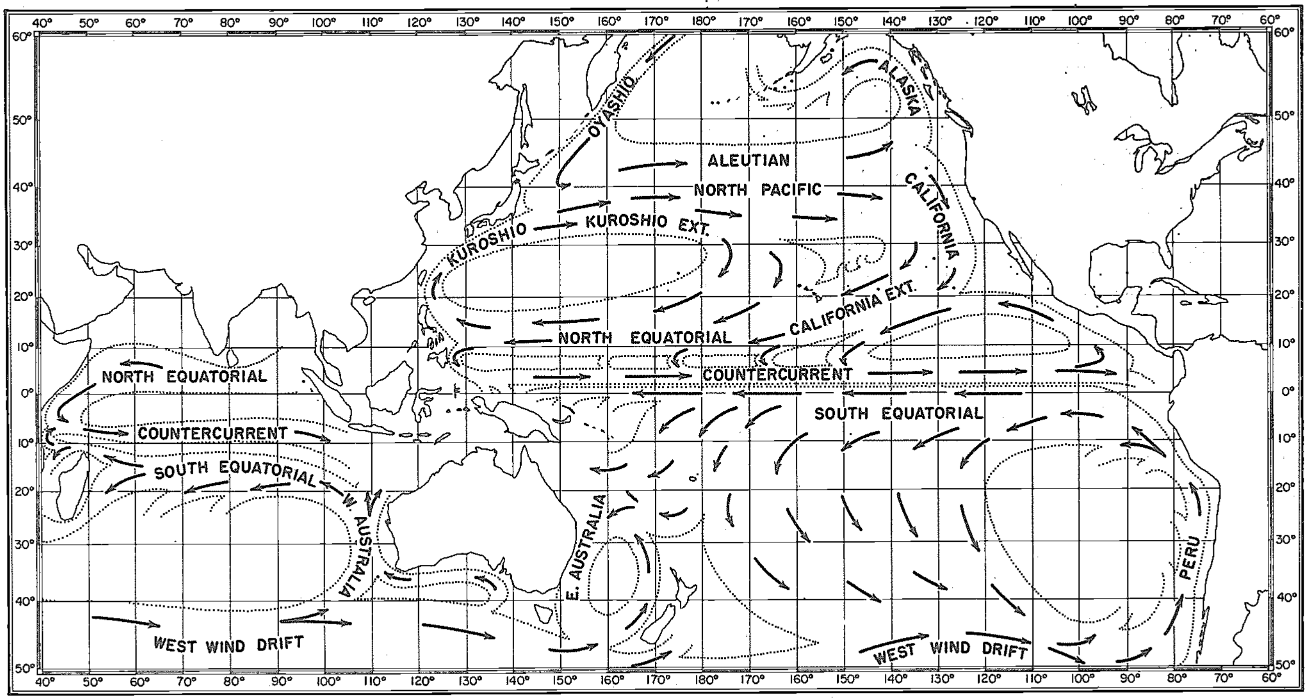

Fig. 3 Ocean current systems (Brock, 1959a)

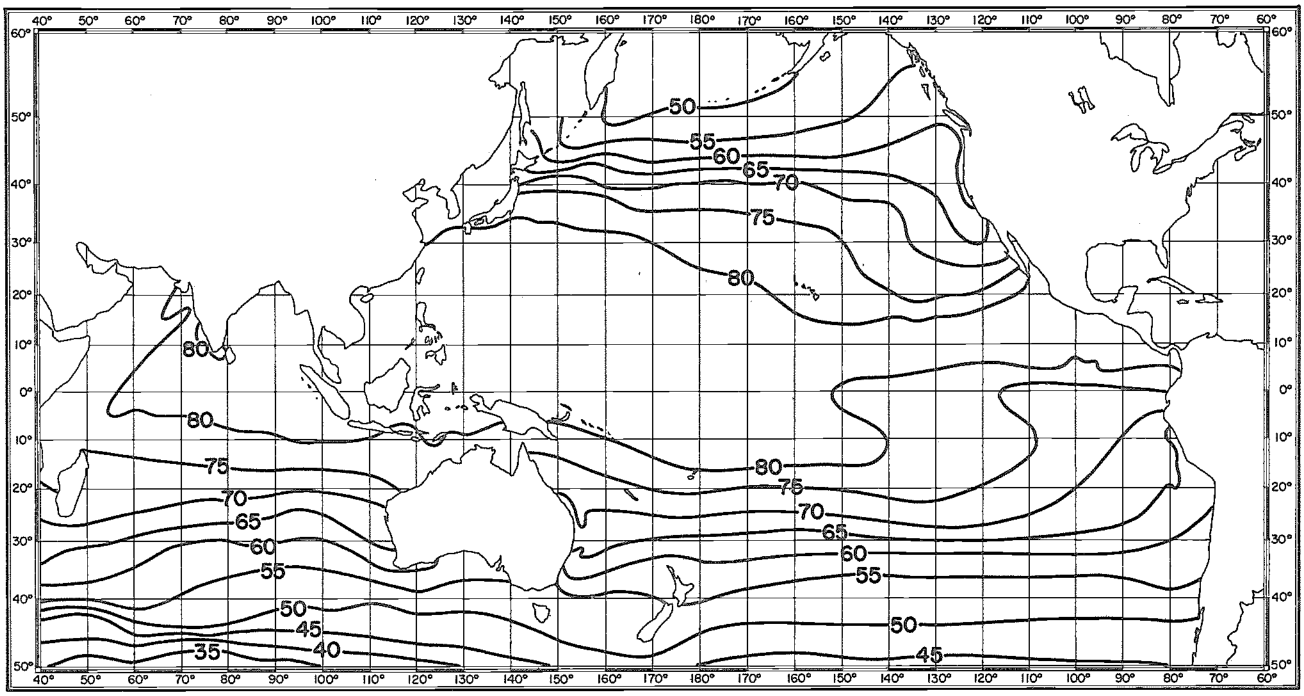

Fig. 4 Summer (August) average surface temperature (°F) (Brock, 1959a)

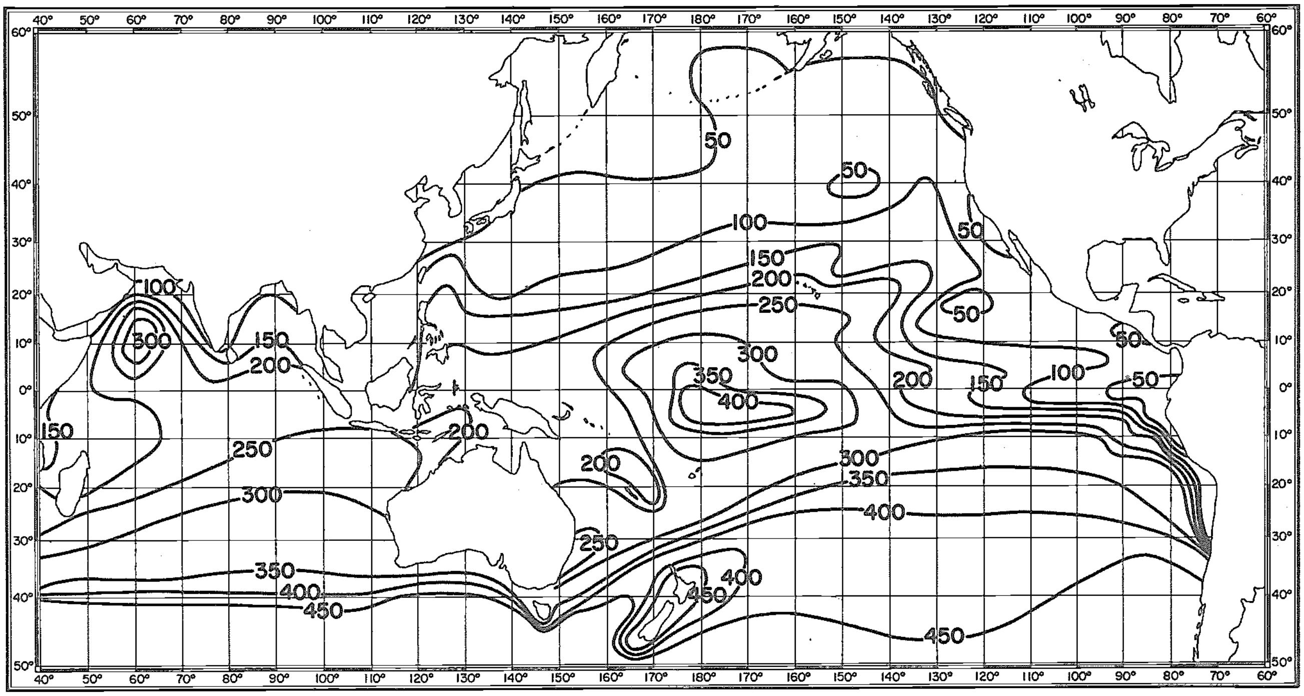

Fig. 5 Summer (August) depth of thermocline (feet) (Brock, 1959a)

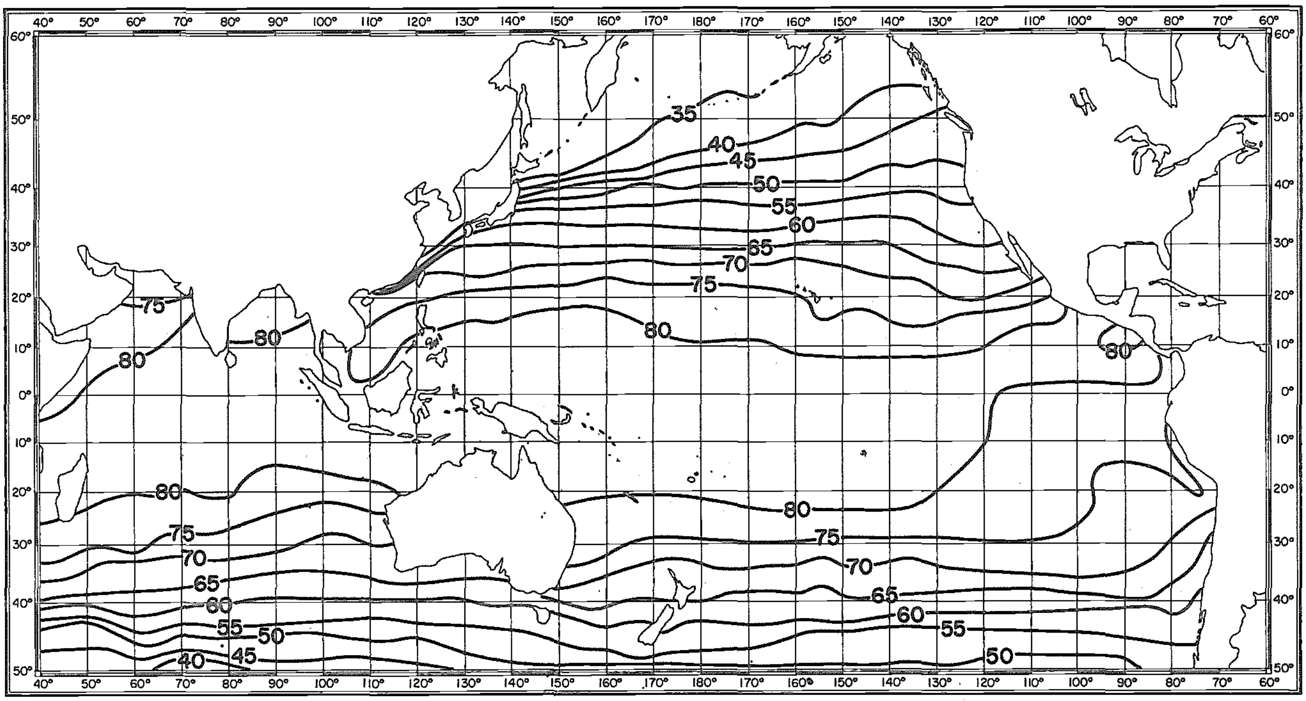

Fig. 6 Winter (February) average surface temperature (°F) (Brock, 1959a)

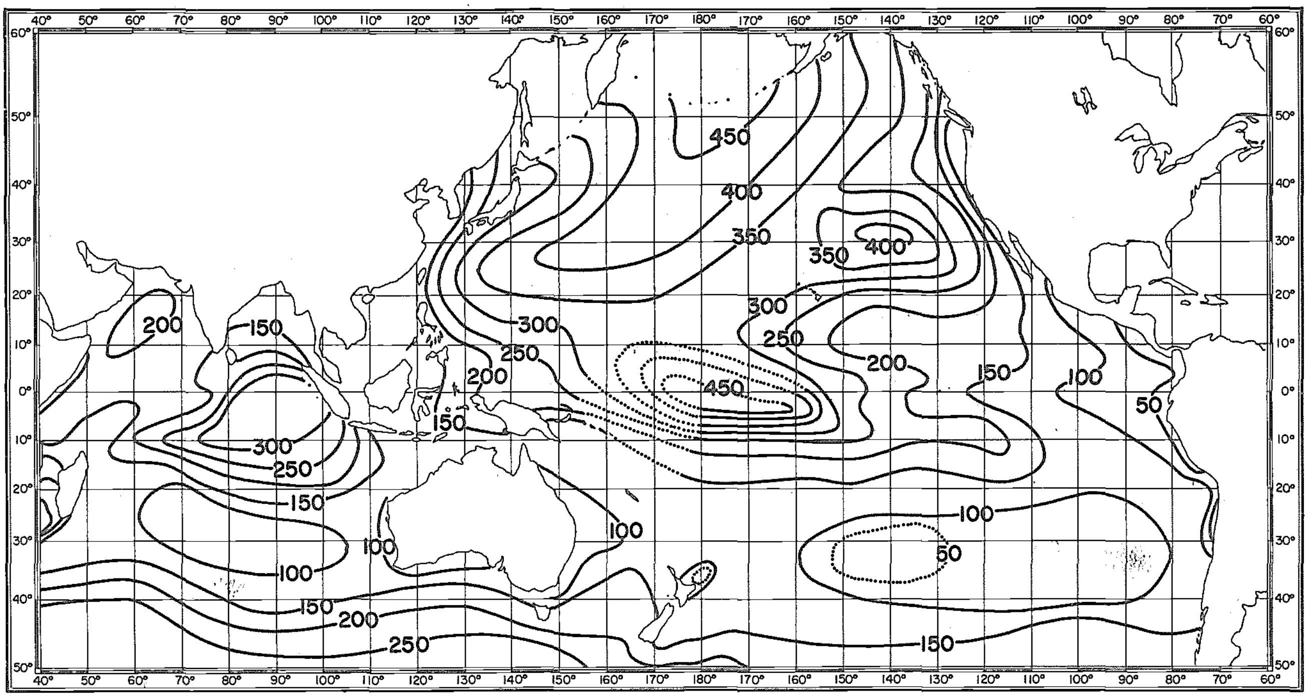

Fig. 7 Winter (February) depth of thermocline (feet) (Brock, 1959a)

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

Radovich (1961) states, "It appears that Pacific albacore distribution along the North American coast is influenced by the environment, of which temperature is a strong indicator if not a primary factor in itself." According to Radovich, about 65 percent of the albacore caught by the California fishery from 1954 through 1956 were from water with surface temperatures between 60° - 64° F.

Clemens (1961) indicates that the movement of albacore along the west coast of the United States is regulated primarily by sea-surface temperatures between 58° - 68° F. According to Clemens, the area where the albacore moves into the fishing grounds shifts north and south with warming and cooling sea-surface temperatures.

In the area bounded by 160° W and the 180th meridian in the North Pacific, McGary, Graham, and Otsu (1960) showed that, during the winter, the latitudinal limits of the distribution of albacore were almost coincident with the southern boundary of the Transition Zone.

The Japanese believe that the devlopment of the surface summer albacore fishery off the coast of Japan is controlled by the way in which the seasonal warming of the area by the Kuroshio progresses (Van Campen, 1960).

In the western South Pacific, Yamanaka (1956) suggests that a "discontinuity layer with considerable convergence which is found extending from east to west in the neighborhood of latitude 10° S" plays an important part as a northern limit in the distribution of the South Pacific albacore.

3 BIONOMICS AND LIFE HISTORY

3.1 Reproduction

3.1.1 Sexuality (hermaphroditism, heterosexuality, intersexuality)

The albacore is heterosexual. There are no external characters known to distinguish between the males and females. A case of hermaphroditism was cited by Legand (MS) in an albacore taken in waters off southwestern New Caledonia, but details were not given.

3.1.2 Maturity (age and size)

It was first reported by Ueyanagi (1955) and later supported by the findings of Otsu and Uchida (1959a) that female albacore attain sexual maturity and thus may first spawn at about 90 cm in length. The smallest mature fish found in samples collected from the western Pacific (Ueyanagi, 1957) was 87 cm long, and the smallest from the central equatorial Pacific measured 89.1 cm (Otsu and Uchida, 1959a). Otsu and Hansen (1961) reported in their study of the central South Pacific albacore that some fish are already mature at 86 cm.

As for the males, Ueyanagi (1957) judged from their general appearance and oozing of milt that testes weighing more than 150 grams were probably ripe. From this, he postulated that the smallest mature fish measured 97 cm. Following the same criteria, Otsu and Hansen (1961) found that some male albacore are probably mature when they attain a length of about 90 cm. However, lacking more objective means of determining maturity of the males, it cannot be said with certainty that this is the size at which male albacore are first capable of spawning.

The age at maturity has not been satisfactorily determined for the albacore. Suda (1958) has postulated that spawning albacore are age-VI and older. Otsu and Uchida (MS) hypothesized that the 6-year-olds (94 cm) and older age groups move south from the Japanese winter longline fishery into sub-tropical waters to form the reproductive unit of the North Pacific population.

3.1.3 Mating (monogamous, polygamous, promiscuous)

No records of observations on spawning fish are available. However, imminently spawning albacore more than likely occur in aggregations and male and female fish probably release their sex products indiscriminately without specifically selecting any particular partner or partners.

3.1.4 Fertilization (internal, external)

External. The eggs of the female and the milt of the male are discharged into the water, where the eggs are fertilized. The eggs and larvae are believed to occur in surface layers.

3.1.5 Fecundity

Estimates of fecundity were based on the assumption that all the eggs comprising the most advanced group within an ovary were released in a single spawning (Ueyanagi, 1955 and 1957, and Otsu and Uchida, 1959a). These estimates ranged between 0.8 and 2.6 million eggs.

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

Otsu and Uchida (1959a) noted only a slight tendency for larger albacore to have more eggs per spawning.

3.1.6 Spawning

- Spawning seasons (beginning, end, peak)

The spawning season of albacore has not been defined in detail. However, on the basis of seasonal changes in gonad maturity, Ueyanagi (1957) inferred that spawning in the western North Pacific occurs in subtropical waters during the summer months with June and July at its peak. Otsu and Uchida (1959a) also found evidence of spawning through examination of gonads of albacore taken in Hawaiian waters during the summer. The most highly developed ovaries were collected during June and July. From these results, it is believed that albacore spawning in the North Pacific occurs largely during the summer months in areas under the influence of the North Equatorial Current, and that the spawning grounds may be over a broad area extending to as far east as the Hawaiian Islands. The determination of the exact spawning period will have to await future field work which will involve the study of the seasonal distribution of larval albacore.

In the South Pacific, Otsu and Hansen (1961) found that the seasonal progression in gonad development peaked during December. The gradual increase in the proportion of late developing ovaries in the monthly samples from the low point in May to a peak in December, with a gradual decrease thereafter, suggested that spawning must take place during the southern summer months. Depending upon the rate of ova development, albacore may be spawning during only a portion of that period, and that portion may be towards the end, perhaps between January and March, when the percentage of late developing ovaries is decreasing. At any rate, the spawning season in the South Pacific is six months out of phase with that in the North Pacific. The spawning grounds appear to cover a broad area between the Equator and 20° S latitude. East-west differences in spawning activity were not discernible within the extent of the area sampled (130° W - 160° E).

Ishii and Inoue (1956) reported on results of examination of ovaries of albacore taken in the Coral Sea (17° S - 20° S, 152° E - 153° E) in January 1954. The authors postulated that the Coral Sea and the adjacent New Caledonia areas are spawning areas for the albacore. More recently Legand (MS) studied the seasonal trend of the ovary volume to body length relationship of albacore taken in waters within 200 miles of the southwest coast of New Caledonia (21° 30' S - 24° S) and reported that albacore spawning probably occurs in the summer (December-January).

In the Indian Ocean, Ueyanagi (1955) reported on highly developed ovaries obtained from albacore taken from waters south of Sunda Islands in February 1953. He concluded that, "The season and area of spawning have never been known concerning the albacore distributed in the Indian Ocean. It is now clear from the above findings that the spawning of this fish takes place in February at least in part."

- Number of spawnings per year (frequency)

Very little study has been conducted on the frequency of spawning in the albacore. The frequency distributions of egg diameters in albacore ovaries show clearly two or more modes which, depending on the growth rate of the egg, may represent eggs that will be spawned in a single season or in succeeding seasons. Otsu and Uchida (1959a) postulated from the presence of egg remnants in late developing ovaries that this species may undergo multiple spawning. The presence of egg remnants together with a group of eggs approaching ripeness suggested that albacore may spawn at least twice during a single spawning season. Further evidence along this line was obtained from the fact that remnants were absent in large, sexually inactive adults taken during late winter in the North Pacific, a suggestion that remnants are not carried over from one year to the next. However, in the absence of any knowledge regarding the rate of resorption of the unspawned eggs, no definite conclusions can be drawn.

- Induction of spawning, artificial fertilization

No instance of successful artificial fertilization in albacore has been recorded. Among the tunas, however, Kikawa (1953) and Kume (MS), both of the Nankai Regional Fisheries Experimental Station in Kochi, Japan, were able to artificially fertilize bigeye tuna eggs. In the latter experiment, conducted in 1961, the eggs were successfully hatched but the larvae soon succumbed to mortality.

These experiments point out the possibility of artificial fertilization in albacore.

3.1.7 Spawning grounds

- Coastal (surface, vegetation, shore, shoal, sand, shelter); bottom

Albacore spawning is believed to take place in oceanic rather than coastal waters.

- Oceanic (surface, bottom)

As in other tunas, the albacore spawns in oceanic waters. The best information available indicates that spawning takes place in tropical and subtropical waters of both the Pacific and Indian Oceans. There is no evidence of temperate water spawning.

3.1.8 Egg: Structure, size, hatching type, parasites and predators

The most highly developed ovarian eggs recorded from the Pacific and Indian Oceans were found in albacore taken in waters around the Hawaiian Islands and Sunda Islands, respectively. These ovaries, although very highly developed, were not fully ripe. They contained eggs which measured about 0.8 mm in average diameter and the largest measured about 1 mm (Ueyanagi, 1955; Otsu and Uchida, 1959a). Ripe albacore eggs are therefore about 1 mm in diameter.

The immature oocytes under about 0.2 mm in diameter, which cannot be seen with the naked eye, are polygonal, colorless, and transparent, and fixed specimens stain deeply with hematoxylin. These oocytes, also referred to as "primitive eggs," are found in ovaries in all stages of development. In early development, the eggs increase in size and become semi-opaque from deposition of yolk granules. The maximum diameter of eggs in this stage is about 0.4 mm. With further development, the eggs become completely opaque from the heavy accumulation of yolk granules and the diameter now ranges from 0.4 to about 0.8 mm. Distinct changes occur in the eggs as they approach ripeness. They lose their opacity and become semi-transparent; the nucleus cannot be detected at this stage, and a conspicuous golden-yellow oil globule appears.

There are no records of capture of albacore with "running ripe" ovaries in the Pacific and Indian Oceans. Furthermore, it is not possible at present to satisfactorily distinguish between the pelagic eggs of the several species of tunas. In the Mediterranean Sea, Sanzo (1933) described the pelagic eggs of Orcynus germo Lütken [=? Thunnus alalunga (Bonnaterre)] taken in plankton net hauls in the Strait of Messina. He found the eggs, between 0.84 and 0.94 mm in diameter, to be buoyant, spherical, and highly transparent. The oil globule, which was always single, measured around 0.24 mm. Matsumoto (MS) in discussing Sanzo's description of the larvae which were successfully hatched from these eggs, cautioned that although the plankton collections were made during specific migratory runs of the species through the Strait, there was no definite assurance that the eggs of one species were collected exclusive of the other species which are also known to spawn during the same period.

No information is available on the hatching type, parasitic infection, and predation on albacore eggs.

3.2 Larval history

3.2.1 Account of embryonic and juvenile life (prelarva, larva, postlarva, juvenile)

No information on the embryonic (prelarva) stages of albacore is available from the Pacific and Indian Oceans. Sanzo (1933) reported on the ova and early larval stages of Orcynus germo (Lütken) [=? Thunnus alalunga (Bonnaterre)] from the Mediterranean Sea. Sanzo collected the fertilized ova in the Strait of Messina and was able to hatch the ova, and to rear the larvae up to seven days in his laboratory. As mentioned in section 3.1.8, however, there is some question whether Sanzo really reported on the ova and early larval stages of albacore or another species.

Recently Matsumoto (MS) was able to make tentative identification of larval albacore from among the larval tunas collected on the "Dana" expedition during 1928-30 (Fig. 8). According to Matsumoto, the larvae of albacore differ from those of yellowfin (Neothunnus macropterus) in having two chromatophores along the ventral edge of the body on the 28th and 33rd myotomes. Furthermore, the distinctive character which sets the albacore apart from bigeye (Parathunnus sibi) and yellowfin is the single chromatophore on the dorsal edge of the trunk.

- Feeding

Sanzo (1933) reported that between the second and third day after hatching the larvae began pecking on the bottom of the rearing jar.

- Rates of: development and survival

The earliest stage of the developing zygote that Sanzo was able to obtain was the stage of the closure of the blastopore. According to Sanzo, at this stage, the embryo extends halfway around the full circumference of the egg; the cephalic region is rather large; the secondary otic vesicles are formed, the otocysts, and about 10 muscle segments are present. After about 7 or 8 hours, the embryo has the tail developed to a greater length, turned upward and forward over the anterior surface of the oil globule, and about 40 segments can be counted. The embryonic development takes place in two days.

The development of the larva immediately after hatching is summarized in Table IV.

- Periods of: development and survival

(See section on rates of: development and survival).

- Parental care

Although no direct observations have been made, the young are most likely left to fend for themselves.

- Parasites and predators

Kishinouye (1923) states, "I found a young germon about 30 cm in length in the stomach of a large germon, caught on January 20th, 1917 near the Ogasawara Islands, and other small ones from a yellow-finned tunny and a spear fish caught on February 27th of the same year."

Table IV

The development of the larvae immediately after hatching (adapted from Sanzo, 1933)

Time after hatching	Development
1st hour	The mouth opening is not yet formed; all signs of the branchial skeleton and the pectoral fins are lacking; the primordial fin fold is rather low anteriorly on the back; the eyes are without pigment; 10 specimens averaged 2.60 mm in length.
On the day after hatching	The primordial dorsal fin has become quite high anteriorly and extends to opposite the otic region; the mouth is not yet open; the heart has already rotated from its embryonic position; very small pectorals have made their appearance; one specimen at this stage measured 2.96 mm.
At the end of the first day	The stomodeum is in process of formation; the pectorals are slightly enlarged; specimens measured from 3.20 - 3.50 mm in length.
On the 2nd day	The mouth opening is formed; Meckel's cartilage is present; the hyoid and branchial apparatus are differentiated; the eye is rounded and has incipient pigmentation.
2 to 3 days	The eyes are completely pigmentated.
On the 5th day	Primordial fins greatly developed; two large olfactory pits on snout; the eyes are large and slightly subrotund; posterior to them are two large otocysts with the semicircular canals differentiated.
After the 5th day	The larvae begin to reduce in length.
On the 7th day	The primordial fin is reduced; one specimen measured 3.20 mm; a toothlet present on upper jaw.

Table V

Some records of predation on juvenile albacore
(Yabe, et al 1958)

Albacore body length	Date	Locality	Predator
188 mm	5-15-49	18°38' N 151°26' E	Black marlin
124 mm	6-11-52	20°57' N 149°36' E	Black marlin
ca 170 mm	2-1-55	18°44' S 176°54' E	Yellowfin
ca 170 mm	2-2-55	18°58' S 176°27' E	Yellowfin
234 mm	12-6-56	20°50' S 155°30' E	Striped marlin
258 mm	3-20-57	25°13' S 99°43' E	Shortnosed spearfish

Table V lists other occasions of predation on juvenile albacore as reported by Yabe, Ueyanagi, Kikawa and Watanabe (1958).

3.3 Adult history

3.3.1 Longevity

Uchida and Otsu (MS) indicate that there are about 10 age groups composing the Japanese winter longline fishery, of which the oldest group is 10 years old. The albacore that are caught in the Hawaiian Islands grow to a greater size (see Fig. 19). Uchida and Otsu did not attempt any age analysis of Hawaiian albacore "because of inaccuracies which may result from possible differential growth between the sexes in such large fish."

3.3.2 Hardiness

The fact that albacore survive after experiencing the handling involved in tagging and then go on to make trans-Pacific migrations may indicate that they are quite hardy.

Clemens (1961) says, "After having tagged several tons of albacore, yellowfin tuna, and skipjack, and a few bluefin and bigeye tuna, I believe that albacore are the hardiest of the five followed by bluefin, bigeye, yellowfin and skipjack."

3.3.3 Competitors

Iversen (MS) reported that, "the similarities in diet between both the albacore and the yellowfin and albacore and the bigeye in the same specific location, as well as in the same general area, are evidence that there is some competition between the albacore and the other two species of tuna."

In the area near New Caledonia, Legand and Wauthy (MS) noted that "albacore and _Alepisaurus_ compete in many ways for food".

3.3.4 Predators

Kishinouye (1923) made some general remarks on the enemies of scombroid fishes. He says, "The gigantic species of the scombroid fishes have few enemies. Their most dreaded enemies are dolphins, especially the killer. Killers often await the passage of large schools of tunnies in a strait, such as Tsugaru Strait, and attack them furiously."

Bennett (1840), in speaking of albacore, says, "It is, probably, as a protection from their chief enemy, the sword-fish, that they seek society of a ship. I am not aware that the shark is also their enemy; but they seemed to have an instinctive dread of this large fish, when it approached the ship, would follow it in shoals, and annoy it in the same manner as the smaller birds may be seen to annoy those of a larger and predaceous kind, as the hawk or owl." However, as mentioned in section 3.3.6 there is some doubt whether Bennett was really reporting on albacore.

Tunas, including albacore, caught by longlines are often damaged by sharks. It is not known whether sharks normally prey on tunas. Strasburg (1957) presents some lines of evidence to indicate that sharks may swim fast enough to catch free-swimming tuna. He says, "For one thing both species of sharks (silky and whitetip) are occasionally caught on trolling lines at vessel speeds of 6 to 8 knots, and for another, one bigeye tuna captured alive bore a pair of large U-shaped scars suspiciously resembling shark jaws in shape."

3.3.5 Parasites and diseases

Table VI lists records of infestation of albacore by various parasites in the Pacific Ocean.

3.3.6 Greatest size

The International Game Fish Association (1960) lists the world record for albacore, which was caught in the Atlantic Ocean, as 69 lbs. In the Pacific Ocean, it lists an albacore weighing 66 lbs. 4 oz as the largest caught by a sport fisherman. According to a table of length-weight relation, albacore weighing 66-69 lbs would be approximately 115-118 cm in length. Albacore of this size are commonly caught by longlines around Hawaii (see Fig. 15). Apparently, the albacore occurring around Hawaii are the largest in the Pacific Ocean, and the largest specimen recorded is the one reported by Otsu and Uchida (1959a), which weighed 93 lbs and measured 128 cm in length.

Bennett (1840) made some observations on the size of albacore. He noted that, "The average length of the examples we captured from the ship was four feet; though some others, which we saw on the coasts of the Polynesian Islands, measured nearly six feet." However, it is rather dubious that Bennett really saw albacore "nearly six feet," (or 189 cm). It is doubtful that albacore ever grow to anywhere near this size.

3.4 Nutrition and growth

3.4.1 Feeding (time, place, manner, season)

Iversen (MS) indicated that troll-caught albacore in the temperate North Pacific feed

Table VI

Parasites of albacore

Parasite	Location of infestation	Reference
Elythrophora brachyptera	Inner surface of operculum	Yamaguti (1936)
Hirudinella spinulosa	Stomach	Yamaguti (1938)
Didymocystis alalongae	Gill arch	" "
Didymocystis opercularis	Operculum	" "
Platocystis alalongae	On skin	" "
Melanematobothrium guernei	In sub-maxillary muscle	" "
Anisakis sp.	------	Yamaguti (1941)
Contracaecum legendrei	Stomach	" "

throughout the day. He also presented some evidence to indicate that albacore are able to feed at night. Iversen found, however, that albacore caught during hours of darkness by gillnets had smaller stomach volumes. He suggests that this is due to less successful foraging by albacore at night.

3.4.2 Food (type, volume)

In a study of albacore food in the South China Sea, Kanamura and Yazaki (1940) found squid, octopus, stomatopods, barracuda, "hairtail," "flatheads," ginkagami (*Mene maculata*), and "sardine" (*Bathylagus nakazewai*) in the stomachs of albacore.

Powell (1950) noted that small rockcod constituted the bulk of the food of albacore taken in the northeastern Pacific with squid, saury, small blackcod, and lantern fish present in varying amounts.

McHugh (1952) studied the food habits of troll-caught albacore off California and Baja California, and reported that, "By far the most important item was the Pacific saury (*Cololabis saira*), which constituted almost 50 percent of the total food volume. Next in order of importance were squids (12 percent); *Pleuroncodes planipes*, the pelagic decapod of southern waters (11 percent); euphausiids (7 percent); and the northern anchovy, *Engraulis mordax mordax* (4 percent)."

Barracuda, a species of "sand borer," and *Ostracion diaphanus* (=*Lactoria diaphanus*) were found in stomachs of albacore caught by longlines in waters around the Bonin Islands (Yabuta, 1953). However, Yabuta noted that albacore fed mostly on crustaceans and small cephalopods.

In the western Indian Ocean, Koga (1958a) found that the following were found in 10 percent or more of the albacore stomachs examined Triacanthidae, Plagyodontidae (= Alepisauridae) Carangidae, and Acinaceidae (=Gempylidae). Among the crustacea, isopods, decapods, and stomatopods occurred in 10 percent or more of the stomachs. Koga (1958b) also examined stomachs of albacore from the equatorial South Pacific and found that the following were present in 10 percent or more of the stomachs: Plagyodontidae, Triacanthidae, Acinaceidae, Ostraciidae, and Menidae. Squid were present in 50 percent, decapod crustaceans in 15 percent, and octopods in 10 percent of the stomachs.

Iversen (MS) examined the stomachs of 544 albacore captured by longlining, trolling and gill net fishing in the central and northeastern Pacific. He found that there were differences in the average volume and the composition of the foodstuffs in stomachs of albacore caught by different fishing methods (Table VII and Fig. 9).

Table VII

Average stomach volumes of 348 albacore, according to method of capture (Iversen, MS)

Method of capture	Number of stomachs	Average volume (cc) per stomach
Longline	182	26.7
Gill net	87	9.8
Troll	79	15.1

3.4.3 Relative and absolute growth patterns and rates

Studies on the age and growth of albacore in the Pacific Ocean have been made by Uno (1936a; 1936b), Aikawa and Kato (1938), and Partlo (1955), based on the vertebral method.

Suda (1954) studied the size composition of albacore taken in the Japanese winter longline season and found modes at 57 cm, 67 cm, 78 cm, 89 cm, 100 cm, and 111 cm. The spacing of the intervals was uniformly 10 or 11 cm, thus representing a straight-line growth if these length groups are assumed to be age classes. Suda concluded that these length groups may be considered as age groups if they are handled as five groups consisting of ages I to IV and an advanced age group which includes the last two modal groups.

Nose, Kawatsu, and Hiyama (1957) made a study of age and growth of albacore based on the scale method. They found that the lengths of albacore at the time of ring formation were as follows: l_1=38 cm, l_2=49 cm, l_3=59 cm, l_4= 68 cm, l_5= 78 cm, l_6= 86 cm, l_7= 96 cm, and l_8= 105 cm.

Otsu (1960) reported on a study of age and growth of albacore based on data obtained from tagging experiments. The growth rates derived by Otsu are presented in Table VIII and Fig. 10. Otsu (1960) also discussed the results obtained

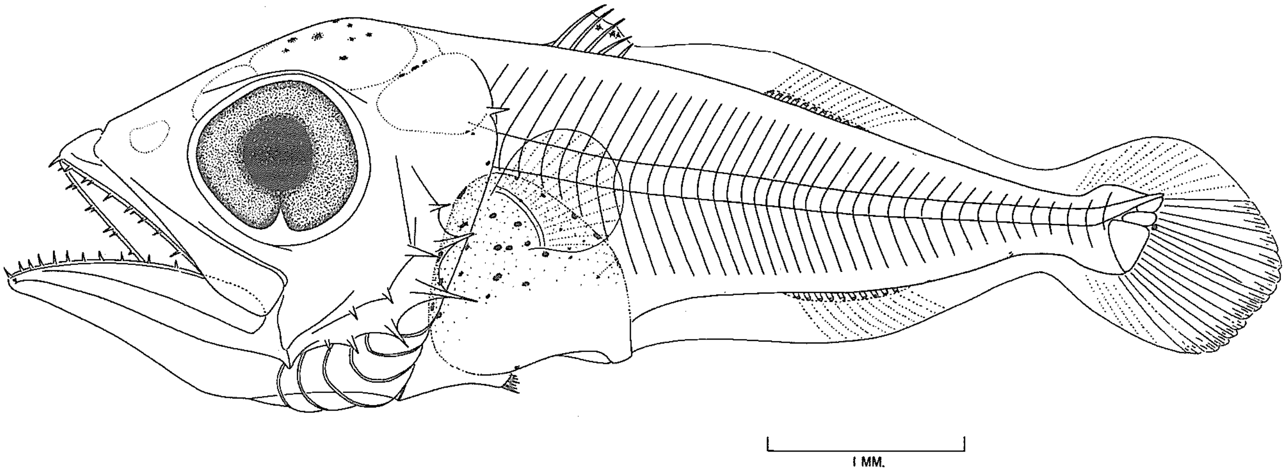

Fig. 8 Thunnus germo, 6.47 mm (reproduced from Matsumoto, MS)

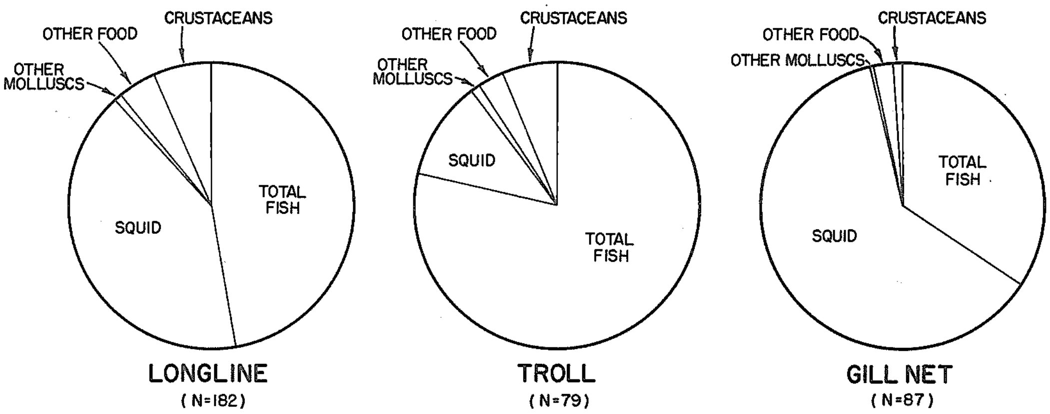

Fig. 9 Comparative importance, by volume, of major food elements found in 348 albacore stomachs (Iversen, MS)

by the earlier workers and noted that all the curves were linear, with the possible exception of Uno's (1936b) (Fig. 11), while the curves he derived were curvilinear. Although the several growth rates did not differ markedly in magnitude, Otsu points out that the linearity of the curves obtained by the earlier workers suggests that the vertebral method of aging albacore is not valid.

Table VIII

Growth rates of albacore derived by fitting tag recovery data to growth curves by the methods of Walford and Riffenburgh (Otsu, 1960)

AGE* (years)	LENGTH (cm) Walford	LENGTH (cm) Riffenburgh
1	---	7.5
2	---	17.3
3	26.3	31.5
4	46.8	46.5
5	62.7	62.5
6	75.1	75.0
7	84.8	86.0
8	92.3	94.5
9	98.2	101.0
10	102.7	106.0

* The ages given are based on an arbitrarily selected origin and are therefore tentative.

More recently, Clemens (1961) and Bell (1962) made albacore age and growth studies based on data obtained by tagging experiments and scale reading, respectively. Both Clemens and Bell fit their data to von Bertalanffy's growth equation. Their results are presented in Table IX and Figs. 12a and 12b.

3.5 Behavior

3.5.1 Migration and local movements (see also section 5.3.1)

The migration of albacore within and among the three important fisheries in the North Pacific Ocean has been described in some detail by Clemens (1961) and Otsu and Uchida (MS).
The account of the migration among the fisheries given by Otsu and Uchida is briefly summarized below and is illustrated in Fig. 13.

A varying portion of the 2-, 3-, and 4-year old fish and nearly all the older fish in the American fishery migrate westward each fall into the Japanese longline fishery. The remainder of the fish from the American fishery move westward into midocean waters of the North Pacific, some as far west as the fringe of the Japanese longline grounds. Those that move into the longline fishery tend to migrate southwestward and later enter the Japanese livebait fishery. The others will return to the American fishery the following season. Thus, some fish may be available to the American fishery for as many as 4 or 5 consecutive seasons.

Table IX

Albacore age and growth as estimated by tagging experiments and scale reading

Age groups	Fork length (cm) Clemens (1961)	Fork length (cm) Bell (1962)	Increment (cm) Clemens (1961)	Increment (cm) Bell (1962)
I	52	57.3		
			13	8.4
II	65	65.7		
			11	11.7
III	76	77.4		
			9	6.3
IV	85	83.7		
			8	4.1
V	93	87.8		
			7	-
VI	100	-		
			5	-
VII	105	-		

Albacore enter the Japanese winter fishery from both the American fishery and the Japanese livebait fishery. Each spring, a large portion of these fish, age groups 2 through 5 years, migrate westward from the longline grounds into the livebait grounds, while a few separate and move eastward into the American fishery. The larger adults, 6 years old and older, move southward from the winter longline grounds into subtropical and tropical waters, to the spawning grounds of the North Pacific albacore.

3.5.2 Schooling

In the eastern North Pacific, albacore are found in school groups (Clemens, 1961). A school group, as defined by Clemens, is a discrete cluster of albacore schools that, although sometimes widely scattered, appear loosely related by having a tendency to act in unison.

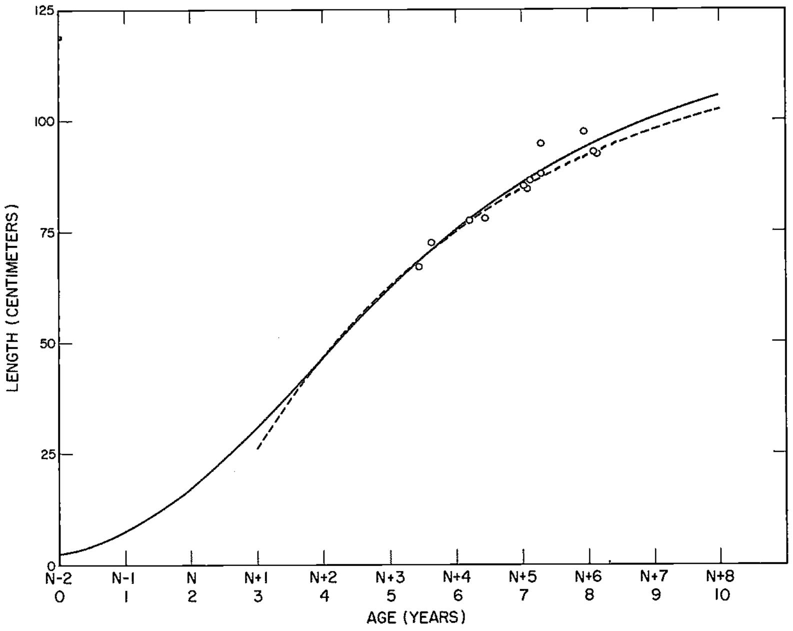

Fig. 10 Growth data fitted to a Gompertz equation by Riffenburgh's short method. The curve obtained by Walford's method (dashed) is superimposed. Observed data are superimposed on the Gompertz curve (Otsu, 1960)

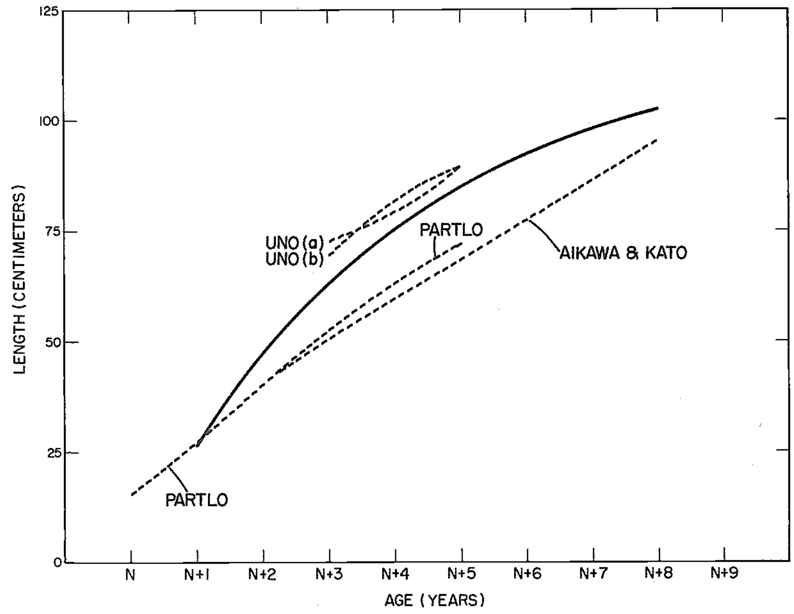

Fig. 11 A comparison of the growth curves obtained by the vertebral method with the Walford curve obtained in this study. Specific ages are disregarded in the plotting of these curves (Otsu, 1960)

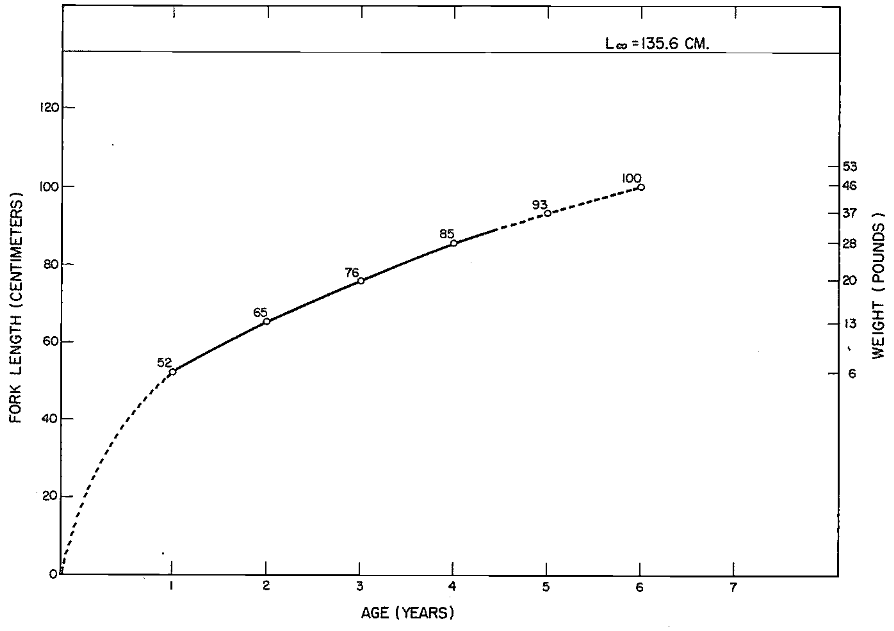

Fig. 12a Albacore weight-length-age curve based on 21 tag recoveries, 1952 through 1957 (Clemens, 1961)

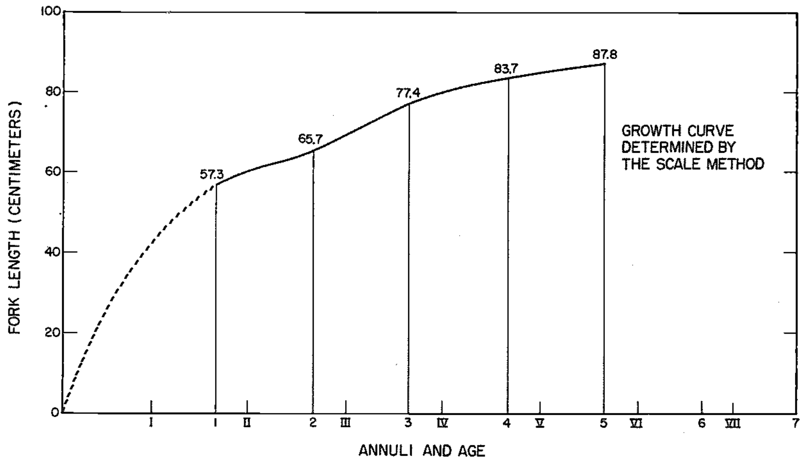

Fig. 12b Albacore growth curve. The scale of the abscissa represents months of the year. The first annulus is set hypothetically at February. The age is set at October. The intercept at y is set at March (Bell, 1962)

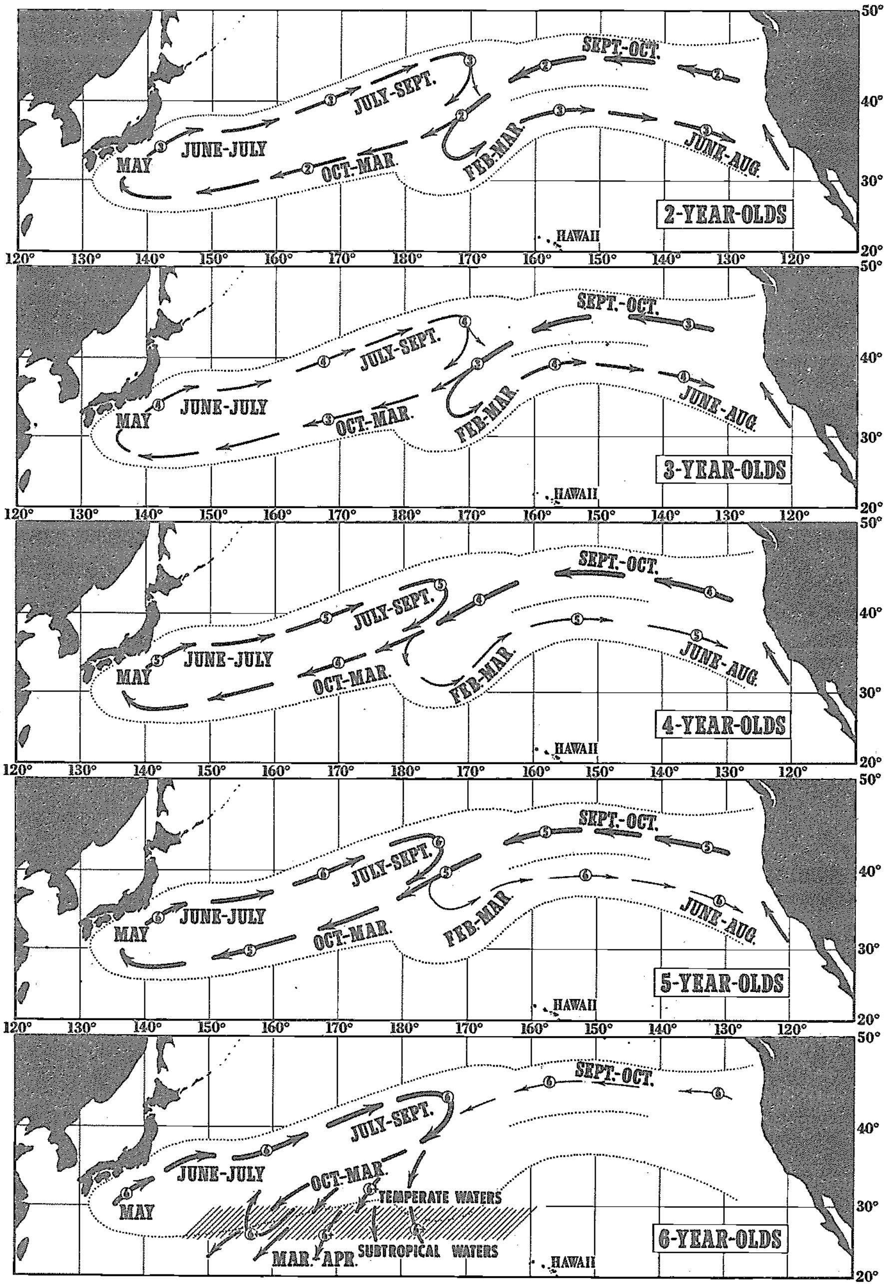

Fig. 13 Model of albacore migrations in the North Pacific Ocean, by age groups (ages encircled) (Otsu and Uchida, MS)

According to Clemens, at the beginning of the albacore season on the west coast of the United States, the school groups are widely separated and are composed of relatively few small, scattered, loosely knit, fast-traveling schools. During the peak of the season, although the individual schools are still somewhat loosely knit, they are larger. The school groups appear more compact and contain a greater number of schools. Albacore larger than 20 pounds usually are more compactly schooled than smaller fish and spend more time in deeper water.

The schools of albacore encountered off Japan appear to be generally small, perhaps partly because of the intensity with which they are harried and broken up by concentrated fleet action (Van Campen, 1960).

3.5.3. Reproductive habits (see section 3.1)

- Physiology

It is generally assumed that tunas, including albacore, have high metabolic rates. For example, Clemens (1961) states, "Albacore are fast-traveling, opportunistic feeders, with high metabolic rates and they need quatities of food." However, there is very little information in the literature on the metabolism or other facets of the physiology of albacore.

4 POPULATION (STOCK)

4.1 Structure

4.1.1 Sex ratio

Brock (1943) analyzed the size distribution by sex of a sample of Oregon albacore taken from July 30 to October 14, 1940. He noted a significant departure from a 1:1 male to female ratio for fish smaller than 67 cm (Fig. 14). He attributed this to incorrect determination of sex in a significant portion of fish smaller than 67 cm. The sex ratio of albacore larger than 67 cm did not differ significantly from 1:1.

Otsu and Uchida (1959a) noted that the sex ratio was nearly 1:1 for a sample of albacore caught in the central equatorial Pacific. In Hawaiian waters, however, they noted that the males predominated (Fig. 15). Otsu and Uchida (1959b) ascribed the unbalanced sex distribution among larger albacore largely to differential growth which sets in with the onset of sexual maturity, after which the males grow at a faster rate than the females.

Suda (1956) found that there was an extraordinarily high proportion of males in the North Equatorial Current area (western North Pacific) (Table X). Although Suda does not mention it, the size distribution of albacore by sex he presents (Fig. 16) also illustrates the differential growth of large albacore, as observed by Otsu and Uchida (1959b).

Other references to sex ratio of albacore are listed in Table XI.

Table X

Sex ratio of albacore in the North Equatorial Current area*
(Suda, 1956)

Date of investigation	Locality	Male	Female	Ratio (♂/♀)
May 4-May 23, 1949	18°18' N -20°59' N 148°10'E -152°02' E	84	40	2.1
June 22-July 2, 1949	21°56' N -22°56' N 148°52' E -152°54' E	59	26	2.3
Mar. 5-Mar. 22, 1949	21°00' N -24°13' N 143°32' E -151°45' E	14	6	2.3
Feb. 14-Feb. 19, 1950	22°12' N -24°42' N 149°52' E -152°28' E	17	3	5.7
Mar. 26-Apr. 6, 1950	22°50' N -24°10' N 143°15' E -146°09' E	56	9	6.2
May 17-June 14, 1952	13°55' N -22°54' N 146°23' E -153°06' E	10	12	0.8
July 2-Aug. 1, 1952	10°08' N -24°04' N 150°23' E -158°43' E	56	16	3.5
	Total	296	112	2.64

*Includes the individuals whose body length was not measured.

Table XI

Sex ration of albacore

Date	Locality	Sex ratio	Reference
Jan. 29-Mar. 12, 1952	08°00' S - 08°02' N 154°56' W - 179°50' E	1 male:1.32 female	Murphy and Shomura (1953)
Oct. 17-Nov. 28, 1952	05°00' S - 21°11' N 150°39' W - 170°08' W	1 male:1.6 female	Murphy and Shomura (1955)
Jan. 1959-July 1960	New Caledonia	27.5 percent females	Legand (MS)

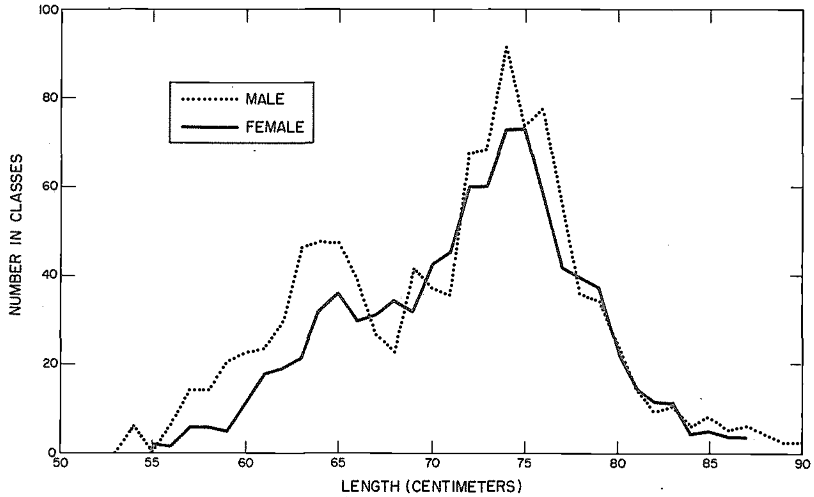

Fig. 14 Length-frequency curves of males and females, Oregon albacore (Brock, 1943)

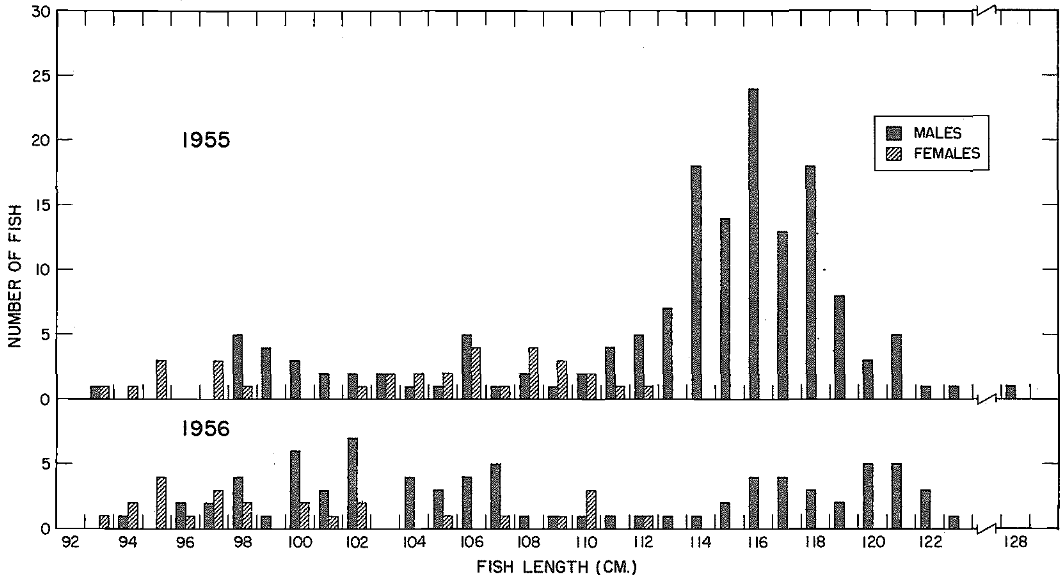

Fig. 15 Size and sex distribution of albacore sampled from landings in the Hawaiian Islands, (a) 1955 (b) 1956 (Otsu and Uchida, 1959a)

4.1.2 Age composition

In conjunction with studies on age and growth, attempts have been made to determine the age composition of the catches from the albacore fisheries in the temperate North Pacific. Uno (1963a) measured 1,500 albacore taken by pole-and-line fishing in the waters east of Cape Nojima, Japan during May to June 1935. He made age determinations on 300 of these fish and found that 6 percent were of age IV, 86 percent of age V, and 8 percent of age VI (Table XII). Based on the size distribution of these age groups he estimated that of the 1,500 fish sampled, 4 percent were age IV, 91 percent age V, and 5 percent age VI. Uno (1936b) sampled the same fishery the following year, during June, and made age determinations on 688 albacore (Table XIII).

Aikawa and Kato (1938) determined the ages of 10 large albacore taken near Midway Island and 5 small albacore taken off northeastern Japan, and calculated the size and weight ranges of albacore at different ages. They present a size frequency distribution of albacore caught between 28° - 34° N, 170° - 173° E, and suggest that the modes at 25 cm, 45 cm, 56 cm, 62 cm, 74 cm, and 83 cm correspond respectively to age classes from fish of the year to the sixth year (Fig. 17).

In the British Columbia albacore fishery, Partlo (1955) points out that four size groups were represented in the catches during 1949, 1950 and 1951. The average lengths of these size groups were 54.3, 62.9, 71.7 and 81.9 cm and the corresponding ages were III, IV, V and VI (Table XIV and Fig. 18).

Table XII

Age composition of albacore (from Uno, 1936a)

Date landed	Number landed	Number of age determinations			Totals	Age composition (%)		
		Age IV	Age V	Age VI		Age IV	Age V	Age VI
(1) V. 1 - V.19	15,500	4	35	1	40	10	87	3
(2) V.20 - VI.2	89,863	3	67	2	72	4	93	3
(3) VI. 3 - VI.10	62,355	8	42	0	50	16	84	-
(4) VI.11 - VI.17	21,555	0	65	5	70	-	93	7
(5) VI.18 - VI.30	13,344	2	51	15	68	3	75	22
	202,617	17	260	23	300	6	86	8

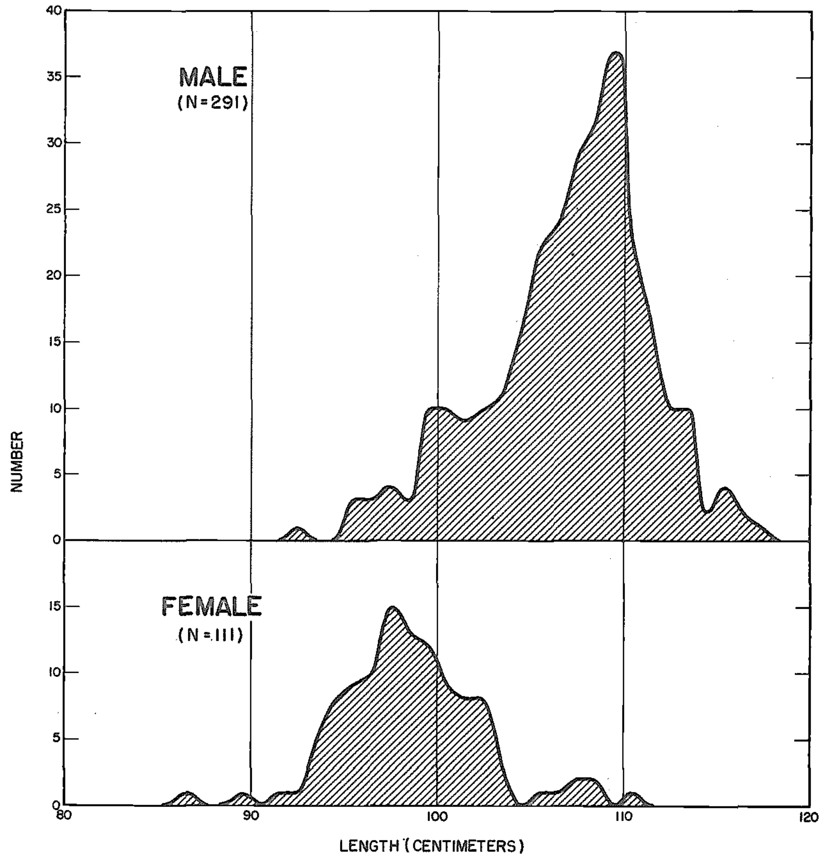

Fig. 16 Length frequency of males and females caught in the North Equatorial Current Area (Suda, 1956)

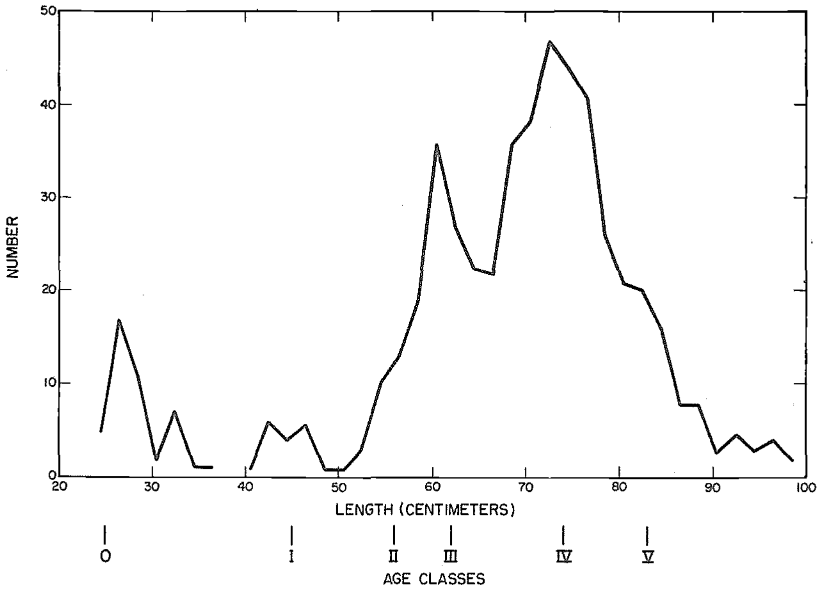

Fig. 17 Age composition of a sample of albacore caught between 28°-34° N., 170°-173° E. (Aikawa and Kato, 1938)

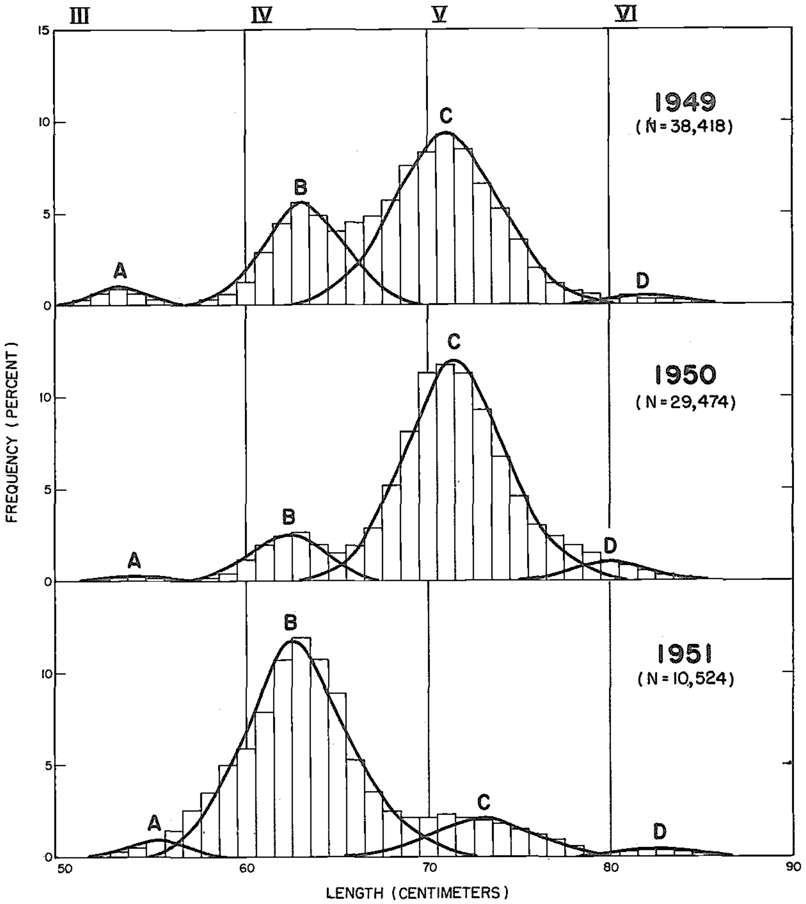

Fig. 18 Comparison of length frequency distribution of the 1949, 1950 and 1951 British Columbia albacore catches (Partlo, 1955)

Table XIII

Age composition of albacore (from Uno, 1936b)

	Body length (cm)						Body weight (kg)					
	Age IV		Age V		Age VI		Age IV		Age V		Age VI	
	M	S D	M	S D	M	S D	M	S D	M	S D	M	S D
(1)	72.70	0.73	79.32	4.22	88.00	?	8.075	1.546	9.924	2.040	14.150	?
(2)	72.50	1.81	78.80	2.81	88.30	0.50	7.950	0.071	9.496	1.040	12.925	0.177
(3)	72.06	1.26	79.25	3.32	-	-	8.287	0.415	9.260	0.750	-	-
(4)	-	-	80.21	3.42	88.40	0.92	-	-	11.049	1.340	13.720	0.352
(5)	73.35	0.84	81.57	3.84	90.22	2.49	7.575	0.079	10.488	1.670	13.276	1.800
	72.38	1.30	79.15	3.68	89.55	2.25	8.094	0.824	10.149	1.520	13.380	1.490

Date landed	Number of age determinations			Totals	Age composition (%)		
	Age IV	Age V	Age VI		Age IV	Age V	Age VI
VI.1 - VI.9	69	252	44	365	18.9	69.0	12.1
VI.10- VI.15	23	111	18	152	15.2	73.0	11.8
VI.16- VI.20	21	119	31	171	12.3	69.6	18.1
Totals	113	482	93	688	15.5	70.5	14.0

Age group	Body length (cm)		Body weight (kg)	
	M	S D	M	S D
IV	69.04	4.65	7.607	0.815
V	81.56	3.82	11.774	1.670
VI	89.70	1.98	15.192	0.948

Table XIV

Percentage composition, mean length, standard deviation, standard error of the mean, and availability (fish per boat-hour fished) of component size-groups of the 1949, 1950, and 1951 British Columbia Albacore Catches. Total availability estimates for each year are included (Partlo, 1955)

Year	Total availability	Size group	Percentage composition	Mean length (cm)	S D	S E	Availability
1949	5.04	A	3.05	53.25	1.35	0.040	0.15
		B	28.95	63.30	2.07	0.020	1.46
		C	65.50	71.10	2.82	0.018	3.30
		D	2.50	82.95	2.87	0.093	0.13
1950	3.39	A	0.40	54.27	1.75	0.160	0.01
		B	11.90	62.35	2.05	0.030	0.40
		C	80.70	71.35	2.62	0.017	2.74
		D	7.00	79.70	2.37	0.05	0.24
1951	2.19	A	3.50	55.25	1.65	0.086	0.08
		B	81.50	62.90	2.75	0.029	1.78
		C	13.10	72.75	2.75	0.074	0.29
		D	1.90	82.95	3.02	0.214	0.04

All the studies listed above were based on determining the age of albacore by reading marks on the vertebrae. There is some doubt about validity of that method, for Otsu and Uchida (1959b) found that they could not satisfactorily duplicate the results of the earlier workers.

However, size frequency analyses of albacore catches in the temperate North Pacific have indicated that the various size groups appearing in the fisheries can be regarded as year-classes (Brock, 1943; Suda 1954). Furthermore, growth data obtained from tagging experiments have corroborated these observations (Otsu, 1960; Clemens, 1961).

Otsu and Uchida (MS) and Uchida and Otsu (MS) have estimated the ages of the different size groups occurring in the various fisheries, based on growth data derived from tagging experiments and other information (Fig. 19). An estimate of the percentage composition, by number, of each age group occurring in the albacore fisheries in the Pacific Ocean is found in Table XVI.

Bell (MS) gives the age composition of the albacore catch during September-November 1959 in California (Table XV). It should be pointed out that there is a discrepancy of one year between the age estimates made by Bell and Otsu and Uchida (MS). Therefore, although it is generally agreed that the size groups of albacore are year-classes, there is still no agreement on the absolute ages of these year-classes.

4.1.3 Size composition

The size composition of the catches of albacore in the various fisheries in the Pacific Ocean is well documented. In general, each fishery is dependent on certain characteristic size groups, which appear rather regularly each year. Uchida and Otsu (MS) summarized published and some unpublished data on albacore size frequency distributions into composite size frequency distributions for the fisheries in the Pacific Ocean (see Fig. 19).

Mimura (1957) has reported on the size composition of the catches of albacore in the Indian Ocean (Figs. 20a and b).

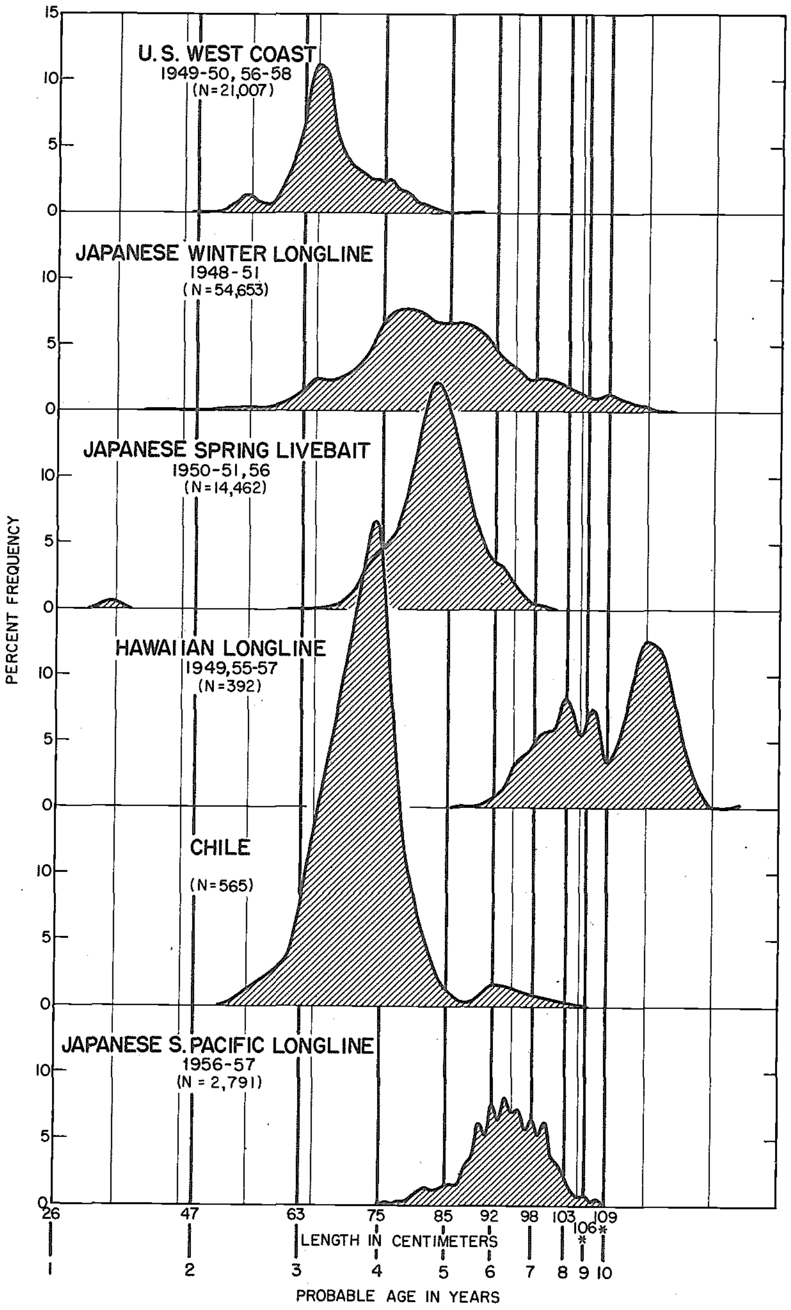

Fig. 19 Combined length frequency distribution separated into component age groups using growth rates derived by Otsu (1960) (Uchida and Otsu, MS)

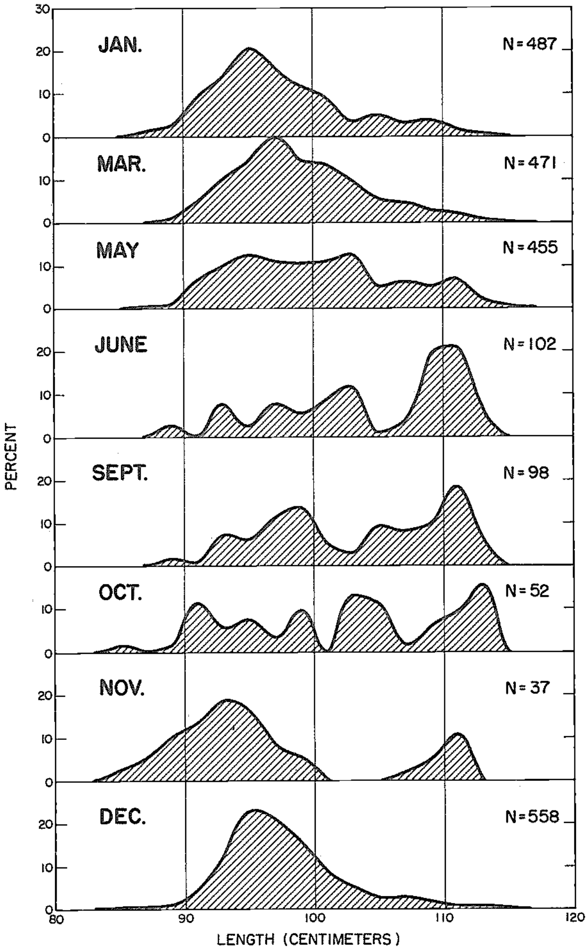

Fig. 20a Length frequency of albacore by month, caught in the South Equatorial Current Area (9°-25° S, 90°-120° E) (Mimura, 1957)

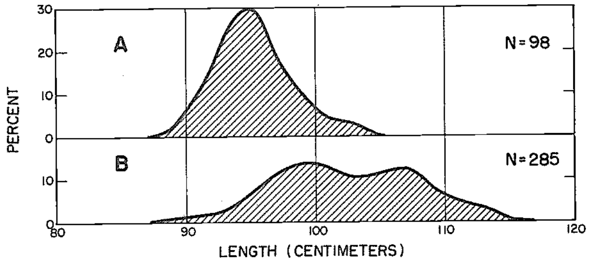

Fig. 20b Length frequency of albacore, caught in the Equatorial Area, (a) 0°-3° N, 1955, Apr. Jun., (b) 0°-4° S, 1955, Apr. (Mimura, 1957)

Table XV.

The age composition of the catch - September, October, November 1959
(adapted from Bell, MS)

Fork length (cm.)	Number of fish, by age, in the catch				
	I	II	III	IV	V
44	233				
51	466				
52	2,331				
53	3,330	1,332			
54	6,993	1,165			
55	16,081				
56	11,012	3,671			
57	17,196	2,149			
58	11,071	2,214			
59	11,265	2,253			
60	13,285	4,428			
61	9,012	18,024			
62	5,461	32,762			
63	10,848	48,317			
64	15,344	76,717			
65		108,842			
66	20,714	89,759			
67	10,365	62,187	10,365	5,182	
68		48,925	4,447		
69		17,784	11,116		
70		8,823	3,529		
71		5,827	2,331		
72		1,199	2,996		
73			4,429		
74		599	2,997	599	
75			5,360		
76		1,166	3,496		
77			4,661	932	
78		1,099	4,395	2,197	
79		1,224	6,118	2,447	
80			3,088	7,720	1,544
81			7,738	11,607	
82			9,230	13,844	
83			7,924	11,887	
84		2,823	2,823	19,759	
85			2,963	14,817	2,963
86			3,329	4,995	3,329
87			1,398	4,195	2,098
88			1,010	4,040	1,010
89			1,332	333	666
90				1,048	350
91					233
92				233	233
93					233
94				233	
95					233
96					
97					233
98					233
Totals	165,007	543,789	107,075	106,068	13,358

Table XVI

Percentage composition, by number of each age group occurring in the catches of the albacore fisheries in the Pacific (Uchida and Otsu, MS)

Age (years)	North Pacific			South Pacific	
	United States	Japanese winter longline	Japanese spring livebait	Japanese longline 0° - 30° S	Chile
1	-	< 0.1	1.0	-	-
2	17.6	2.1	< 0.1	-	5.7
3	70.8	16.2	5.5	0.1	76.1
4	11.4	35.6	50.4	5.9	15.4
5	0.2	24.7	37.2	22.2	1.7
6	-	9.5	5.7	41.7	0.9
7	-	4.7	0.2	24.8	0.2
8	-	3.1	<0.1	4.0	-
9	-	2.2	-	1.3	-
10	-	1.9	-	0.1	-

4.2 Size and density

4.2.1 Average size

No one, insofar as is known, has attempted to make estimates of the size of the albacore populations in the Pacific or Indian Oceans.

4.2.2 Changes in size

Otsu (1959) surveyed the fisheries of the North Pacific for the period 1930-1957 and made a few observations on their condition. Although he did not give absolute numbers, he stated that "it seems unlikely that the exploitation has seriously affected the albacore stock" and "there is no indication of a declining resource."

4.3 Natality and recruitment (see section 4.5)

4.4 Mortality, morbidity

4.4.1 Rates of mortality

Tauchi (1940), on the basis of the size composition of albacore catches during 1934-1937 in Japan, estimated that the survival rate was .66, the fishing rate about .18, and the natural mortality rate .20.

4.5 Dynamics of population

Suda (1958) made a study of the "interchange" of albacore in the Japanese North Pacific fisheries. He defines "interchange" as the recruitment and dispersion of albacore into the exploited population. Suda found that the interchange of albacore in the North Pacific fishing grounds takes place once a year around March and that the fishing condition of the following year is greatly influenced by this interchange.

In a later report Suda (1959) examined the recruitment phase of the interchange in greater detail. Suda calculated an index S, which is an estimate of the magnitude of recruitment of a year class into the fishing ground. This index was calculated from data obtained from the longline fishery. Suda also calculated an index C, which is an estimate of the total number of albacore caught by both the longline and livebait fisheries. He found that although there is some relationship in the relative magnitude of index S and C, index C does not agree perfectly with index S. He also found that the yearly variation in recruitment was very large; that after a certain level of index S was attained, it tended to be maintained for several years; that there was a tendency for a clear biennial variation during a period of generally high level of recruitment, which become obscure during periods of low recruitment; that there was no definite relation between the size of the spawning group and the size of the recruitment.

4.6 Relation of population to community and ecosystem, biological production etc.

From his study of the recruitment of albacore in the Japanese North Pacific fisheries, Suda (1959) concluded that there seem to be variations in the basic productive potentials of the sea area inhabited by albacore larvae. He based this conclusion partly on the observation that after a certain magnitude of recruitment was attained, this magnitude tended to be maintained for several years and that the size of the spawning group was not related to the size of recruitment.

5 EXPLOITATION

5.1 Fishing equipment

5.1.1 Fishing gear

The U.S. west coast fishery takes albacore by trolling and livebait fishing. The trolling gear consists of a 20- to 30-foot pole, usually eucalyptus, rigged on each side of the boat, to which several lines with fishing lures are attached A detailed description of the trolling gear is given by Scofield (1956).

The gear used in the livebait fishing method consists of a bamboo pole with a barbless hook at the end of a 6-foot line. The pole averages between 8 and 9 feet in length, varying according to the size of the fish being caught and the preference of the fishermen. The gear and fishing method are essentially similar to that described by Godsil (1938) for the yellowfin and skipjack livebait fishery in the eastern Pacific.

In general, the fishing gear used in the Japanese livebait fishery for albacore is similar to that used on the U. S. west coast. A detailed description of the gear and fishing methods is given by Cleaver and Shimada (1950).

Longline gear is used in the Japanese winter fishery, the fishery based at Samoa and the New Hebrides in the South Pacific, the fishery in the Indian Ocean, and the Hawaiian fishery. The gear probably differs only in minor details in the various fisheries. The following excerpt describing longline gear is taken from Shimada (1951).

"The basic unit of longline fishing gear is the 'basket'. A basket consists of several sections of main or trunk line, usually cotton, to which are tied a number of branch lines and a float line (Fig. 21). Each branch line is made up of a length of cotton line; or a 'sekiyama' or 'shanawa' (cotton thread wound around a core of wire or fiber); a wire leader and hook. Lines, including the 'sekiyama', are coated with tar to prevent deterioration and to add rigidity for ease of handling.

"The baskets are tied in one continuous line when a set is made. Glass or metal floats, varying in diameter from 10 to 12 inches, are used to buoy the main and branch lines at subsurface level."

5.1.2 Fishing boats

In the U.S. west coast fishery there apparently are no boats that may be called "typical" albacore livebait or trolling boats. According to Clemens (1955), the fishery comprises vessels of myriad sizes, shapes, and descriptions using two types of gear, livebait and trolling. The smaller boats usually under 30 feet in length, catch fish by trolling, while the larger boats, usually over 30 feet in length, are equipped for livebait fishing (Fig. 22).

The following, taken from Van Campen (1960), is a brief description of the type of boat used in the Japanese livebait fishery.

"The most conspicuous characteristics of these craft are the long, high bowsprit bearing prolongations of the fishing racks, the racks extending along one or both sides of the vessel and around the stern, only about 1 foot below the high gunwale, and the spray-system pipes, with closely spaced nozzles, paralleling the racks. The superstructure is all abaft the beam, and the long open welldeck has 9 or 12 hatches. Those hatches along the sides lead to the iced fish holds and those along the midline open into the live wells. Pump circulation for bait wells has not yet caught on in Japan, and the practice of circulating the water through simple openings in the vessel's bottom is almost universal in Japanese bait boats. Most of the boats of less than 130 tons gross are of wooden construction; all of the larger ships are steel." (Fig. 23).

"The typical Japanese longline vessel resembles an Atlantic well-deck trawler and is characterized by a strong shear line (Fig. 24). Power is usually supplied by a Diesel engine and, in many cases, auxiliary gaff-rigged sails are also carried to supplement the main engine. The wheelhouse is located amidships and the engine room is aft. This setup provides ample working space forward, which is free of excess deck structures, except for the longline hauler which may be situated on the port or starboard side. Often, two longline haulers are so installed that fishing gear may be taken in from either side. Removable doors are cut into the bulwark for bringing fish and gear aboard." (Shimada, 1951).

Otsu (1954) gives a description of the boats used in the Hawaiian longline fishery. Briefly, the boats are built along the lines of the Japanese sampan-type livebait boats, with a high and narrow bow, a modified V-bottom, and a moderately low freeboard aft. The afterdeck has sufficient space for handling the fishing gear efficiently. The boats range in size from 40 to 63 feet in over-all length, with about a 12-foot beam and a 6 foot draft on 60-foot boats. They are powered with a Diesel main engine of 115 to 165 horsepower, usually of the high-speed type, driving a single screw through a reduction gear (Fig. 25).

In Chile, the albacore fishing boats are generally 7.20 meters long, 0.62 meters deep, with a beam of 1.50 meters, and are called "bongos". Power is supplied by outboard motors (de Buen, 1958).

5.2 Fishing areas

5.2.1 General geographic distribution

The general localities of the major Pacific and Indian Ocean albacore fisheries are shown in Fig. 26a and 26b.

5.2.2 Geographical ranges (latitudes, distances from coast, etc.)

Clemens (1961), in speaking of albacore says, "In the eastern North Pacific individuals have been recorded off Mexico's mainland at Clarion Island, of the Revilla Gigedo Islands group, and northward along coastal Baja California, California, Oregon, Washington, British Columbia, and in the Gulf of Alaska. The most productive fishing grounds, however, lie between central Baja California and the Columbia River."

The fishing grounds of the Japanese livebait albacore fishery are in the form of an arc averaging about 200 to 300 miles in breadth and extending from around 30° N, 140° E to 32° - 33° N, 160° - 165° E. The extreme western end of the grounds is within 100 miles of port and the extreme eastern end is over 1,000 miles away (Van Campen, 1960).

The longline fishing grounds for albacore in the South Pacific extend from about 10° N to 30°S latitude and from about 140° W to 160° E longitude. This area is fished by Japanese and a few Korean longliners operating out of Samoa and the New Hebrides, Japanese longline boats which operate in mothership fleets, and independently operating longliners (Otsu, 1959).

In the Indian Ocean there are two longline fishing grounds for albacore. One is located between 5° N and 5° S latitude, stretching from about 50° E to 100° E longitude. The other extends from about 8° S to 25° S latitude and from 50° E to 120° E longitude (Mimura, 1957).

In the Pacific Ocean, other localities where albacore are exploited commercially are the waters off Chile, Australia and around the Hawaiian Islands. However, the landings of these fisheries constitute only a small portion of the total albacore landings in the Pacific Ocean.

In the Chilean fishery, the area of largest catches covers central Chile, in the provinces of Aconcagua and Valparaiso, and exceptionally albacore may be taken off Taltal, and to the south as far as Talcahuano (de Buen, 1958). This fishery is conducted within 15 miles of the coast (Manning, undated report).

The longline fishery in Hawaii, which takes albacore only incidentally with other more numerous species of tunas and spearfishes, is confined to within 20 miles of the island (Otsu, 1954).

In Australia, albacore are taken on the south-eastern coast from Port Macquarie in New South Wales on the north to Westernport in Victoria on the south. It is also caught on the east and south coast of Tasmania and on the south coast of western Australia (Roughly, 1951).

5.2.3 Depth ranges

Albacore are caught at the surface by trolling or livebait fishing on the U.S. west coast, and in the Japanese livebait, the Chilean and the Australian fisheries.

Deep-swimming albacore are caught by longline gear in the Japanese winter fishery in the North Pacific, in the Indian Ocean fishery, the fishery in the South Pacific, and around the Hawaiian Islands. Although longline gear fishes subsurface levels, the absolute depths fished by the gear has not been reliably determined. However, it has been shown that in the central equatorial Pacific, albacore are generally caught in greater numbers on the relatively deeper fishing hooks of the longlines (e.g., Murphy and Shomura, 1953).

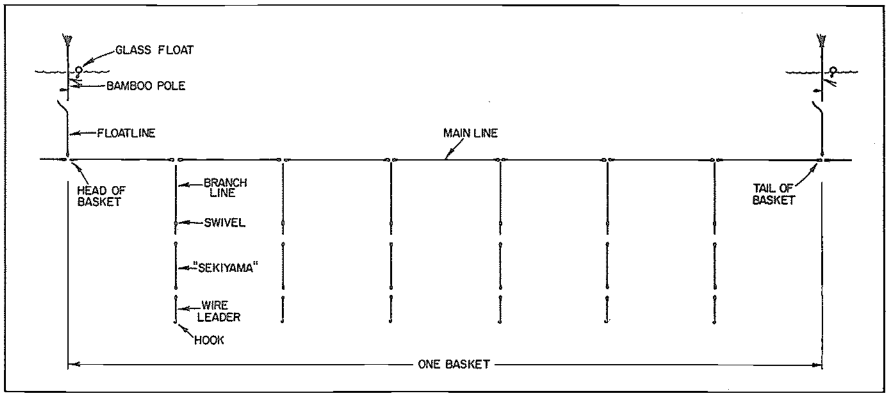

Fig. 21 Diagram showing the component parts of a basket of tuna longline fishing gear (Shimada, 1951)

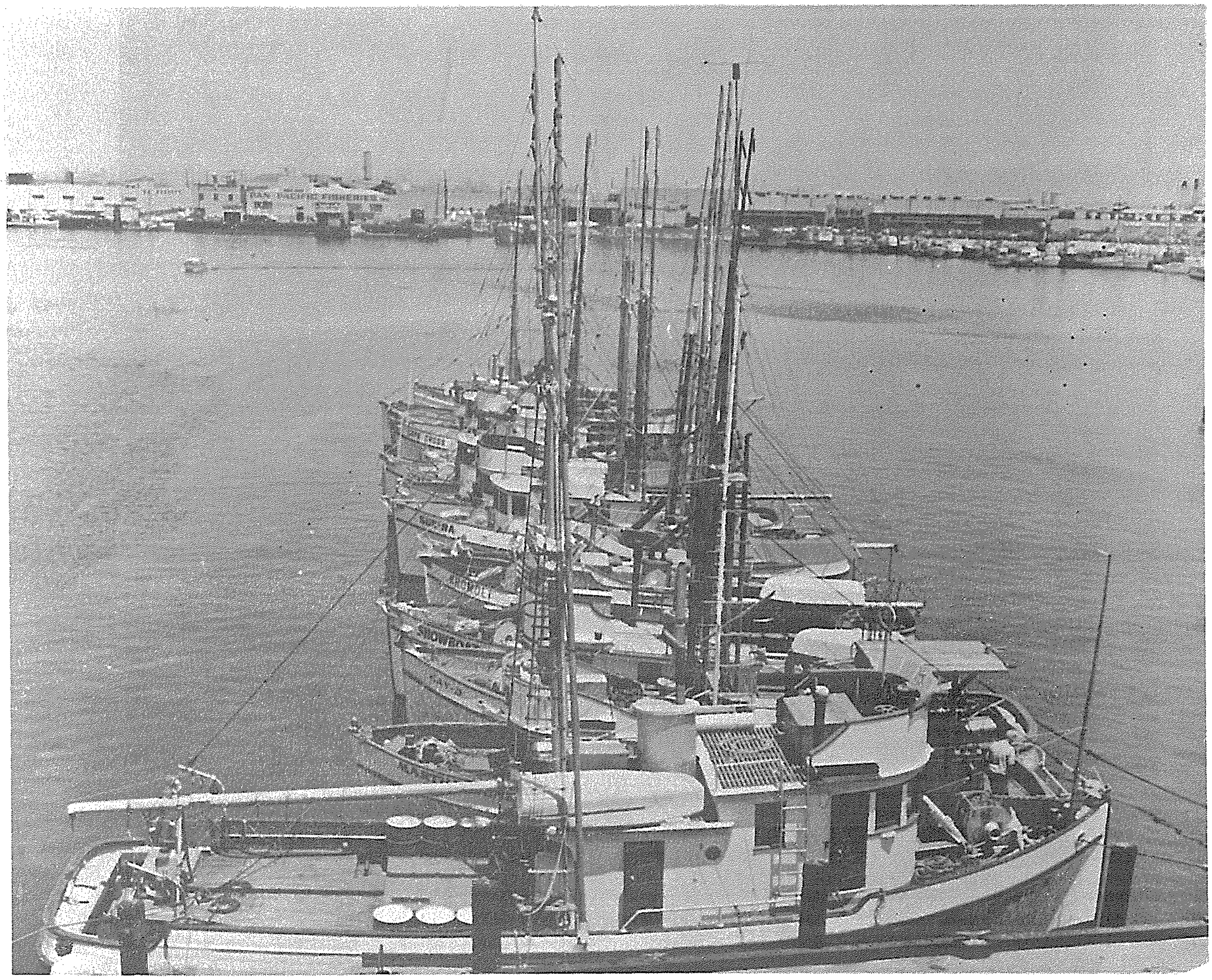

Fig. 22 U. S. west coast albacore boats (photograph courtesy of Harold B. Clemens, California Department of Fish and Game)

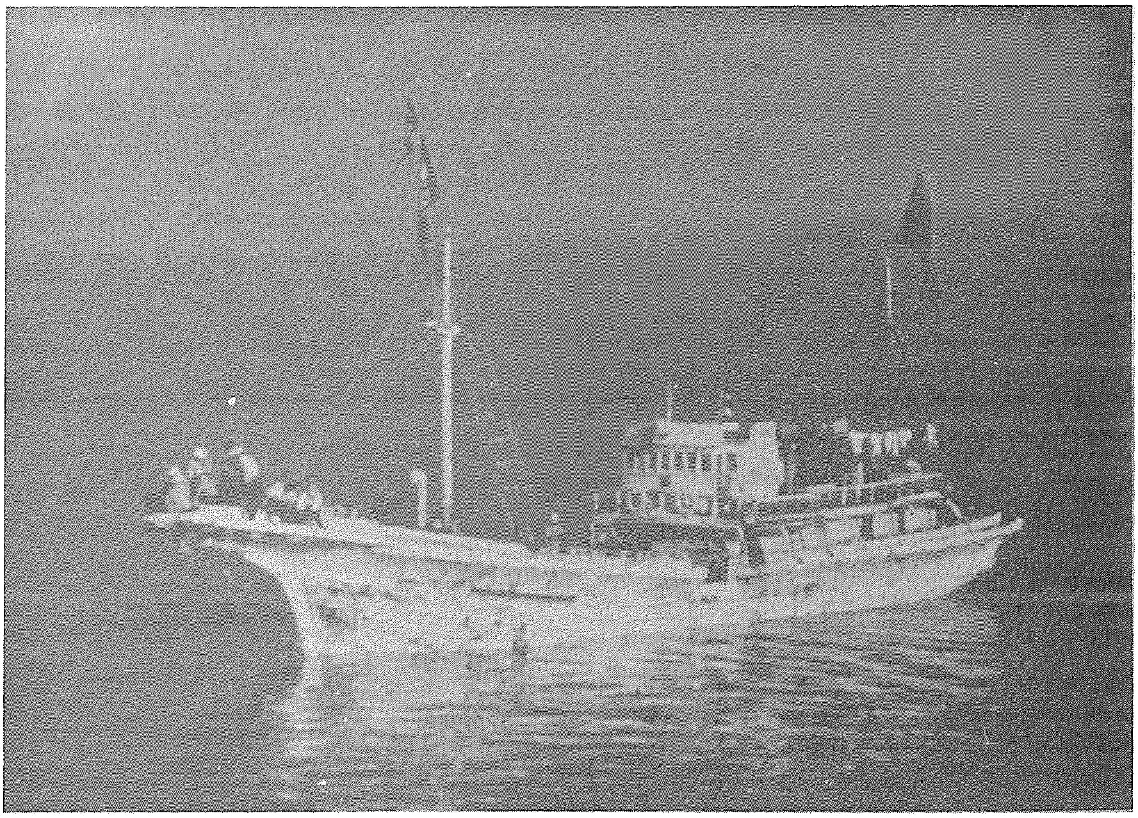

Fig. 23 Japanese livebait fishing boat

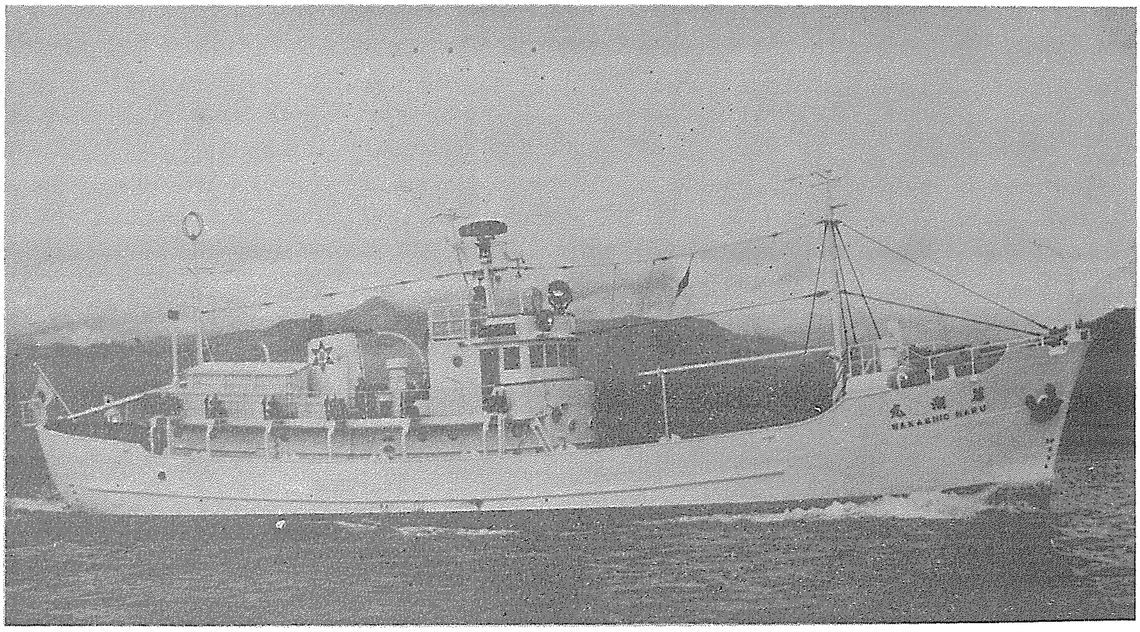

Fig. 24 Japanese longline fishing boat

Fig. 25 Hawaiian longline fishing boat

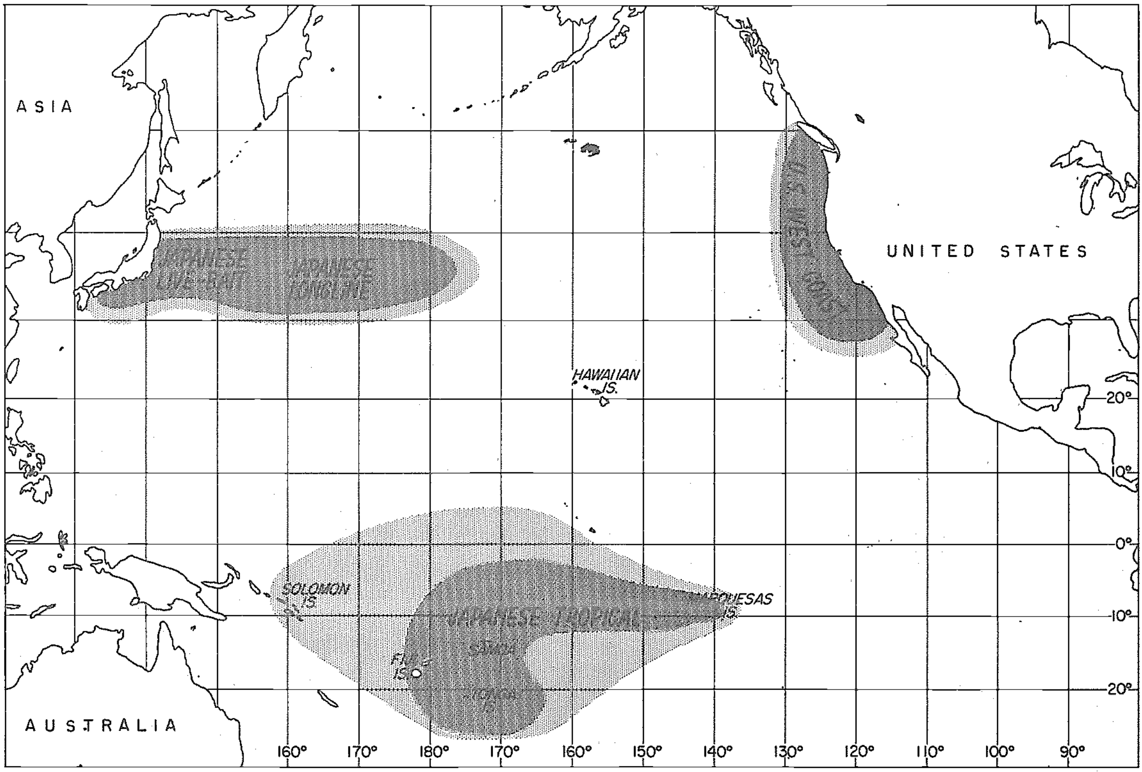

Fig. 26a General localities of the major Pacific albacore fisheries (Otsu, 1959)

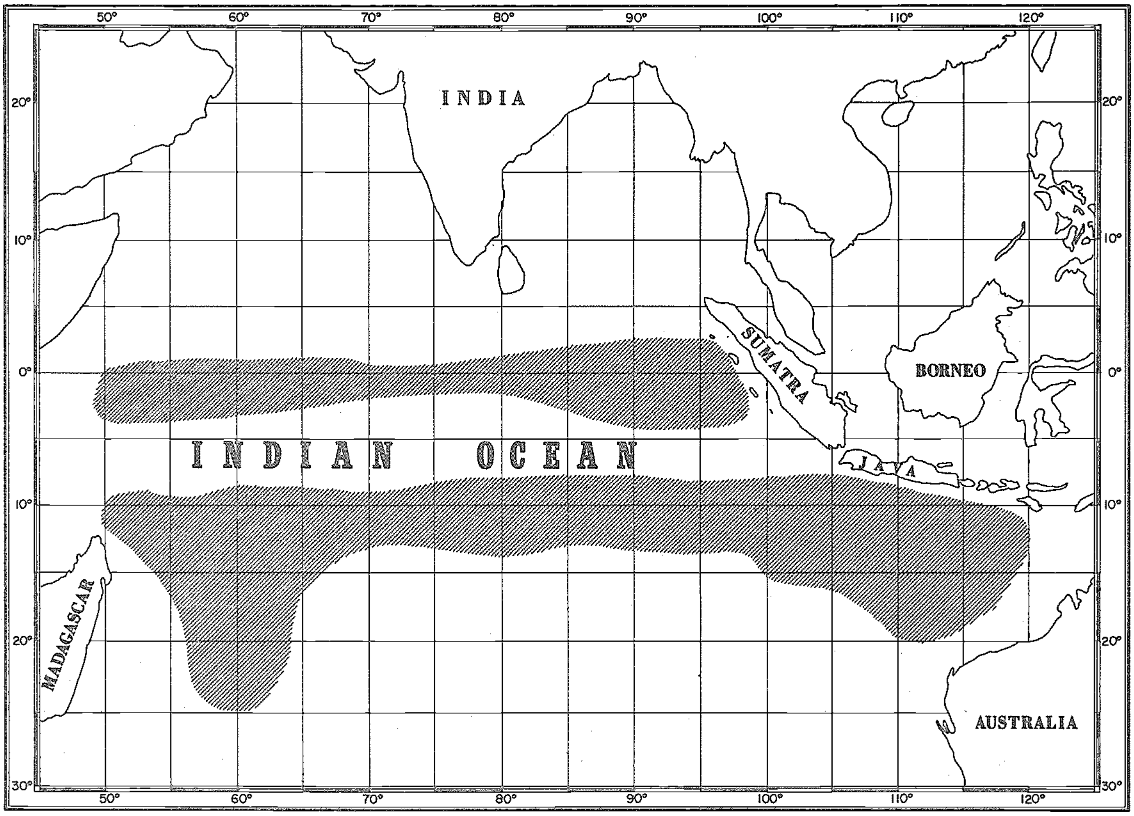

Fig. 26b Fishing grounds of albacore in the Indian Ocean (Mimura, 1957)

Shomura and Otsu (1956) reported on exploratory longline fishing for albacore in the central North Pacific. The albacore catches by relative depths of capture showed that, in general, albacore were caught in equal numbers throughout the range of fishing depths, a different situation from that of the central equatorial Pacific. Shomura and Otsu suggested that the difference in the vertical distribution of the North Pacific albacore and equatorial albacore may be associated with the difference in water temperatures between the two areas. The water temperatures which occur at the surface in the North Pacific are found in deeper layers near the Equator.

5.3 Fishing seasons

5.3.1 General pattern of fishing season

The Japanese livebait fishery begins off southern Japan, gradually moves north and northeast, and ends far offshore at about 160° E longitude (Van Campen, 1960).

The Japanese longline fishery begins in mid-ocean generally between 170° E and the 180th meridian and along 38° N latitude. There is a gradual southwestward shift of the areas of highest catch rates. Towards the end of the fishing season the center of concentration shifts to around 30° N latitude, 140° E longitude (Nakamura, 1951; Suda, 1954).

The American fishery tends to move northward up the coast and off-shore as the season progresses (Clemens, 1955).

5.3.2 Duration of fishing season (See section 5.3.3)

5.3.3 Dates of beginning, peak, and end of season

In the United States west coast albacore fishery, typically, the fishery buds in June, develops very rapidly in July, is in full bloom by August and September, wanes during October and November, and finally dies in December. In exceptional years fish are caught from May through January (Clemens, 1955).

The normal seasonal pattern of development of the Japanese summer fishery for albacore is for sporadic catches of small numbers of fish to begin in March and continue through much of April. Sometime between the latter part of April and the end of May the first large catches are made. By the middle of June the landings rise steeply to their peak of the season. In July the landings decline rapidly and by the end of July the season is virtually over (Van Campen, 1960).

The Japanese winter longline fishery is conducted between November and April over a broad area of the North Pacific. The season reaches a peak, in general, between December and February (Suda, 1954).

Albacore are caught throughout the year in the South Pacific longline fishery. There is no clear seasonal variation in landings, but the more productive months appear to be from August through February (Otsu, 1959).

In the Indian Ocean, the fishing season extends from April to September in the albacore fishing grounds straddling the Equator. On the grounds south of 8°S latitude, albacore are fished throughout the year. The catch rates here are higher during April through September than during the rest of the year (Mimura, 1957).

5.3.4 Variation in time or duration of fishing season

Apparently during certain years some albacore remain along the United States west coast over the winter. According to Clemens (1961), during the winter of 1955-56 a few albacore were caught in December, January, and early February. During the winter of 1956-57 some were taken from December through April; and in 1957-58 albacore were caught in December, January, February, March, and May.

The seasonal patterns of the Japanese livebait and longline fisheries described in the sections above are overly simplified versions of a more complex picture. Van Campen (1960) pointed out that while Japanese writers often imply that all pole-and-line fishing is done in the spring and summer and all longlining in winter, some albacore are taken by both methods in all months of the year.

5.3.5 Factors affecting fishing season

Clemens (1961) discusses in some detail the movements of albacore in relation to surface water temperatures off the United States west coast, which has an effect on the fishing season.

He points out that there is a definite albacore catch-temperature relationship in the eastern North Pacific. In the past a majority of the albacore has been caught while traveling within the narrow temperature range of 60° - 67° F. The development of these surface water temperatures seems to play a part in the movement of albacore along the coast, which in turn affects the development of the fishery.

In Japan also the way in which the pattern of surface temperature distribution develops is thought to affect the summer albacore fishing season. It is believed that the manner in which the warm Kuroshio pushes northward, resulting in isolated masses of water with suitable temperatures close to the coast of Japan, favors successful fishing (Van Campen, 1960). According to Sasaki (1939) albacore are taken in waters ranging from 18° to 24° C in temperature and the range of favorable temperatures is 19° to 23° C.

5.4 Fishing operations and results

5.4.1 Effort and intensity

Otsu (1960) made a survey of the American and Japanese albacore fisheries in the Pacific and noted that "it has not been possible to compile satisfactory statistics on fishing effort to be examined in relation to gross landings statistics." However, he noted that following Second World War the Japanese have continued to enlarge their fishing fleets, and have built larger vessels capable of fishing more distant waters. Table XVII, taken from Johnson (1959), illustrates the growth of the Japanese tuna fleet.

Table XVII

Increase in size of Japanese Tuna Fleet, 1947-56. (Johnson, 1959)

Year	Vessels	Gross tonnage	Average gross tonnage
1947	1,314	78,517	60
1948	1,811	101,008	56
1949	1,893	106,897	56
1950	1,895	108,753	57
1951	1,698	103,978	61
1952	1,590	108,319	68
1953	1,672	124,132	74
1954	1,801	154,133	86
1955	1,825	176,243	97
1956	1,772	197,760	112

Clemens (1961), speaking of the United States west coast albacore fishery noted that, "although the size of the commercial fleet has declined since 1950, well over 1,000 vessels fished for albacore during the 1950 to 1959 seasons inclusive."

5.4.2 Selectivity

Brock (1959b) presents typical examples of albacore sizes taken by the different types of gear (Fig. 27).

5.4.3 Catches

Japan is by far the world's greatest producer of albacore tuna. Since 1952 the Japanese annual landings of this species have been from two to three times as large as those of the United States, the second largest producing nation (Van Campen, 1960).

Table XVIII, taken from Uchida and Otsu (MS) gives the annual landings of albacore by the various Pacific albacore fisheries for the period 1950-1959.

The annual landings of the Indian Ocean longline fishery for albacore during the period 1952-1957 are presented in Fig. 28.

5.5 Fisheries management and regulations

Reproduced below from Clemens (no date) is a brief historical review of regulations concerning albacore in the State of California.

1909 - A commercial fishing license was required for the taking of albacore for profit.

1913 - A sport angling license was required for taking albacore for sport.

1933 - Albacore may be taken at any time of the year. A weight limit in some form has been in effect since 1915-- First weight limit imposed.
A brief history follows:

1. 1915-1933 - No albacore less than 6 pounds may be bought, sold, or offered for sale; and no more than 50 pounds may be possessed.

Table XVIII

Annual landings of albacore by the various Pacific albacore fisheries 1950-1959 (in tons) (Uchida and Otsu, MS)

Year	United States west coast	Japan			Hawaii	Chile
		Winter longline	Spring livebait	South Pacific		
1950	36,207	18,423	14,179	48	30	271
1951	17,245	12,549	15,984	137	28	408
1952	26,278	19,401	46,109	79	52	496
1953	17,417	20,522	36,301	320	25	735
1954	13,499	26,145	30,950	4,190	14	316
1955	14,866	17,842	26,724	8,637	10	709
1956	20,669	17,396	47,205	7,850	7	892
1957	23,329	20,335	54,582	9,643	5	485
1958	19,222	26,472	24,437	15,775	8	142
1959	23,142	35,979	15,706	19,328	6	13

2. 1933-1935 - No albacore weighing less than 9 pounds may be sold.

3. 1955-1957 - No albacore weighing less than 7 pounds may be sold.

4. 1957 to present - No albacore weighing less than 7 pounds may be sold, purchased, or processed.

1935 - A law prohibiting the use of spears to take albacore was passed.

1939 - A bag limit on albacore taken by authority of an angling license was passed. The holder of a commercial fishing license, while on a boat carrying sport fishermen for hire is subject to the same limit.

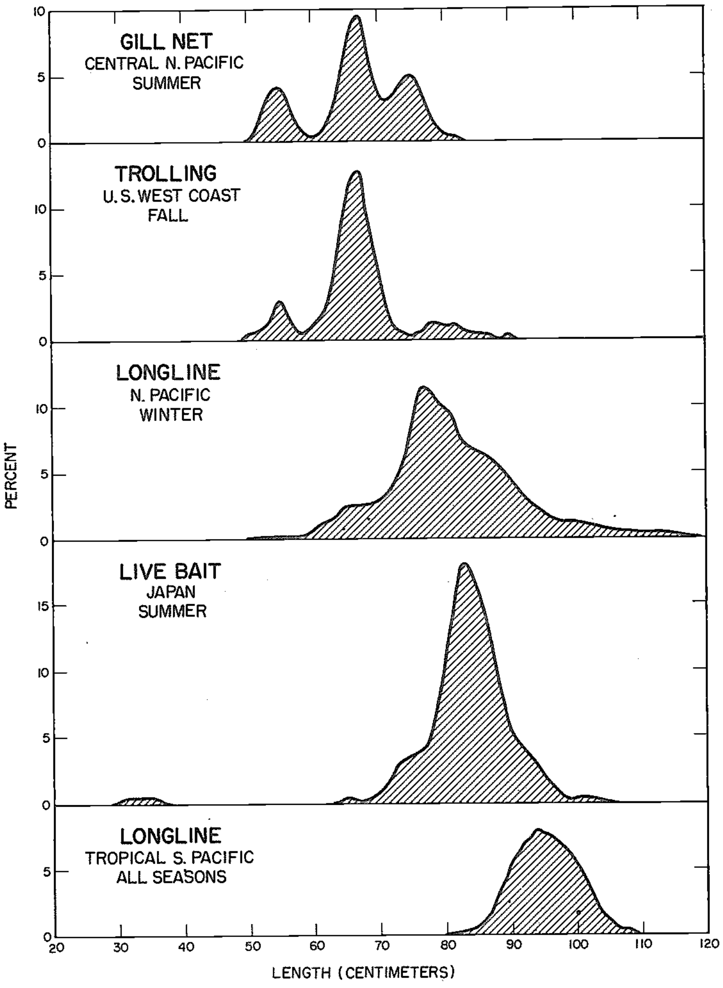

Fig. 27 Albacore sizes taken by various kinds of fishing gear (Brock, 1959b)

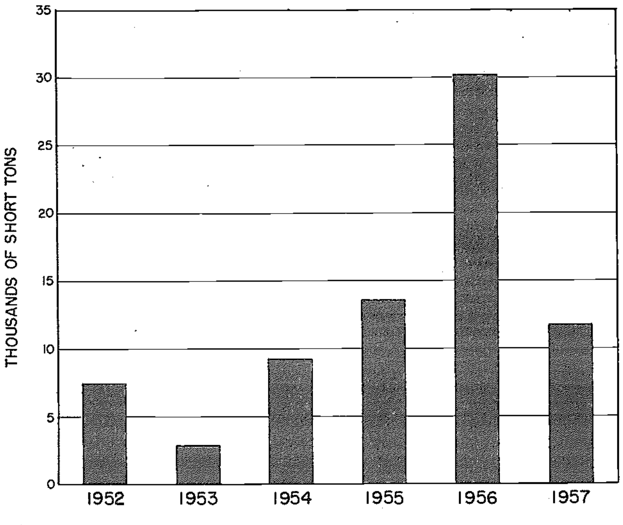

Fig. 28 Annual landings of albacore by the Indian Ocean longline fishery, 1952-57 (Johnson, 1959)