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SYNOPSIS ON THE BIOLOGY OF YELLOWFIN TUNA
Thunnus *(Neothunnus)* *albacares* (Bonnaterre) 1788 (PACIFIC OCEAN)

Exposé synoptique sur la biologie du thon à nageoires jaunes
Thunnus *(Neothunnus)* *albacares* (Bonnaterre) 1788 (Océan Pacifique)

Sinopsis sobre la biología del atún de aleta amarilla
Thunnus *(Neothunnus)* *albacares* (Bonnaterre) 1788 (Océano Pacífico)

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1 IDENTITY

1.1 Taxonomy

1.1.1 Definition

/Following Berg (1940) modified according to Fraser-Brunner (1950)/:

Phylum VERTEBRATA
 Subphylum Craniata
  Superclass Gnathostomata
   Series Pisces
    Class Teleostomi
     Subclass Actinopterygii
      Order Perciformes
       Suborder Scombroidei
        Family Scombridae
         Subfamily Scombrinae
          Genus Thunnus South 1845
           Species Thunnus (Neothunnus) albacares (Bonnaterre) 1788

Berg, following Kishinouye (1923), places the tunas in a separate order, Thunniformes (Placostei), on the basis of their greatly developed vascular system. although he recognizes only a single family (Thunnidae), whereas Kishinouye placed Katsuwonus, Euthynnus, and Auxis in a separate family (Katsuwonidae). Fraser-Brunner's revision, however, shows rather convincingly that all of these should be included within the family Scombridae. We also follow Fraser-Brunner in placing in a single genus, Thunnus, the groups Neothunnus, Parathunnus, and Kishinoella, which should, at most, be given subgeneric status.

The detailed morphometric studies which have been made by a number of researchers in recent years (Godsil 1948; Schaefer 1948; Schaefer and Walford 1950; Godsil and Greenhood 1951; Schaefer 1952, 1955; Royce 1953; Tsuruta 1954), which have most recently been summarized and re-examined by Royce (1961), and the reviews of Fraser-Brunner (1950) and Rivas (1951) leave little doubt that there is but a single species of yellowfin tuna throughout the world ocean, although there are morphometrically distinguishable populations in various places which, however, are of less than specific rank.

1.1.2 Description

- Genus Thunnus South 1845

" Body plump, wholly covered with scales, which differ in size and form in different parts of the body. Corselet well developed but its boundary is not distinct. The lateral line has a peculiar curve above the pectorals. Teeth rather feeble. Single series of small conical teeth in both jaws. They are sharp and curve inward. Villiform teeth on the vomer, palatines and pterygoids. Many dentigerous calcareous plates are found on the palate. The denticles on these plates are quite similar to those found on the vomer, palatines and pterygoids. Thus the roof of the mouth-cavity is quite rough, contrary to the nearly smooth roof in the Katsuwonidae. Three lobes of the liver subequal. Intestine rather long, with three folds. Pyloric tubes developed only on the posterior convex side of the duodenum. Pyloric caeca heteroclitic, irregular in size. Those found at the distal end being longer and thicker than those at the proximal part. This heterochrony is more marked in primitive forms. Rectum short, it has nearly the same diameter as the preceding part of the intestine. Air-bladder present, except in Neothunnus rarus" (= Thunnus tongol).

" Cutaneous blood-vessels above and below the lateral median line are united both at the anterior and posterior ends, and are connected by short horizontal vessels with the chief blood-vessels in the haemal canal at the caudal peduncle. The cutaneous veins are large and unite with the Cuvierian ducts directly or with the cardinal vein. Each of the paired cutaneous arteries arises just behind the pharyngeal muscles or somewhat behind it, runs backwards and downwards behind the root of either the third or fifth rib, and is divided into two nearly parallel branches, a little before it comes to the surface of the muscle, between two consecutive intermuscular bones. The dark red portion of the lateral muscle is rather narrow, and meets the axial skeleton with a narrow neck or root in the hypaxial portion only".

" Ligament in a deep median groove between the anterior end of the frontals is attached to the skin, anterior to the median foramen of the skull".

" The transverse process of some precaudal vertebrae is broad, well developed. The first vertebra is greatly reduced in height and firmly anchylosed to the skull. Inferior foramen is small, and is found in the caudal vertebrae only.

Number of vertebrae is constant, 39 in total, of which 18 are precaudal, and 21 caudal. The haemal canal is closed in the tenth or eleventh vertebra, i.e. near the middle of the precaudal region. Alisphenoids meet at the ventral median line. Anterior precaudal vertebrae are broader than high". /Kishinouye's (1923) diagnosis of his family Thunnidae, which corresponds to our genus Thunnus/.

No groove along the abdomen; pelvic fins moderate or small. Interpelvic processes developed, but separate. Teeth in jaws slender, conical, scarcely or not compressed. Teeth on palatine and vomer as well as in jaws. The two dorsal fins contiguous or separated only by a very narrow interspace (not wider than eye). Large medial keel on each side of caudal peduncle. Scales small or minute; body completely scaled; scales of corselet and lateral line usually larger. Not more than 28 gill rakers on lower limb of first branchial arch. 39 vertebrae. Dorsal spines 13 to 15, the first spine about as long as or longer than the second and third; the following spines rather abruptly decreasing in length; outline of first dorsal fin concave. (Modified from Fraser-Brunner 1950, and Rivas 1951).

- Thunnus albacares (Bonnaterre) 1788

Body fusiforme, elongated, head small, and the caudal portion long. Scales minute, about 270 in lateral line. Air bladder present. Pectorals long, reaching to or beyond the origin of the second dorsal except in some very large specimens. Second dorsal and anal often much elongated in large specimens. No venules(striations) on the surface of the liver, the left lobe of which is sometimes divided in two, and the right lobe of which is longer than the other. Air bladder narrow and long, not divided at the anterior end. Vertebrae 39. Vertebral column long and slender; posterior caudal vertebrae much elongated. Parapophyses long and flattened. Haemal canal closed on tenth vertebra. Haemal canal wide, especially in the precaudal region, where the breadth of the cavity is nearly equal to the diameter of the centrum of the vertebra. Dorsal fin with 13 or 14 spines. Eight to 11 dorsal finlets; eight to ten anal finlets. Gill rakers seven to 11 + 19 to 22.

1.2 Nomenclature

1.2.1 Valid scientific names

- Thunnus (Neothunnus) albacares (Bonnaterre) 1788

There is some doubt whether the valid name of this species is albacares or argentivitattus (Cuvier and Valenciennes 1831). Albacares was described by Bonnaterre from a description and drawing of Sloane (1707). Fraser-Brunner calls this species albacora (Lowe 1839), listing albacares and argentivitattus in the synonymy, the latter with a question mark. He does not, however, indicate why he believes argentivitattus to be questionable. Rivas (1951) notes that Sloane's figure and description may relate to this species but observes that there are certain discrepancies relating to the length of the pectoral fin. Schaefer and Walford (1950) used the name argentivitattus because this is the earliest described species for which the specimens on which the description was based are still available (in the Paris Museum). Royce (1961) having examined Sloane's description and drawing, concludes that, because of the very long second dorsal and anal fins, despite the short pectoral (which may have been broken), it must be a yellowfin tuna. He, therefore, concurs with Ginsburg (1953) that albacares is a valid name and, since it has priority, states that it is the appropriate name for a single worldwide species of yellowfin tuna.

1.2.2 Synonyms

? Scomber sloani Cuvier and Valenciennes 1831

Thynnus argentivitattus Cuvier and Valenciennes 1831

Thynnus albacora Lowe 1839

Orcynus species dubia Poey 1868

Orcynus subulatus Poey 1875

Thynnus macropterus Temminck and Schlegel 1842

Thunnus allisoni Mowbray 1920

Neothunnus itosibi, N. catalinae Jordan and Evermann 1926

Semathunnus quildi Fowler 1933

Thunnus nicolsoni Whitley 1936

1.2.3 Standard common names, vernacular names

English (American)	- Yellowfin tuna
Japanese	- Kihada; kiwada. Kimiji, for young
Spanish	- Atún aleta amarilla
French	- Thon à nageoires jaunes
German	- Gelbflossenthun

1.3 General variability

1.3.1 Subspecific fragmentation (races, varieties, hybrids)

The yellowfin tuna in the Pacific Ocean, and elsewhere, are divided into a large number of sub-populations which evidently do not interbreed, or do so to only a limited extent. These local races, or varieties, are often characterized by differences in morphological characters, including various body dimensions and the relative lengths of the pectoral, the second dorsal, and the anal fins.

Royce (1961),in a paper presented at the Pacific Tuna Biology Conference at Honolulu in 1961, has summarized the considerable amount of information respecting morphometry of yellowfin tuna in the Pacific collected by him and his colleagues, and by numerous other researchers. This analysis indicates that in a broad band along the Equator, between 10°N and 10°S latitude, from the Caroline Islands to the eastern Pacific, there is a cline, or character gradient. For specimens of the same size, yellowfin in the eastern Pacific have larger heads, slightly shorter pectoral fins, much shorter second dorsal and anal fins, and greater distances from snout to insertion of first dorsal, second dorsal, ventral, and anal fins; they also have a greater body depth and a greater distance from the insertion of ventrals to the vent. Samples taken from areas away from the equatorial belt, from which they are generally separated by regions of low abundance, were also found to be distinct, and different from those most nearly adjacent along the equator, although in each case the specimens were morphologically similar to those from some part of the cline. Thus, the groups from near Japan, Philippines, Bikini, and Society Islands are almost certainly separate or quasi-separate populations. Schaefer (1955) has also found differences in average number of gill rakers of yellowfin from Hawaii compared with those from the American west coast and from southeast Polynesia.

Royce's "cline" along the equator may represent a gradual mixing of a large number of adjacent population components. It could, however, also be interpreted as a step function, with partial discontinuities at some longitudes, such as near 120°W, representing major population boundaries across which some mixing occurs.

Along the coast of the Americas in the eastern Pacific, although there is no rapid intermixing of adult yellowfin from one end of the range to the other, as shown by tagging results (Schaefer, Chatwin and Broadhead, 1961), no morphometric differences have been demonstrated (Broadhead 1959).

Although it is evident from morphometric studies and results of tagging experiments that Pacific yellowfin tuna consist of a series of population units with restricted intermixing, the rate and degree of interbreeding, if any, between these units is not yet known. Their exact taxonomic status is, therefore, in doubt.

1.3.2 Genetic data

Research on the genetic structure of yellowfin tuna hs recently commenced, employing blood-typing techniques, but there have yet been published no resulting comparisons of populations of different Pacific regions. Research in progress by staff members of the Inter-American Tropical Tuna Commission has shown that Hawaiian yellowfin differ from those of the eastern Pacific in the frequency of occurrence of phenotypes representing at least two of the compenents of one blood system. Frequencies of these phenotypes in different areas of the eastern Pacific appear to be the same.

Suzuki (1961) has found a number of blood types in yellowfin tuna but did not compare populations of different regions.

2 DISTRIBUTION

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

Yellowfin tuna are circumtropical, occurring in all warm seas of the world, except the Mediterranean. In the Pacific (Fig. 1) they occur in commercial abundance in a broad band across the ocean between, approximately, the surface isotherms of 20°C (68°F) although they also occur sporadically in waters several degrees cooler. This species has been recorded on the eastern side of the Pacific from Point Conception, California to San Antonio, Chile. On the western side, it has been encountered from Hokkaido, Japan through the Indonesian Archipelago to Cape Naturaliste, Australia, and North Island, New Zealand.

Research by the Inter-American Tropical Tuna Commission and the Scripps Institution of Oceanography in the eastern Pacific indicates that temperature is an important ecological factor determining the distribution of adults at the extremes of their range. The seasonal appearance of this species off Baja California, and off northern South America, follows the march of the isotherms. Annual variations in the distribution of the yellowfin near the extremes of the range also correspond to temperature anomalies (Schaefer 1961b, Blackburn 1960).

Low abundance of yellowfin tuna in the warmest part of the sea area off Central America during the warm years 1957 and 1958 suggests that high temperatures, above 28°C, may also tend to be avoided by yellowfin tuna.

Within the range of acceptable temperatures, the most important determinant of abundance of yellowfin tuna appears to be their food supply. It has been shown in the eastern Pacific that the abundance of surface-schooling yellowfin is greatest where there is high productivity of phytoplankton and high standing crops of zooplankton, supporting the forage organisms eaten by the tunas. The highly productive areas, in turn, occur where deeper water, rich in plant nutrients, is brought to the sunlit upper layer of the sea by upwelling, "doming", mixing along current boundaries and other processes (Brandhorst 1958, Holmes, Schaefer and Schimada 1957, Blackburn 1960, Schaefer 1961b). Researchers of the Hawaii Laboratory of the U. S. Bureau of Fisheries (Sette 1955) have, likewise, shown that large, sub-surface yellowfin, taken by longline in the equatorial central Pacific, are most abundant where physical processes of fertilization of the upper layer of the sea lead to large standing crops of zooplankton and forage organisms.

2.2 Differential distribution

2.2.1 Areas occupied by eggs, larvae and other junior stages

Collections of larvae in plankton nets, and of larvae and small juveniles by dip net and in the stomachs of vertebrates, indicate that they occur generally in the same regions as the adults, but that their range does not extend as far poleward as that of the adults (Matsumoto 1958; Klawe, in press). Similarly, at the colder extremes of the range of the adults, specimens with advanced ovaries are scarce or absent (Orange 1961). Data to assess annual variation in distribution of larvae and juveniles are not available but, in view of the apparent correlation between water temperature and spawning, such annual variations may be expected.

2.2.2 Areas occupied by adult stages

As noted above, there have been observed marked seasonal and annual variations of the extremes of the range of commercial distribution related to water temperature.

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

Yellowfin tuna are completely oceanic at all stages of their life history and are apparently confined, in major part at least, to the waters of the upper mixed layer. As noted above, temperature seems to have a dominant role in determining the general limits of distribution and the seasonal and annual variations in distribution and abundance. Within the limits of tolerable temperatures, abundance of food is an important determinant.

Yellowfin seldom occur in coastal waters, but the reason for this is not known. Salinity does not seem to be an important factor in this respect. It is possible that turbidity is of importance, since in turbid coastal waters the tunas may have difficulty in locating and capturing their prey (Murphy 1959) but this is speculative.

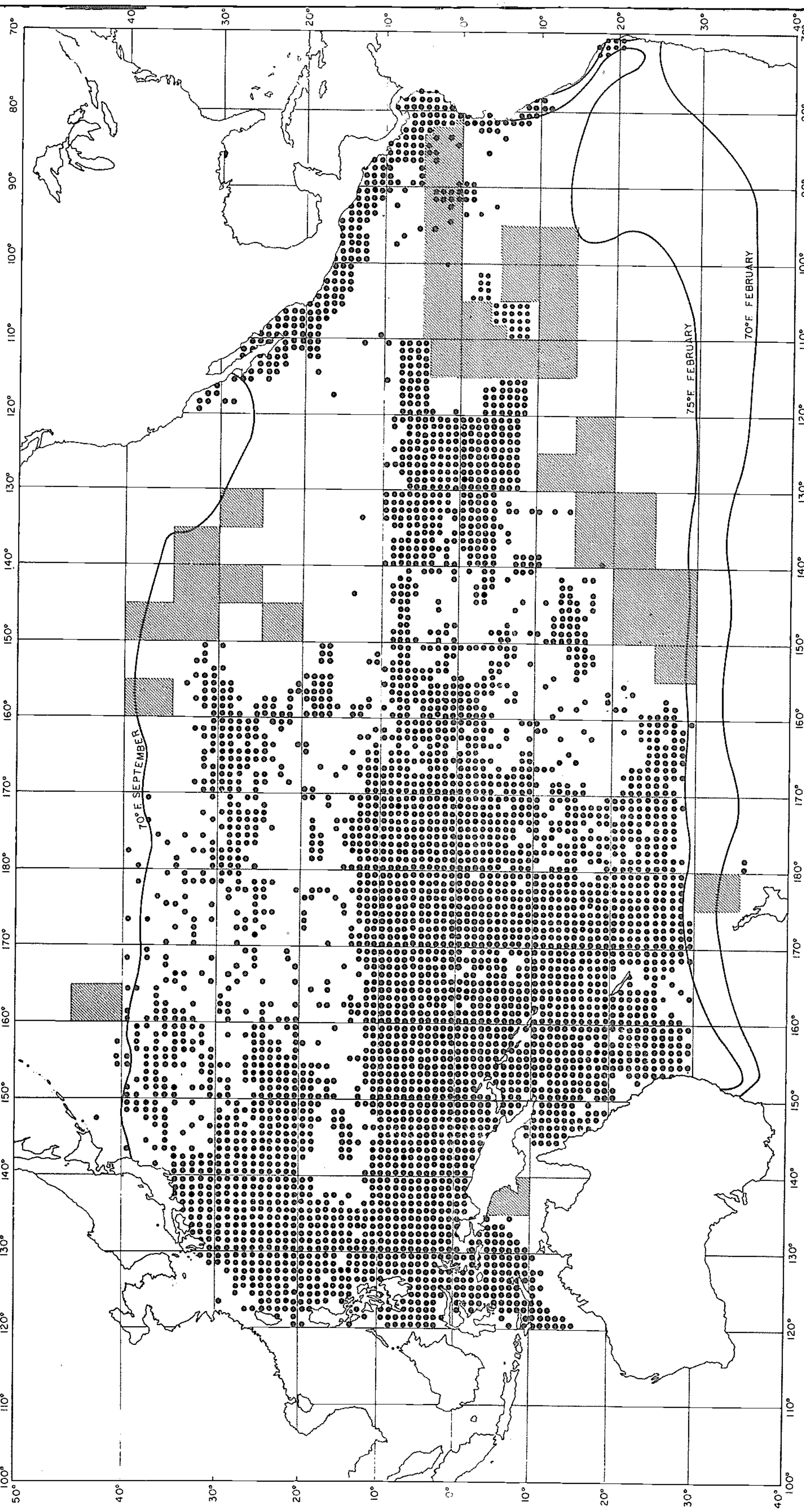

Fig. 1 Distribution of yellowfin tuna as indicated from catches by commercial gear. Solid spots show one-degree areas where catches have been recorded, while the shading indicates five-degree areas where yellowfin have been taken with no indication as to the one-degree areas involved.

3 BIOMETRICS AND LIFE HISTORY

3.1 Reproduction

3.1.1 Sexuality (hermphroditism, heterosexuality, intersexuality)

The yellowfin tuna is heterosexual. No externally observable characters are known to distinguish males and females.

3.1.2 Maturity (age and size)

The estimated size of yellowfin at first maturity varies considerably throughout the Pacific Ocean. Buñag (1956) collected a maturing female 57 cm fork length from the region near the Philippine Islands. Yuen and June (1957) estimated the size of first spawing for fish in the central Pacific to be approximately 70 cm, although the greater share of the females did not reach maturity until about 120 cm. Orange (1961) reported a wide range in size of first maturity for areas within the eastern Pacific Ocean. In the north, around the Revillagigedo Islands, few yellowfin mature below 80 cm total length, and the average size of first maturity is estimated at 100 cm. However, in areas off Central America, a substantial share of maturing females is found in the size-group from 50 to 60 cm total length.

Hennemuth (1961a) notes that the rates of growth for yellowfin tuna from the eastern, central and western Pacific are similar although the assignment of actual ages to the modal groups which can be traced is not entirely firm. However, the combination of the age estimates with estimates of size at first maturity, suggests that yellowfin tuna, for the most part, spawn initially during their second year of life.

3.1.3 Mating (monogamous, polygamous, promiscuous)

The spawning of yellowfin has not been observed but the fish are almost certainly promiscuous in their spawning relations. Distribution of the larvae taken in plankton collections suggests that spawning occurs in open ocean areas where water temperatures in the surface layer are about 78° F or warmer.

3.1.4 Fertilization (internal, external)

External. The eggs are pelagic and are fertilized while they float in the surface layers of the open ocean.

3.1.5 Fecundity

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

Within the ovaries of sexually mature yellowfin, several groups of developing ova may be distinguished. These groups of ova mature and are spawned in batches. It is though that several such groups mature and are spawned by a female each year. Estimates of the numbers of eggs contained in the most mature group have been made by June (1953) for fish from the central Pacific and by James Joseph (personal communication) for the eastern Pacific region. These data indicate that a yellowfin tuna may spawn, at one time, from one to eight million eggs, the number increasing with the size of the fish.

3.1.6 Spawning

- Spawning seasons (beginning, end, peak)

Yellowfin tuna spawn during all months of the year, with the peak of spawning activity occurring at different times of the year, throughout the tropical Pacific. Orange (1961), who examined gonad development and Klawe (in press) who examined the distribution of larvae have made extensive contributions to our knowledge of the spawning habits of the yellowfin in the eastern Pacific region.

Examination of gonad development suggested that there was little spawning in areas of Baja California and Peru, at the extremes of the fishery range. Spawning in the vicinity of the Revillagigedo Islands was extensive, but quite seasonal, peaking during July and August each year. Considerable spawning takes place off southern Mexico, with the peak during the second and third quarters of the year. Waters off the coast of Central America are also a major spawning region, with some females being found in advanced stages of sexual maturity during nearly every month of the year. Maximum spawning occurs during January and February each year.

Considerable spawning was also indicated for the areas around the offshore islands; Clipperton, Cocos and the Galapagos group. These inferences of spawning from the examination of gonads were supported by the work of Klawe (in press) who found larval yellowfin in these areas and also in the areas extending offshore to approximately 120°W longitude. The greatest numbers of larvae were obtained from an area which included the waters off Cape Corrientes, Mexico to the Gulf of Panama and offshore to a distance of several hundred miles. Larvae were also abundant around the offshore islands and in the North Equatorial Countercurrent.

Matsumoto (1958) reported the occurrence of larvae from all areas where adults were taken; from 25°N to 15°S latitude and from 120°W to 180° longitude in the central Pacific. Few larvae were taken in the area between 120° and 140°W longitude. The highest abundance of larvae were noted as being between 140°W and 180° longitude. The larvae were found to be concentrated at or near the surface, especially at night.

Yabe and Ueyanage (1961) examined the larval tuna collected by research vessels of the Nankai Regional Fisheries Research Laboratory, and vessels of the Fishery Agency of Japan during the period 1949-60. Most of the larvae were taken in the tropical areas of the western Pacific but some came from subtropical areas which are under the influence of the warm Kuroshiwo current in the north and the east Australian current in the south Pacific. Larvae were collected in the equatorial region during nearly all months of the year but occurred seasonally in the subtropical regions; May and June in the Kuroshiwo-current area and November and December in the area influenced by the east Australia current.

Kikawa (1961) reports, from examination of the gonads of yellowfin taken by the Japanese longline vessels, that in the north Pacific there is spawning in the waters off Luzon Island to southern Japan during April, May and June. In the south Pacific spawning probably takes place in the Coral Sea and its adjacent waters and from the area near the Tuamotu Islands (150° to 130° W longitude and 10° to 25°S latitude). The spawning season appears to be from October to March. Legand (1961) reports the spawning of yellowfin along the coasts of New Caledonia from October through March.

- Number of spawners per year, frequency

The consensus of numerous investigators is that the female yellowfin tuna matures and spawns at least two batches of eggs each year.

- Spawning time of day

As spawning has never been observed and yellowfin tuna eggs taken in plankton hauls have not been distinguished from those of other scombrids, this information is not known.

- Induction of spawning, artificial fertilization

Although maturing yellowfin tuna of both sexes are readily taken by the commercial fishing gear, very few mature (running ripe) fish are captured. No artificial fertilization of yellowfin tuna eggs has been successful. Little is known of the climatic factors which induce spawning although water temperature almost certainly has some influence.

3.1.7 Spawning grounds

See section 3.1.6

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

When the ova are about to be spawned they undergo distinct morphological changes. The opaque color changes to one which is translucent. The ripe ova, although not exactly spherical, measure approximately 1 mm in diameter. Embedded in the yolk is a single, conspicuous, golden-yellow oil globule, which is about 0.26 mm in diameter. The ripe ova break from the follicles in which they develop and collect in the lumina of the ovaries. The eggs, which are pelagic, apparently hatch within two days into larvae from 2 to 3 mm in length.

Yuen and June (1957) report that of 25 ovaries examined for nematodes, 22 were infested. However, the extent of infestation was not serious as there were seldom more than five worms in a single ovary. Fish with infested ovaries have been reported from both the central and eastern Pacific regions.

Nothing is known about predation on the eggs in the ocean but it is certain that many members of the plankton community act as predators on eggs of yellowfin tuna.

3.2 Larval history

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

Using plankton-net tows and night-light and dip-net methods for the collection of young tunas, a number of workers have identified and described the larval, postlarval and juvenile stages of the yellowfin tuna. Schaefer and Marr (1948), Mead (1951) and Klawe (in press) have studied the development and also the distribution of these larvae taken in the eastern Pacific region. Wade (1951) identified and described larvae collected from waters around the Philippine Islands. Matsumoto (1958) studied the development and outlined the distribution of the larval yellowfin tuna from waters of the central Pacific. Identification is based primarily on pigmentation and morphology of the larvae and on the distribution of the adults within the area studied. There is still some doubt as to the validity of the identity of the very small larvae which may be quite similar to the larvae of the bigeye tuna, Parathunnus sibi. Recently Watson and Mather (1961) have employed soft X-rays to examine internal characters for positive identification of the various species of the genus Thunnus found in the western Atlantic.

Matsumoto (1958) described in detail the structural development of the larval and postlarval stages from 3.9 to 14.25 mm total length, from a series of 264 specimens taken from the waters of the central Pacific. Two of his drawings have been reproduced in Fig. 2. The specimens are characterized by the lack of chromatophores on the trunk, except over the visceral mass and by the darkly pigmented distal half of the interradial membrane of the first dorsal fin.

Larval yellowfin tuna have been taken from nearly all the tropical waters of the Pacific Ocean. They are found in the surface layer above the thermocline and drift, in their earlier stages, with the ocean currents. Some vertical diurnal migration is postulated by Strasburg (1960) for larval tunas taken in the central Pacific but data presented by Klawe (in press) for the eastern Pacific do not substantiate this thesis.

- Feeding

Little is known of the food habits of the young stages of the yellowfin tuna. Clemens (1956) noted that juvenile tunas (Euthynnus and Auxis sp.) kept in an aquarium aboard ship, rejected vertebrate planktons as food but fed avidly on soft-bodied larval fish which were offered to them. Strasburg (1960) found on dissection a small fish larva in the stomach of an 8 mm skipjack larva. These indirect evidences suggest that the young larvae of the yellowfin tuna are feeding on fish larvae.

- Rates of: development and survival

Little is known concerning the rate of development of larval yellowfin tuna although it is thought to be rapid.

No studies have been made concerning the survival rates of the larvae although Matsumoto (1958) notes a sharp decline in the frequency of occurrence of the larger larvae taken in plankton tows. However, this is certainly due, in part at least, to the inability of the sampling gear to capture all sizes of the larval and postlarval stages with equal efficiency.

- Parental care

None.

- Parasites and predators

Nothing is known of the parasites of larval yellowfin tuna. No studies have been conducted on the amount and type of predation on these young stages, although it is certain that they are eaten by other members of the plankton population and by the juveniles of many species of pelagic fish. Peterson (personal communication) reports that about 30 larvae were eaten by the tropical anchovy, Cetengraulis mysticetus in the bait tanks of the M.V. Mary Lou while fishing off Cabo Blanco, Costa Rica. However, because of the disjunct distribution of these fish, it is doubtful if the anchoveta can be considered a predator on larval stages of the yellowfin tuna.

3.3 Adult history

3.3.1 Longevity

Hennemuth (1961a) estimates the asymptotic

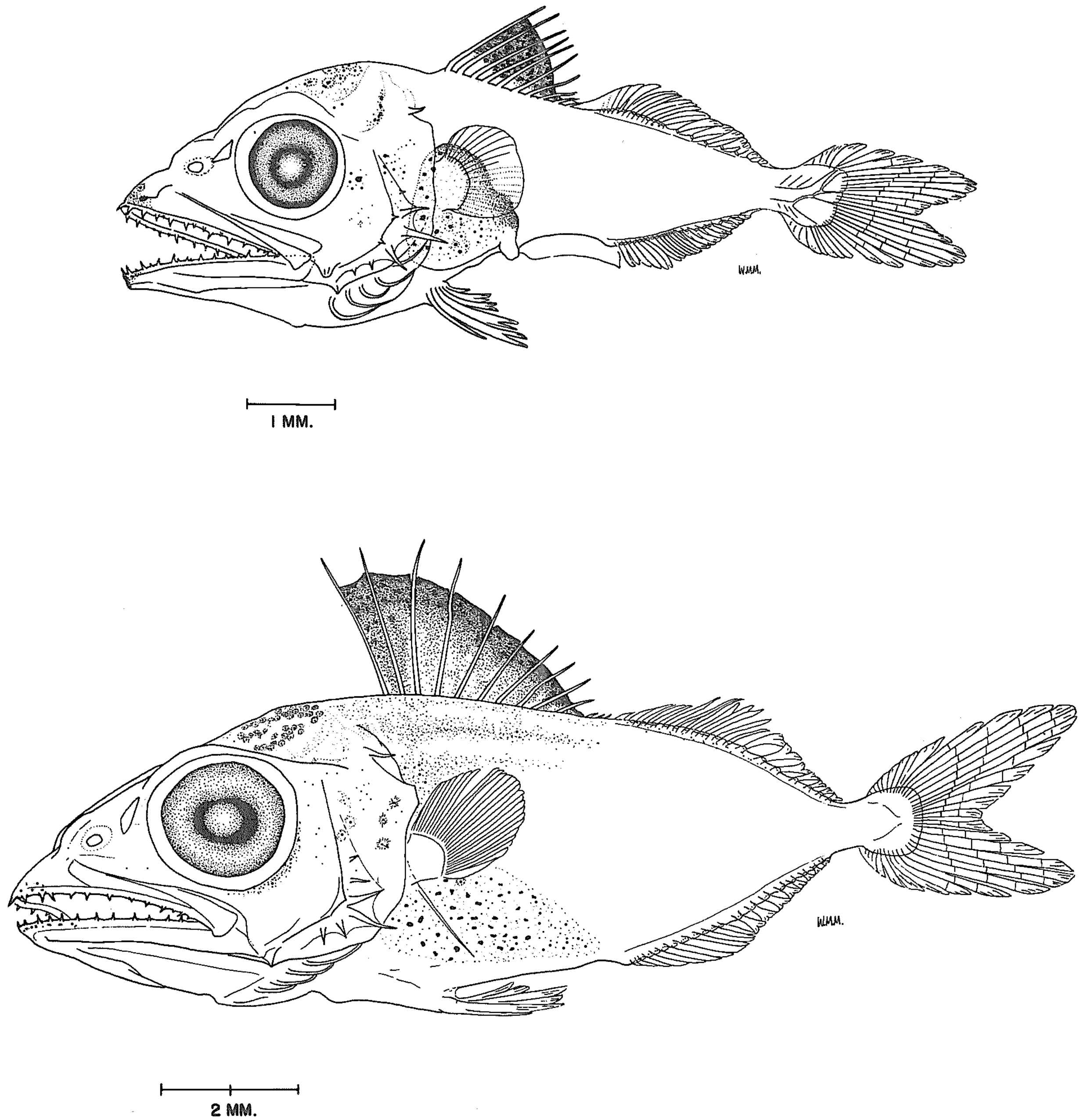

Fig. 2 Drawings (from Matsumoto 1958) of larval yellowfin tuna taken from waters of the Central Pacific.

weight for yellowfin tuna from the eastern Pacific region to be 218 lb. Moore (1951) in studies of yellowfin from the central Pacific and Yabuta and Yakinawa (1961) for yellowfin tuna from the waters off Japan estimate the asymptotic weight as approximately 295 lb. Of course, some few individuals are taken by the commercial fishery which are larger than these estimates. The precision of age estimates for yellowfin tuna decreases rapidly for these larger fish but the very largest specimens which have been taken are probably ten or more years of age.

3.3.2 Hardiness

Schaefer (1961a) estimates that yellowfin tuna of commercially-exploited sizes from the eastern Pacific region are subjected to about 55 per cent mortality each year from natural causes. There are not sufficient data available to make estimates of this parameter for the yellowfin stocks from other areas of the Pacific Ocean.

Broadhead (1959) and Schaefer, Chatwin and Broadhead (1961) have noted that these fish are powerful but delicate, and handling during the tagging operations has resulted in injury and muscular fatigue that has contributed to the subsequent death of a large portion of the tagged individuals. Barrett and Connor (1962) in their studies of the relationship of activity to blood lactate level have suggested that the tunas may well be living near to the environmental limit of their oxygen requirements.

3.3.3 Competitors

Little quantitative information is available on this subject but it is certain that most of the large carnivorous fish which inhabit the surface layers of the subtropical and tropical regions of the Pacific are food competitors.

3.3.4 Predators

Large tunas, billfishes, sharks and perhaps killer whales are the chief predators of the yellowfin tuna. However, the juvenile and young adult tunas are most certainly eaten by nearly all of the large carnivorous fish whose distribution is coincident with that of the yellowfin.

3.3.5 Parasites and diseases

The external parasites are mostly copepods and trematods which are found on the upper surface of the pectoral fin, the inner side of the opercle, gill lamellae, in the nasal cavity and the mouth cavity. The internal parasites are chiefly trematodes and nematodes living in the alimentary canal, circulatory system muscles and the tissue of the viscera. Table I is a partial list of the parasites which are known to inhabit the yellowfin tuna, together with the area of infestation and the reference which sites the information.

3.3.6 Greatest size

See section 3.3.1.

3.4 Nutrition and growth

3.4.1 Feeding (time, place, manner season)

Reintjes and King (1953), King and Ikahara (1956), Watanabe (1958, 1960) Legand and Desrosieres (1961) and Alverson (in press) report that the yellowfin tuna is an opportunistic feeder having a quite varied diet of fish, crustacea and cephalopods. Feeding is during the daylight hours and mainly in the surface layers of the open ocean. Alverson (in press) reports that yellowfin tuna captured in the vicinity of the Revillagigedo Islands in the eastern Pacific region contained many benthic forms.

Tester, Yuen and Takata (1954) studied the response of tuna (Euthynnus affinis and Neothunnus macropterus) to chemicals and to extracts of fish flesh, viscera, etc. In captivity, these fish respond violently to certain of these olfactory stimuli. However, the same stimuli failed to attract or hold schools of skipjack tuna (Katsuwonus pelamis) during experiments conducted at sea. Unfortunately none of these latter tests were made with yellowfin tuna schools. Nevertheless, the negative results, together with other data, suggest that the sense of sight and not smell is the major motivating force in the feeding activities of tuna.

Table I

Partial list of parasites known to inhabit the yellowfin tuna

Name of parasite	Where found in host	Reference
Pennella sp.	partly embedded in flesh	Klawe (personal comm.)
Capsalla martinieri	nasal cavity	Klawe (personal comm.)
Caligus productus	skin and mouth cavity	Shino (1959a)
Caligus corypnaene	skin	Shino (1959a)
Pseudocycnus appendicularis	gills	Shino (1959b)
Elystrophora hemiptera	inside gill cover	Shino (1959b)
Unidentified nematode	ovaries	Yuen and June (1957)
Unidentified nematode	dorsal aorta	Kishinouye (1923)

3.4.2 Food (Type, volume)

The food of the yellowfin tuna is quite varied although only a few kinds of the numerous forage organisms present in a given locality are taken in quantity. Reintjes and King (1953) reported finding 38 families of fish and ten orders of invertebrates in the stomachs of yellowfin caught in the central Pacific, but noted that only seven families of fish and three orders of invertebrates contributed more than two per cent of the total volume of food examined. Ronquillo (1953) and Watanabe (1958) record similar data from the examination of stomachs of yellowfin from the western Pacific. Alverson (in press) examined the stomach contents of 3, 763 yellowfin tuna (253 to 1963 mm total length) from various areas of the eastern Pacific. 24 per cent of the stomachs were empty. Fish (47 per cent), crustacea (45 per cent) and cephalopods (8 per cent) comprised, by volume, the three major categories of food eaten. Representatives of 43 families of fish and 12 orders of invertebrates were found in the yellowfin stomachs. However, only a few items were of any importance in the diet of the fish. Six families of fish and two orders of invertebrates contributed, by volume, 77 per cent of the total volume of stomach contents examined. The data suggest that the yellowfin tuna has a high metabolic rate, is probably quite nonselective in its diet and makes use of a great variety of forage items. The diet changes in response to the distribution of the prey and the failure of a specific food to be present does not in itself limit the distribution of the yellowfin tuna.

3.4.3 Relative and absolute growth patterns and rates

Direct determination of age by the analysis of marks on scales, vertebrae or other hard parts, has not proven reliable for the tropical tunas. For this reason estimates of yellowfin tuna growth have been derived from analysis of length-frequency distributions of fish taken in the commercial catches, and from changes in length exhibited by recaptured tagged fish. Moore (1951) examined the length-frequency data for fish taken by the commercial longline fishery in the central Pacific; Iversen (1956) examined data from fish from the central and western Pacific; Yabuta and Yukinawa (1957b) examined data from fish from Japanese waters; and Hennemuth (1961a and 1961b) studied data for fish from waters of the eastern Pacific. Blunt and Messersmith (1960) and Schaefer, Chatwin and Broadhead (1961) reported on the growth of recovered tagged yellowfin tuna from the eastern Pacific region. All authors were in general agreement that the yellowfin tuna grow at a rapid rate and enter the commercial fishery (for surface schools) at about the end of their first year of life. Hennemuth (1961a) concluded that the rates of growth of fish from the western, central and eastern Pacific regions were quite similar.

In the eastern Pacific the fish are first recruited to the surface fishery at the end of their first year and the beginning of their second year of life. The entering year class is fully recruited at 18 months of age, when the average weight is 7.5 lb. The fish grow rapidly, reaching a weight of about 149 lb at four years of age.

3.5 Behavior

3.5.1 Migration and local movements

Knowledge on the migration of yellowfin tuna has been studied only in the eastern Pacific Ocean where an intensive marking program has been carried out since 1952. Blunt and Messersmith (1960) report on the tagging (13, 213) and subsequent recovery (263) of fish by scientists from the California Department of Fish and Game, while Schaefer, Chatwin and Broadhead (1961) discuss the tagging (20, 479) and recovery (747, through December, 1959) of yellowfin tuna in this same region by scientists of the Inter-American Tropical Tuna Commission. None of these many recoveries has been from either the central or the western Pacific, although a large number of fairly extensive movements of tagged fish have been noted within the eastern Pacific region. The data are too numerous to review adequately here and the reader is referred to the above papers and to the Annual Reports of the Inter-American Tropical Tuna Commission for details. Briefly, some of the results may be summarized as follows:

(a) Evidence from recoveries of fish tagged in different areas, and from recoveries of fish tagged at different water temperatures in the same areas, indicates that the rate of recovery is inversely related to water temperature at the time of tagging.

(b) Initial tagging mortality is high at all times, and may average as much as 70 or 89 per cent.

(c) Yellowfin tuna disperse from the point of release more rapidly in the central region of the fishery than they do in the region near the ends of the range.

(d) Yellowfin tuna disperse more slowly from the point of tagging than do skipjack, this difference being marked near the northern and southern ends of the range.

(e) Yellowfin tuna found around the offshore islands in the eastern Pacific are, in part at least, coextensive with the stocks off the mainland.

(f) The data on yellowfin migrations among the several regions of north of the Gulf of Tehuantepec indicate that these regions are inhabited in large part at least, by a common stock of fish.

(g) There is at least some movement of fish from the regions off Central America into at least part of the area inhabited by the populations off southern Mexico. At the same time, the southerly migrations from off Panama to as far south as the vicinity of the Gulf of Guayaquil indicate that the stocks off South America receive at least some recruits from off Central America.

(h) There is evidence of a distinct seasonal pattern of movements between the region near the Gulf of Guayaquil and farther south off Peru, the tuna tending to move south during the warmer months and north during the cooler months. This is analogous to the northerly and southerly migrations of yellowfin off Baja California and southern Mexico, the fish moving polewards with the warming of the water, and equatorwards as the water cools.

3.5.2 Schooling

The geographic distributions of the yellowfin, skipjack and bigeye tunas in the Pacific Ocean overlap to a large degree, and that of the yellowfin and bluefin tuna to a minor degree. However, yellowfin tuna generally school by species and a large share of the total catch from the eastern Pacific, by purse-seine and bait vessels, is made from single-species schools. Broadhead and Orange (1960), from a study of the catches by the commercial fishery in this area, note that schooling by size is also demonstrated, as the individuals from each school are more like each other than would be expected if they were drawn at random from the entire population. Schooling by size is evidently somewhat modified by the special relationship, as yellowfin tuna from schools of mixed composition (with skipjack) are smaller and vary less in length range than do yellowfin from pure schools.

Schools of yellowfin tuna are known to accumulate under floating objects such as logs, dead whales or drifting vessels. One hypothesis is that the protection afforded by these objects attracts small fish, which are then preyed upon by the tunas. Another suggestion is that logs and free-floating objects tend to concentrate at oceanic frontal areas, where the currents accumulate food organisms. The tunas are then attracted by the food supply.

Yellowfin tuna are also found in association with porpoise schools, whales and sharks. Again little is known of the behavior mechanism involved in these associations.

4 POPULATION (STOCK)

4.1 Structure

4.1.1 Sex ratio

The sex ratio in catches of yellowfin tuna either from surface schools, or by longline from sub-surface aggregations, is related to the size of the fish. Schaefer and Orange (1956) found that the two sexes are about equally represented in samples from the surface fishery in the eastern Pacific up to a total length of about 120 cm, but thereafter males become progressively dominant. This was confirmed by an even larger number of specimens examined by Orange (1961). These observations agree, in general, with previous observations of Murphy and Shomura (1955), and Shomura and Murphy (1955) on yellowfin taken by longline gear in various parts of the equatorial Pacific further westward. They found the two sexes about equally represented in their samples from the western Pacific up to about 122 cm, after which males predominated. In the central Pacific and eastward of 120°W longitude, the size at which males predominated was somewhat larger.

The predominance of males at larger sizes may be due to differential growth rate, differential mortality rate, or some sex-connected differential behavior making large males more amenable to capture than large females. We cannot at present choose among these possibilities on evidence available.

4.1.2 Age composition

The ages of individual yellowfin tuna cannot be determined from scales or other hard parts. Age determination depends on identification of modes in size-frequency samples. Employing this technique, Hennemuth (1961a) has estimated the age and growth of yellowfin tuna in catches in the surface fishery of the eastern Pacific. He found that the fish enter the catch at about one year of age, that they are fully recruited at about one-and-a-half years of age, and that very few remain at four years of age. The bulk of the catch consists of two age groups.

Yabuta and Yukinawa (1957b), from examination of size frequencies in Japanese surface and longline catches, arrive at a growth curve very similar to that of Hennemuth. From their data it appears that yellowfin enter the Japanese surface fishery at about six months of age and continue to be available for about another year and a half. Fish taken on longlines appear from their data to be from one-and-a-half to five years of age, with most of the catch consisting of fish two years old and older.

Moore's (1951) study of size frequency of yellowfin tuna taken by longline near Hawaii indicates that the catch is composed of fish from one to six years old, most of the fish being two years of age or more.

Due to the high mortality rate of yellowfin tuna (Hennemuth 1961b) the relative numbers of fish in the catch drop off rapidly after the age of full recruitment. This is reflected in the size-frequency data from all parts of the Pacific.

4.1.3 Size composition

The relation between age and length, and age and weight, of yellowfin tuna in the eastern Pacific is shown in Fig. 3, reproduced from Hennemuth's (1961a) Fig. 30. As may be seen from his Fig. 31, this corresponds fairly well also to the data from Hawaiian and Japanese waters, although in the latter cases the fish are perhaps somewhat larger at the same age for fish above two years old, which may be the result of selectivity of fishing gear.

The size composition of the catch varies with the type of gear employed. In the surface fishery in the eastern Pacific yellowfin range from about 7.5 lbs (the minimum legal size in the State of California) to as much as 200 lbs. The mean size of fish taken by live-bait fishing is in the neighborhood of 20 lbs but it varies with area and season (due to the differential distribution in space and time of fish of different ages) from less than ten to over 40 lbs. Fish taken by purse-seiners, on the average, are somewhat larger than those taken by live-bait, due to selectivity of the seiners against fish of the smaller sizes (Hennemuth 1961a, 1961b).

From the size composition of longline catches it appears that the deep-swimming yellowfin consist almost entirely of the larger (and older) members of the population. Most of the longline catch, in all parts of the Pacific, consist of fish larger than 80 cm (about 25 lbs) and the dominant modal size is commonly about 110 cm (about 60 lbs). Size composition and, consequently, average size varies geographically and seasonally. There is a striking gradient of size composition of longline catches along the Equator, between

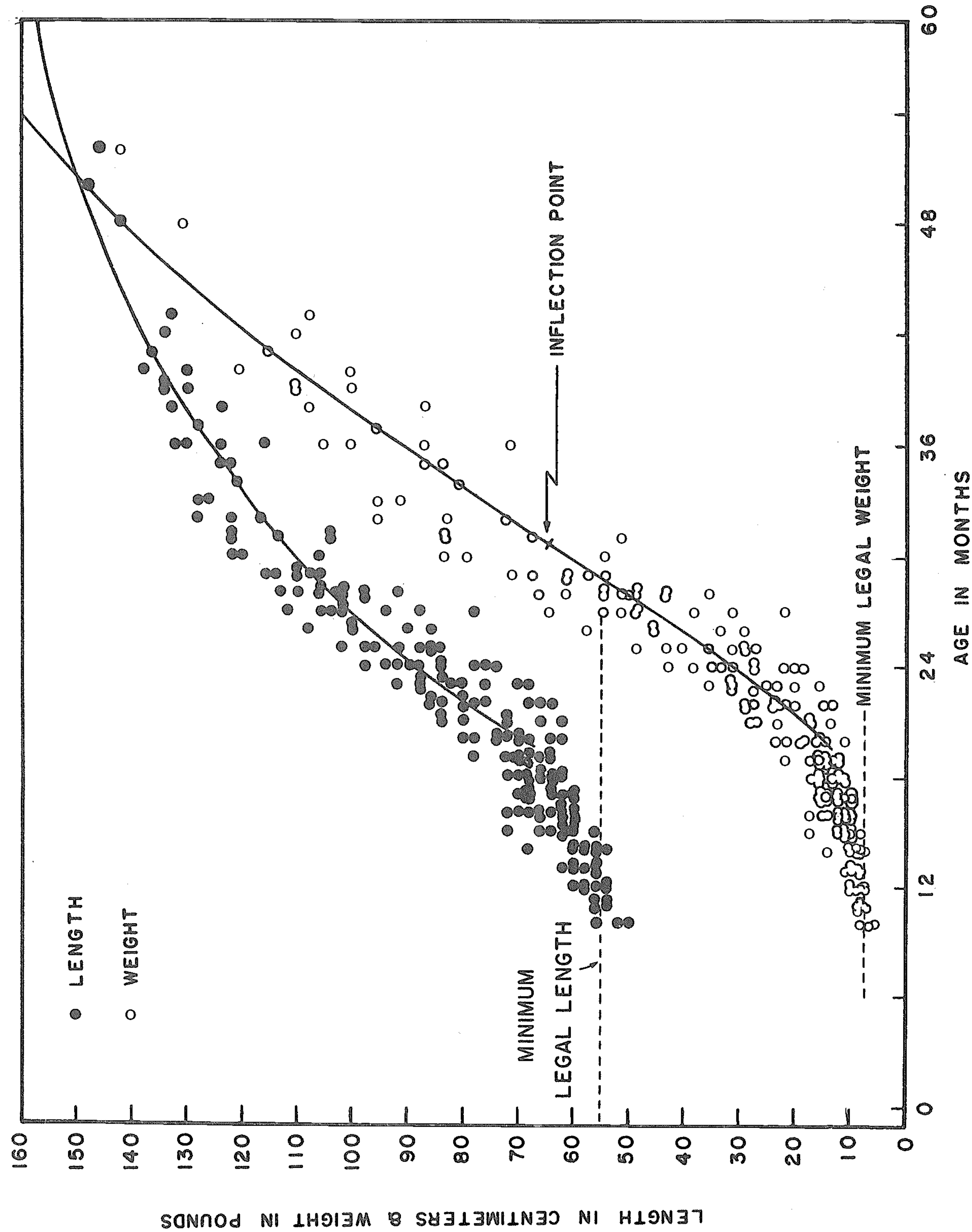

Fig. 3 Modal lengths (closed circles) and corresponding weights (open circles) of age groups of year classes 1953 through 1957 for yellowfin tuna for all northern areas of the fishery in the eastern Pacific Ocean.

140°E longitude and 120°W longitude, the larger sizes becoming progressively more abundant relative to smaller sizes as one goes from west to east (Nankai Regional Fisheries Research Laboratory 1959; Moore 1951; Yabuta and Yukinawa 1957a, b, c; Murphy and Shomura 1955; Shomura and Murphy 1955).

Kamimura and Honma (1961) attribute the latitudinal gradient of size composition of longline catches to migration. However, in view of the morphometric differences of the fish at the same size at different latitudes along the Equator (Royce 1961), this seems an unlikely explanation.

4.2 Size and density

Relative density (abundance) of yellowfin tuna in the eastern Pacific Ocean is estimated by the average catch-per-day's fishing of commercial vessels, standardized to a standard size class (Shimada and Schaefer 1956; Schaefer 1957). The density thus measured is related inversely on the average, to the amount of fishing effort, indicating that the abundance of fish of commercial sizes is reduced as fishing effort increases.

From a mathematical analysis of catch and effort data over the period 1934 to 1955, Schaefer (1957) estimated the relationship between fishing effort and abundance. At 25,000 standard units of fishing effort he estimated the fishing mortality coefficient to be 0.95, but indicated it might well be as low as 0.69 or as high as 1.20. One may apply the fishing mortality coefficient to the equilibrium catch at the given level of fishing effort to estimate the fishable stock in absolute terms.

Relative density of the stock of fish available to longlines in different areas and seasons has been estimated by the catch in numbers of fish caught per hundred hooks per fishing day by the various Japanese authors already cited. There is, at present, no means of relating these data to absolute stock size.

4.2.1 Average size

See section 4.1.3

4.2.3 Average density

See section 4.5

4.2.4 Changes in density

See section 4.5

4.4 Mortality

4.4.1 Rates of mortality

Hennemuth (1961b) from analysis of catch-curves of yellowfin tuna from the surface fishery in the eastern Pacific has estimated the total mortality coefficient of the level of fishing effort obtaining in 1954 to 1959 to be 1.72 with 95 per cent confidence limits 1.60 to 1.85. At a similar level of fishing effort Schaefer (1957) estimated the fishing mortality coefficient to be 0.95, as noted above. Hennemuth has estimated the natural mortality coefficient to be between 0.64 and 0.90, with 0.77 the most probable value.

4.4.2 Factors or conditions affecting mortality

The only factor affecting the rate of mortality of fish of commercial sizes that has so far been identified and estimated is the commercial fishery.

4.5 Dynamics of population

Morphometric studies, tagging studies, serological studies, and examination of commercial catch statistics indicate that the yellowfin tuna of the Pacific (and of the Indian Ocean) are composed of a number of separate populations or population groups. Historical series of data on catch-per-unit-of-effort indicate that for some, at least, of these populations the amount of fishing is sufficiently large to measurably affect the abundance of the catchable stock. In most regions, however, there are useful data only on catch-per-unit-of-effort; information on total catch of total effort is not available. Consequently, it is not possible to make any quantitative assessment of the relationships among fishing effort, stock abundance, and sustainable harvest in such regions.

Adequate catch-statistical data for study of population dynamics of yellowfin tuna exist only for those stocks supporting the commercial fishery in the eastern Pacific off the coast of the Americas. In this region there have been compiled quite complete statistics of effort and catch from 1934 to date. These data have been analyzed by Schaefer (1957) and his colleagues on the staff

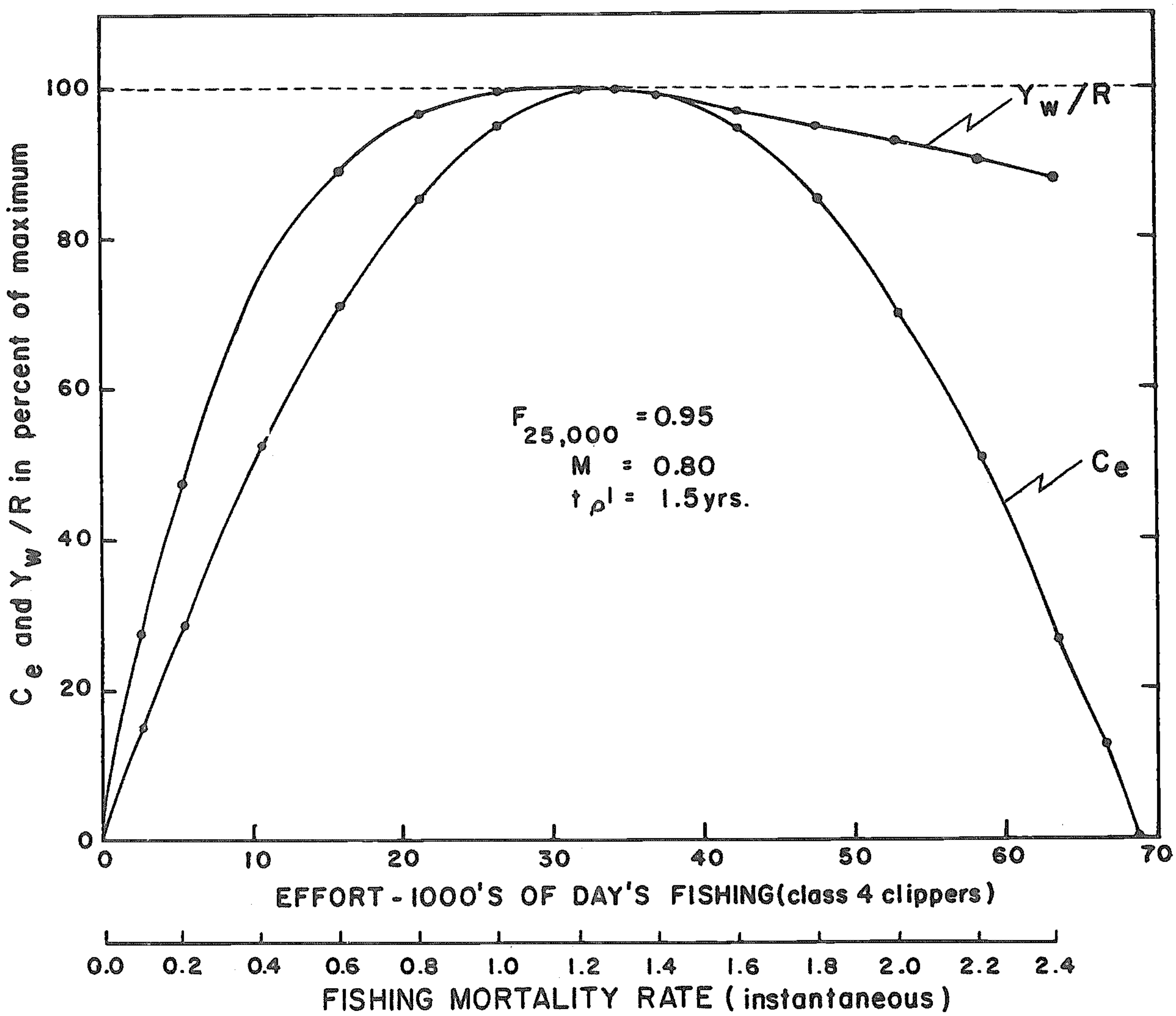

Fig. 4 Yield and yield-per-recruit curves for yellowfin tuna for $F_{25,000}$ = 0.95 and M = 0.80

of the Inter-American Tropical Tuna Commission, and these analyses are kept continuously up to date (Schaefer 1961a). The analysis of these data, assuming a density-dependent model of population replacement, conforming to the Verhulst-Pearl logistic, indicates that the maximum average sustainable harvest from the eastern Pacific, with an initial age of recruitment of about 1.5 years, is in the neighborhood of 97,000 tons and is to be attained with about 35,000 standard units of fishing effort per year.

Hennemuth (1961b) and Schaefer (1961a) have also published catch-per-recruit diagrams for the yellowfin tuna of the eastern Pacific. They employed growth rates estimated from size-frequency studies, for several different values of coefficient of natural mortality which almost certainly encompass the true value, using the simple Beverton-Holt (1957) model. From these it appears that the maximum yield-per-recruit, with an entering age of 1.5 years, occurs at a level of fishing effort near to that for which maximum sustainable total catch is estimated to occur by the Schaefer (1957) model. Above the level of fishing effort corresponding to maximum sustainable total catch, and maximum catch-per-recruit, the catch-per-recruit (calculated from the Beverton-Holt model) falls off much more slowly than the total catch (calculated from the Schaefer model); see Fig. 4 reproduced from Schaefer (1961a, Fig. 6.) The difference is, of course, due to the implicit assumption of density-dependence of recruitment in the Schaefer model. In the event that recruitment is density-independent, that is that recruitment which cannot now be determined, on the average, is constant at all levels of population density, the total catch curve will correspond to the catch-per-recruit curve. In either event, the sustainable total catch is expected to decrease at fishing effort above some 35,000 standard units of effort, the only question being whether it decreases rapidly or slowly.

If it is assumed that the Schaefer model correctly estimates the relationships among fishing effort, population density and yield, and that the Beverton-Holt model correctly estimates the relationships among fishing effort, population density, and yield-per-recruit, there is implied a relationship between population density and recruitment, which may be calculated from the numerical data. This has been done in yet unpublished research of the IATTC, and it has been found that the resulting relationship bears a close similarity to the theoretical stock recruitment relationship of Ricker (1958).

Yield-isopleth diagrams calculated for the Beverton-Holt simple model, published by Schaefer (1961a) and by Hennemuth (1961b) for the yellowfin tuna of the eastern Pacific, indicate that a significant increase in yield-per-recruit might be obtained by increasing the age of entry into the catchable population from its present value of 1.5 years to about 2.0 years, or somewhat higher.

It is most regrettable that in other regions of the Pacific, and other oceans, the nations engaged in the tuna fishery do not compile and make available to the scientific community the catch-statistical data required for similar research on the dynamics of yellowfin tuna populations.

4.6 Relation of population to community and ecosystem

The yellowfin tuna are a part of the pelagic, high-seas, tropical community. They prey on a large variety of cephalopods, fishes and crustacea. They are, at smaller sizes, often found in mixed association with skipjack (*Katsuwonus pelamis*) and at somewhat larger sizes in association with several species of porpoises, with which there is, presumably, some food competition. Deep-swimming yellowfin tuna are often captured in association with bigeye tuna, *Thunnus (Parathunnus) sibi*.

As noted in sections 2.1 and 2.3, the yellowfin tuna are encountered in greatest abundance, within the tolerable temperature range, in regions of highest general biological productivity, where they find the most to eat.

5 EXPLOITATION

5.1 Fishing equipment

5.1.1 Fishing gear

Yellowfin tuna are captured by a variety of methods, the more important being purse seine, live-bait and longline. The first two methods are used mainly by the U.S. fishermen, while the latter is the most commonly applied by Japanese vessels.

In the eastern Pacific fishery for yellowfin tuna the use of live-bait was the most popular method (75 per cent of the catch was made by this means) prior to 1959. During the period 1957-61 most of the large live-bait vessels converted to purse-seine fishing and by 1961 the predominate portion of the catch of yellowfin tuna in the eastern Pacific Ocean was made by this gear.

McNeeley (1961) reports in detail the construction of a purse-seine net and the gear used to operate the net. Basically, the purse seine consists of a wall of webbing with floats on top, chain weights and steel wire purse-line on the bottom. The seine is placed around a school of tuna, the bottom of the net is closed (pursed) and the circumference of the net is decreased by retrieving one end of the net. The fish, forced into a compact group close to the surface, are then brailed on the vessel into refrigerated holds. The nets now used are made of synthetic materials, 385-550 fathoms in length and 35-55 fathoms in depth. About 85,000 tons of yellowfin caught by purse seines were delivered to U.S. ports during 1960.

The live-bait gear, as described by Godsil (1938), is still being used in the eastern Pacific and this method of fishing has changed very little in the course of the years. It requires the fishermen to capture live-bait before proceeding to the tuna fishing grounds. After a school of tuna is located, the live-bait is used as chum to attract the fish to the boat. While the tuna are avidly feeding on the bait, they are being caught with feathered jigs or baited hooks attached by short lines to bamboo poles. During 1960 about 25,000 tons of yellowfin caught by this method were delivered to U.S. ports.

A good description of longline gear is given by Mann (1955). The gear consists of a main line, float line, float assembly, bamboo pole assembly, droppers and hooks, canvas skid, and longline hauler. Several hundred baskets of gear are laid end to end to make a long line of baited hooks suspended by floats. Due to lack of published data, it is not possible to determine the exact tonnage of yellowfin tuna captured from the Pacific Ocean by this method, but it is the dominant gear in the Japanese high-seas fishery in the Pacific area of concern here (Nankai Regional Fisheries Research Laboratory, 1959).

In the western Pacific, yellowfin are caught incidentally by gear designed for other fisheries. The descriptions given below are taken from Okahara (1960) and the tonnage figures from Kitahara (1960). These types of gear are used in the Japanese fisheries.

The Japanese pole-and-line fishery for skipjack in the western Pacific captured 4,540 tons of yellowfin during 1959. In this fishery the gear and methods employed are similar to those used in the live-bait fishery in the eastern Pacific. However, there are many differences and the reader is referred to Cleaver and Shimada (1950) for details of the Japanese skipjack fishery and to Godsil (1938) for similar data for the American west coast fishery for yellowfin and skipjack.

The two-boat purse seine is operated from two vessels, each carrying one half of the net. Each boat makes half a circle while laying out the net; the bottom is then closed by pulling the purse-lines, thus trapping the school of fish within the bag of webbing. These nets range from 45 to 90 fathoms in length and seven to 17 fathoms in depth. Vessels using this gear and fishing in both coastal and offshore waters caught 4,317 short tons of yellowfin tuna in 1959.

The one-boat surrounding net is constructed much like the two-boat purse seine. However, it is carried on one vessel and is set around a school using a small skiff to hold the bow end of the net. Although made of lighter synthetics, the net is much like the purse-seine nets used in the eastern Pacific. Vessels using this type of gear, in both coastal and offshore waters, caught 128 short tons of yellowfin in 1959.

During 1959, 433 short tons of yellowfin were caught by means of set nets, which are used in the fishery in coastal waters off Japan. Basically, these traps consist of a guide fence, one or two main nets of various types and many anchors.

When fish enter the main net, the opening is closed and the net lifted to remove the trapped fish.

A small amount of tuna is caught in gill nets used in the surface fishery. These nets are of two types, one is anchored and the other is a drift gill net. The net is about 15 fathoms long and three fathoms deep and often several nets are connected and used as one. The tunas are caught (gilled) in the meshes or get entangled in the net.

5.1.2 Fishing boats

Nearly all of the catch of yellowfin tuna taken from the eastern Pacific is made by the long-range fleets of purse-seine and bait vessels. The predominant portion of the fleet consisted of the latter. However, since 1957 many (90 at the time of writing) have been converted to purse-seiners. Construction details of the tuna clipper are given by Traung (1955) in FAO's "Fishing Boats of the World" and details of the conversion of these vessels to purse-seiners are given by McNeely (1961).

The typical tuna clipper is constructed of wood or steel, is about 115 feet in length and is about 330 gross tons. The main diesel engine, diesel auxiliaries, and electrical equipment are forward. Brine wells for frozen fish and live-bait are located on both port and starboard, aft of the engine room, close to the stern, and are separated by a shaft alley. The main deck forward contains the engine room work space, refrigeration machines and food storage; the galley is amidship and the brine well openings are from amidship to almost the stern. Two or three tanks for live-bait or frozen fish storage space are located on the stern main deck. The raised deck houses the crew's quarters and unloading hatches. The bridge deck has a radio room, chart room and pilot house. Fishing operations are conducted by fishermen standing in lowered racks, placed on the portside and stern railing.

A clipper converted for the use of purse-seine gear has had removed, or modified, the stern live-bait boxes, the upper deck aft of the crew's quarters, and the fishing racks. Other modifications include the addition of a purse-seine winch, power block, net turntable or platform, tuna net and a heavier mast, boom and rigging.

Prior to 1958, the tuna purse-seine fleet consisted largely of vessels originally designed to fish sardines. These vessels were later converted to enable them to fish for tropical tunas. Typically, they are constructed of wood, have a diesel engine of about 400 hp., are about 80 feet in length and have a breadth of 25 feet. The engine room is forward and contains most of the refrigeration and electrical equipment. The fish hold, refrigerated by a "brine-spray" system, is aft of the engine room and has a capacity of about 110 tons of frozen tuna. The main deck has the crew's quarters forward, galley amidship, deck work space astern of the galley, and net turntable on the stern. The bridge deck, containing the radio and chart room and pilot house, is located above the crew's quarters. The FAO "Fishing Boats of the World"(1955) gives a good description of a vessel similar to a wooden purse-seiner. Purse-seine gear and vessels were described by Scofield (1951).

One other type of small seine vessel is predominant in the Peruvian fishery. These vessels are diesel powered, 45-60 feet in length, built of wood (some of steel), using nylon nets, power block, and power winches, and are without refrigeration. These are designed as "day boats" and have no living quarters (Anonymous 1957).

Tuna longline vessels operating from Japan may be classed as either medium or large types. The large type is built of steel, ranges in size from 200 to 1,300 gross tons, and has refrigerated holds for frozen-fish storage. The larger vessels are especially constructed for this fishery. They are long-poop vessels with diesel engines aft and freezing space below the wheel house and main deck. The longline gear is carried on the poop deck, laid from the stern, and retrieved with the line haulers on the large open deck forward.

Medium longline vessels are generally of wood construction with gross tonnages of 70 to 200 tons. They have diesel engines aft, the fish holds, mostly refrigerated, are forward. The crew's quarters are in the deck house and under the aft deck.

Japanese pole-and-line vessels are constructed of wood or steel and range in size from 20 to 300 gross tons. They have diesel engines aft with fish holds, often refrigerated, amidship. Live-bait tanks are placed near the center line.

The larger vessels have a fishing platform on the port side from the bow continuous to the stern, while fishermen on the smaller vessels fish from the boat deck and are often stationed all around the vessel's side rails.

Two-boat seiners are wooden craft of 20-50 gross tons. They have a fish hold forward, engine room amidship and the crew's quarters in the aft section. The deck house is amidship and the net space is on the aft deck. Power is furnished by a diesel engine. One-boat seiners are designed much the same as two-boat seiners, but somewhat larger, 60-85 gross tons.

The set-net tenders vary greatly in design but generally are small, of wide beam, shallow draft, and little shear, and are made of wood. They are characterized by heavy, durable construction. They do not have engines and are towed to and from the fishing area.

5.2 Fishing areas

5.2.1 General geographical distribution
5.2.2 and geographical ranges

The distribution of yellowfin catches with commercial gear is shown in Fig. 1. This is a compilation of data published by the Nankai Regional Fisheries Research Laboratory (1959), Alverson (1959 and 1960), Griffiths (1960), the monthly publications of Tuna Fishing Magazine (1959-61), and some records of the U.S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii. The surface isotherms are drawn from H.O. No. 225, World Atlas of Sea Surface Temperatures. Each one-degree rectangle in which catches by commercial fishing gear is recorded contains a solid spot. Five-degree rectangles in which catches are known to have been made but where the particular one-degree rectangles of catch is not known to us, are shaded.

Fig. 1 shows that the major fishing region of the eastern Pacific is a moderately narrow band off the coasts of Northern, Central and South America. The fishing conducted primarily by Japanese longline craft catches yellowfin from a broad band, more or less centered on the equator, generally bounded by the 70°F surface isotherm on the north and the 75°F surface isotherm on the south.

5.2.3 Depth ranges

The purse seines have a maximum fishing depth of about 270 feet; however, few of the nets will reach this depth under normal fishing operations. Fish caught by live-bait are taken near the surface. However, schools of such fish may be chummed up from deeper water.

The longline method captures yellowfin in deeper water than live-bait or seining. Murphy and Shomura (1955) report on longline sets, which had line depths up to 372 feet, on which yellowfin were captured; they did not, however, report on the maximum depth at which yellowfin were caught during these sets.

In general, from commercial fishing data, it appears that most, if not all, of the yellowfin population is confined to the upper mixed layer.

5.3 Fishing seasons

5.3.1 General pattern of fishing seasons

The major seasonal variation in the fishery for yellowfin tuna is observed near the northern and southern limits of the range where, in response to the advance and retreat of the surface isotherms, the fishery moves poleward during the warm months and equatorward during the cold months (see also 2.1 and 2.2).

Within the region where temperatures are tolerable at all months of the year, there are more or less regular seasonal variations in abundance on different fishing grounds. These are too complex to describe in detail here, and are related both to oceanographic variations and to the migratory cycle of the tunas. For further details, the reader is referred to the various publications of the Nankai Regional Fisheries Research Laboratory, the Inter-American Tropical Tuna Commission, and the U.S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii.

5.3.2 Duration of fishing season

Yellowfin are caught during the entire year in the Pacific Ocean; however, in some parts of the ocean the catches are very seasonal. Alverson (1959) demonstrated that yellowfin are caught in waters off Central America (5-15°N latitude, 80-95°W longitude) during the entire year; however, substantial tonnages of yellowfin are caught in oceanic waters north of 23°N latitude only during the third and fourth quarters.

The Nankai Regional Fisheries Research Laboratory (1959) reports year-round longline catches of yellowfin from the central and western Pacific, but with definite seasonal variations in areas and quantities of catch. One example is the duration of the southern longline fishery bounded by 20-30°S latitude and 150-160°E longitude. Catch rates from this area are very small from February through June. The most productive fishing months are from August to January. The Hawaiian longline fishery also captures yellowfin during the entire year, but the fishery is most successful during May to September (Otsu 1954).

5.3.3 Dates of beginning, peak and end of season

Historically there never have been legal opening or closing dates for yellowfin fishing. Each country participating in the yellowfin fishery allows its vessels to fish during the entire year. Peak catches of yellowfin by vessels having limited cruising duration (such as the Hawaiian longline vessels and small vessels operating from American ports) are related to seasonal local abundance of yellowfin. Vessels which have extended cruising ranges, such as the Japanese longline vessels and the American distant-water tuna vessels, operate seasonally in those areas where the best catches can be expected and are, thus, not limited by seasonal variation of catch in any specific area.

5.3.4 Variation in time of duration of fishing season

Murphy and Otsu (1954) analyzed the catch statistics of nine Japanese tuna longline expeditions to the western Pacific. They found a relatively constant catch rate within the longitudes and time compared, but did find considerable catch rate variations with latitude when compared with time changes.

Alverson (1959 and 1960) discussed the seasonal variations of yellowfin tuna catches from the eastern Pacific. He pointed out the extreme variation of catches in the northern and southern parts of the region, and the more nearly constant catch rate in the central parts of the eastern Pacific.

5.3.5 Factors affecting fishing seasons

Seasonal, short-term, and year-to year variations in the temperatures of the upper mixed layer apparently cause much of the variation in success of fishing. Tester (1956) demonstrated the variability of yellowfin catches, per 100 hooks of longline gear, related to water temperature changes. He reported that the lowest catches were recorded at lower temperatures. Alverson (1959) described the seasonal changes of fishing areas in the eastern Pacific, and pointed out that the lowest catches from some major fishing areas are generally during the months of lower water temperature.

Major shifts in fishing areas, other than seasonal changes, are often caused by large-scale oceanographic phenomena which cause abnormal warming of regions usually outside the yellowfin range, and thus cause major changes in the availability of this species to the fishery (Schaefer 1961b; Bjerknes 1961).

Weather changes also cause major seasonal fishing changes. If an area is noted for having severe storms during certain seasons of the year, vessels tend to remain away from it. An example is the area near the Revillagigedo Islands during the third quarter. This area is noted for "chubascos" (hurricanes) during that time of the year, and fishing effort is greatly reduced. The stormy waters of the Gulf of Tehuantepec during the winter months also handicap fishing and reduce the catches that might otherwise be made.

As noted under 5.3.1, there are also other factors, too complex to attempt to summarize here, many of which are poorly understood, related both to seasonal oceanographic variations and the migratory cycle of the tunas.

5.4 <u>Fishing operations and results</u>

5.4.1 Effort and intensity

Detailed records of fishing effort are available only for the surface fishery in the eastern tropical Pacific. Data on changes in total fishing effort in other parts of the ocean are not available, although it is believed that there has been a general increase during the past decade, at least in many parts of the Pacific.

The amount of effort applied to the yellowfin tuna in the Pacific Ocean by the far-ranging longline vessels is not published. Catch-per-unit-of-effort statistics are published by the Nankai Regional Fisheries Research Laboratory (1959) and elsewhere, but the amount of effort, or total catch by regions, is not.

See also 4.2 and 4.5.

5.4.2 Selectivity

See 4.1.

5.4.3 Catches

Statistics of total catch of yellowfin tuna from the eastern Pacific are collected and published annually by the Inter-American Tropical Tuna Commission (e.g. Schaefer 1961a). Hawaiian landings are published by the State of Hawaii and by the U.S. Bureau of Commercial Fisheries. Landings in Samoa are published by FAO and also in the Japanese Annual Report of Catch Statistics on Fishery and Aquiculture (e.g. Kitahara 1960). The last cited publication also shows, separately identified: (1) landings of vessels based at foreign ports (Samoa and Espiritu Santo in the Pacific Ocean in 1959); and (2) catches by Japanese factory ships (Pacific Ocean). Unfortunately, the landings by vessels other than factory ships at Japanese ports are shown under "Domestic Marine Fisheries" wherein the category "tuna longline" apparently includes catches of vessels landing fares from both the Indian Ocean and the Pacific Ocean (and perhaps a few catches from the Atlantic Ocean as well). Since this category amounts to (for 1959) 67,247 metric tons from a total of 76,886 metric tons of catches of "Domestic Marine Fisheries", it is not possible to arrive at any exact total for the yellowfin harvest from the Pacific Ocean.

A recapitulation of data available to us for 1959 follows:

Area	Quantity in short tons
Captured in the eastern Pacific	72,400
Captured near and landed at Hawaii	284
Landed at Samoa	1,984
Landed at Espiritu Santo	654
Japanese factory ships (Pacific)	3,219
Japanese "domestic marine fisheries" other than longline	10,603
Identified landings from Pacific Ocean	89,144
Japanese "domestic" landings by tuna longline (from Pacific in unknown parts)	73,972
Grand total, Pacific, not more than:	163,116

There are, of course, in addition some local fisheries for local consumption throughout Oceania, in the Philippine Islands, and elsewhere but their production is, we believe, small.

The best we can say for the year 1959, which is the most recent year for which published data are available for the major components of the catch, is that the total production of yellowfin tuna from the Pacific Ocean was at least 89, 100 short tons and not more than 163, 100 short tons. It is regrettable that a more precise figure cannot be given.

5.5 Fisheries management and regulations

Management of sea fisheries, in general, usually has two kinds of objectives: (1) regulations designed for purely economic purposes and (2) regulations designed for "conservation", that is the maintaining of a fish population at a desirable level to provide for sustainable future harvests of desirable magnitude (and sometimes composition). This desirable level is most often defined as the "maximum sustainable average yield".

Regulations now in effect in the tuna fisheries have primarily economic objectives. The Japanese Government controls tuna fishing by a licensing system, apparently employed to achieve a desirable economic balance among different components of the industry and not concerned primarily with conservation objectives.

Likewise, the State of California has had for many years a prohibition on the landing of yellowfin tuna below 7.5 lb. This was, it seems established to avoid the handling of uneconomically small fish in the canneries, although it does have the effect of slightly increasing the yield-per-recruit above what would probably otherwise be obtained (see 4.5).

Regulation of the yellowfin tuna fishery, for conservation purposes, in the eastern Pacific Ocean has recently been recommended to the High Contracting Parties to the Convention under which it operates by the Inter-American Tropical Tuna Commission. This Commission is directed and authorized to conduct scientific investigations to determine the effects of natural factors and of the fishery on the abundance and yield of the populations of yellowfin tuna (and other species) supporting the fisheries in the eastern Pacfic Ocean pursued by fishermen of its members, and to recommend, as needed, joint action to maintain such populations in a condition capable of yielding maximum sustainable catches year after year. The scientific staff of the Commission has, during the past 11 years, conducted extensive research pursuant to these objectives. Results of these investigations are outlined in other sections of this synopsis, and are published in detail in the publications of the Commission. The research demonstrated clearly that the amount of fishing effort applied to the yellowfin tuna in the eastern Pacific has been sufficient to have measurable effect on the abundance of this tuna species, but that through 1960, it had not exceeded the level corresponding to maximum average sustainable yield. During 1961, the fishing effort reached a level higher than this critical value, and the yellowfin of concern to the Commission are now being "overfished". The Commission has, therefore, recommended to the High Contracting Parties joint action to limit the fishery by means of annual catch quotas, in order to restore and to maintain the yellowfin stocks in a condition which will provide continuing sustainable maximum harvests.

5.6 Fish farming and transplanting

None in existence and none contemplated.