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DRAFT FOR COMMENT

STATUS OF KNOWLEDGE ON THE BIOLOGY AND RESOURCES OF THE FRIGATE MACKEREL, GENUS *AUXIS*

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STATUS OF KNOWLEDGE ON THE BIOLOGY AND RESOURCES OF THE FRIGATE MACKEREL, GENUS *AUXIS*

I. INTRODUCTION

Unlike a number of tuna species in the world's oceans which are heavily exploited and possibly are being harvested near the upper limit of rational utilization, frigate mackerel, the most primitive member of the family Scombridae, give every indication of being an underutilized fishery resource. Further development and eventual management of this resource, however, should be given every encouragement. In planning for the rational utilization of this resource, it is imperative to have on hand information concerning the biology of the species and estimates of present and potential catches. The purposes of this status report, therefore, are (1) to update our current knowledge of the species by bringing together and extracting all the available information on the biology and fisheries for frigate mackerel and (2) to review and evaluate in depth the results of past research, indicating in particular where conflicting evidence exists.

II. IDENTITY

A. TAXONOMIC CLASSIFICATION - *AUXIS THAZARD* AND *A. ROCHEI*

Phylum Vertebrata

Subphylum Craniata

Superclass Gnathostomata

Series Pisces

Class Teleostomi

Subclass Actinopterygii

Order Perciformes

Suborder Scombroidei

Family Scombridae

Genus *Auxis* Cuvier 1829

Species *Auxis* thazard (Lacépède) 1802

Auxis rochei (Risso) 1810

Genus *Auxis*

"Body robust, fusiform, almost cylindrical in cross section, only slightly compressed. Head large, tapering rapidly to a pointed snout. Mouth moderate, oblique, end of maxillary not covered by preorbital. Teeth small, pointed, present on jaws. Occasionally few teeth on vomer. Gill rakers, close set, long, and slender. Lateral line without a distinct arch, slightly curved and with small undulations. Caudal peduncle with small lateral keels. Body scaled anteriorly, forming a corselet. Corselet with a posterior prolongation of scales along lateral line. Fins small, first dorsal fin roughly triangular in shape and not continuous or closely adjoining second dorsal. Second dorsal and anal each followed by 8 and 7 finlets." (Wade 1949.)

The most primitive among the higher tunas to have developed a prootic pit and a partial subcutaneous circulatory system, Auxis differs from Euthynnus and Thunnus, two more advanced genera, by lacking the prominent fronto-parietal foramina which is present in the crania of those groups (Collette and Gibbs 1963a). It resembles Euthynnus in that both have a naked body behind the well-developed corselet.

Members of the genus Auxis are the smallest of the tunas and can be distinguished at all sizes from all the other scombrids except Scomber, Pneumatophorus, and Rastrelliger (Collette and Gibbs 1963a; Fitch and Roedel 1963; Williams 1963). Auxis have widely separated dorsal fins with the interspace almost equal to the length of the head, and also have axillary scales between the pelvic fins, which are about as long as the pelvic fins. In the rest of the tunas, they are about half the length of the pelvic fins. Having eight dorsal and seven anal finlets, Auxis can be told from Scomber and Pneumatophorus which have only five of each. Auxis has a scaly corselet anteriorly and is naked posteriorly whereas Rastrelliger has a body entirely covered with scales and lacks a corselet.

Species Auxis thazard and A. rochei

In a paper presented at the World Scientific Meeting on the Biology of Tunas and Related Species, Fitch and Roedel (1963) wrote "Whether the frigate mackerels, genus Auxis, properly should be referred to a single cosmopolitan species or to several species with more limited distributions has remained an open question for

many years. Most of this confusion has stemmed from the general similarity of these fish in different areas of the world and from a lack of sufficient material upon which to base an opinion. Under the circumstances, it has been common practice to regard Auxis thazard (Lacépède 1802) as cosmopolitan and to place in synonymy with it the several species described." Figure 1 shows a photograph of A. thazard.

Fig. 1

It would be appropriate to quote a statement made by Roedel and Fitch[2] in a paper presented for discussion at the Pacific Tuna Biology Conference in Honolulu, Hawaii, in August 1961. About the genus Auxis, they stated (p. 12) "We mention these fishes only because they fit in the group as we have defined it. For some years we have been working on genus Auxis as an off-time avocation. Any comment, other than to mention that this genus is as muddled as any we have discussed, would be premature."

Works of other investigators are summarized here to illustrate the confusion that surrounded the genus Auxis.

Kishinouye (1915) stated that there are two species of Auxis in Japanese waters and they can be distinguished by differences in the number of scales on the lateral line and in the breadth of the body. The species he named A. hira had a short corselet which ended slightly posterior to the pectoral fin whereas in the species he named A. maru, the corselet was long and extended to the anal fin. Kishinouye stated that A. maru is probably the same species as A. thazard, but it is not known whether A. thazard corresponds to A. hira

or A. maru. Kishinouye believed that Bleeker's A. tapeinosoma may be A. maru but the figure and description of this species were unclear so that a positive identification could not be made. This compelled Kishinouye to assign these fishes the new specific names of hira and maru.

Fraser-Brunner (1950) recognized only a single worldwide species, A. thazard (Lacépède), but others such as Wade (1949), Jones (1958), and Cadenat (1950) have followed Kishinouye in recognizing at least two species of Auxis. Wade (1949) described a long-corseletted Pacific form, A. tapeinosoma Bleeker, but Matsumoto (1959, 1960), finding the nomenclature of the long-corseletted form quite confused, resurrected the name A. thynnoides, stating that the long-corseletted A. tapeinosoma of Wade (1949) and Herre and Herald (1951) appears to be a misnomer because it is actually a short-corseletted form. Furthermore, Matsumoto regarded A. hira and A. maru of Kishinouye and A. tapeinosoma of Bleeker as synonyms of the short-corseletted, worldwide A. thazard.

Matsumoto (1959) also argued that the number of gill rakers, by itself, may not be a reliable character in identifying the two types of Auxis. Wade (1949) and Herre and Herald (1951) pointed out that A. thazard in the western Pacific normally has fewer gill rakers than A. thynnoides. Of A. thazard taken in the eastern Pacific, Mead (1951) also mentioned a lower gill-raker count. To add to the confusion, Godsil (1954) reported that all the A. thazard he examined, which were taken off Baja California and the Galapagos Islands, had

high gill raker counts similar to those reported by Wade (1948) and Herre and Herald (1951) for A. thynnoides. Tortonese (1965) also observed that the Mediterranean forms of A. thazard have character not entirely identical with those of the Indo-Pacific form and suggested that geographical variation may be involved. Tables 1 and 2 give the counts of the various anatomical features of the two forms of Auxis.

Tables 1 and 2

The confusion whether one or two valid species exist stems in part from the overlap in the width of the corselet. Klawe (1963) indicated that in the eastern Pacific, there are intermediate forms of the two types of corselets. From the Indian Ocean, a few large adults of A. thazard from the southwest coast of India were recognized as having a corselet that narrowed gradually somewhat as in A. thynnoides instead of one which tapered abruptly (Jones 1963). This intermediate condition is shown in Figure 2.

Fig. 2

The overlap occurs not only in the width of the corselet but also in the number of gill rakers in the two forms of Auxis. Jones (1963) believes, however, that the overlap is not serious; the gill raker counts are definitely on the lower side in A. thazard. Therefore, in cases of doubtful identification from external characters, a combination of corselet width and gill raker counts should facilitate specific identity (Jones and Silas 1964). The range and mean gill raker counts for specimens of A. thazard and A. thynnoides from Indian waters are given in Table 3.

Table 3

Fitch and Roedel (1963) examined numerous adult Auxis and attempted to unravel the confusion involving this genus. Their analyses of measurements failed to show any significant differences among A. thazard from the western, central, and eastern Pacific (Table 4). But based on gill raker counts (Table 5), they concluded that the eastern Pacific population seems to be separable from those in the central and western Pacific.

Tables 4 and 5

For A. rochei, Fitch and Roedel (1963) found apparent differences in the body measurements computed as percentages of standard length (Table 6) among areas. Also, there appeared to be differences in the average number of scale rows in the corselet. Whereas Matsumoto (1960) had revealed that the number of scale rows in the corselet increased with fish length, Fitch and Roedel added that there was also an increase in the average number of scale rows for similar-sized fish from west to east. A. rochei in the western Atlantic had the fewest scale rows whereas those in the eastern Pacific had the most (Table 7).

Table 6

Table 7

Based on their findings, Fitch and Roedel (1963) tentatively recognized two worldwide species, A. thazard and A. rochei (Figure 3). The three most obvious characters that differentiate A. thazard from A. rochei in the field are a pattern of 15 or more oblique to nearly horizontal dark wavy lines in the bare area on each side of the back, a corselet of scales running along the lateral line and is at most three rows wide where it passes beneath the second dorsal fin, and pectoral fins that extend beyond a vertical from the anterior margin

Fig. 3

of the patterned bare area on the back. A. rochei, in contrast, has a pattern on the bare area consisting of 15 or more broad, nearly vertical dark bars, a corselet with more than six rows of scale where it passes beneath the second dorsal, and pectoral fins that fail to reach a vertical beneath the anterior end of the dorsal bare area

Fig. 4 (Figure 4).

As a further aid to identification, Jones and Silas (1964) have used the shapes of cross-sections of the body, but Collette and Gibbs (1963b) have warned that this character is difficult to utilize by untrained observers. Nevertheless, A. thynnoides, according to Jones and Silas, is more rounded and robust whereas A. thazard is

Fig. 5 more compressed from side to side (Figure 5). Cross-sections also showed that the shape of the abdominal cavity is entirely different between the two species. And in A. thynnoides, the number of myotomes cut was slightly more than for A. thazard.

Jones and Silas (1964) also found differences in the position

Fig. 6 of the visceral organs (Figure 6). In a ventral view of A. thazard, the right lobe of the liver takes a complete loop crossing over the midventral longitudinal axis, whereas in A. thynnoides the right lobe does not show such a curve and even the hepatic vein does not fall in line with the midventral longitudinal axis. Furthermore, the stomach of A. thazard extends to slightly behind the anal opening as does the right lobe of the liver. But in A. thynnoides the stomach is shorter with the distal end hardly reaching the vent and although the right lobe of the liver may extend backwards it apparently does

not surpass a line drawn from the origin of the anal fin. In A. thynnoides, the caecal mass is more developed and occupies a greater space than in A. thazard and the spleen is larger. The left lobe of the liver in A. thazard is relatively longer than in A. thynnoides. And in lateral view, part of the gall bladder can be seen in A. thynnoides but not in A. thazard

Another feature of Auxis that differ between the two species is in the appearance of the temporal crests. Godsil (1954) noted that the temporal crests of the skull of the long-corseletted form (A. maru) are parallel with each other and the supraoccipital crest, whereas in the short-corseletted A. thazard the temporal crests diverge anteriorly so that they are not parallel to one another. Yoshida and Nakamura (1965) also noted these differences in A. thazard and
Fig. 7 A. rochei taken in Hawaiian waters (Figure 7).

Godsil (1954) and Yoshida and Nakamura (1965) also examined the skulls of frigate mackerel and noted that the skulls of A.
Fig. 8 thazard were wider than those of the other species. In Figure 8, Yoshida and Nakamura plotted the width of the cranium against its length and found that in those instances where the skull lengths of the two species overlapped, the skulls of A. thazard were wider than those of A. rochei.

Another striking difference in the axial skeletons of the two species of Auxis, according to Yoshida and Nakamura (1965), was the length of the anterior branch of the haemal processes. These processes were longer and also touching the preceding haemal arches on the 24th to 28th vertebrae in A. thazard. But in A. rochei, the

anterior branches of the haemal processes were shorter, more fragile, and separated from the preceding haemal arches (Figure 9).

Fig. 9

B. SPECIES NOMENCLATURE

1. Scientific Names

The scientific names which are ascribed to A. thazard or some of the other closely related species are given below (de Beaufort and Chapman 1951; Rose 1950).

Scomber thazard	Lacépède 1802
Auxis taso	Cuvier and Valenciennes 1831
Auxis thynnoides	Bleeker 1855
Auxis rochei	Gunther 1860; Steindachner 1868; Mellis 1875; Goode 1880; Jordan and Gilbert 1882; Steindachner and Doderlein 1885; Kitahara 1897; Hoek 1914; Borja 1920; Jenkins 1925; Travis 1925; Jordan, Evermann, and Clark 1930; Irvine 1947
Auxis hira	Kishinouye 1915; Jordan and Hubbs 1925; Soldatov and Lindberg 1930
Auxis maru	Kishinouye 1915; Soldatov and Lindberg 1930
Auxis tapeinosoma	Verhand 1846; Bleeker 1854; Gunther 1860; Wade 1949

From the western Atlantic Ocean, Idyll and de Sylva (1963) listed the following synonyms:

Scomber rochei	Risso 1810
Scomber bisus	Rafinesque 1810
Thynnus rocheanus	Risso 1826
Auxis vulgaris	Cuvier and Valenciennes 1831
Auxis tapeinosoma	Bleeker 1854
Auxis thynnoides	Bleeker 1855
Auxis rochei	Gunther 1860

From the Indian Ocean, Williams (1960, 1963) gave the synonyms of *A. thazard* as follows:

Scomber thazard	Lacépède 1802
Scomber rochei	Risso 1810
Scomber bisus	Rafinesque 1810
Auxis vulgaris	Cuvier 1831
Auxis taso	Cuvier 1831
Auxis tapeinosoma	Bleeker 1854
Auxis thynnoides	Bleeker 1855
Auxis hira	Kishinouye 1915

From the eastern Atlantic, the following synonyms were given by Collignon (1960):

Scomber thazard	Lacépède 1802
Scomber bisus	Rafinesque 1810
Scomber rochei	Risso 1810

Thynnus rocheanus	Risso 1810
Auxis vulgaris	Cuvier and Valenciennes 1831; Lowe 1850
Auxis bisus	Cadenat 1950
Auxis rochei	Gunther 1869; Melliss 1875

For *A. thynnoides* in the Indian Ocean, Williams (1960) and Jones (1963) provided the following list of synonyms:

Auxis thazard	Jordan and Evermann 1896; Partim Herre 1934; Walford 1937; Fowler 1938; Partim Molteno 1948; Partim Fraser-Brunner 1950; Partim Rosa 1950; de Beaufort 1951
Auxis rochei	Partim Gunther 1860
Auxis maru	Kishinouye 1915
Auxis tapeinosoma	Bleeker 1854; Herre and Herald 1951; Herre 1953; Jones 1958; Talbot 1962

2. Common Names

The standard common names and vernacular names of *A. thazard* were abstracted from the lists published in Fiedler (1945), Rosa (1950), Collignon (1960), FAO (1960), Idyll and de Sylva (1963), Uchida (1963), Williams (1963), Instituto del Mar del Peru (1971), and Miyake and Hayasi (1972).

Country	Common and vernacular names
Algeria	Auxide, Scunno, Bisu, Melva, Melvara
Angola	Judeu
Australia	Frigate mackerel, Leadenall

Country	Common and vernacular names
Brazil	Bonito cachorro
British Guiana	Frigate mackerel, Blowgoat
British West Indies	Frigate mackerel, Blowgoat, Round-belly bonito
Canada	Frigate mackerel, Thazard
Denmark	Auxide
East Africa	Frigate mackerel, Sehewa (Kiswahili) also refers to Euthynnus and Katsuwonus sp.
Ecuador	Botellita
France	Auxide, Bonitou, Bounitou, Bounicou, Palamida, Auxide bise, Tazard, Bizet
French Morocco	Melva
French West Africa	Melva
Ghana	Okpopu, Odaabi, Poku-poku
Gold Coast	Frigate mackerel
Greece	Kopáni
Haiti	Maquereau
Hawaiian Islands	Frigate mackerel, Keokeo, Mexican skipjack
India	Frigate mackerel, Churai, Urulan-churai, Kutteli-churai (Tamil)
Israel	Tuna nanasit
Italy	Strumbo, Tambarello, Strombo, Scurmo, Tombarello, Tamburella, Tambarella, Sgionfetta, Tumbarel, Bisu, M'pisu, Pisantuni, Mazzita, Sangulu, Culariau, Sgamiru, Tunnacchiu, Biso

Country	Common and vernacular names
Ivory Coast	Boku-boku, Poku-poku, Bongu
Japan	
Auxis sp.	Sodagatsuwo
A. thazard = *A. hira*	Hirasōda, Hirasōdakatsuo, Hiramejika, Obosogatsuwo, Shibuwa, Soma, Suma, Oboso (Hirasohda, Hiragatsuo, and Hiramedika are variations in spelling of some of the above names)
Korea	Mul-chi-da-rae, Mul-chi, Mu-tae-da-raeng, Mog-man-dung-i
Madeira	Chapouto
Malta Island	Tombrell, Mazzita, Tombitombi, Zgamirru
Mexico	Bonito
Morocco	Melva
Norway	Auxid
Papua New Guinea	Deho
Peru	Melva, Macarela
Philippine Islands	Frigate mackerel, Tunungan, Manko, Mangko (Marinao, Samal, Visaya, and Tao Sug)
Portugal	Gayado, Judea, Serra, Cachorra, Bonito
Sarawak	Tongkol
Seychelles	Bonite folle
Somalia (Mijurtein coast)	Tubani (Somali)
South Africa	Frigate mackerel

Country	Common and vernacular names
Spain	Melva, Visol, Melvara, Bis, Bonito del Norte, Macaela
Spanish Morocco	Melva
Sri Lanka (Ceylon)	Frigate mackerel, Rogodwa (Winhalese), Alagoduwa
Sweden	Auxide
Taiwan	Chien yu
Thailand	Pla O
Turkey	Gobene
Union of South Africa	Frigate mackerel, Boo hoo
Union of Soviet Socialist Republic	Auksida, Makrelevyi tunets
United Kingdom	Plain bonito
United States	Frigate mackerel, Bullet mackerel, Boo hoo
Venezuela	Cabaña negra
Yugoslavia	Trupac, Tunjcic, Rumbac
International Organization	
Food and Agriculture Organization of the United Nations (FAO)	Frigate mackerel, Auxides, Melvas
International Commission for the Conservation of Atlantic Tunas (ICCAT)	Frigate mackerel, Auxide, Melva

Jones (1963), Uchida (1963), and Instituto del Mar del Peru (1971) provided the following common and vernacular names of *A. rochei* = *A. tapeinosoma* = *A. thynnoides* = *A. maru*.

Country	Common and vernacular names
Australia	Long corseletted frigate mackerel, Maru frigate mackerel
Ecuador	Botellita
India	
Malayalam (North)	Kuttichoora (means small tuna and generally applied to *A. thazard* and young of *E. affinis*)
Malayalam (South)	Urulan-choora (means rounded tuna and applied to *A. thazard* also from which this species is not generally distinguished)
Tamil	Eli-choorai (means ratlike tuna), Kutteli-choorai (means small ratlike tuna)
Japan	Marusōda, Marusōdakatsuo, Marugatsuwo, Marumejika, Magatsuwo, Manba, Mandara, Chiboh, Dainanpo, Nodoguro, Rohsoku, Subota, Uzawa, Majika, Soku, Soda, Subo (Marumedika, Marugatsuo, Magatsuo, and Dainanbo are variations in spelling of some of the above names.) Other names mentioned by Rosa (1950) are Kogatsuo, Fukarai, Kobukura
Peru	Melva, Fragata

Country	Common and vernacular names
Union of Soviet Socialist Republic	Skumbrievyi tunets, Auksida
United States	Bullet mackerel
International Organization	
FAO	Bullet mackerel
ICCAT	Bullet mackerel

To avoid confusion throughout the remainder of this paper, the name *A. rochei* will be used where investigators in the past had used *A. tapeinosoma*, *A. thynnoides*, and *A. maru* to describe the long-corseletted frigate mackerel.

III. DISTRIBUTION

A. GEOGRAPHICAL DISTRIBUTION

Both species of frigate mackerel are widely distributed in tropical and subtropical waters of the Pacific, Atlantic, and Indian Oceans and are most abundant close to land masses (Figure 10) (Laevastu and Rosa 1963).

Fig. 10

In the North Pacific, A. thazard has been reported from off the coast of the United States from San Pedro, California southward to about Panama (Rosa 1950). It also occurs in the Hawaiian Islands, Philippine Islands, Formosa, coast of China around Ningpo and southern Manchuria, Ryukyu and Bonin Islands, coast of Japan as far north as Hokkaido, and off Korea.

From the South Pacific, A. thazard has been reported from around the coast of Papua New Guinea and along the eastern coast of Australia as far south as Tasmania (Rosa 1950). Whitley (1964) showed the distribution of A. thazard off the Australian coast (Figure 11) and noted that this species is common in summer in the western and subtropical regions of Australia and around southern New South Wales.

Fig. 11

In the Atlantic, A. thazard occurs throughout the tropical and subtropical waters and also in the Mediterranean and Black Seas (Miyake and Hayasi 1972). Collignon (1960) described its distribution as extending from lat. 45°N to 35°S. In the North Atlantic, A. thazard occurs rarely off the southern coast of Norway as far north as Bergen and the canal of Oslo (Rosa 1950). It is also rare in British waters. It has been reported from off the coast of Spain,

Portugal, Azores, Madeira, Canary, and Cape Verde Islands, French Morocco, Spanish Sahara, French West Africa, Gambia, Portuguese Guinea, Sierra Leone, Liberia, and the Gold Coast. Off the United States, it occurs from Cape Cod to the coast of Florida. The northernmost record is off Barnstable, Massachusetts in the Gulf of Maine (Mather and Gibbs 1957).

It is also found in waters around the Bahama Islands, Caribbean Sea, Gulf of Mexico, Leeward, Windward, Tobago, and Trinidad Islands, Puerto Rico, Dominican Republic, Haiti, Jamaica, Mexico, and British Guiana (Rosa 1950).

Rosa (1950) reported A. thazard also occurs in the South Atlantic off the coast of French Equatorial Africa, Belgian Congo, Angola, Union of South Africa on Cape waters, Ascension and St. Helens Islands, and Brazil.

In the Mediterranean Sea, it has been reported from off the coast of Spain and Balearic Islands, France, Italy, Sicily, Malta Islands, Yugoslavia, Greece, Algeria, and Spanish Morocco.

In the Indian Ocean, A. thazard has been recorded from South Africa, Natal, and Cape Province (Williams 1963; Nair, Rao, and Dorairaj 1970). It also occurs off Mauritius, coasts of Tanganyika, Kenya, and the Zanzibar Protectorate, Seychelles including Aldabra Island, coast of Somalia and Gulf of Aden, west and east coasts of India, Maldive and Laccadive Archipelagos , Indonesian Archipelago, and Australia except on the south coast. The extreme southern boundary of this species in the Indian Ocean is roughly a line drawn from Cape Agulhas, South Africa to Cape Leeuwin, Western Australia.

A. rochei has a distribution similar to that of A. thazard. In the Pacific, it has been recorded from the coast of Indonesia, east Australia, New Guinea, Philippine, Ryukyu Islands, South Korea, Ogasawara Islands, southern Manchuria, Formosa, Japan, Galapagos Islands, and the eastern tropical Pacific off central America (Nair et al. 1970). Matsumoto (1960) noted a new distribution record for the long-corseletted Auxis from Hawaiian waters. He remarked that although the long- and short-corseletted Auxis are known to occur on both sides of the Pacific, only the short-corseletted A. thazard has been reported previously from the central Pacific.

Around Australia, A. rochei was first recorded from Newcastle New South Wales, but larvae, possibly of this species, had been captured in 1929 in the Tasman Sea during the 'Dana' expedition (Whitley 1964). Watanabe (1964) also reported capture of A. rochei from off Queensland for the first time.

Jones and Silas (1964) collected A. rochei from Malpe near Mangalore (S. Mysore); Calicut, Quilandy, Vizhingam (Kerala State); and Colachel and Cape Comorin (Madras State) in the Indian Ocean. It also occurs off South Africa and South Australia in the Indian Ocean (Nair et al. 1970).

In the eastern Atlantic, Cadenat (1950) reported that A. rochei was abundant in the area of Cape Verde Islands.

According to Yabe, Yabuta, and Ueyanagi (1963), the distribution of A. thazard and A. rochei cannot be separated from each other because of difficulties involved in distinguishing one from the other. In Japanese waters, they claim, A. thazard extends farther southward than A. rochei.

Watanabe (1964), on the other hand, saw conspicuous differences between the pattern of occurrence of A. thazard and A. rochei. Studying the pattern of distribution of both species of frigate mackerel through the stomach contents of tunas and marlins, Watanabe found that in the Banda Sea, although both species occurred there, A. rochei specimens were found with considerably greater frequency than those of A. thazard. Watanabe suggested that this pattern of occurrence in the stomach contents of predators reflected the difference in abundance of the two species in the Banda Sea and off the Queensland coast. Also, the results led Watanabe to believe that Auxis hardly occurred in oceanic areas. Compared to distributions of Thunnidae and Katsuwonus, Auxis was found to be more coastal.

B. ECOLOGICAL CHARACTERISTICS OF AREAS

As a direct influence on the distribution of tunas as far as the subtropical and tropical areas are concerned, temperature may be excluded as a direct influence but in the fringe of their distribution, or more generally in the temperate zone, temperature can be a limiting factor. Therefore, it is an important indicator of their distribution (Yabe et al. 1963).

Concerning the tropical and subtropical waters of the Indian Ocean, Williams (1963) has stated that they are characterized by a scarcity of plankton offshore. Strong development of phytoplankton and subsequent zooplankton is restricted to the immediate coastal areas, except for areas of vertical mixing of water masses off such

areas as Somalia and in the Gulf of Aden. In East African surface waters, plankton dry weight decrease with increasing distance offshore. In the Java area, maximum zooplankton abundance occurred 40-65 km offshore or just outside the zone of rich phytoplankton (Delsman and Hardenberg, 1934).

Williams (1963) believes that the extreme southern boundary of the geographical distribution lies at about lat. 36°S which is extremely close to the position of the 20°C isotherm for the greater part of the year, including the southern summer. The occurrence of frigate mackerel in South Africa and Australia coincides with the time of maximum water temperature. Likewise, in East Africa and the Seychelles, frigate mackerel occurs in the months of the northeast monsoon when the temperature is maximal at about 29°-30°C. The inshore appearance of frigate mackerel in East African waters also coincides with the time of greatest fertility of the surface waters.

IV. BIOLOGY AND ECOLOGY

A. REPRODUCTION

1. Sexuality

Like all other scombroids, the frigate mackerel is heterosexual. There are no externally visible characters that would aid in distinguishing males from females. Internally, the paired and elongated gonads are nearly symmetrical and are suspended in a fold of the peritoneum, extending almost the entire length along the roof of the abdominal cavity. At the posterior end of the abdominal cavity, the gonads extend along both sides of the anal fin. This posterior extension, according to Kishinouye (1923), is due to the narrowness of the abdominal cavity.

2. Maturity

Studies of gonads of troll-caught fish from waters of Kaneohe Bay, Oahu in the Hawaiian Islands indicate that frigate mackerel are nearly mature at a size of about 35 cm (Tester and Nakamura 1957). One male, which measured about 40 cm had testes that were classified as mature.

In the Indian Ocean, Rao (1964) reported collecting two specimens of A. thazard that had ovaries in "spawn-ripe" condition (Table 8). The pinkish pale yellow ovaries, which came from fish measuring 41.6 and 44.2 cm, were collected from Vizhinjam in November 1959 and weighed 52 and 125 g, respectively. According to Rao, the smaller of the two frigate mackerel may "have been captured while in the act of spawning since most of the ripe ova were already lost by the time it was examined."

Table 8

Compared to ovaries of Euthynnus affinis, those of A. thazard are smaller (Rao 1964). Ripe ovaries of A. thazard occupied the whole body cavity and appeared very delicate but the vascularization was not as intense as those of E. affinis.

Ripe ova flowed freely out of the ovaries on the application of slight pressure (Rao 1964). Fresh ripe ova were perfectly spherical with a colorless homogeneous yolk mass and had an average diameter of 0.97 mm. Preserved ova were somewhat transculent and had an average diameter of 0.86 mm. Each ripe ovum contained a fairly large, spherical, single oil globule which measured about 0.22 mm in
Table 9 diameter (Table 9). In the Laccadive Sea, spawning of Auxis sp. appears to occur around January to April (Nair et al. 1970).

Yasui (1975) used a somewhat different approach to determine maturity of frigate mackerel taken in Japanese waters in the Izu Islands and at Mera, Shizuoka Prefecture. Plotting liver weight against body length, Yasui discivered a point of discontinuity at
Fig. 12 body length of about 29 cm (Figure 12). His data also showed that 97% of the fish smaller than 29 cm were caught after September whereas 95% of those larger than that were caught before August. The reproductive index, according to Yasui, is highest in July. And almost all the fish larger than 29 cm had a high reproductive index. This led Yasui to hypothesize that liver weight is related to oogenesis and that it can be used as an indicator of sexual maturity.

Rodriguez-Roda (1966) studied the sexual maturity of A. thazard caught in the Spanish trap-net fishery located in and around the Strait of Gibraltar. The classifications he used for the six stages of development of the testes and ovaries were as follows:

I	Immature
II	Maturing
III	Ripening
IV	Pre-spawning
V	Spawning
VI	Spent

Table 10 Table 10 shows the percentage frequency distribution, by sex, of the developmental stages of the gonads of A. thazard examined by Rodriguez-Roda in May-September. In May, he noted a large proportion of the males and females were in stage III, but in June-August, some had advanced to stage IV, and by September about one-third of the males and one-fourth of the females sampled had gonads that appeared to be spent. Rodriguez-Roda noted that gonad classification based on external characteristics such as he used could lead to misleading conclusions; however, he indicated that the relative gonad weight (gonad weight in relation to body weight) tended to confirm his conclusions. The size at first spawning, according to Rodriguez-Roda, is 35 cm for the females and 36.5 cm for the males.

3. Fecundity

Rao (1964) determined that an A. thazard of moderate size would produce about 280,000 ova per spawning and that about

Table 11 1.37 million ova are extruded over the entire spawning season (Table 11).

From frigate mackerel caught in drift nets in Indian waters, Silas (1969) also determined their fecundity (Table 12). He estimated from ovary samples that A. thazard spawned anywhere from 197,000 to 1.056 million eggs and averaged 601,000 eggs. For A. rochei, Silas found fewer eggs, ranging from 31,000 to 103,000 eggs and averaging 52,000 eggs.

Table 12

4. Spawning

Knowledge of the time and place of occurrence of Auxis larvae has been used to make inferences about the time and area of spawning. Matsumoto (1958, 1959) hypothesized recently hatched larvae of Katsuwonus pelamis and Thunnus albacares measure about 3 mm. Being planktonic, larvae of this size, like the ova which precede them, are displaced from the area of spawning due to drift of the ocean currents. Except in a few areas where currents are swift, this displacement of ova and larvae appears to be relatively insignificant. Matsumoto, therefore, believed that localities where larvae of 3 mm occurred represented actual spawning site.

Judging from the localities in which Auxis larvae were taken, it has been inferred that this species spawns nearshore close to land masses as well as in offshore oceanic waters (Matsumoto 1959; Klawe 1963; Yabe et al. 1963). Figure 13 shows the localities of capture of frigate mackerel larvae on a worldwide basis.

Fig. 13

Klawe (1963) found A. thazard most numerous in the collection of larvae and juveniles from the eastern Pacific. The most northerly area where this species spawns is around Cedros Island and at the head of the Gulf of California (Figure 14). Klawe pointed out waters off Baja California were sampled regularly by vessels of the California Cooperative Oceanic Fishery Investigations (CalCOFI) program and no larvae have been captured north of these areas. Whereas spawning appears to be more in coastal waters off Baja California, it apparently takes place in more oceanic habitat away from continents or islands in the more southern areas. The southern limit for spawning appears to be off Point Santa Elena in Ecuador.

Fig. 14

Klawe (1963) also observed that Auxis larvae were collected in the vicinity of all major oceanic islands in the eastern tropical Pacific Ocean. He delimited the general area of occurrence by drawing a straight line from Point Santa Elena to the intersection of lat. 10°N and long. 116°W and from there to Cedros Island off Baja California (Figure 14).

Klawe (1963) also showed that frigate mackerel spawns throughout the year, although in the northern region of the eastern Pacific, it appeared to be restricted (Figures 15 and 16). This phenomenon of seasonal spawning in the northern region of the eastern Pacific may be similarly reflected in the most southern region but data are inadequate to confirm this. Data from collections made off Cape Blanco indicated that Auxis spawns off Costa Rica throughout the year but peak spawning occurs in December-April. Table 13 shows

Figs. 15 and 16

Table 13

the average catch of Auxis larvae per hour of surface tow made in different months off Cape Blanco.

In a later study, Klawe, Pella, and Leet (1970) observed that the spawning of Auxis varied significantly among months and that from August through November, and especially in October, the larvae

Fig. 17 were more abundant than in other months (Figure 17). The differences in spawning peak suggested by samples examined earlier by Klawe (1963) and those by Klawe et al. (1970) may be due to differences in sampling locations within the general area, to environmental changes, or to other causes.

In the central Pacific, it was inferred by Matsumoto (1958) that frigate mackerel spawn in Hawaiian waters and in waters to the

Table 14 west and south of the Hawaiian Islands. Table 14 shows the size range of A. thazard larvae captured in Hawaiian and equatorial waters. It can be seen that the size range included some larvae less than 3 cm in length. Strasburg (1959), in reporting an incident of natural mass mortality of frigate mackerel in Hawaiian waters, also had some small specimens with sizes ranging from 2.2 to 8.3 mm in total length. Although all these small larvae of 3 mm or less were past the yolk-sac stage, it argues from Matsumoto's hypothesis that the smaller larvae are

Fig. 18 recently hatched fish. Figure 18 depicts the localities of capture of Auxis larvae in the Pacific Ocean by research vessels Dana and other Danish vessels and those of the Pacific Oceanic Fishery Investigations (POFI).[3]

Yoshida and Nakamura (1965), reporting on pole-and-line fishing of schools of A. thazard and A. rochei, 1.8 km off Kaena Point, Oahu in the Hawaiian Islands, observed the sexual condition of fish landed from these schools. They noted that milt was flowing from the vent of males of both species when landed on the deck of the vessel. The females, however, showed no signs of free-flowing ova even after pressure was applied externally. Subsequent examination revealed that the females had ovaries that were flaccid, transculent, and grayish such as those usually seen in spent females of yellowfin tuna (June 1953).

Microscopic examination of ovaries from eight A. thazard and five A. rochei revealed that both species had ova in stages of resorption. One specimen of A. thazard still contained residual ova in the lumen; their diameters varied between 0.75 and 1.30 mm and averaged 1.08 mm. No free residual ova were found in A. rochei. Concerning primordial ova, two size groups--one ranging from 0.07 to 0.10 mm and the other from 0.17 to 0.22 mm in diameter--were noted in ovaries of A. thazard. In A. rochei, there was only one group of primordial ova ranging from 0.07 to 0.08 mm in diameter. Yoshida and Nakamura concluded that their findings present further circumstantial evidence of summer spawning of A. thazard and A. rochei in Hawaiian waters.

Nakamura and Matsumoto (1967) also collected Auxis larvae in waters around the Marquesas Islands. Although skipjack tuna larvae were the most numerous among all the tuna larvae collected in the Marquesas, larval Auxis was the second most abundant of the larvae

collected at the diel variability station (station occupied for 24-h periods). Because currents around the Marquesas Islands are suspected to be weak, Auxis larvae as well as those of other tunas could not have drifted very far from the spawning site; therefore, it is reasonable to assume that Auxis spawning occurs throughout Marquesan waters.

In the western Pacific, Wade (1951) showed a number of probable tuna-spawning areas, inferred from collection of larval forms in Philippine waters and the Celebes, Sulu, and South China Seas.

Fig. 19 Figure 19 shows large areas bounded by broken lines where tunalike larvae were captured in consecutive or closely related plankton tows. Small diamond-shaped areas are those in which a single, isolated tow

Fig. 20 produced sufficient larvae to seem significant. Figure 20 shows the locations where Auxis larvae were captured.

Wade also observed that juveniles of Auxis are taken in fish traps and several types of local nets close to shore and in open waters of well-sheltered Batangas and Balayan Bays. Furthermore, he noted that the largest catches of Auxis larvae occurred in January-March, whereas for the remainder of the year, the catch was very meager. He observed small juvenile Auxis appearing on the market in late November, becoming more abundant in January-February, then decreasing so that after May, he found no juveniles on the market. From these observations, he concluded that adults of Auxis spawn in protected, more or less shallow areas, fairly close to land, that the principal spawning activities occur during the winter months, and that scattered spawning takes place the remainder of the year.

Concerning A. rochei in the Philippines area, Nair et al. (1970) reported that the spawning period appears to be from November to August with peak spawning apparently in January-March.

Also in the western Pacific, Japanese studies have shown that A. rochei with ripening gonads are caught in April-June, whereas those with ripe and spent gonads are taken in June-July and July-August, respectively (Suzuki and Morio 1957). Larvae identified as A. rochei also have been reported from off Japan and from the Celebes and South China Seas. Near Japan, Yabe and Ueyanagi (1962) reported collecting larvae of A. rochei from May through July, whereas Yokota et al. (1961) collected larval A. rochei, measuring 3 to 5 mm in total length, from south of Shikoku and Kyushu in June-August with the peak in collection occurring in July. This was confirmed by Hamada, Morita, Ishida, and Takezawa (1973) who examined the gonad condition factors of A. rochei caught in waters off Kochi Prefecture and found that spawning t took place in late June. They also examined the gonad condition of A. rochei taken off Taiwan in June-July and found that the gonad index was very high indicating perhaps that spawning was imminent. In the Celebes and South China Seas, larval A. rochei were collected predominantly during January and February (Yabe and Ueyanagi 1962).

Larval Auxis have also been captured in the Tasman Sea off Sydney, Australia (Figure 18). Whitley (1964) reported that larval and juvenile Auxis are common in the Tasman Sea. Two traps of Auxis larvae were identified from the collection made by the Dana expedition in 1929 (Matsumoto 1959; Appendix Table 2); these specimens probably represent A. thazard and A. rochei. According to Whitley

(1964), similar specimens have been washed up on Collaroy Beach in August-September 1958. The presence of larval and juvenile Auxis in waters of the Tasman Sea would indicate that adult Auxis also spawn in this region of the Pacific.

Fig. 21 Figure 21 shows the localities of capture of Auxis larvae in the Indian Ocean. Jones and Kumaran (1963) studied the distribution of tuna larvae collected by the Dana expedition from the Indian Ocean and found that almost all the specimens of A. thazard were obtained from an area west of long. 50°E between lat. 3° and 24°S in December-January. Furthermore, larvae collected by the Dana expedition in the eastern Indian Ocean, and those obtained from the Laccadive Sea in January-April also belong to this species. Jones and Kumaran concluded that A. thazard has an extended spawning period in the Indian Ocean from August to April. Bogorov and Rass (1961) have confirmed the presence of spawning schools of A. thazard in the Indian Ocean.

Concerning inferences on spawning of A. rochei in the Indian Ocean, Matsumoto (1959) has reported finding two types of Auxis larvae present in the collections made by the Dana from the eastern Indian Ocean southward off Sunda Archipelago in August-November (Figure 21). Table 15 shows the distribution, by months, of the time of capture of larval A. thazard and A. rochei in November-January. The data indicate that most of the larval Auxis were captured in January perhaps suggesting that peak spawning may occur early in the year.

Table 15

Low latitudinal areas of the eastern Indian Ocean, primarily southwest of Sunda Archipelago, and the western Indian Ocean between Madagascar and the mainland of Africa are also considered likely spawning sites of A. rochei. Yabe and Ueyanagi (1962), however, believe that the data available at present are too meager to draw more definite conclusions about the spawning of A. rochei in the Indian Ocean.

Rao (1964) determined the probable spawning period of A. thazard in the Indian Ocean by examining the time of appearance of mature, spawning, and spent individuals in the commercial landings. He found, however, that specimens of Auxis were not available in all months of the year. Nevertheless, from the samples he was able to examine, he found the percentage of maturing and mature ovaries was highest in March. In August and September, the majority of the fishes examined were actually in spawning condition and some individuals completely spent. Samples obtained subsequently in November comprised of only spent fish. Rao also attempted to determine the spawning periodicity of Auxis by examining ova-diameter frequency polygons (Table 16 and Figure 22). He found several modes of maturing and mature ova separated from the last mode which he assumed represented ripe ova. He suggested that the ripe ova would be spawned soon and that the maturing ova in the next to the last mode would become ripe and ready for the next spawning within the same spawning season.

Table 16
Fig. 22

For the Atlantic Ocean, Figure 18 shows the localities of capture of Auxis larvae by the Dana. Kazanova (1962) reported on the collection of tuna larvae in the eastern tropical Atlantic off the west coast of Africa, mainly in the region of Dakar at the western tip of Africa, and off Takoradi in the Gulf of Guinea. Among the various species of larval tuna and tunalike fishes collected, those identified as frigate mackerel were most numerous. Kazanova had at his disposal a series of Auxis larvae some as small as 3 mm. Furthermore, in addition to larvae identified as A. thazard, there were others which were similar to A. thazard but differing in some characteristics. Kazanova referred to them as the second of the two groups (Type II of Matsumoto 1959) of Auxis larvae. Therefore, it can be inferred that these regions of the Atlantic are also spawning grounds of the two species of frigate mackerels.

Duclerc et al. (1973) reported capturing recently hatched larvae of A. thazard in waters surrounding the Balearic Islands, located off the Mediterranean Spanish coast. In August-September 1971, 140 larval A. thazard were captured by the research vessel Ichthys whereas in June-July 1972, an additional 52 A. thazard larvae were taken. According to the authors, larval A. thazard was the most abundant among the larval tunas captured which included T. thynnus, T. alalunga, and Sarda sp. The presence of the planktonic stages of all these tuna species in the plankton-net catches provided evidence that these species spawned in waters surrounding the Balearic Islands.

Postel (1964) examined the gonads of A. thazard caught in madragues (traps) off Tunisia and found them to be mature and determined that spawning also took place in Tunisian waters in June-August. For A. thazard taken in Algeria, Postel reported that spawning probably occurs in August.

In the western Atlantic, the Gulf of Mexico appears to be a large spawning ground for frigate mackerel. Hayasi (1972) reported collecting larvae of bigeye tuna, skipjack tuna, frigate mackerel, and yellowfin tuna in Gulf waters (Figure 23). Klawe and Shimada (1959) collected juvenile A. thazard from a large number of stations spread widely over the Gulf of Mexico. The north central Gulf region is definitely a spawning locality for this species. And although the area southeast of the Mississippi delta is another possible spawning site because most of the larvae were captured in this locality, the collection may reflect sampling intensity rather than actual distribution of young Auxis. In the Gulf, juvenile Auxis were present in the collection in March-April and in June-August. Klawe (1961) reported collecting young Auxis in the Strait of Florida in May-June and August.

Fig. 23

Other evidence of spawning has been reported by Tibbo and Beckett (1972). On a cruise from Cape Hatteras to Cuba and return in February-March 1970, surface plankton tows yielded scombroid larvae at 21 stations in 51 tows. Most numerous in the collection were larvae of A. thazard, followed by larvae of K. pelamis, E. alletteratus, and T. albacares, in that order.

V. LIFE HISTORY

A. EGGS AND LARVAE

1. Development

There has been considerable progress in studies on egg and larval development of tuna and tunalike fishes in recent years. Most impressive are the experiments on artificial fertilization of eggs and the subsequent rearing of the larvae conducted by Japanese scientists. Among the species that have been used in these experiments were yellowfin tuna, skipjack tuna, and frigate mackerel.

In 1970, the Japan Fisheries Agency coordinated a 3-yr cooperative program to artificially fertilize and rear tunas (Ueyanagi et al. 1973). The experiments were conducted through the cooperative efforts of Tokai University, Kinki University, Shizuoka Prefectural Fisheries Experimental Station, Mie Prefectural Owase Fisheries Experimental Station, Nagasaki Prefectural Fisheries Experimental Station, and the Far Seas Fisheries Research Laboratory of the Japan Fisheries Agency.

Harada, Murata, and Miyashita (1973) and Ueyanagi et al. (1973) published the results of these tuna-rearing experiments. To carry out artificial fertilization, fish in advanced stages of sexual maturity were necessary. Of three conventional fishing methods attempted, only purse seining proved effective in capturing mature yellowfin and skipjack tuna and set nets for collecting mature frigate mackerel.

Mature eggs from ripe female frigate mackerel generally oozed out when pressure was applied to the abdomen; therefore, no incision was necessary (Ueyanagi et al. 1973). Using the "dry method," the investigators then obtained mature males and applied pressure to force the sperm-bearing milt over the eggs. The mixture was gently stirred before any water was added.

Collected and fertilized at sea, the eggs were then transported to the various laboratories to be hatched (Ueyanagi et al. 1973). Fertilized eggs of frigate mackerel were transported to the laboratories in 2-4 h on eight different occasions. The mortality of the eggs, which were transported in plastic bags filled with oxygen-saturated seawater, was negligible. The details of the success obtained in fertilizing and rearing both *A. thazard* and *A. rochei* follow.

a. *Auxis thazard*

The collection and fertilization of mature eggs of *A. thazard* at Mera, Shizuoka Prefecture, were successful on five occasions in July 15 to August 15, 1971 (Ueyanagi et al. 1973). Larval rearing was most successful on the first trial when survival lasted up to 10 days after hatching. Hatching of the eggs first occurred 25 h after fertilization and the newly hatched larvae measured 2.59 mm in total length. Heavy mortality usually occurred 4-5 days after hatching.

At Kushimoto, Wakayama Prefecture, mature eggs were collected, successfully fertilized, and transported to the Marine Laboratory of Kinki University on three occasions in 1972 (Harada, Murata, and Miyashita 1973; Ueyanagi et al 1973). The spherical, fertilized eggs were buoyant and varied from 0.93 to 0.98 mm in diameter (Figure 24). Hatching occurred 34 to 62 h after fertilization at temperatures ranging between 21.4° and 23.5°C. The newly hatched larvae measured
Fig. 24 between 3.26 and 3.60 mm in total length (Figure 24). Three days after hatching, the larvae were fed rotifers, which were replaced with marine plankton, mainly copepods, 7 days after hatching. Twenty days after hatching, the larvae were fed several types of fish flesh. Placing the larvae in various-sized aquaria to determine the effects of tank capacity on growth and survival, the investigators found that growth was rapid in the 0.5-ton aquarium during the first 30 days
Table 17 after which time the rate slowed appreciably (Table 17 and Figure
Fig. 25 25). Maximum survival was 36 days. Larvae reared in aquaria with capacities of 3 tons and 70 tons grew faster than those reared in the 0.5-ton aquarium, reaching a length of 12 cm in 33 days (Table
Table 18 18 and Figure 25). Growth decreased significantly after that and the last larvae died on the 41st day.

b. Auxis rochei

In 1972, collection and fertilization of eggs from mature female A. rochei were successful seven times at Mera, Shizuoka Prefecture (Ueyanagi et al. 1973). On one experiment, the larvae, which were fed rotifers, copepods, larvae of sea bream and goby,

chopped bivalve meat, and chopped fish flesh, survived up to 67 days after fertilization.

Harada, Murata, and Furutani (1973) reported on other trials of A. rochei conducted at the Shirahama Fisheries Laboratory of Kinki University, Wakayama Prefecture. In June 1972, mature A. rochei were taken by a trap net near Oshima Island near Cape Shionomisaki. About 40,000 eggs were collected, fertilized, and transported to the laboratory. The fertilized eggs, buoyant, spherical, and measuring between 0.97 and 0.99 mm in diameter (Figure 26), hatched 38 to 52 h later at temperatures ranging from 21.4° to 23.5°C. The newly hatched larvae ranged from 3.3 to 3.6 mm in total length (Figure 26). Fed the same diet as that given larvae of A. thazard as previously described and confined in one small 0.5-ton aquarium and two larger aquaria of 3- and 30-ton capacities, the larvae of A. rochei, like those of A. thazard, grew faster in the large aquaria than in the small aquarium (Tables 19 and 20 and Figure 27).

Fig. 26

Tables 19 and 20
Fig. 27

Experiments on artificial fertilization were continued in 1973. On July 15, 1973, at 0500, ripe eggs were collected from A. rochei caught in a set net off Kashino, Oshima (Kushimoto, Wakayama Prefecture) and artificially fertilized (Kinki University Fisheries Experimental Station 1974). The water temperature at the time of fertilization was 25°C. The fertilized eggs, which averaged 0.903 mm in diameter, were transported to the Experimental Station at Shirahama. On the following day, an estimated 7,000 newly hatched larvae were placed in a 3-ton aquarium and at age 2 days were fed

rotifers and marine plankton. At age 18 days, the total length reached 3 cm. After the 23d day, the larvae were fed minced fish flesh and at age 27 days, they were about 5-6 cm in total length. However, mortality was high and only 36 larvae were observed. On the 35th day, the survivors had grown to 7.7-7.9 cm and one larva survived for 50 days. The Japanese investigators observed that this rate of growth was slower than in previous experiments and believed it due to lack of fish larvae as food. They emphasized, however, that the experiments succeeded in producing artificially, "seedling" of A. rochei which were several centimeters in length.

Other experiments at Kinki University Fisheries Experimental Station (1974) involved cross-fertilization of A. thazard and A. rochei. Taken from A. thazard caught by set net at Kashino, Oshima on July 17, 1973 at 0530, the ripe eggs were fertilized and transported to the Experimental Station at Shirahama. At 1350 on the same day, there were about 35,120 viable eggs which averaged 0.86 mm in diameter and about 7,000 dead eggs. Twenty five thousand viable eggs were placed in a 3-ton tank and 10,000 in a 1-ton tank. Water temperature in the tanks was about 26°C. Larvae started to emerge the next day, approximately 30 h after fertilization and all hatching was completed during the day. The larvae were kept in seawater with chlorella which had a density of 400,000/cc. Aeration was also provided. Rotifers were added to the tank 2 days after hatching and marine plankton was added the next day. All the larvae in the 3-ton tank died after 6 days. In the 1-ton tank, although

mortality was heavy, there were some survivors. At 14 days, the water was circulated and at 18 days after hatching, artemia and eggs of frozen yellowtail, Seriola quinqueradiata, were used to supplement the marine plankton. Mortality continued and the last survivor, which attained a length of 4.8 cm and a weight of 0.907 g, died after 31 days. Growth was considerably slower than that observed in previous experiments.

In general, then, these experiments on the two species of frigate mackerels have shown that:

1. The eggs are buoyant, spherical, and measure between 0.93 and 0.99 mm in diameter;
2. the eggs hatch from 34 to 62 h after fertilization in water temperatures ranging between 21.4° and 23.5°C;
3. the newly hatched larvae measure 3.26 and 3.60 mm in total length;
4. the larvae feed on rotifers, copepods, and minced fish flesh, in that order, after hatching;
5. the growth and survival rates of larvae are better in large rather than in small aquaria; and that
6. under the best condition, A. thazard larvae grew 120 mm in 33 days whereas A. rochei larvae grew 157 mm in 52 days.

2. Postlarval Growth

Clemens (1956) also observed growth of postlarval Auxis and Euthynnus. He noted that Auxis had a more rapid rate of growth than Euthynnus. Of five postlarval Auxis placed in an aquarium for observation, he discovered that three died several hours later from injuries received in handling. The two remaining Auxis, measuring 20 and 30 mm in total length, survived 6 days. The smaller of the two specimens grew to 40 mm whereas the larger grew to 46 mm in 6 days.

3. Larval Identification

The criteria for specific identification and separation of frigate mackerel larvae from those of other tuna and tunalike fishes appear to be quite well established. Ueyanagi (1964) has provided a key to identifying frigate mackerel larvae and this is given below:

Key to the larvae of the tunas[4]

a_1 Melanophores appear on the forebrain.

b_1 One conspicuous melanophore present on the caudal peduncle. No chromatophores on the isthmus or directly anterior to the anus.

. . . . . skipjack

b_2 There is a dotted line of melanophores along the midlateral line on the posterior part of the body. Chromatophores appear on the isthmus and directly anterior to the anus.

. . . . . little tunny

a_2 No melanophores visible on the forebrain.

c_1 Melanophores appear on the sides of the body.

d_1 Chromatophores appear on the isthmus and directly anterior to the anus.

e_1 Melanophores appear as dotted lines along the mid-dorsal, mid-lateral, and mid-ventral lines of the caudal region (usually in three lines).

. . . . . frigate mackerel

d_2 Chromatophores do not appear on the isthmus nor directly anterior to the anus.

f_1 One or several melanophores appear along the dorsal and ventral sides of the body.

g_1 The most anterior of the chromatophores on the dorsal side is located posterior to the origin of the second dorsal fin.

. . . . . bluefin tuna

g_2 The most anterior of the chromatophores on the dorsal side is located anterior to the origin of the second dorsal fin.

. . . . . long-tailed tuna

f_2 One or several melanophores appear along the ventral side of the body.

. . . . . bigeye

c_2 No melanophores appear on the sides of the body.

h_1 Chromatophores appear at tip of lower jaw.

In the profile of the head, the center of the eye is clearly located higher than the tip of the snout.

. . . . . yellowfin

h_2 No chromatophores appear on tip of lower jaw. In the profile of the head, the center of the eye is about on the same level as the tip of the snout or slightly higher.

. . . . . albacore

Briefly, larval Auxis can be distinguished from other larvae of tuna and tunalike fishes by the presence of a dotted line of melanophores along the dorsal, lateral, and ventral center lines of the caudal peduncle (Ueyanagi 1964). The standard pattern is three lines, but sometimes only two--the dorsal and ventral--are seen. In small specimens, however, the line on the ventral side is not confined to the vicinity of the caudal peduncle but extends farther forward. Other characteristcis include the appearance of melanophores on the isthmus and just anterior to the anus, late appearance of chromatophores on the forebrain (they do not appear until the fish reaches a body length of about 8 mm), and poorly developed chromatophores on the first dorsal fin (they do not appear until the fish becomes about 10 mm long). The outline of the anterior surface of the head gives an impression of roundness and the separation between the first and second dorsal fins becomes quite apparent at lengths of 10 mm or greater.

Jones (1963) gave additional observations on the morphology of the larval Auxis. The snout of the larvae is relatively shorter than in other tuna and tunalike larvae of comparable size. In addition, there are 39 myotomes and a large chromatophore at the symphysis of the pectoral girdle. Fin ray development is also late.

Matsumoto (1959), who described the morphology of larval and postlarval Auxis on a worldwide basis, observed that there were variations in pigmentation among the larval Auxis with which he worked. He pointed out the possibility that this variation may well be due to the presence of two species of frigate mackerel; therefore, he provided two separate descriptions calling them Type I and Type II, as shown in Figures 28 and 29.

Figs. 28 and 29

Type I and Type II larvae show minor differences only with the most obvious one being the variation in pigmentation in the region of the caudal peduncle (Matsumoto 1959). Type I, which resembles the form described as A. thazard in Matsumoto (1958), has three equally developed rows of pigment whereas in Type II the middorsal edge of the caudal peduncle usually contains only one or two chromatophores and the midlateral line has none.

Subsequent to Matsumoto's description of Type I and Type II Auxis larvae, Jones (1961) observed that larval A. rochei could be distinguished from those of A. thazard by the relatively smaller body depth and later development of the spinous dorsal. He made a provisional identification of these two types, calling Type I larvae, which are more stout than Type II larvae A. thazard, and Type II

larvae, which are relatively elongated, A. rochei. Yabe and Ueyanagi (1962) then published the results of a study on larval tuna in which they identified frigate mackerel specimens as A. rochei.

The work done by Mito (1961) on the egg and larval development of Auxis (Figure 30), has been discussed by Jones (1963), who brought out that because A. rochei is the most common frigate mackerel in Japanese waters, the eggs and larval stages described by Mito may be this species. But he also noted that there were striking differences between larvae described by Mito and those described in Jones (1960) and Matsumoto (1959). These differences, he believed, should be explained by Mito. However, with the breakthrough in artificial rearing accomplished by the Japanese, it should be possible now to compare known specimens of each species obtained with those obtained from net tows and night lighting.

Fig. 30

4. Larval Nutrition

Yokota et al. (1961) studied the feeding habits of postlarval A. rochei of between 3.0 and 5.4 mm in length and found them feeding on nauplius which ranged in size from 0.10 to 0.30 mm and copepodite of about 0.55 mm.

5. Larval Distribution

The distribution of larval frigate mackerel, like that of larvae of other tuna, is confined to tropical and subtropical waters, whose boundaries are demarcated by the Subtropical Convergence (Yabe et al. 1963). The specific areas of the world's ocean where

frigate mackerel larvae have been taken have already been discussed in an earlier section (spawning) and will not be repeated here.

Concerning their vertical distribution, Strasburg (1960) reported that frigate mackerel larvae were captured at the surface very infrequently during daylight hours, but were often taken there in large numbers at night. Furthermore, he observed that at sunset, there was an almost complete disappearance of tuna larvae from the surface and explained that this temporary phenomenon was related to the rise of the deep scattering layer towards evening and the resulting increase in invertebrate plankton in the surface layers. He hypothesized that this inverse relationship in the behavior of tuna larvae and invertebrate plankton was due primarily to differences in their reaction to light intensity; therefore, he inferred that tuna larvae are not likely to be a constituent of the deep scattering layer.

Klawe (1963), who studied the vertical distribution of frigate mackerel larvae taken in the eastern Pacific, also observed that they are limited to the layer above the thermocline. Comparing average catches of tuna larvae for two types of plankton tows, Klawe found that the surface tows usually caught 9.2 times as many larvae as the deep tows. But comparison of catches made by surface and by 140-m oblique tows showed that the former caught an average of only 3.2 times as many larvae as the latter. In fact, the number of larvae caught in the simultaneous surface and oblique tows correlated significantly. Klawe calculated that the relative number of tuna larvae taken in surface and oblique hauls approximates the ratio obtained

from the depth of the oblique tow to the depth of the layer above the thermocline thus substantiating the conclusion earlier reached by others that larvae are limited to the layer above the thermocline.

In a still later study, Klawe et al. (1970) observed that there were no significant diel vertical movement of Auxis larvae in the water column. They interpreted from the statistical test they conducted for time of day as well as for interaction between time of day and type of tow that if vertical movement had occurred, an interaction between type of tow and time of day would have been detected. For example, the surface hauls should differ between times of day whereas the oblique hauls should not because the latter descended to the thermocline and hence throughout the depth inhabited by larval tunas.

Treating temperature, salinity, and zooplankton volumes as covariates, Klawe et al. (1970) also tested whether these environmental features were associated with spawning of Auxis. They found no relationship between zooplankton volumes and larval catches; therefore, their findings are in agreement with those of Strasburg (1960) and Nakamura and Matsumoto (1967) who observed this phenomenon for tuna larvae in general. Salinity, likewise, showed no relationship with catches of larval Auxis. Klawe et al. (1970), however, reasoned that this lack of relationship may be due to the narrow range of salinity encountered during the period that the study was made. Salinity, however, may have an important effect under a different temperature regime. They found temperature to be clearly a highly important

Fig. 31 factor in explaining the distribution of Auxis larvae. Figure 31 shows the curvilinear relationship between average catches of larval Auxis against the surface temperature and suggests an optimum temperature of between 27.0° and 27.9°C.

In the Indian Ocean, Jones and Kumaran (1963) separated the catches of larval A. rochei made by the Dana according to depth

Table 21 of haul (Table 21). The catch rate, expressed as the number of larvae caught during a 1-h haul, was highest about 30 m below the surface but low both above and below this level. The lowest catch rate of 0.02 larvae per hour occurred at the 100- to 200-m depth.

B. JUVENILES

1. Identification

The morphological features used to distinguish the juvenile stages of Auxis from those of other tunas are from Schaefer and Marr (1948), Wade (1949), Mead (1951), and Matsumoto (1961).

The juvenile stages of Auxis can be distinguished from other tunas by the wide gap between the first and second dorsal fins and the virtually colorless appearance of the first dorsal. Compared with Katsuwonus, however, the first dorsal are somewhat similar, both having a lightly pigmented or colorless fin. Katsuwonus, nevertheless, possess more pigment in the first dorsal, which is also more or less brown or tan in color distally, whereas in Auxis, the distal portion of the first dorsal is colored by a few scattered chromatophores along several of the anterior rays. Compared with Euthynnus, Auxis are

rounder in cross-section, being relatively less compressed laterally with head length and length of the caudal region shorter in comparison to total length. Juvenile Auxis also possess a black spot at the isthmus which is seen only in one other genus, Euthynnus. In young Euthynnus, however, the first and second dorsals are continuous.

Young Auxis can also be confused with Rastrelliger and Pneumatophorus. These genera also possess the wide interspace between the dorsal fins but have only five dorsal and anal finlets in contrast to eight dorsal and seven anal finlets in Auxis.

Among other morphological features used by Schaefer and Marr (1948) to identify juvenile scombroid specimens to family Katsuwonidae and to which Auxis belongs were the vertebral count, the elongated right lobe of the liver, the presence of a caudal keel, and the absence of an air bladder. The large interspace between the dorsals, the low ray count of the first dorsal, and the absence of an elaborate "trellis" of the vertebrae placed the specimens into the genus Auxis rather than Euthynnus or Katsuwonus.

Concerning the pigmentation of juvenile Auxis, Schaefer and Marr (1948) wrote "In the smaller specimens the prominent areas of pigmentation are on the upper and lower jaws, above the snout, around the postero-ventral margin of the orbit, on the upper operculum, between the orbits, along the midline of the body, along the bases of the dorsal and anal fins including the finlets, and around the posterior end of the urostyle. Large chromatophores in the peritoneum show through the body wall along the upper half of the body cavity.

None of the fins or finlets bears pigment spots, with the exception of the first dorsal. The first dorsal bears a few scattered chromatophores, largely distributed along the spines."

The separation of juvenile Auxis into two species can be accomplished on the basis of gill-raker counts (Tables 22 and 23). Because of the small size of the specimens, errors in gill-raker counts are possible, but Wade (1949) stated that no difficulty should be experienced in specimens 25-30 mm in standard length; however, Schaefer and Marr (1948) observed that on their smallest specimens (21 mm), the gill rakers are very tiny projections and are difficult to count. The rakers, first apparent near the angle of the arch, increase in length and new rakers added distally on each arm as the fish increase in size. Schaefer and Marr judged by counts on specimens of various sizes that the full complement of rakers on A. thazard is attained at about 50 mm total length, but Klawe and Shimada (1959), who plotted the total gill-raker counts against corresponding total lengths, found that the full complement of gill rakers was attained at sizes 40 mm or larger (Figure 32). From the results of their study, Fitch and Roedel (1963) suggested that Auxis of 55 mm standard length probably had their full quota of gill rakers (Table 24).

Tables 22 and 23

Fig. 32

Table 24

Noting their specimens differed in some respects with observations made by Stark (1910) and Kishinouye (1923), Schaefer and Marr (1948) suggested that some of the specimens they examined may be juveniles of an undescribed species. Wade (1949) also suggested the possibility that Schaefer and Marr examined juvenile forms of two species of Auxis based on gill-raker counts. Schaefer and Marr

listed two specimens--52 and 54 mm total length--with gill-raker counts of 48 and 47, respectively, well within the limits of the total gill-raker counts for A. rochei. For their specimens 42, 48, and 68 mm in total length, gill-raker counts were 39, 41, and 42, respectively, which fall within the limits for A. thazard.

Concerning the gill-raker count of A. rochei, Wade (1949) noted that small specimens (32 mm) has its full complement of gill rakers (Table 23). Jones (1960) originally described 26 juvenile specimens collected from Vizhingam on the west coast of India and based on comparison with graded series available called them A.

Table 25 rochei (Table 25). But in a later paper, Jones (1961) pointed out that on reexamining the material, specimens measuring 44.0 to 132.0 mm in length cannot be definitely assigned to A. rochei; rather, they could more correctly be assigned to A. thazard. Juveniles from 181.0 to 209.8 mm, according to Jones, are unmistakably A. rochei

In the Atlantic, Klawe and Shimada (1959) examined 533 larval and juvenile Auxis ranging in size from 5.5 to 145.0 mm. They observed that the gill-raker counts of juvenile Gulf of Mexico Auxis fall within the ranges for fish from the Pacific (40-49) as reported by Godsil (1954) and for those from the Mediterranean (40-45) as reported by Postel (1956). None of the specimens, however, had raker counts that approached the upper limits observed in Pacific frigate mackerel.

One of the methods by which information on early life history of tunas, before they are recruited into the commercial fisheries, can be obtained is through the examination of stomach contents of large predators. Studies by Yoshida (1965, 1969, 1971a, 1971b) of stomach contents of large pelagic fishes have yielded a wealth of information on age and growth, distribution, and abundance of juvenile stages of a variety of tunas. In this respect, it is essential that the juvenile tunas and tunalike fishes found in the stomachs be identified accurately.

Watanabe (1964) used the following six characters, of which the first two were the most important, to identify juvenile *Auxis* collected from stomachs of predators:

1. The form of the free parapophyses. In *A. thazard*, the free parapophyses extend downward and almost touch the haemal spine of the preceding vertebra whereas in *A. rochei* they are short. This difference in length of the parapophyses is particularly evident on specimens of 111 mm or more (Figures 33 and 34).

Figs. 33 and 34

2. Gill-raker counts. For specimens examined by Watanabe, the gill-raker counts varied from 38 to 43 for *A. thazard* and 43 to 49 for *A. rochei* (Table 26).

Table 26

3. The number of the vertebra on which the first free parapophysis occurs. In *A. thazard*, it occurred most frequently on the 23d vertebra, whereas in *A. rochei*, it occurred on the 21st or 22d vertebra on 80% of the specimens; however, there were some in which it occurred on the 23d vertebra (Table 27).

Table 27

4. The number of the vertebra on which the first inferior foramen occurs. To use this character, Watanabe warns that it is necessary to take into account the stage of growth. In the young stage, the foramen occurs on the 27th or 28th vertebra in A. thazard and usually on the 29th and 30th vertebra in A. rochei (Table 28).

Table 28

5. Ratio of the length of the caudal to the precaudal vertebra. For young stages, Watanabe found the ratio to be 0.973 or less in A. rochei and 0.985 or more for A. thazard (Table 29 and Figure 35). This character also changes with growth; therefore, the stage of growth needs to be considered in making a diagnosis.

Table 29
Fig. 35

6. Ratio of the body height at the origin of the anal fin to the distance between the origins of the first and second dorsal fins. Figure 36 shows a plot of the ratios on standard lengths and except for a single specimen which showed an intermediate value, those for A. thazard tend to be higher than for A. rochei.

Fig. 36

2. Distribution

Juvenile Auxis have previously been recorded from several different parts of the world and generally occur in those areas where the adults are also captured. Figures 13 and 37 also show that the distributions of juvenile and larval Auxis are in good agreement. As Yabe et al. (1963) have suggested, the juveniles occur mostly in waters close to land masses. This is brought out in Table 30 which shows the number of juvenile tunas taken by midwater trawl in Hawaiian waters. Higgins (1970) observed that in July-September 1967, the

Fig. 37

Table 30

catch rate of juvenile Auxis sp. reached 3.5 per tow, the highest among all the young tunas collected in inshore waters off the island

Fig. 38 of Oahu (Figure 38). Offshore, the catch rate dropped to 0.2 juvenile per tow.

Although not discussed by Higgins because of the small

Table 31 sample size for frigate mackerel, it would appear from Table 31 that juveniles of Auxis are vulnerable to the midwater trawl at night rather than at other time periods of the day and that they are more readily caught in shallow tows than in deeper ones. Also, they probably do occur down to 100 m. Higgins contended that the majority of juvenile skipjack and other tunas as well are caught at the indicated sampling depths rather than elsewhere.

3. Feeding

In Japanese waters, juvenile A. rochei, which were recovered from the stomachs of yellowfin and skipjack tunas, fed on larval copepods and decapods (Kishinouye 1924).

Clemens (1956), who observed the feeding of juvenile scombroids kept in shipboard aquaria, suggested that juvenile Auxis sp. had learned to eat unnatural food that was offered them by watching other species--mahimahi, Coryphaena sp.; jacks, Caranx sp.; pompano, Trachinotus sp.; threadfins, Polydactylus sp.; and pomacentrids, Chromis sp.--feeding on it. The food offered included live planktonic organisms, ground flesh of anchovetas, Cetengraulis mysticetus; yellowfin tuna, skipjack tuna, and mahimahi, particles of coagulated

fish blood, and mahimahi eggs. Clemens added that competition for food appears to be of fundamental importance in inducing the young scombroids to feed. In a tank with a large number and variety of fish that splashed and moved about the tank swiftly and voraciously striking at everything in sight, the juvenile frigate mackerel soon commenced feeding.

Fish constitutes an important part of the diet of juvenile Auxis. Thomas and Kumaran (1963) and Kumaran (1964), reporting on the food and feeding habits of 11 juvenile A. thazard (49-132 mm) and 31 pre-adult A. rochei (170-252 mm) taken in Indian waters, observed that among small specimen of juvenile A. thazard of less than 75 mm, fish constituted 88% and crustacea 12% by volume with squid entirely
Fig. 39 absent (Figure 39). In larger specimens of 75 mm or more, fish formed 39% and crustacea 42% by volume with squid very infrequent. Anchoviella sp. and Leiognathus sp. were the most common among the fish species consumed.

4. Abundance

Table 32 On the basis of Tables 30 and 32, the relative abundance of juvenile tunas is highest for skipjack tuna in Hawaiian waters during the summer, followed by yellowfin tuna, which was estimated at 2.2 juveniles per tow (Higgins 1970). For other tunas, the estimates were 1.6 per tow for frigate mackerel and below 1.0 per tow for bigeye tuna, albacore, and kawakawa.

C. ADULTS

1. Behavior

Most studies on tuna behavior require direct observations and among the behavior most intensely studied are feeding and schooling behavior. Data relevant to tuna behavior also have been collected through indirect methods such as examination of stomach contents, distribution of catches such as on longline, and catch records of commercial fishing vessels.

a. Feeding behavior

Scombroids usually swim to the shallower strata of water at night and return to the deeper layer in the daytime (Kishinouye 1923). This type of vertical migration is the result of following the movement of plankton and the fishes that feed on them.

Frigate mackerel use their caudal fins to hold their position in swift currents to capture food which drifts down to them (Imamura 1949). They have also been observed to migrate away from the swift currents in search of food and school near the surface during morning and evening and also during periods of cloudy weather.

Uchihashi (1953) studied the ecology of teleosts in Japanese waters in relation to brain morphology and concluded that *A. rochei* seeks food not only by sight but also by their lateral line senses.

b. Schooling

The schooling instinct, according to a number of sources, is very strong and disciplined in frigate mackerel. According to Jones (1963), the tendency of A. rochei to school and form large shoals is strong not only among the adults but also among juveniles. Apparently, like other scombroids, individuals tend to school by size because those landed are more or less of the same length. The fish scatter when disturbed but soon school again.

Nakamura (1938) observed that dense schools of Auxis sp. migrate into coastal waters of Taiwan during certain times of the year. In the Ryukyu Islands, schools of A. thazard appear in large numbers in midsummer (Shapiro 1949). In Australian waters, schools of A. thazard composed of hundreds of individuals appear in the southwestern part of the continent in the summer (Serventy 1941). But in Japanese waters, Imamura (1949) observed that A. thazard do not form large schools.

In East African waters, schools comprised of 100 to 1,000 fish are observed and those around the Seychelles Islands are described as "large" (Wheeler and Ommanney 1953).

There are also reports indicating that A. thazard are found mixed with A. rochei and also with other tuna and tunalike fishes. In Hawaiian waters, Gosline and Brock (1960) reported that frigate mackerel are occasionally found mixed with schools of kawakawa Euthynnus yaito. Matsumoto (1960) has reported capturing both A. thazard and A. rochei from the same school. Similar observations

were made by Kishinouye (1915) of frigate mackerel in Japanese waters and by Jones (personal communication with Matsumoto 1959) of those that occur in Indian waters. Imamura (1949) has observed that A. thazard in Japanese waters are also found occasionally mixed with skipjack tuna.

There also appears to be some evidence that frigate mackerel schools distribute themselves throughout the water column by size. Morita (1972), who studied the movement of tagged A. rochei off Japan, indicated that small fish usually schooled near the surface and moved faster than schools of large fish, which usually occupied the middle and deeper layers of the water column.

c. Adaptability to environment

Yasui (1975), who made some observations on frigate mackerel which migrates into Japanese waters, took 16 external body measurements and examined their relationship to body length. The results of his measurements were divisible into three categories: minus growth in relation to body length, no growth, and positive growth. He observed that minus growth was restricted to the cephalic region, that no growth occurred in the pectoral region, and that positive growth occurred only in the caudal region. He concluded that adult fish within the size range he examined (18.2-37.5 cm) had greater swimming power and, hence, greater feeding capability than young fish.

2. Competitors

In general, the frigate mackerel live in competition with other tuna and tunalike fishes during all stages of their lives. Reports on food studies indicate that most of the organisms the frigate mackerel consume are also part of the diet of other tuna and tunalike fishes; therefore, most pelagic fishes are potential competitors with *Auxis* for food.

More specifically, Gosline and Brock (1960) have observed that in Hawaiian waters, *A. thazard* are sometimes caught from a school that is mixed with kawakawa.

In Japanese waters, Yokota et al. (1961) listed, by type of gear, the various species usually taken and presumably in competition with the frigate mackerel. These are given in Table 33.

Table 33

A. thazard was listed by de Jager et al. (1963) as a possible competitor occurring in association with yellowfin tuna, albacore, bluefin and bigeye tunas in African waters. Other possible competitors of these tuna species and perhaps of *A. thazard* also are given below.

Blue shark, *Glyphia glaucus*
Mako shark, *Isurus glaucus*
Brown shark, *Carcharhinus obscurus*
Thresher shark, *Alopias vulpinus*
Moonfish, *Lampris regius*
Angelfish, *Brama raii*
Mackerel, *Scomber japonicus*
Lancetfish, *Alepisaurus ferox*
Stockfish, *Merluccius capensis*

Snoek, Thyrsites atun
Yellowtail, Seriola lalandii
Skipjack tuna, Katsuwonus pelamis
Gannet, Morus capensis
Cormorant, Phalacrocorax capensis
Cape penguin, Spheniscus demersus
Wandering albatross, Diomedia exulans
Cape fur seal, Arctocephalus pusillus
Sperm whale, Physeter catodon
Sei whale, Balaenoptera borealis

Jones (1963) reported on competitors of A. rochei in Indian waters. In addition to A. thazard with which A. rochei frequently associate, Jones listed Megalaspis cordyla, Stromateus niger, and Euthynnus affinis as other species commonly caught with A. rochei in gill nets. For A. rochei taken by hook and line, Jones listed carangids, seerfishes, thunnids, and perches.

3. Parasites

Table 34

Table 34, extracted from Silas (1967a) and Silas and Ummerkutty (1967) gives the monogenetic and digenetic trematodes, cestodes, and copepods that are parasitic on frigate mackerel.

4. Biochemistry

The relationship between sexual maturity and the amount of iron, copper, and zinc in various body tissues of A. rochei was examined by Suzuki and Morio (1957) for fish in various stages of sexual maturity. Their results showed that in the liver, the iron content decrease progressively with maturation, is at a minimum

when the gonads become ripe, then increase significantly when the gonads are spent (Figure 40). The contents of copper and zinc show a similar tendency to decrease with maturation but the minimum is reached at a stage when egg formation is still continuing in the ovaries (Figures 41 and 42).

Fig. 40

Figs. 41 and 42

Suzuki and Morio also determined that there is a negative correlation between the fat content of the liver and the amount of iron and copper (Figure 43). The relationship, however, is not consistent; it tends to break down in fish that have gonads approaching the ripe stage.

Fig. 43

Concerning molybdenum and nickel in the tissues of A. rochei, Morio and Suzuki (1959) determined that the former occurred in highest concentration in the liver whereas the latter showed up highest in the pyloric caeca (Table 35). Further analysis indicated that the contents of molybdenum and nickel in the liver showed no relationship to sexual maturity, rate of growth, and area of catch.

Table 35

5. Food

There is little information on the type of food consumed by frigate mackerel taken in the central Pacific. Tester and Nakamura (1957) examined the stomach contents of two frigate mackerel taken in Hawaiian waters off Kaneohe Bay, Oahu and found that they had fed on crab megalops, stomatopod larvae, anomuran larvae, and octopus.

In Japanese waters, Auxis feed on plankton and fishes such as Atherina sp., Stolephorus sp., Spratelloides sp., and

immature Engraulis sp. (Kishinouye 1923). Concerning A. rochei, Okada (1955) observed that they fed on small pelagic organisms, anchovies, silvery anchovies, silversides, and other small fishes. Of A. rochei taken in Australian waters, Whitley (1964) found the stomach crammed with anchovies and young mullet.

Yokota et al. (1961) examined A. thazard caught by trolling in Japanese waters in June 1959 and discovered that their diet included the young of skipjack tuna as well as frigate mackerel. Among the other items in their diet were jack mackerel, flyingfishes, filefishes,
Table 36 Mene maculata, Spratelloides japonicus, anchovy, and squids (Table 36). Concerning A. rochei, Yokota et al. (1961) found that whereas those caught by trolling ate anchovy as the principal food with other items occurring only infrequently, those taken in set net fed predominantly on jack mackerel with anchovy next in importance. Spotted mackerel and lizardfish were also found in fair numbers in stomachs of fish caught by set net but were usually absent in stomachs of
Table 37 fish taken by trolling (Table 37).

Morita (1972) also reported on stomach contents of A. rochei taken off Japan by pole-and-line vessels and set nets. The most common food items he found were Mysis, Sardinia, Spratelloides, Teuthoidea, and Scomber. Attempting to find the maximum size of fish eaten and also the total weight of food consumed by different sizes of A. rochei, Morita plotted these variables against body lengths of A. rochei and derived formulas for calculating them. For the relationship between length of prey and body length of the predator, he calculated the following formula:

$$Y = -0.015X^2 + 0.358X + 9.075$$

where X = length of predator in centimeters

Y = length of prey in centimeters.

Fig. 44 The curvilinear relationship can be seen in Figure 44.

The linear regression describing the relationship between

Fig. 45 weight of stomach contents and body length is shown in Figure 45. The equation is as follows:

$$Y = 2.33X - 40.78$$

where X = length of A. rochei

Y = weight of the stomach contents in grams.

More information is available on food studies from the Indian Ocean. Nath (1962) stated that frigate mackerel definitely avoid phytoplanktonic food but show preference for crustaceans, small fish and fish larvae. Among the species commonly consumed were crustaceans such as Rhopolophthalmus sp., Hyperia bengalensis, Oxycephalus clausi, Pseudophausia latifrons, Acetes erythreus, and Squilla larvae. Pteropods were relatively unimportant in the diet. The most common fish found in the stomach was Anchoviella commersoni.

Among the pre-adult specimens of A. rochei, Kumaran (1964) also found fish the most important item of food, constituting 42%

Fig 46 by volume and found in 80% of the samples (Figure 46). Crustacean formed the next item of importance accounting for 24% by volume and found in 77% of the samples. Cephalopods formed 22% of the food consumed. Sardinella sp., Anchoviella sp., Leiognathus sp., and

Table 38 carangids were the fishes most frequently consumed (Table 38). Among the crustaceans, larvae of megalops and Alima and mysids predominated. Kumaran also discovered that larval stomatopods and Lucifer constituted a major portion of the diet of some specimens captured near Quilandy on the west coast of India. Other items of food occasionally seen were chaetognaths, halobates, and polychaetes.

6. Predators

The frigate mackerels, according to several studies, constitute a significant part of the food of adult tunas and billfishes. Predators listed by several investigators are as follows:

Tunas

Albacore (Kishinouye 1917; de Jager et al. 1963; Dragovich 1969)

Bigeye tuna (Kishinouye 1917; King and Ikehara 1956; Yokota et al. 1961; de Jager et al. 1963; Watanabe 1964

Bluefin tuna (Yokota et al. 1961; de Jager et al. 1963)

Bonito (Kishinouye 1923; Ronquillo 1953; Dragovich 1969)

Skipjack tuna (Kishinouye 1917; Ronquillo 1953; Yokota et al. 1961)

Yellowfin tuna (Kishinouye 1917; Nakamura 1936; Mead 1951; Ronquillo 1953; King and Ikehara 1956; Yokota et al. 1961; Alverson 1963; de Jager et al. 1963; Watanabe 1964; Dragovich 1969)

Billfishes

Black marlin (Nakamura 1942; Watanabe 1964)

Blue marlin (Krumholz and de Sylva 1958; Erdman 1962)

Sailfish (Jones 1958)

Striped marlin (Royce 1957)

Other species

Barracuda (Idyll and de Sylva 1963)

Mahimahi (Ronquillo 1953)

Thresher shark (Whitley 1964)

Tiger flathead (Whitley 1964)

Wahoo (Idyll and de Sylva 1963)

Perhaps because of their abundance, *Auxis* is considered an element of forage which occupies an important position in the food chain. In the eastern Pacific, *A. thazard* is of no commercial importance but this species, according to Alverson (1963), contributes to the tropical skipjack tuna and yellowfin tuna fishery indirectly because it forms a significant proportion of the food of adult yellowfin tuna. In the western Pacific, Suda (1953) observed that because of their abundance, skipjack tuna is important in the forage of tunas and billfishes in oceanic areas. Watanabe (1964), on the other hand, believes that *Auxis*, because of their distribution and abundance close to land masses, forms the main part of the forage of tunas and billfishes that are similarly distributed.

In Australian waters, Whitley (1964) noted that *Auxis* constituted a significant proportion of the stomach contents of the commercial tiger flathead, *Neoplatycephalus richardsoni*.

In waters around Africa, de Jager et al. (1963) listed A. thazard as one of the most important among the fish found in the stomach contents of tunas taken there.

Erdman (1962), who examined stomachs of blue marlin caught in the sport fishery off Puerto Rico, found that fishes were the chief food with A. thazard constituting the most frequent item. The results of Erdman's study also showed that blue marlin fishing was better than average whenever frigate mackerel occurred in abundance as indicated by good catches of this species on trolling lines or by beach seine.

Concerning size of frigate mackerel consumed, Klawe (1963) noted that specimens of A. thazard found in the stomachs of skipjack,
Table 39 yellowfin, and little tunas varied from 60 to 125 mm (Table 39). Krumholz and de Sylva (1958) reported that frigate mackerel ranging in size from 200 to 250 mm have been recovered from stomachs of blue marlin caught near Bimini in the Bahamas. Watanabe (1964) has shown that frigate mackerel up to 320 mm still fall prey to large predators
Table 40 like tunas and marlins (Table 40).

7. Condition Factor

Table 41 Table 41 shows the condition factor (K) of A. thazard captured in the trap-net fishery in 1961 at La Linea, located on the Mediterranean Spanish coast near the Strait of Gibraltar. Condition factor or coefficient of condition is interpreted as expressing the relative well-being of the fish. It is used occasionally to indicate suitability of an environment or to compare fish from one

area with a general average for an entire region. Older fish tend to gain proportionately more in weight than in length; therefore, the value of K increases with age. The formula for K is

$$K = \frac{100,000W}{L^3}$$

in which W = weight in grams

L = standard length in millimeters

(Rounsefell and Everhart 1953).

Rodriguez-Roda (1966) examined the condition factor of A. thazard taken at La Linea and concluded that the average values of K for each length group were usually larger for males than for females (Table 41). Furthermore, he noted that the values of K decreased from May to August, but increased in September which coincided with the spawning period. Comparison of K among the size groups showed no significant differences.

Ishida (1971) calculated a factor for fatness of Auxis caught off Japan. Between the two species, he found A. thazard caught at both Mikomoto and Shionomisaki had higher indices of fatness compared
Table 42 with A. rochei (Table 42). Between areas, there appeared to be no appreciable difference.

8. Hardiness

The literature contains no direct evidence in reference to the hardiness of frigate mackerels. Kishinouye (1923) stated that the salinity preference of scombroid fishes differs widely for different species. For fishes of family Scombridae and Cybiidae, he

estimated a density preference from 1.022 to 1.025. Plecostean fishes, according to Kishinouye prefer a high density between 1.025 and 1.027. He added that Auxis are sometimes found in littoral waters of low density and apparently are not affected.

9. Growth

Hotta (1955), who collected length data of A. rochei caught in the northeastern sea area off the Pacific coast of Japan, used monthly length-frequency histograms and by following the progression of the modal lengths during the fishing season, he was able to estimate the growth of A. rochei. He constructed a growth curve depicting body length at ages 0-IV. From the curve, shown in Figure
Fig. 47 47, it appears that A. rochei reach about 17 cm 1 year after hatching. Compared to results on larval growth obtained through artificial fertilization, however, the rate of growth estimated from modal progression of length-frequency data appears to be rather slow. Harada, Murata, and Furutani (1973) estimated that larvae of A. rochei under the best condition grew to 15.7 cm in 52 days (Figure 27).

10. Length-Weight Relationship

The length-weight relationship is useful not only to the biologist in converting length-frequency data to weight-frequency data and vice versa but also is of value to fishermen as well. Technologically, it can help the fishermen determine how many fish of a particular size he must catch to achieve a particular tonnage. It has only been within the last decade that studies describing the length-weight relationship of frigate mackerel have appeared in the literature.

From the western Pacific, Ishida (1971) calculated the length-weight relationship of A. thazard and A. rochei caught off Mikomoto and Shionomisaki (Table 43). The expression for the relationship is

Table 43

$$W = aL^n$$

in which W = weight in grams

L = length in centimeters

a and n = constants.

Yasui (1975) also calculated a length-weight relationship for A. rochei taken by set nets, trolling, and gill nets in waters around Hachijo Island in the Izu Archipelago and Mera in Shizuoka Prefecture (Table 43 and Figure 48).

Fig. 48

For the Indian Ocean, Sivasubramaniam (1966) has calculated the length-weight relationship for A. thazard and A. rochei taken in waters surrounding Sri Lanka (Table 43 and Figures 49 and 50). The expression for this relationship uses weight in ounces and length in centimeters.

Figs. 49 and 50

For A. thazard caught in Spanish waters around Barbate, Tarifa, and La Linea, which are located in and around the Strait of Gibraltar, Rodriguez-Roda (1966) calculated a length-weight relationship, based on 744 fish (Table 43). Table 44 gives the average and calculated weights for the length groups studied by Rodriguez-Roda and Figure 51 depicts the length-weight relationship.

Table 44

Fig. 51

For the Atlantic Ocean, Lenarz (1974) calculated a length-weight relationship for Auxis sp.; the statistics for the relationship computed and the data used in the study are given in Table 43.

In order to compare the various length-weight relationships, the weight in grams of a frigate mackerel 30 cm in length was calculated. Table 45 shows the results of the calculations.

Table 45

For a 30 cm A. thazard, the calculated weights varied from 391 to 453 g. These extremes were calculated from equations derived by Ishida (1971) for fish caught off Mikomoto and Shionomisaki in Japanese waters. Equations derived by Rodriguez-Roda (1966) and Sivasubramaniam (1966) gave calculated weights that were almost identical.

Concerning A. rochei, the extremes were 391 g from the equation supplied by Yasui (1975) and 511 g from that calculated by Sivasubramaniam (1966). The smaller value is not dissimilar from those calculated by Ishida's (1971) equations. The high from Sivasubramaniam's equation may be the result of a small sample size (28 fish).

11. Greatest Size

Collette and Gibbs (1936b) observed that in the Indian Ocean, A. thazard reaches at least 42 cm whereas A. rochei attains about 60 cm. Whitley (1964), however, listed the maximum size of A. rochei from Australian waters as about 43 cm.

In the eastern Atlantic, the maximum size of A. thazard has been reported as 66 cm (Collignon 1960). Talbot (1964) estimated that in African waters, A. rochei attains about 60 cm but specimens over 50 cm are rarely seen in the catch. Idyll and de Sylva (1963) reported that the largest specimen of A. thazard seen by the junior author was 39 cm which was removed from the stomach of a dolphin caught off Miami, Florida.

VI. RESOURCE

Frigate mackerel usually are caught together with other species as there are few if any specific fishery or attempts made by the fishermen to catch them.. In the following sections, the fisheries for frigate mackerel, either as the principal species or incidental species, are discussed by oceans. Figure 10 shows the fishing areas of A. thazard and A. rochei on a worldwide basis.

A. PACIFIC OCEAN

1. Japan

Japan lands, by far, more frigate mackerel than any other country and is in fact, the only country with a well-established fishery that lands commercial quantities of frigate mackerel. In 1953-73, the catch of frigate mackerel averaged 25,400 MT (metric
Table 46 tons), varying from 15,600 MT in 1953 to 48,300 MT in 1963 (Table 46).

Okachi (1958), who established the fishing areas for Auxis in Japanese waters through examination of catch statistics, discovered that almost all the frigate mackerel caught in the Japan Sea were A. rochei whereas catches of A. thazard were infrequent. By regions, he found that the South Pacific region had 62% of the catch and the middle Pacific region 22% whereas the Japan Sea and East China Sea regions produced only 12%. Usually, catches from the west Japan Sea region and the East China Sea region were about equal whereas catches
Table 47 in the north Japan Sea region were smaller than either one. Table 47
Table 48 gives the catches of these regions in 1952-56, Table 48 gives the catches

Table 49 for larger areas around Japan in 1960-73, and Table 49 gives the names of the prefectures in each region. The locations of these

Fig 52 prefectures are shown in Figure 52.

Yamashige (1974) also studied the catches of A. rochei from Japanese waters. He calculated the mean, standard deviation, and coefficient of variation of the annual catches of A. rochei in

Table 50 1952-61, 1961-71, and 1952-71 and these are given in Table 50. His study showed that the catches of tunalike fishes, which for the most part consist of A. rochei but also include small amounts of A. thazard, S. orientalis, and E. yaito, tended to increase after 1963 in all regions except in the North Pacific region.

According to Yokota et al. (1961), frigate mackerel are caught in Japanese waters by a variety of gear including pole-and-line, trolling lines, and set net. In the Japan and East China Seas, the main fishing gear for frigate mackerel is the set net or trap net which produces the largest proportion of the catch (Okachi 1958). Trap-net fishing in the Japan Sea is more active in some prefectures than in others; therefore, catches are high in prefectures such as Niigata, Toyama, Ishikawa, Fukui, Kyoto, and Yamaguchi where trap-net

Table 51 fishing is very intensive (Table 51). In the East China Sea region, Nagasaki and Kagoshima Prefectures produce the bulk of the catch with other prefectures contributing only small quantities.

Japanese trap net or set net consists of a leading net that may be as deep as 100 m and stretches as far as 4,000 m offshore (Asia Kyokai 1957). Shaped like a cube, the bag is set near the coast and may be 5 m deep. Fishermen tending these traps wait for migrating schools that travel close to shore. Trap nets are drawn up twice a day, usually in the morning and again in the evening, but the time of hauling may vary with the size of the catch in the net.

2. Taiwan

In Taiwan, frigate mackerel are caught by trolling lines, purse seines, gill nets, and set nets (Kume 1973). Table 46 shows the catch of frigate mackerel from Taiwan for 1961-68. Examination of the catch statistics from Taiwan for the years 1958-63 (FAO 1964) showed the catches to be rather high. In 1961-63, for example, they were as follows:

Year	Catch (1,000 MT)
1961	11.9
1962	18.2
1963	15.1

But in FAO (1967), the frigate mackerel catches in 1961-63 were listed as follows:

Year	Catch (1,000 MT)
1961	0.7
1962	0.8
1963	0.6

Further research into the method of compiling catch statistics indicated that data from FAO (1964) included other species under frigate mackerel. Kume (1973) revealed that Taiwan uses a category called "bonito" in which are included frigate mackerel as well as little tuna and perhaps other small tunas. Kume gave the "bonito" catch for 1970 as 15,500 MT but estimated that of this total, only 778 MT or roughly 5% were frigate mackerel. Furthermore, the frigate mackerel catches in 1961-63 as given in FAO (1967) amounts to only 4% to 6% of the catches as given in FAO (1964). Therefore, it can be presumed that roughly 5% of the catches of frigate mackerel in Taiwan as given in FAO (1964) are actually of this species with the remainder constituting catches of various other small tunas. In 1961-68, the Taiwan catches of frigate mackerel varied between 600 and 1,200 MT and averaged 900 MT.

3. Philippine Islands

The Philippine Bureau of Fisheries (1973) lists frigate mackerel as one of the common and commercially important pelagic fish species that are usually caught by purse seines and bag nets. The major fishing grounds for the pelagic fishes are concentrated in the coastal and shallow seas between the many islands of the Philippine group. Specifically, they include the northern Palawan area, Manila Bay, Sulu Sea, Visayan Sea, Sibuyan Sea, Sibugyay Bay, Tayabas Bay, Davao Gulf, Lamon Bay, and Samar Sea.

In June-October, when the southwest monsoon prevails in the region of the Philippines, fishing for pelagic species is restricted to shallow waters and during calm weather in open waters. Tropical storms at this time originate east of the Philippines; therefore, exploitation of the pelagic fish resources east of the Philippines is limited. The fishing seasons for frigate mackerel for different parts of the Philippines are shown in Table 52. Annual catches for 1972 and 1973 are given in Table 46.

Table 52

To accelerate commercial development of pelagic fisheries in the Philippines, chartered commercial purse seiners and research and survey vessels under the South China Sea Fisheries Development and Coordinating Programme have been active in exploratory work involving the detection and estimation of the abundance of the pelagic resources. Rosenberg and Simpson (1975), reporting on voyage 3 of the purse seiners Royal Venture and Southward Ho, stated that during the period when both vessels worked the southeasterly portion of Moro Gulf, many floating logs were discovered, some of which had good signs of tuna. The total landings of the two vessels, by species, are shown in Table 53.

Table 53

Rosenberg and Simpson also observed that although roughly two-thirds of the catch were composed of skipjack tuna, considerable quantities of little tuna and frigate mackerel were also taken by the seiners. Large quantities of the latter two species are consumed fresh in the Philippines, but there is no market for them when frozen. It is anticipated however, that as the cost of animal protein rises

throughout the world, these species will eventually find a ready market in the frozen or some other state.

The total landings of the two vessels after voyage 4 are given in Table 54. Reporting on the results of this voyage, Rosenberg, Simpson, and Renwick (1975) observed that the seiner Southward Ho usually landed less frigate mackerel than the Royal Venture. The reason was that the Southward Ho's slightly larger mesh size in the bunt section of the seine; therefore, the frigate mackerel, which is smaller than either skipjack or yellowfin tunas, tended to gill and had to be discarded.

Table 54

4. Thailand

Besides Taiwan and the Philippines, other countries that harvest frigate mackerel in the South China Sea region are Sabah, Sarawak, Thailand, and West Malaysia (Table 55). In Thailand, the landings of *Auxis* sp., *E. affinis*, and *T. tonggol* are combined and called "bonito" or "pla o" locally in the catch statistics (Kume, 1973). Caught mostly by Thai and Chinese purse seiners, these species are fished mostly at night in the Gulf and along the west coast of Thailand. Catches are usually good during the latter half of the year. In 1971, Thai and Chinese seiners landed 5,090 MT or 78% of the 6,548 MT of "bonito" reportedly caught in Thailand.

Table 55

5. West Malaysia

In West Malaysia, more than half of the Auxis sp., together with E. affinis and T. tonggol, are caught by handlining, trolling, and small-scale longlining, whereas the rest are taken by seine nets and drift gill nets (Kume 1973). Trolling, however, is the principal gear on the east coast whereas this gear is less productive on the west coast. Penang on the west coast and Trengganu on the east coast are the main ports of landing. The catches of these small tunas are better during the latter half of the year. In 1958-71, the production of these three species combined, called "little tunas" in Table 56, varied between 789 MT in 1959 and 5,578 MT in 1967 and averaged 3,131 MT annually.

Table 56

6. Hawaii

Frigate mackerel taken in Hawaiian waters are only of slight commercial importance (Gosline and Brock 1960). Usually, frigate mackerel or keokeo as they are known in Hawaii, are taken incidentally in skipjack tuna fishery operations; therefore, landings are very small.

7. Australia

In Australia, frigate mackerel are also of very little commercial value (Serventy 1941). Although large schools of frigate mackerel are seen and caught by beach seining during the summer months in southwestern Australia specimens that do appear on the market are usually sold cheaply as bait; thus, the economic feasibility of commercially exploiting this species has yet to be demonstrated in Australia (Roughley 1951).

B. INDIAN OCEAN

1. India

Most common among the tuna species landed from Indian waters is E. affinis followed by T. tonggol. Small numbers of Auxis are also captured in the tuna fishery along the coast of India (Jones 1967). Of the two species of Auxis landed in India, A. thazard are the most common whereas A. rochei are rarely seen in the commercial catch. Occasionally, however, A. rochei occur in very large schools close to shore and considerable quantities are landed by beach seine (Jones and Silas 1964).

The fishery for A. thazard in Indian waters is seasonal. They are caught along with other tunas from about August to December. There is no selective gear for this species; they are caught by beach seines, drift nets, trolling gear, and pole-and-line (Nair et al. 1970). Silas (1967b), however, reported that frigate mackerel were very rare in the multiple troll catches made along the Tinnevelly coast in the Gulf of Manar. In the Laccadive Islands, which are part of the territory of the Republic of India, they are caught in small numbers together with skipjack tuna on pole-and-line and troll gear. Fishing vessels, generally consisting of dugout canoes and catamarans, fish mostly within inshore waters. Thomas (1967) revealed that Auxis are taken in the Laccadive Islands but that catches of this species were usually combined with those of "other fishes" such as E. affinis, Acanthocybium solandri, Istiophorus gladius, Elagatis bipinnulatus,
Table 57 Caranx sp., Chorinemus sp., and sharks (Table 57). Sivasubramaniam

(1974) estimated that the frigate mackerel catches in India account

Table 58 for about 5% of the tuna and tunalike catches (Table 58). It is also apparent from the data that the west coast of India yielded about 200 MT of frigate mackerel annually, or about 5 times more than the annual catch from the east coast. In 1971-73, India's frigate mackerel catches averaged 240 MT annually.

For a little over a decade, India has been active in upgrading her tuna-fishing capability. In January 1962, the Indo-Norwegian Project made available to the Central Marine Fisheries Research Institute of India, the research vessel Varuna for fishery and oceanographic surveys in the Indian Ocean (Silas 1969). Among the work conducted was exploratory fishing the offshore and oceanic areas to discover new resources of tunas and billfishes, estimate their abundance, design gear suitable for capturing them, and under the environmental factors affecting their distribution.

Two types of gear--drift net and purse seine--were used in exploratory fishing. Each unit of the nylon drift net was 25.85 m long and 6.10 m wide. Five mesh sizes were used--2.5, 5.5, 10.0, 12.5, and 17.0 cm. The smaller mesh sizes were used primarily to capture juvenile pelagic fishes to learn more about their early life history.

Both species of Auxis were taken by the drift net in the

Fig. 53 continental shelf area as well as in the oceanic area. Figure 53 shows the number of sets made with the drift net, the number of specimens collected, the average weight, and the length-frequency distribution of the tunas taken.

Silas pointed out aspects of the drift-net fishing results that were of significance. Where previously both A. thazard and A. rochei were reported to occur only sporadically along the southwest coast of India and the Laccadive Sea, the results indicated that both species occur in fair abundance in inshore as well as oceanic waters. Furthermore, "silent" surface schools (not defined by Silas) of A. rochei were very frequently found at dusk over the shelf edge.

Concerning exploratory purse seining in Indian waters, Silas reported that the initial attempt by the Research vessel Varuna in the Laccadive Sea was unsuccessful. Subsequent attempts by the motor vessel Tuna with the Varuna doing the scouting were reasonably successful. The purse seine used in the exploratory work was 540 m long and 67 m wide with a mesh size of 10 cm. Of 38 purse seine operations, 10 were successful with the maximum catch exceeding 10 MT in one instance. The catch was mainly composed of schools of E. affinis and A. thazard. Figure 54 shows the locations of the purse seine operations, catch per operation, and sizes of tuna caught whereas Table 59 gives the range in length of A. thazard and A. rochei and the average weights of the specimens collected. Of these early attempts to use the purse seine to capture tuna in Indian waters, Silas remarked that they were not highly successful because the net was not sinking fast enough to prevent the schools from escaping and that the crew was inexperienced in this type of fishing. The failures, he felt, should not deter from further attempts at purse seining.

Fig. 54

Table 59

2. Maldive Islands

Information on the tuna fishery operating in the Maldive Islands, which attained independence in 1965, was obtained through the courtesy of Dr. K. Sivasubramaniam (personal communication; information extracted from a project report--Tuna Canning Plant--prepared by India for the Government of the Republic of Maldive in 1974).

The tuna fishery in the Maldives is carried out by sailing vessels; therefore, fluctuations in the catches are associated with various environmental conditions such as wind direction and velocity and ocean surface currents. In 1972, the Maldivian fishing fleet had an estimated 5,100 fishing vessels which included 2,980 trolling vessels (called vadu dhony) and 2,100 pole-and-line tuna fishing vessels (called mas dhony) operating within a 46-km radius of the islands.

The vadu dhony or trollers are about 6.1 m long and 1.8 m wide. Each vessel usually fishes 3-4 baited trolling lines. Concerning the traditional pole-and-line tuna fishing vessel, the mas dhony are about 10.7-12.2 m long, 3.4 m wide, and have a draft of nearly 0.8 m. The vessels are constructed of coconut wood, beautifully streamlined, and keeled for windward sailing. Compartments for carrying live bait have continuous water circulating through holes along the bottom of the compartments. The fishermen fish at the stern atop a U-shaped removable wooden platform.

Live bait used in the Maldives includes dussumierids, apogonids, caesiodids, pomacentrids, labrids, and atherinids. Collected from the shallow lagoons of the numerous atolls in the archipelago, bait is sufficiently abundant so that fishing at a much higher intensity throughout the year is possible. Skipjack tuna, yellowfin tuna, little tuna, and frigate mackerel are the main species caught by the pole-and-line vessels. The method consists of a combination of bait-throwing, water spraying, and hooking with pole-and-line. Hiebert and Alverson (1971) pointed out that one of the factors hindering the development of the Maldivian tuna fishery is the limited access of the vessels to more distant fishing grounds. Lack of refrigeration also precludes long trips; therefore, the tuna fishing vessels leave port for the fishing grounds at about 3 a.m. and return to port late in the evening. It has been suggested that the introduction of motorized, refrigerated vessels can increase the present fish catch 3 to 4 times.

In 1965-73, the catches from the Maldives have fluctuated between 1,700 MT in 1970 and 6,200 MT in 1973 and averaged 3,000 MT annually. There are serious discrepancies in the catch statistics
Table 60 given in Tables 46 and 60. For 1970 and 1971, Sivasubramaniam (1974) gave the catch of frigate mackerel from the Maldives as 1,700 MT and
Table 61 1,800 MT, respectively. Data in Table 61 indicate catches of 3,094 MT in 1970 and 26,871 MT in 1971. Based on landings in 1965-69 and in 1972-73, it appears that the 1971 catch in Table 61 is unreasonably high. Furthermore, FAO (1974) estimated the 1970 frigate mackerel catch

to be 20,000 MT and the 1971 catch as 26,900 MT, also unreasonably high; therefore, until these discrepancies can be corrected, data from Sivasubramaniam (1974) will be accepted as more reasonable.

Table 62 Table 62 gives the monthly catches of frigate mackerel combined with those of little tuna for large and small fishing vessels. In 1965, catches of these two species in the Maldives peaked in January, declined sharply in February-May, then fluctuated irregularly until September after which the catch rose to a second minor

Fig. 55 peak in November before declining again in December (Figure 55).

3. Sri Lanka

In waters around Sri Lanka frigate mackerel are caught on a commercial scale from all the main fishing grounds (Sivasubramaniam 1968). Being the smallest member of the tuna and tunalike fishes, the frigate mackerel's contribution to the total catch, by weight, is 15% to 20% but it is the most abundant of all the tuna varieties in the waters around Sri Lanka.

Limited to coastal waters within 28 km of the island, Sri Lanka's tuna fishery exploits four species of tuna of which "baleya" or skipjack tuna is the predominant species followed by "attavalla" or mackerel tuna, E. affinis, "kelawalla" or yellowfin tuna, and "alagoduwa" or frigate mackerel (Sivasubramaniam 1965). Other species of less importance are the "thora-baleya" or bonito, Sarda orientalis,

Fig. 56 and "asgedi kelawalla" or bigeye tuna. Figure 56 shows the relative importance of each species in the catch; the histograms are further subdivided by type of gear used. Because of the coastal nature of

the fishery, Sri Lanka's tuna catch is highly influenced by the smaller species of tuna.

Frigate mackerel are caught throughout the year in the southwest and south coasts of Sri Lanka. Sivasubramaniam (1968) reported that although both species appear in the commercial catches, A. thazard contributes 92% and A. rochei 8% of the total annual production.

Five types of gear are used to exploit Sri Lanka's tuna resources--longline, pole-and-line, trolling line, drift net, and beach seine. The longline is used for large, deep-swimming tunas and will not be discussed here. The remaining four are used in varying degrees to catch frigate mackerel.

The beach seine is not a selective gear for schools of frigate mackerel; therefore, the catch of frigate mackerel produced by this method is insignificant (Sivasubramaniam 1965, 1968). Beach seining for frigate mackerel, made possible because some schools migrate very close to shore in places like Tangalle, Udapu, and Trincomalee, operates within 0.9 km of shore and requires about 30 men for hauling.

The trolling gear, the most important among the types of gear used for capturing frigate mackerel, is an adaptation of the salmon troll and, therefore, is unlike the standard tuna trolling gear used extensively by the Japanese and U.S. fishermen (Sivasubramaniam 1965). Consisting of three main lines each with 30 branch lines ending in jigs, the trolling gear is well suited for Sri Lanka's waters

because of the denseness of the schools of frigate mackerel and mackerel tuna (Sivasubramaniam 1968). Trolling, usually limited to the morning hours when the frigate mackerel schools are at the surface and lasting 3-5 h, is very effective during periods when the seawater is turbid; therefore the gear is popular during monsoons. The gear was formerly operated from "orus" (outrigger canoes with sail) but the results were poor because of the difficulty involved in maneuvering the vessel. Nowadays, 3.5-GT motorized vessels, manned by crews of at least three fishermen, are used and because of their efficiency of operation, have become popular in fishing the various species of tunas. Trolling contributes over 50% of the total frigate mackerel production and the vessels average about 9 kg of fish per day.

Pole-and-line fishing vessels in Sri Lanka concentrate primarily on skipjack tuna but also catch significant quantities of other tunas including mackerel tuna, yellowfin tuna, and frigate mackerel (Figure 56). Sivasubramaniam (1965) pointed out that Sri Lanka's pole-and-line vessels operate with gear similar to that used by fishermen of Minicoy, Laccadive, and Maldive Islands. The vessels carry live bait in cane baskets partly submerged alongside the craft, which is manned by at least five fishermen. Wooden spades are used for spraying water. Where originally this type of fishing was restricted to waters off the southwest coast of the island, mechanization of the vessels have expanded this type of fishing to the east coast. As with other pole-and-line fisheries operating in the Indian Ocean, the availability of live bait has limited the popularity and expansion of this fishing method.

Although pole-and-line fishing is effective for skipjack tuna, it has not proved to be equally effective for frigate mackerel (Sivasubramaniam 1968). The reason cited was that frigate mackerel respond poorly to chumming probably because the live bait used is larger than the most common food items in their stomachs. Furthermore, the fishery exploits skipjack and yellowfin tunas of about 45-55 cm. In mixed schools where Auxis are mixed with either skipjack or yellowfin tunas, the proportion of Auxis in the 45-55 cm size group is small. The gear is not very effective during periods of southwest monsoon, because water turbidity makes baiting difficult.

The principal bait used in Sri Lanka is red bait, Dipterygonotus leucogrammicus. Congregating over large rocks in waters 9-18 m deep, the red bait are caught by a specially constructed dip net. When the red bait appears near the surface, a scoop net is used to capture them.

The best season for pole-and-line fishing is in November-March off the southwest coast and in July-September off the east coast. Tuna production depends heavily on the availability of bait during these periods.

The drift net is in operation around the entire island of Sri Lanka (Sivasubramaniam 1968). A 3.5-GT vessel usually carries 15 pieces of netting whereas an 11-GT vessel carries 60 pieces. With mesh sizes varying from 10.2 to 14.0 cm, the synthetic drift net has been found effective for skipjack tuna and large mackerel tuna. For frigate mackerel, however, fish less than 30 cm in length are too

small to be enmeshed. Catch of frigate mackerel, therefore amounts to only about 18 kg per day for a 3.5-GT vessel and about 54 kg per day for an 11-GT vessel. A. rochei, being smaller, are very rare in drift-net catches. Frigate mackerel are usually taken by drift net from about September to March.

According to Sivasubramaniam (1965), frigate mackerel are most abundant along the southwest coast of Sri Lanka and less abundant along the northwest and east coast (Figure 57). Frigate mackerel predominate in the tuna catches from off the southwest coast of the island during periods of southwest monsoon. In 1964-73, Sri Lanka's production of frigate mackerel ranged between 3,200 and 5,500 MT and averaged 4,500 MT annually (Table 46). Percentagewise, frigate mackerel constituted more than a third of the tuna and tunalike fish catches of Sri Lanka in 1964-67. The proportion fell to about a fourth in 1968-69, one-fifth in 1970, and has been about one-sixth of the total production in 1971-73 (Tables 63 and 64).

Fig. 57

Tables 63 and 64

C. ATLANTIC OCEAN

In the Mediterranean region, Cyprus, Greece, Italy, Malta, Morocco, Spain, and Yugoslavia exploit frigate mackerel along with several other tuna and tunalike species.

1. Spain

Spain, which annually lands about 3,500 MT of frigate mackerel (Table 46), exploits mackerel, Scomber scombrus; bluefin tuna, Thunnus thynnus; bonito, Pelamys sarda; and occasionally albacore, T. alalunga along the Mediterranean Spanish coast (Bas 1967).

Mackerel are caught by ring net and trawl; bluefin tuna, bonito, and frigate mackerel are caught sometimes by very large ring nets but primarily by special trap nets called "almadrabas" and "almadrabillas" depending on the size and construction of the trap (Table 65). Fishing effort for bonito and frigate mackerel is concentrated along the southern region of the Mediterranean Spanish coast whereas bluefin tuna, which is of considerable economic importance to the Spanish fishing industry, are fished along the entire Mediterranean Spanish coast. Pole-and-line, trolling gear, and purse seine are also used by Spanish fishermen in the Mediterranean to capture tuna and tunalike fishes (Cendrero and Garcia-Cabrera 1972).

Table 65

Spanish fishermen also catch frigate mackerel in the Canary Islands (Cendrero and Garcia-Cabrera 1972). In the Canaries, the tuna fishing vessels are large, averaging 400 GT (gross tons), have refrigerated holds, and carry about 20 men. Smaller, artisan-type vessels of about 10 GT also operate in this area. Crewed by four to five fishermen, these vessels are 12 m long and have open decks and bait tanks. They are propelled by engines that vary in size from 50 to 120 hp and usually fish with pole-and-line and occasionally with purse seine.

Rodriguez-Roda (1966) studied catches of A. thazard taken in the Spanish trap-net fishery located at Barbate, Tarifa, and La Linea. Barbate is on the Atlantic Spanish coast near the Strait of Gibraltar, Tarifa is in the middle of the Strait, and La Linea is on the Mediterranean Spanish coast near the entrance of the Strait.

In addition to frigate mackerel, the trap fishery at these localities also takes little tuna, E. alleteratus, and bonito, S. sarda. The average annual production of these three species in 1929-64 at Barbate, and in 1963-64 at Tarifa and La Linea is given in Table 66. A. thazard appear in the trap catches at Barbate in May-July with the heaviest catches occurring in the first 2 months. About 53% of the catch was composed of A. thazard with the remainder consisting of little tuna and bonito. At Tarifa, frigate mackerel production averaged 67.1 MT and about 95% of the catch was A. thazard. Here, the trap fishery is active in May-June. The traps at La Linea make the largest catches of these small tunas with A. thazard constituting about 97% of the catches. The fishing season extends from August to October with most of the catches occurring in the first 2 months.

Table 66

Annually, the catches of frigate mackerel at these traps vary widely. Figure 58, which shows the number of small tunas caught at the trap fishery at Barbate, reveals that catches in some years were very low, falling below 2,000 fish per year and very high in other years. Rodriguez-Roda (1966) reported that in 1964 102,470 A. thazard weighing a total of 112.7 MT were taken at the Barbate trap.

Table 46 shows the annual production of frigate mackerel in Spain whereas Table 67 gives a partial breakdown of the catches by type of gear. In 1953-73, the annual landings varied from 1,700 MT in 1968 to 10,000 MT in 1958 and averaged 3,500 MT.

Table 67

2. Morocco

Morocco, one of the world's major producers of sardines, Sardina pilchardus, and therefore concentrating on her fishery for that species, has relegated the commercial fishery for tuna to second place in recent years (Lamboeuf 1972). In addition to traps installed in the northern region of Morocco, some tuna are also taken by trolling gear, pole-and-line, and purse seine. Occasionally, when oceanographic conditions are favorable in autumn, sardine fishermen from central Morocco switch temporarily to fishing for medium-size tunas. Catches are relatively good considering that they have practically no specialized tuna fishing gear and fish within 55 km of land on 1-day trips.

Frigate mackerel are taken in Moroccan waters mostly by trap fishermen. Set primarily to catch bluefin tuna that make their spawning migration toward the Mediterranean Sea along the Moroccan coast in April-July, these traps are located in the Larache area and at Cape Spartel (Figure 59). Traps in the M'diq area in the Mediterranean also capture tuna as they exit after spawning. Table 68 shows that in traps located along the Atlantic Moroccan coast, frigate mackerel account for only 3% of the tuna landed, whereas in those situated along the Mediterranean Moroccan coast, they represent 98% of the tuna catch. Another trap set in the Agadir area catches bonito, Sarda sarda; skipjack tuna; plain bonito, Orcynopsis unicolor; and frigate mackerel rather than bluefin tuna.

Fig. 59

Table 68

According to Table 67, surface gear is also employed in landing frigate mackerel in Moroccan waters. Lamboeuf (1972) provided some details of the temporary fishery for tuna which operates during autumn in the central area of Safi and Essaouira. Both bait boats and seiners are employed. Bait boats which are usually old sardine vessels of low tonnage that have been converted to carry bait, chum fish to the surface and keep them there long enough for the seiners to set the nets around the school. Lacking such bait boats frequently results in an unsuccessful set.

In 1953-73, the annual catches of frigate mackerel fluctuated between 200 MT in 1961 and 4,000 MT in 1953 and averaged 1,500 MT (Table 46). Table 69, which shows the percentage composition of the tuna catch from Moroccan waters, reveals that in 1963-69 the landings of frigate mackerel gained in relative importance rising from about 15% to 20% of the total tuna landings in 1963-65, falling to about 12% in 1966, then rising steadily to about 27% of the total tuna catch in 1959. The change in the percentage composition of the catch resulted from the very sharp decrease in the landings of bluefin tuna from Moroccan waters. It should be noted that slight discrepancies exist in the catches for frigate mackerel as reported in Table 67 and 69, the most serious being for 1969. Whereas Table 67 shows only 200 MT were landed in Morocco in 1969, Table 69 reveals that the 1969 catch amounted to 588 MT.

Table 69

Table 70

Table 70 shows that traps contributed 91% of the frigate mackerel landed in the Mediterranean Moroccan coast with the remaining 9% produced by vessels. Along the Atlantic Moroccan coast, vessels, however, landed 69% of the frigate mackerel with traps contributing less than half or 31% of the Atlantic landings from Morocco.

3. Portugal

Dias and Barraca (1972) reported on the tuna fisheries in Portugal and the islands of Azores and Madeira. The main tuna fishing gear in Portugal is the trap which is usually set off the southern coast of the country. The catches on the north and west coasts are made by small, pole-and-line vessels but are of lesser importance and have been declining each year. Off the islands of Azores and Madeira, tuna is usually caught by medium- and small-sized pole-and-line vessels.

Off Angola, the yield of tuna is much higher. According to De Campos Rosado (1972), yellowfin and skipjack tunas are the principal species caught. The fishery is carried on by small, pole-and-line vessels, 12-20 m long, that operate within a narrow strip along the coast about 75 km wide and 370 km long. The contribution of pole-and-line vessels to the overall production of frigate mackerel landings from traps were much higher than those from pole-and-line vessels. De Campos Rosado (1972) estimated that the catches of little tuna, bonito, and frigate mackerel represent roughly 60% of the total tuna catch in Angola.

4. Ghana

Ghana's modern fishing industry was developed only since the early 1960's and the fleet is probably the best among African nations (Di Palma 1968). At Tema, the harbor accommodates dugout canoes as well as large, motorized steel fishing vessels.

Tunas, mackerels, and scads figure importantly in the catch in Ghana. Most of the tuna landings at Tema are accounted for by foreign longline, pole-and-line, and purse-seine vessels. Ghana's canoe and motorized fishing vessels, however, account for some of the landings of tuna and tunalike fishes.

Di Palma (1968) revealed that confusion exists in data concerning mackerels and scads because some vessels do not differentiate between the various species. For example, Di Palma mentioned that the species reported together may include Spanish mackerel, Scomber collias, various species of horse mackerels of the family Carangidae, frigate mackerel, and mackerel scad, Decapterus rhoncus. Miyake, DeBoisset, and Manning (1974) reported that Ghana's landings of frigate mackerel by unclassified gear varied between 1,800 and 5,300 MT and averaged 3,160 MT in 1968-72. In 1973, they reported a catch of 1,600 MT of frigate mackerel by purse seine gear (Table 67).

5. Japan (Overseas Bases)

Japan's resurgence as a fishing power after World War II was not restricted to the Pacific and Indian Oceans. Japanese tuna longliners first made their appearance in the Atlantic in 1957 and by 1961 at least 60 vessels were fishing there for yellowfin tuna

and albacore (Borgstrom 1964). In 1962, the Japanese placed pole-and-line fishing vessels of 239-GT each in Ghana to fish for surface schools of tuna. Yellowfin and skipjack tunas are the main species landed by these Japanese bait boats but frigate mackerel and bigeye tuna are also taken in limited quantities (Shomura 1966; Hayasi 1973).

Table 71 Table 71 shows the number of Japanese purse seine and pole-and-line fishing vessels that operated in the Atlantic Ocean in 1962-63 and in 1967-72. The contributions of both types of fishing gear to the Japa-

Table 72 nese catches of tuna and tunalike fishes are given in Table 72.

According to Di Palma (1968), Tema with excellent shore facilities, including cold storage, serves as a base for Japanese

Fig. 60 pole-and-line, purse seine, and longline vessels. Figure 60 shows the location of Atlantic tuna fishing grounds; frigate mackerel are taken along with yellowfin tuna, skipjack tuna, and small amounts of bigeye tuna along the coast of Africa and the coastal waters of the

Table 73 offshore islands. Table 73 shows that in 1967-73, Japanese seiners annually landed from 200 MT to 1,300 MT of frigate mackerel and averaged 670 MT. The bait boats (pole-and-line vessels) caught from 400 MT to 3,200 MT annually in 1965-73 and averaged 1,375 MT (excludes

Table 74 1971 (Table 74).

Hayasi (1973, 1974) showed that frigate mackerel catches by Japanese bait boats vary widely. Table 74 indicates that in 1972, frigate mackerel catches were insiginificant, whereas in 1969, landings represented about a third of the total bait boat landings. The proportion of the purse seine landings consisting of frigate mackerel, however, varied less; it was about 3% in 1969 and reached 15% in 1972 (Table 73).

The Japanese fishing vessels fish not only in the eastern Atlantic but also in the western Atlantic. The Caribbean
Fig. 61 region, shown in Figure 61, is an important fishing ground for tunas and tunalike fishes including frigate mackerel. Wise and Jones (1971) pointed out that the catch of several species of tunas and related fishes occurring in the Caribbean region are shared by several countries
Fig. 62 (Figure 62). Japan lands about two-thirds, Cuba and Venezuela each take about one-tenth, and the remaining countries, each with less than 2,000 MT annually, land the balance of the catch. Among the species landed, yellowfin tuna is the most important, contributing slightly
Fig. 63 over a third of the total landings (Figure 63). Second most important is the "bonitos" but this category includes few true bonitos and is made up largely of skipjack and blackfin tunas, with small amounts of other species such as little tuna and frigate mackerel included. Bigeye tuna is third in importance followed by bluefin tuna and albacore.

6. Cuba

Wise and Jones (1971) discussed the Cuban surface fishery which has been described in detail by Rawlings (1953) and more recently by Suarez Caabro and Duarte Bello (1961). The following brief description is taken from Rawlings (1953) and Wise and Jones (1971).

The Cuban pole-and-line fishery for tuna, which began in 1940, produces about 1,000-1,500 MT annually. Blackfin tuna comprises 60%-75% of the catch with skipjack tuna contributing most of the remainder. Small amounts of frigate mackerel and yellowfin tuna are also landed.

Operating motorized sailing vessels (a modified sloop with a gaff-rigged mainsail usually with a flying jib), the Cuban tuna fishermen work the southwest coast of the island and in the Gulf of Batabano. The vessels seldom fish more than 5.6 km from shore on the south coast whereas on the north coast, they may range up to 28 km offshore. Each vessel has a crew of seven consisting of a captain, engineer, chummer, and four fishermen.

The primary bait used in the "majua," Jenkinsia lamprotaenia, a small fish 2.5-3.8 cm in length. They school well but survive only about a day in the baitwells. A second species called "cabezona," Atherinomorus stipes, is more hardy. The baiting grounds are located in the waters surrounding the innumerable keys in the Gulf of Batabano; the "majua" are particularly abundant in protected shoal areas.

Tuna vessels operate 10-11 months each year. Fish are abundant in the early season (March-April), bite well, but are very small. Toward the end of the season (September-October), the fish are less abundant and bite poorly but are much larger.

7. Venezuela

The start of Venezuela's tuna fishery coincides with the rise of the international Atlantic tuna fishery (Griffiths 1971). The principal species caught by the Venezuelan longliners are yellowfin tuna, which constitutes about 70% of the total tuna catch, and albacore contributing another 20%. Small and variable amounts of bigeye and blackfin tunas are also taken and, from time to time, bluefin tuna is landed. Sharks and spearfishes make up the bulk of the remaining catch.

Among the other scombroids of commercial interest are Sarda and Auxis sp., Scomberomorus maculatus and S. cavalla, and Scomber colias (Griffiths 1971). The catches of Sarda and Auxis, primarily by baited hooks ("cordel") and gill nets along eastern Venezuela, are grouped in the official statistics into "cabañas"
Table 75 (Table 75). Unfortunately, the proportion of each species in this category is unknown. Griffiths noted that the proportions may be variable among the fishing areas and also with time. "Cabañas" are usually sold fresh locally or salted and sometimes canned as "tuna" or "bonito." In 1963-67, the landings of "cabañas" fluctuated between 1,002 and 1,763 MT and averaged 1,342 MT.

8. Brazil

Brazil's fishery for tuna and tunalike fishes is not organized along industrial lines; therefore, catches are usually small (Paiva 1972). The yield of tuna from this fishery results mostly from seasonal and artisanal fishing along the coast and actually includes only occasional catches of large, modern fishing vessels. There is, however, an acute national interest in developing the tuna fishery along the Brazilian coast. Paiva published statistics of catches of tuna and tunalike fishes in 1969 and 1970 (Table
Table 76 76). Unfortunately, frigate mackerel is not identified by a separate category; rather, it was included in a group with bonito, wahoo, and king mackerel and labeled "others." There is no way to determine what proportion of the catch under this category represents frigate mackerel.

9. United States

During the 1940's and early 1950's, the major portion of the catch of tuna from the middle Atlantic coast states of the United States were made by pound nets (Anderson, Stolting, and Associates 1953). Pound nets, hung on pilings or attached to floating timber, are large structures that divert the movement of fish along the shore (Figure 64). Although constructed principally for taking other species, the pound net also captured bluefin tuna, little tuna, bonito, and frigate mackerel. The catch of tuna by this gear frequently exceeded 450 MT annually. Other gears that caught frigate mackerel from time to time were the otter trawl, purse seine, trolling gear, drift gill net, and handline (Anderson and Power 1946, 1947, 195; Anderson and Peterson 1952).

Fig. 64

Table 77

Table 77 shows the landings of A. thazard in New York and New Jersey in 1940-51. The annual catches from these two states have been highly variable; for example, only 0.4 MT of fish was landed in New Jersey in 1951. On the other hand, the catch was as high as 107.7 MT from the two states in 1943.

D. SIZE COMPOSITION AND SEX RATIO

Hotta (1955) and Yokota et al. (1961) reported that the size range of A. rochei in the Japanese commercial catch varied between 4 and 50 cm, but the bulk of the catch usually fell between 20 and 35 cm (Figure 64). In the Japanese fishery, the average size of the frigate mackerel varies considerably among the months of the year.

Hotta (1955), Ishida (1972a), and Morita (1972) all found that the average size of the fish in the commercial catch usually was smallest in August or September after which it increased gradually until early June of the following year then decreased sharply (Figures 65-67).

Figs. 65-67

Not only the average size but also the size range varies in the Japanese commercial catch from month to month. Hamada, Morita, Ishida, and Takezawa (1973) examined lengths of A. rochei caught in waters off Kochi Prefecture in Shikoku (northeastern) and Tohoku Prefecture in Japan and off Taiwan and determined that the lengths of fish caught in October-November usually had a narrow range whereas those of fish caught in May-June had a wide range (Figure 68). Also, from the samples they collected, they determined that the catches made from April to December 1971 showed a predominance of females as shown by the sex ratios calculated (Table 78).

Fig. 68

Table 78

The size composition of frigate mackerel taken by the Royal Venture and Southward Ho in the Philippines is shown in Figure 69. In general, the fish ranged from about 25 to 55 cm with the majority of the fish in the 40-45 cm range.

Fig. 69

In Indian waters, Silas (1969) showed that A. thazard taken by drift net ranged from about 20 to 51 cm with a large proportion of the catch between 38 and 43 cm (Figure 53). Silas also showed that compared to A. thazard, A. rochei were much smaller ranging from about 19 to 29 cm with most of the fish at about 20-21 cm. The purse seine apparently catches frigate mackerel of more uniform sizes. Figure 54 shows that A. thazard caught by purse seine in Indian waters

ranged from about 32 to 46 cm with the largest proportion of the catch falling at 40-42 cm (Silas 1969).

In Sri Lanka, the size of A. thazard in the commercial catch range from 20 to 58 cm, but a large proportion falls between 22 and 40 cm (Sivasubramaniam 1968). A. rochei appearing in the commercial catch are smaller with sizes varying from 16 to 34 cm; however, most are between 22 and 30 cm.

Sivasubramaniam (1968) examined the catches of A. thazard from around Sri Lanka, by type of gear, and found that the beach seine is biased with respect to size-frequency sampling because the large A. thazard present in the population are usually caught by other gear and are not proportionately represented in the beach seine
Fig. 70 catches (Figure 70). Most often medium-sized A. thazard are taken by this gear and occasionally, large schools of A. rochei are captured. Beach seine catches ranged from about 28 to 44 cm with the largest proportion of the catch in the 32-36 cm length group.

A. rochei appear frequently in the troll catches because the gear is effective in taking small tunas as well as larger ones. Sivasubramaniam (1968) calculated that although the trolling gear samples a very wide size range of fish, it is particularly effective for fishes in the 28-32 cm length group, a group for which none of
Fig. 71 the other gears used has been effective (Figure 71).

The smallest sizes of frigate mackerel usually appear in waters around Beruwela or further south (Sivasubramaniam 1965). The modal size groups exploited by the Sri Lanka trolling fishery

are 26-28 cm (0.26-0.34 kg), 32-34 cm (0.52-0.64 kg), and 36-38 cm (0.78-0.93 kg), whereas the pole-and-line fishery captures two larger size groups; these are 44-46 cm (1.52-1.76 kg) and 48-50 cm (2.03-2.32 kg).

Sivasubramaniam (1968) also found no noticeable difference in the size composition of the catches of A. thazard when the catch data were separated by sex. The data, however, showed that in the catches from the southwest coast, the proportion of females in the catch increased slightly (1:1.5) during the southwest monsoon.

Figs. 72 and 73

Figures 72 and 73 show the percentage frequency distribution of lengths of A. thazard caught in various years at the Barbate, La Linea, and Tarifa trap-net operations in Spain. Rodriguez-Roda (1966) reported finding two size groups in the Barbate and Tarifa samples--one around 38.5-39.5 cm and the other at about 45 cm--and hypothesized that these two groups may possibly correspond to two age groups. Furthermore, he noted that at La Linea, the smaller modal group was at 40.5 cm and the larger at 42.5 cm. This led him to suspect that two distinct populations of A. thazard may be involved in the catches at these localities. When examined by sex, Rodriguez-Roda found no significant differences in the length-frequency distributions (Figure 74).

Fig. 74

Table 79

Table 79 shows the sex ratio of the trap-net catches made at Barbate, Tarifa, and La Linea. Rodriguez-Roda (1966) tested the ratios of the number of males to the number of females caught in the traps at those localities particularly for those months where a ratio of 1:1 was in doubt. The results indicated that there were no significant departures from the 1:1 ratio except at La Linea where in September 1961, there were significantly more males taken in the trap.

E. SUBPOPULATIONS

Studies of electrophoretic patterns of muscle protein of *A. rochei* taken from various localities in the western Pacific were reported by Hamada, Morita, Ishida, and Takezawa (1973, 1974). Studying samples taken in waters off Kochi and Tohoku Prefectures in Japan, and off Taiwan, Hamada, Morita, Ishida, and Takezawa (1973) determined that there were no significant differences in the A-gene frequencies from these three areas, indicating little isolation in the three subpopulations of *A. rochei*. Concerning studies of the Philippine and Kochi samples, Hamada et al. (1974) also found no significant differences in the A-gene frequencies except in one
Table 80 sample (Table 80).

F. MIGRATION

By examining the fluctuations in landings of frigate mackerel along the coast of Japan, Hotta (1955) determined that frigate mackerel occur in the Satsunan Sea region and off Shikoku early in the year
Fig. 75 (Figure 75). As the year progressed, larger catches were made farther north and by June frigate mackerel were being landed in the Izu Archipelago region. The schools of frigate mackerel reached their most northern point around Hokkaido in September, then moved southward until in December they appeared to be concentrated most off the Izu Archipelago and Shikoku.

Detailed studies of long-term movement of A. rochei in Japanese waters were reported by Yamashige (1974). Fish caught, tagged and released in August, September, and November 1965, September 1970, and September 1972 showed a general southward migration (Table 81 and Figure 76). Yamashige (1974) also determined from his tagging studies that there is differential migration according to size in the population of A. rochei off Japan. The large influx of small fish into the fishery as shown by the length-frequency distribution (Figure 77) is the consequence of small fish moving south before the movement of large fish begins.

Table 81, Fig. 76

Fig. 77

Short-term movement of tagged A. rochei off Japan was discussed by Morita (1972), Hamada, Ishida, Morita, Takezawa, Okabayashi, and Ishii (1973), and Hamada et al. (1974). Tables 82 and 83 give the date, area, and body lengths at the time of release and recapture. Figure 78 shows that late in the year, the fish tend to move southward although some northward movement is seen. But early in the year, there appears to be a definite northward migration (Figures 79 and 80).

Tables 82 and 83

Fig. 78

Figs. 79 and 80

G. ABUNDANCE

An aerial survey of the offshore waters around Sri Lanka, conducted for a quick evaluation of the potential surface tuna resources, revealed that a very good fishery for tuna is possible in Sri Lanka (Sivasubramaniam 1971). The survey, made during the period of the southwest monsoon when weather was usually unfavorable, showed

Table 84, Fig. 81 very few tuna schools within the southwest region (Table 84 and Figure 81). Those that were seen were identified as small tuna and tunalike fishes. The suggestion was that these could be schools of E. affinis, A. thazard, and A. rochei, because these species usually appear in this region at this time of the year and are heavily exploited by the trolling fleet.

The eastern region showed relatively more schools, mainly skipjack and yellowfin tunas. The north and northeast regions were devoid of fish schools, whereas the northwest and southern regions could not be surveyed due to poor weather conditions.

Sivasubramaniam (1971) noted that whereas schools in the southwest region appeared to be drifter, those observed in the eastern side were foamers and hence easily located. The evidence gathered from this aerial survey suggested that the offshore waters around Sri Lanka could be rich and that the southwest monsoon influence the waters in the eastern region. Total school sightings, however, were below expectation. But examination of the catches from 11-ton class drift netters indicated that fishing was good in the western and southwest regions and reasonable in other regions during the period of the aerial survey (Table 85).

Table 85

Sivasubramaniam (1968) revealed that major recruitment to the exploitable stock occurs annually along the south and southwest coasts between March and August. There is also evidence that sporadic recruitment also occurs during the rest of the year. Off the east coast, recruitment has been observed in July-September, but no clear trend in recruitment has been found in catches along the north coast.

For A. rocbei, Sivasubramaniam (1968) conjectured that recruitment probably takes place at about the same time as that for A. thazard. Therefore, the exploitation of new recruits start around the middle of the year and fishing then shifts to large size classes until the following year's recruitment (Figures 82 and 83).

Figs. 82 and 83

1. Fluctuations in Catches

The average monthly landings of frigate mackerel at Tosa-Shimizu (Kochi Prefecture), at Hachijo (Izu Archipelago), and at Mera (Shizuoka Prefecture) are shown in Figure 84. At Tosa-Shimizu, where a pole-and-line fishery operates, frigate mackerel are caught throughout the year, although peak fishing extends from October through May (Yasui 1975). One of the reasons for the decline in the catch in June-September is that some of the pole-and-line vessels fish other species during this period; hence, there is a reduction in fishing effort for frigate mackerel.

Fig. 84

Yasui (1975) also noted that severe fluctuations in the monthly landings usually occur in October-December whereas landings are stable in January-March. He examined these periods of stable and unstable landings in 1954-73; however, he could find no consistent relationship between them (Figure 85).

Fig. 85

Yasui found a better relationship between sea-surface temperature and monthly landings. He observed that in years of good fishing, there was a complex distribution of surface temperature with 28°C water very close to shore (Figure 86). In poor years, the warm water was displaced farther offshore (Figure 87). He concluded that

Fig. 86

Fig. 87

the location of the 28°C isotherm in July-September significantly influenced fishing conditions in subsequent months. Temperature, it seems, affects the concentration of frigate mackerel schools, that is, their general availability to the vessels and the length of their stay on the fishing grounds.

Examination of monthly landings at Mera, where the fish are taken by set nets, shows that the peak fishing season is in July-September (Figure 83). Yasui (1975) noted that in this fishery, the largest fish are usually taken in June, and that progressively smaller fish are taken in subsequent months. The reproductive index also was highest in June. The proportion of immature fish in the catch increased in July-August and by September all fish were immature. Yasui concluded from these findings that the production of frigate mackerel at Mera is influenced to a large extent by a seasonal in-migration of fish from the west and south.

At Hachijo, where frigate mackerel are landed by surface trollers, catches are made throughout the year except in October (Figure 83). Yasui (1975) observed two seasons for frigate mackerel at Hachijo--one in April-August and another in November-January. The appearance of frigate mackerel in April-May at Hachijo coincides with the end of the gill net fishery for flyingfish, which are preyed on by the frigate mackerel. Yasui also noted that the fish taken in April-May are sexually immature. Larger fish that are sexually mature migrate into the area in July.

At Ashizurimisaki in Kochi Prefecture, Ishida (1972b) also noted considerable fluctuations in landings of frigate mackerel. To determine whether it would be possible to predict in advance a good or poor fishing season, Ishida examined catch statistics for 1952-67, sorting out years of outstanding and poor catches. Plotting the relationship between the catch in October-March in a given year j against that for the same months in year j + 1, he found that when Cj was small, $\Delta Cj + 1$ the difference between Cj and Cj + 1, tended
Fig. 88 to be positive and vice versa (Figure 88). Ishida also looked at the relationship between catches and water temperature. Figures
Fig. 89 89A and 89B illustrate that in both October and November, larger catches tended to be associated with cooler temperatures.

Continuing studies started at Kochi Prefectural Fisheries Experimental Station, Yamashige (1974) examined the relationship of A. rochei catches in August-July to the difference between the mean surface temperature in August and in October of a given year. The
Fig. 90 equation describing the relationship (Figure 90) between these two variables is

$$Y = 1.42 + 1.15\ (t_8 - t_{10})$$

where Y = catch, in 1,000 MT, from August (n year) to July (n + 1 year)

t_8 = mean surface temperature in August at Ashizurimisaki (°C)

t_{10} = mean surface temperature in October at Ashizurimisaki (°C).

Sivasubramaniam (1968) dealt with seasonal and annual variations in the catches of frigate mackerel from waters surrounding Sri Lanka. His analysis showed that in the southwest and south coast of Sri Lanka, A. thazard are caught throughout the year whereas in the east and north coasts, the season is restricted to June-September with sporadic small catches in March-April (Figure 91). Sivasubramaniam also noted that the catch rate for A. rochei peak during the same time as that for A. thazard in all areas fished, but this species was available to the fishermen throughout the year only in the southwest coast of Sri Lanka. He maintained that his findings disagreed with information published by Williams (1963) who reported that the main fishing season for frigate mackerel in Sri Lanka extended from October or November to May. Sivasubramaniam revealed that this is the period of the northeast monsoon and inter-monsoon when beach seines are usually operated off the west, southwest, and south coasts of the island. But although this gear made important contributions to frigate mackerel catches in past years, mechanization has brought about drastic changes in that the vessel were able to fish along the above coasts even during periods of southwest monsoons at which time peak catches are made.

Fig. 91

Despite seasonal variations in catches within the various geographical locations, it was evident that all areas had peak fishing during the end of the southwest monsoon. Sivasubramaniam believes that this good fishing period may be associated with the heavy recruitment season and the vulnerability of the recruits to trolling gear.

The result is that the number of fish caught per day rises abruptly, but the net tonnage landed did not rise proportionately.

Concerning annual variations in frigate mackerel catches, Sivasubramaniam (1968) found that they varied widely. In some years, catches of A. rochei were insignificant. Catches of A. thazard, he noted, peaked in 1964 and 1968 during which years production was 120% above the average annual production in 1963 and 1965-67.

Evidently, the time of recruitment influences the annual production from Sri Lanka (Sivasubramaniam 1968). When recruitment occurs during the southwest monsoon, the schools that enter the fishery are available at a time when the relative abundance of skipjack tuna, yellowfin tuna, and mackerel tuna is low and are fished until the beginning of the northeast monsoon. But when recruitment occurs late in the year (Figures 82 and 83), the fishing effort expended on frigate mackerel is less intense because of the presence of more desirable species such as skipjack and yellowfin tunas. Thus, fishing emphasis shifts from trolling to pole-and-line, longline, and drift netting. November-March marks the peak fishing season for the skipjack tuna pole-and-line fishery in the south and southwest coasts of Sri Lanka. Large frigate mackerel (40-50 cm) usually mixed with skipjack and yellowfin tunas are often caught at this time.

2. Relative Abundance

The relative abundance of frigate mackerel in Japanese waters off Ashizurimisaki and Tosa-Shimizu was discussed by Ishida (1972a). Using data collected in the frigate mackerel pole-and-line fishery from October 1964 to June 1967, Ishida found two peaks in
Fig. 92 the average number of vessel operating per day each month (Figure 92). The first peak occurred in March and the other in October and during these months about 200 vessels per day participated in the fishery for frigate mackerel.

Taking a vessel-day as a unit of fishing effort, Ishida (1972a) calculated the monthly landings per day and found that this index fluctuated in a similar fashion as the number of vessels in
Fig. 93 operation per day (Figure 93). Ishida also constructed a frequency distribution of the landings per day and found that the mode fell
Fig. 94 at 30 MT per day (Figure 94). The annual mean was 52.4 MT per day, but during the fishing season the mean was higher, reaching 56.5 MT per day. A plot of landings per day on number of vessels operating per day showed that an increase in fishing intensity was usually
Fig. 95 accompanied by a similar increase in relative abundance (Figure 95).

Off the coasts of Sri Lanka, frigate mackerel are distributed in all waters surrounding the island but their densities vary widely (Sivasubramaniam 1968). Using the number of fish caught per standard trolling unit (a vessel with a fixed number of lines) per day, Sivasubramaniam found that for A. thazard the highest density occurred along the southwest coast with 21.7 fish per boat-day with

density along the southern coast almost equally high at 21.3 fish per boat-day. Densities were lower on the east and west coasts with relative abundance of 18.9 and 14.3 fish per boat-day, respectively. The lowest density occurred off the north coast with only 4.2 fish per boat-day. Catches of A. rochei followed a similar pattern. Sivasubramaniam (1968) has estimated that usually a fishing vessel will encounter two to three mixed schools per day in Sri Lankan waters.

3. Potential Yield

Gulland (1971) estimated that the worldwide potential production of frigate mackerel could be of the order of 1 million metric tons (Table 86). Evidence available to Gulland at the time of this estimate indicated that frigate mackerel appear to be an important resource in several areas. Klawe (1963) has shown that in the eastern Pacific Ocean, yellowfin tuna and frigate mackerel are similarly distributed; however, the latter were three times as abundant. Gulland, using pre-1965 data, assumed that if yellowfin tuna larvae represent the complete production from the adults that are fished in the eastern Pacific, then, a rough estimate of the frigate mackerel potential could be 3 X 70,000 MT or about 200,000 MT. This also assumed that both yellowfin tuna and frigate mackerel have the same larval production per unit of adult biomass. Gulland noted that this rough estimate is likely to be an upper limit because not all the yellowfin tuna may spawn and that the spawning stock of yellowfin tuna has been reduced by fishing.

Table 86

Gulland's estimate for the eastern Pacific would have to be revised upward in view of current data. The Inter-American Tropical Tuna Commission (1975) set a quota of 159,000 MT of yellowfin tuna for 1975 with provision for increases of 9,000 MT in two successive increments if in the opinion of the Director of Investigation, such increases would not endanger the stock of yellowfin tuna. Based on this potential for yellowfin tuna, the frigate mackerel potential in the eastern Pacific could reach 477,000 MT, bringing the worldwide potential closer to 1.3 million metric tons.

Gulland further noted that information from EASTROPAC and EQUALANT and studies done in the Indian Ocean suggest that frigate mackerel is widely distributed in all oceans and that it may be the most abundant oceanic scombroid. Gulland pointed out, however, that there is a great urgency for more information not only on frigate mackerel but for other tuna and tunalike fishes. For exploited populations, the needs are mainly better data for management and the establishment of better and more efficient machinery for implementing management.

For frigate mackerel, it is apparent that catch statistics, as a whole, are unsatisfactory. In many areas where frigate mackerel are captured as an incidental species, catches are grouped with those of others such as bonitos and little tunas. Better data are required not only on area of capture but also on month of capture. More extensive data are also needed on sizes of fish caught by the different types of gear used.

Kume (1973) noted that for the South China Sea area, statistics on catch of tunas should be organized by species and fishing effort separated by type of gear. Nomenclature, both vernacular and scientific names, should be resolved and standardized. Furthermore only little is known about the structure of the stocks of frigate mackerel in this area. Biological studies are needed and information on size and maturity should be collected at landing sites. Kume believes that fishing for small-size coastal species of tuna and tuna-like fishes could be expanded in the South China Sea area and exploratory fishing should be conducted to examine this possibility.

Gulland (1971) indicated that substantial improvement to estimates of potential can be made only after exploitation has increased. Enough information exists to show that there is a potential for increase in frigate mackerel and the immediate need is for information that will help develop fisheries to exploit presently underutilized or unexploited stocks.

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Table 1.--Counts of various anatomical features of the short-corseletted frigate mackerel by various investigators.

	Anatomical features							
	First dorsal fin	Second dorsal fin	Dorsal finlets	Anal fin	Anal finlets	Gill rakers	Vertebrae	Branchiostegals
Hawaii								
Jordan and Evermann (1903)	X	12	8	13	7	30+10	--	7
Matsumoto (1960)	XI	10-12	8	13	7	9-10+1+28-31 = 39-42	20+19	--
Yoshida and Nakamura (1965)	--	--	--	--	--	9-10+1+29-31 = 39-42	--	--
Japan								
Kishinouye (1923). *A. hira*	X-XI	12	8	13	7	9+30	20+19	--
Southern California								
Barnhart (1936)	X	12	8	13	7	--	--	--
Philippines								
Wade (1949)	X-XII	10-12	8	II, 8-11	7	9-10+1+27-32 = 37-43	--	7
South Africa								
Fowler (1934)	XII	iv, 10	7-8	iv, 10	7	10+31 = 41	--	--
Smith (1960)	XI	11-12	8	13	7	30 (lower limb)	--	--
East Africa								
Williams (1963)	--	--	7-9	--	--	9-10+30-31 = 39-41	38-39	--
East Indies								
DeBeaufort and Chapman (1951)	X	11	6-9	14	6-8	--	--	--
Ceylon								
Munro (1955)	X	11	6-9	14	6-8	30 (lower limb)	--	--
Australia								
Munro (1958)	X-XII	12	8	13	7	10-11+28-32	--	--
India								
Jones (1958)	X	13	8	ii, 11	7	40	--	--

Table 2.--Counts of various anatomical features of the long-corseletted frigate mackerel by various investigators.

	Anatomical features						
	First dorsal fin	Second dorsal fin	Dorsal finlets	Anal fin	Anal finlets	Gill rakers	Vertebrae
Hawaii							
Matsumoto (1960) *A. thynnoides*	X-XI	10-11	8	12-13	7	10-11+1+32-36 = 43-48	20+19
Yoshida and Nakamura (1965) *A. rochei*	--	--	--	--	--	10-11+1+33-37 = 44-49	--
Japan							
Kishinouye (1923) *A. maru*	IX-X	10-12	8	13	7	10+36	20+19
Philippines							
Wade (1949) *A. tapeinosoma*	X-XI	10-12	7-8	II, 10-12	7	10-12+1+31-35 = 44-48	--
Indonesia							
DeBeaufort and Chapman (1951) *A. thynnoides*	10	11	6-9	14	6-8	--	--
South Africa							
Talbot (1964) *A. thynnoides*	10-12	11	8	14	6-7	9-10+32-34	--
India							
Jones (1963 *A. thynnoides*	10-11	13	8	13	7	8-12+31-36	--

Table 3.--Range and mean gill raker counts for specimens of *A. thazard* and *A. thynnoides* from Indian waters (Jones and Silas 1964).

Species	No. of specimens	Range Mean	Gill rakers		
			Upper limb	lower limb	Total
Auxis thazard	10	R	9 to 10	29 to 32	39 to 42
		M	9.6	30.2	39.8
Auxis thynnoides	13	R	8 to 12	31 to 36	40 to 47
		M	9.5	34.5	44.8

Table 8.--Date of collection, size of fish, and maturity and weight of ovaries from ripe specimens of A. thazard landed at Vizhingam, India (Rao 1964).

Fish No.	Date of collection	Fork-length (Cm.)	Wt. of fish (Kg.)	Stage of maturity	Wt. of ovary (Gm.)
AT. 3	3. IX 1959	41.6	0.91	VI	52
AT. 12	7. IX 1959	44.2	0.92	VI	125

Table 9.--Size range of ripe ova and oil globule in four species of tuna from Indian waters (Rao 1964).

Species	Diameter of ripe ovum in mm.				Diameter of oil globule in mm.	
	in preserved material		in fresh material			
	Range	Average	Range	Average	Range	Average
Auxis thazard	0.78-0.98	0.86	0.88-1.09	0.97	0.21-0.22	0.22
Euthynnus affinis	0.68-0.95	0.81	0.85-1.12	0.99	0.24-0.27	0.25
Sarda orientalis	0.88-1.15	1.04	1.02-1.19	1.13	0.29-0.31	0.29
Kishinoelia tonggol	..	..	1.03-1.13	1.09	0.31-0.33	0.32

Table 11.--Estimated number of ova produced per spawning and during the breeding season by A. thazard (Rao 1964).

Fish Number	Fish length (Cm.)	Fish weight (Kg.)	Number of ova produced per spawning (Millions)	Total number of ova produced during the breeding season (Fecundity) (Millions)
AT. 12	44.2	0.92	0.28	1.37

Table 12.--Fecundity of tunas from drift net catches off India (Silas 1969)

Species	No. of ovaries examined for counts	Estimated number of ova	
		Range	Mean (Rounded to nearest hundred
Auxis rochei	4	31236-102902	52000
Auxis thazard	9	197223-1056458	601400
Euthynnus a. affinis	7	493617-1393882	866900
Sarda orientalis	4	268930-403603	354100
Katsuwonus pelamis	1	268373	268400

Table 12.--Number and size range of larval *Auxis thazard* collected by the RV *Hugh M. Smith* in Hawaiian and equatorial waters (Matsumoto 1958).

Cruise and station	Number of larvae	Size range (mm.)
HAWAIIAN WATERS:		
Cruise 6:		
No. 1A	1	3.6
No. 7	1	6.2
No. 8	4	2.5-8.2
No. 10	10	2.7-3.7
No. 11	2	7.02, 8.1
No. 13	12	3.0-5.2
Total	30	2.5-8.2
EQUATORIAL WATERS:		
Cruise 5:		
No. 21	2	2.6
No. 51	2	4.2, 5.5
Cruise 14:		
No. 26	1	3.6
No. 29	1	3.1
Cruise 15: No. 3	1	7.2
Cruise 18: No. 31	1	4.0
Total	8	2.6-7.2

Table 13.--Measurements on Auxis thazard larvae reared in a 0.5 ton (500 liters) aquarium (Harada, Murata, and Miyashita 1973b).

Days after hatching	Total length (mm)	Fork length (mm)	Body depth (mm)	Body weight ~~(mm)~~ g
10	5.95	–	0.97	–
10	4.90	–	1.10	–
15	11.4	–	2.6	–
20	29.0	25.0	5.0	–
28	55.0	52.0	9.5	–
28	53.5	50.0	9.0	–
30	56.0	53.0	10.0	–
30	47.0	43.0	9.0	–
31	63.0	59.5	10.5	–
31	46.0	43.0	8.5	–
33	55.0	51.0	10.0	1.1
33	55.5	52.0	9.5	1.1
36	60.0	56.5	10.0	1.8

Table 14.--Measurements on Auxis thazard larvae reared in 3- (3,000 liters) and 5-ton (5,000 liters) aquaria (Harada, Murata, and Miyashita 1973b).

Days after hatching	Total length (mm)	Fork length (mm)	Body depth (mm)	Body weight (g)
0	3.47	–	0.66	–
2	3.8	–	0.78	–
17	64.0	–	7.5	1.8
33	120.0	112.0	18.0	10.6
"	89.0	84.0	14.0	5.5
"	120.0	115.0	18.0	10.6

Table 15.--Monthly distribution of tuna larvae in Indian waters (Jones and Kumaran 1963)

	Month			Total
	November	December	January	
Katsuwonus pelamis	40	452	591	1,083
Neothunnus macropterus	5	541	199	745
Euthynnus affinis affinis	--	91	88	179
Auxis rochei	--	1	19	20
Auxis thazard	--	17	114	131
Unidentified tuna larvae	--	17	8	25

Table 16.--Percentage frequency of ova-diameter measurements from samples of ripe ovaries collected at Vizhingam from tunas caught in Indian waters (Rao 1964).

Species	Fish No.	Micrometer Divisions																															
		9-10	11-12	13-14	15-16	17-18	19-20	21-22	23-24	25-26	27-28	29-30	31-32	33-34	35-36	37-38	39-40	41-42	43-44	45-46	47-48	49-50	51-52	53-54	55-56	57-58	59-60	61-62	63-64	65-66	67-68	69-70
Euthynnus affinis	EA. 350	3.65	3.67	9.30	7.70	5.90	7.70	5.15	9.30	5.15	3.96	3.66	..	..	..	..	0.77	1.46	3.96	5.50	6.30	7.90	4.70	3.16	1.56	..	..	..	..	..	..	..
	EA. 235	0.64	2.91	4.45	10.36	12.36	8.36	13.91	8.18	10.64	4.18	1.27	..	..	..	1.18	1.09	1.36	2.00	5.00	3.82	4.27	2.64	0.82	0.54	..	..	..	..	..	..	..
	EA. 236	1.68	1.96	4.95	5.98	8.97	6.64	7.57	6.26	13.27	8.97	4.95	1.68	..	..	..	1.03	1.31	2.80	5.14	6.74	5.42	2.06	1.78	0.84	..	..	..	..	..	..	..
	(Average)	1.99	2.85	6.23	8.01	9.08	7.57	8.88	7.81	9.69	5.70	3.29	0.56	..	..	0.39	0.96	1.38	2.92	5.21	5.62	6.86	3.13	1.92	0.98	..	..	..	..	..	..	..
Sarda orientalis	SO. 16	1.19	1.42	3.09	3.57	6.67	6.90	4.05	5.00	6.19	5.71	4.76	5.00	2.62	8.33	3.57	3.05	0.24	..	..	..	..	1.19	1.19	3.57	3.05	7.62	5.48	2.38	2.62	0.95	0.71
	SO. 10	3.22	3.55	5.12	8.92	8.68	5.95	4.63	5.70	9.26	4.30	5.70	3.80	4.63	4.88	2.73	2.97	1.65	1.07	..	..	..	..	0.16	0.33	0.83	2.32	1.32	1.65	1.98	2.97	1.65
	(Average)	2.20	2.49	4.10	6.24	7.68	6.42	4.34	5.35	7.73	5.00	5.22	4.40	3.62	6.60	3.65	3.00	0.99	0.53	..	..	..	0.59	0.68	1.95	1.94	4.68	3.22	2.01	2.30	1.96	1.18
Auxis thazard	AT. 12	2.12	2.50	3.42	8.32	5.70	9.64	13.82	10.06	14.85	10.18	3.82	0.42	..	..	..	..	..	..	0.54	3.21	4.91	3.03	1.57	1.35	0.36	0.18	..	..	..	..	..

Table 17.--Measurements on A. thazard larvae reared in a small tank (0.5 ton) (Harada, Murata, and Miyashita 1973).

Days after hatching	Total length (mm)	Fork length (mm)	Body depth (mm)	Body weight ~~(mm)~~ (g)
10	5.95	–	0.97	–
10	4.90	–	1.10	–
15	11.4	–	2.6	–
20	29.0	25.0	5.0	–
28	55.0	52.0	9.5	–
28	53.5	50.0	9.0	–
30	56.0	53.0	10.0	–
30	47.0	43.0	9.0	–
31	63.0	59.5	10.5	–
31	46.0	43.0	8.5	–
33	55.0	51.0	10.0	1.1
33	55.5	52.0	9.5	1.1
36	60.0	56.5	10.0	1.8

Table 18.--Measurements on A. thazard larvae reared in large tanks (3 tons and 70 tons) (Harada, Murata, and Miyashita 1973).

Days after hatching	Total length (mm)	Fork length (mm)	Body depth (mm)	Body weight (g)
0	3.47	–	0.66	–
2	3.8	–	0.78	–
17	64.0	–	7.5	1.8
33	120.0	112.0	18.0	10.6
"	89.0	84.0	14.0	5.5
"	120.0	115.0	18.0	10.6

Table 19.--Measurements on A. rochei larvae reared in a small tank (0.5 ton) (Harada, Murata, and Furutani 1973).

Days after hatching	Total length (mm)	Fork length (mm)	Body depth (mm)	Body weight (g)
0	3.49	–	0.62	–
2	3.58	–	0.70	–
10	5.18	–	1.05	–
15	7.10	–	1.70	–
15	6.65	–	1.15	–
15	8.50	–	1.95	–
15	9.10	–	2.25	–
20	11.00	–	2.70	–
20	9.95	–	2.50	–
20	8.50	–	2.35	–
20	9.50	–	2.60	–
43	95.00	89.00	14.00	7.0
43	89.00	85.00	15.00	6.2

Table 20.--Measurements on A. rochei larvae reared in large tanks (3 tons and 30 tons) (Harada, Murata, and Furutani 1973).

Days after hatching	Total length (mm)	Fork length (mm)	Body depth (mm)	Body weight (g)
0	3.49	–	0.62	–
2	3.58	–	0.73	–
18	49.00	–	7.70	0.8
36	88.00	82.0	18.00	4.2
40	140.00	120.0	30.00	25.0
51	152.00	142.0	32.00	32.5
51	144.00	138.0	24.00	21.9
51	152.00	143.0	28.00	28.2
52	145.00	136.0	26.00	24.0
52	157.00	152.0	28.00	37.0
52	155.00	145.0	26.00	31.7
58	120.00	112.0	18.00	–
58	155.00	145.0	30.00	–

Table 21.--Distribution of larval tunas according to depth of haul (*Dana* collection) (Jones and Kumaran 1963).

Depth of haul in metres	No. of fishing hours	*K. pelamis*		*N. macropterus*		*E. affinis affinis*		*A. rochei*	
		No. of specimens	No. per one hour of haul	No. of specimens	No. per one hour of haul	No. of specimens	No. per one hour of haul	No. of specimens	No. per one hour of haul
0-Ca. 20	38	323	8.5	219	5.8	41	1.1	5	0.1
Ca. 30	82	350	4.3	387	4.7	111	1.4	106	1.3
Ca. 50-70	62	261	4.2	70	1.1	13	0.2	15	0.2
Ca. 100-200	245	152	0.6	69	0.3	14	0.1	5	0.02

Table 22.--Standard length and gill-raker count of juvenile *A. thazard* (Wade 1949).

Standard length (millimeters)	Gill-raker count
21.8	[1] 4+1+18=23
22.6	10+1+30=41
26	7+1+29=37
26	10+1+31=42
43.5	10+1+29=40
44	8+1+29=38
46	8+1+30=39
47	9+1+29=39
47	9+1+29=39
48	9+1+29=39
49	8+1+30=39
55	9+1+29=39

[1] Lesser count possibly is due to the small size of the specimen with undeveloped gill rakers.

Table 23.--Standard length and gill-raker count of juvenile *A. rochei* (Wade 1949).

Standard length (millimeters)	Gill-raker count
32	10+1+35=46
42	11+1+34=46
48	10+1+34=45
51.5	10+1+35=46
58.5	10+1+34=45
61	10+1+34=45
75	10+1+36=47

Table 24.--Selected meristic counts made on 10 cleared and stained *Auxis* from the eastern Pacific (Fitch and Roedel 1963).

Standard length (mm)	First dorsal spines	Spines in dorsal interspace	Pectoral rays	Gill rakers,[1] First arch	Vertebrae[2] HA - HS - Total
13.2	XII	III	12	1-1-8	13-21-39
20.0	IX	V	20	4-1-19	13-21-39
21.5	X	VI	-	4-1-21	14-21-39
28.5	X	VII	-	6-1-25	14-21-39
33.3	XI	VI	24	9-1-31	14-21-39
39.4	XI	VI	24	9-1-31	15-21-39
41.5	XI	VI	24	9-1-32	14-21-39
43.7	XI	VI	23	10-1-32	17-21-39
88.9	XI	VIII	24	11-1-32	- - - -
89.0	X	VIII	22	11-1-33	20-21-39

[1]Count always includes a central raker with roots into both the upper and lower limb.

[2]Numbers correspond to vertebra upon which the first haemal arch, first haemal spine, and hypural occur.

Table 26.--The frequency of occurrence of the gill-raker counts by species and areas (Watanabe 1964).

	Species	Count	Upper Limb					Angle	Lower Limb										Combined Counts											
		Area	8	9	10	11	12	1	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
young stage	Auxis rochei	6°– 7° S 124°–125° E	—	—	11	22	1	34	—	—	—	—	5	10	13	3	1	2	—	—	—	—	—	1	11	5	11	3	1	2
		23°– 25° S 154°–155° E	—	1	6	3	—	10	—	—	—	—	—	5	1	3	—	1	—	—	—	—	—	1	2	3	3	—	—	3
		Total ..	—	1	17	25	1	44	—	—	—	—	5	15	14	6	1	3	—	—	—	—	—	2	13	8	14	3	1	3
	Auxis thazard	6°– 7° S 124°–125° E	—	8	3	—	—	6	1	1	—	—	2	2	—	—	—	—	1	1	—	1	1	2	—	—	—	—	—	—
		24°–37.4′ S 51°28′ E	—	1	—	—	—	1	—	—	—	—	1	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—
		Total ..	—	4	3	—	—	7	1	1	—	—	3	2	—	—	—	—	1	1	—	2	1	2	—	—	—	—	—	—
immature and adult stage	Auxis rochei	9°11′ S 95°45′ E	—	—	—	1	—	1	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
		Japan *	—	—	3	2	—	5	—	—	—	—	1	1	3	—	—	—	—	—	—	—	—	—	2	2	1	—	—	—
		Total ..	—	—	3	3	—	6	—	—	—	—	1	1	4	—	—	—	—	—	—	—	—	—	2	2	2	—	—	—
	Auxis thazard	18°–30° S 175°E–175°W	1	—	1	—	—	2	1	—	1	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—
		Japan *	—	2	2	—	—	4	—	—	4	—	—	—	—	—	—	—	—	—	2	2	—	—	—	—	—	—	—	—
		Total ..	1	2	3	—	—	6	1	—	5	—	—	—	—	—	—	—	—	2	2	2	—	—	—	—	—	—	—	—

* Japan . . . . off the Southern coast of Shikoku.

Table 27.--The number of the vertebra, starting with the atlas, upon which the first free parapophysis occurs in young specimens of frigate mackerel (Watanabe 1964).

	21	22	23
A. rochei	12	13	6
A. thazard		1	5

immature specimen

	21	22	23
A. rochei	2	2	1
A. thazard		1	4

Table 28.--The number of the vertebra, starting with the atlas, upon which the first inferior foramen occurs in young specimens of frigate mackerel (Watanabe 1964).

	27	28	29	30
A. rochei		4	17	9
A. thazard	2	4		

immature specimen

	27	28	29
A. rochei			2
A. thazard	4	1	

Table 29.--Ratio of the length of the caudal vertebra to the precaudal vertebra (Watanabe 1964).

	A. rochei	*A. thazard*
Young stage	0.90~0.973	0.985~1.16
Immature stage	0.91~0.953	0.957~0.99

Table 30.--Total numbers of juvenile tunas and (in parentheses) average numbers per tow collected by midwater trawl in Hawaiian waters, RV Townsend Cromwell cruise 32, 12 July to 25 September 1967. (SJ = skipjack; YF = yellowfin; BE = bigeye; AL = albacore; KK = kawakawa; FM = frigate mackerel.) (Higgins 1970.)

Area	Number of tows	SJ	YF	BE	AL	KK	FM	Total tunas
Inshore Oahu								
July	18	30 (1.7)	16 (0.9)	0 (0)	0	2 (0.1)	7 (0.4)	55 (3.0)
August	10	9 (0.9)	4 (0.4)	5 (0.5)	0	1 (0.1)	9 (0.9)	28 (2.8)
September	8	6 (0.8)	28 (3.5)	9 (1.1)	0	20 (2.5)	111 (13.9)	174 (21.8)
Total	36	45 (1.2)	48 (1.3)	14 (0.4)	0	23 (0.6)	127 (3.5)	257 (7.1)
Offshore Oahu								
July	11	130 (11.8)	11 (1.0)	6 (0.5)	0	2 (0.2)	6 (0.5)	155 (14.1)
August	18	250 (13.9)	88 (4.8)	40 (2.6)	2 (0.1)	0	0	380 (21.2)
Total	29	380 (13.1)	99 (3.4)	46 (1.6)	2 (<0.1)	2 (<0.1)	6 (0.2)	535 (18.4)
Molokai[1]								
August								
Total	2	1 (0.5)	0	0	0	0	0	1 (0.5)
Lanai[1]								
September								
Total	4	0	0	0	0	0	0	0
Hawaii								
September								
Total	12	152 (12.7)	33 (2.7)	12 (1.0)	5 (0.4)	0	0	202 (16.8)
Grand total	83	578 (7.0)	180 (2.2)	72 (0.9)	7 (<0.1)	25 (0.3)	133 (1.6)	995 (12.0)

[1] The duration of these tows was less than 6 hours.

Table 31.--Standard lengths (millimeters) of juveniles of species other than skipjack tuna taken in six types of tow, inshore and offshore Oahu areas, July and August 1967 (Higgins 1970).

Depth and time of day	Number of tows	Yellowfin tuna			Bigeye tuna			Frigate mackerel		
		Number measured	Length		Number measured	Length		Number measured	Length	
			Average	Range		Average	Range		Average	Range
Shallow										
Night	5	34	9.9	6.6–39.0	11	10.8	9.0–14.4	14	[1]11.7	7.1–15.4, 110.5
Morning	5	43	9.6	7.4–13.4	26	11.8	8.9–18.2	2	–	12.6, 159.0
Day	5	33	10.7	7.8–20.0	13	10.9	9.4–13.6	0	–	–
Deep										
Night	4	2	25.4	14.9, 36.0	0	–	–	3	151.7	147.5–157.0
Morning	5	1	–	8.7	0	–	–	2	132.5	127.0, 138.0
Day	5	1	–	14.2	1	–	15.0	0	–	–

[1] Excluding the 110.5-mm specimen.

Table 32.--Species composition and relative abundance of juvenile tunas taken in 83 tows with a midwater trawl in Hawaiian waters, July-September 1967 (Higgins 1970).

Species	Total number collected	Percent of total catch	Average number per tow	Number of tows with species	Percent frequency of occurrence
Katsuwonus pelamis	578	58.1	7.0	54	65.1
Thunnus albacares	180	18.1	2.2	30	36.1
Thunnus obesus	72	7.2	0.9	21	25.3
Thunnus alalunga	7	0.7	<0.1	4	4.8
Euthynnus affinis	25	2.5	0.3	7	8.4
Auxis sp. or spp.	133	13.4	1.6	15	18.1
Total or average	995	100.0	12.0	63	75.9

Table 34.--Monogenetic and digenetic trematodes, cestodes, and copepods that are parasitic on frigate mackerel (adapted from Silas 1967a; Silas and Ummerkutty 1967).

Type of parasite	Family	Species	Scombroid hosts	Locality	Non-scombroid hosts	Body part infested
Monogenetic trematode	Hexostomatidae	Hexostoma auxidi	A. thazard	Mediterranean	None	Gills
Digenetic trematode	Bucephalidae	Rhipidocotyle capitatum	A. rochei E. alletteratus	Woods Hole, Mass.	Holocentrus ascensionis	Not given
	Fellodistomidae	Tergestia laticollis	Scomber japonicus A. thazard E. alletteratus	Japan United States (Florida)	Caranx trachurus Trachurus trachurus Apogon lineatus	Intestine
	Didymozoidae	Didymozoon auxis	A. rochei A. thazard	Mediterranean (Naples) Japan (Taizi)	None	Gills and outer side of gill lamellae
		Phacelotrema claviforme	A. thazard	Japan (Taizi)	None	Pyloric caeca
		Opepherotrema planum	A. thazard	Japan (Taizi)	None	Pyloric caeca
		Colocyntotrema auxis	A. thazard	Japan (Taizi)	None	Pyloric caeca
Cestode	Dasyrhynchidae	Callitetrarhynchus gracilis	S. rocheus (A. thazard) S. scombrus Scomberomorus maculatus Thunnus sp.	Mediterranean Atlantic	Carcharhinus obscurus Dasyatis centrura Hypoprion brevirostris Alutera schoepfi Paralichthys dentatus P. olivaceus Galeichthys felis Chaetodipterus faber Cynoscion regalis Lophius piscatorius Pomatomus saltatrix Remora remora Roccus lineatus Stenotomus chrysops Trichiurus lepturus Tylosurus acus Brama sp. Sparus sp. Muraenesox sp. Scomberoides sp. Seriola sp. Caranx sp. Ceratacanthus sp.	In scombroids and other teleosts, larvae encysted in viscera. Adults in C. obscurus.

Table 34.--Continued.

Type of parasite	Family	Species	Scombroid hosts	Locality	Non-scombroid hosts	Body part infested
Parasitic copepod	Caligidae	Caligus macarovi	A. thazard E. lineatus	Mexico (Gulf of California) Japan	None	Outside of operculum and between scales
		Caligus productus	K. pelamis Scomberomorus sierra S. japonicus T. thynnus T. albacares S. sarda Sarda sp. A. thazard Scomberomorus cavalla	Mediterranean Mexico (Guaymas) United States (Texas coast) Mexico (Sonora) Japan (Hamajima) Japan (Owase)	Coryphaena hippurus Balistes sp. Sphyraena sp. Coryphaena sp. Chrysophrys aurate Seriola dorsalis Paralabrax clathratus P. maculofasciatus Verrunculus polylepis Sphyraena argentea Lutjanus sp. Calamus brachysomus Centropomus sp. Polydactylus opercularis Pogonias cromis Monacanthus sp. Naucrates ductor	Inner surface of gill cover and outer surface of body of host
		Caligus auxisi	A. thazard	India (southwest coast)	None	Inner surface of opercle of host

Table 35.--The amounts of molybdenum and nickel found in various body tissues of tunas (Morio and Suzuki 1959).

Table. 1 The distribution of Mo and Ni contents in several fishes

* trace·····Mo:under 0.03 γ/g Dry basis
Ni:under 0.08 γ/g Dry basis

Element	Species	Date of catch	Site of catch	Sex	Body length cm	Liver weight g	Gonad weight g	Ordinary muscle		Dark muscle		Liver		Gonad		Pyloric coeca		Heart	
								γ/g Dry basis	γ/100g Wet basis	γ/g Dry basis	γ/100g Wet basis	γ/g Dry basis	γ/100g Wet basis	γ/g Dry basis	γ/100g Wet basis	γ/g Dry basis	γ/100g Wet basis	γ/g Dry basis	γ/100g wet basis
Molybdenum	Auxis rochei (BIEEKER) (マルソーダ)	1956-4	Tosashimizu	♀	32.2	19.6	13.3	0.08	2.8	0.32	9.8	0.68	27.3	0.07	2.1	0.45	10.7	trace	
	Albacore (ビンナガ)	1957-3	15°-27° E 87°-102° E	♂	106	115.0	125.5	trace		trace		1.14	36.5	0.25	6.5	trace		—	—
	Yellowfin tuna (キハダ)	1958-8	9°54′-15°1′ S 100°5′-103°21′ E	♀	104	79	40.5	0.20	4.6	0.47	12.5	1.09	30.4	0.38	9.5	trace		—	—
	Yellowfin tuna (キハダ)	1958-8	〃	♀	69	44	27	trace		0.40	12.5	2.05	60.9	trace		—	—	0.17	5.0
	Bigeyed tuna (メバチ)	1959-3	6°30′N 153° E	♂	125	—	—	0.29	7.0	0.32	8.0	3.57	82.8	—	—	—	—	—	—
Nickel	Auxis rochei (BIEEKER) (マルソーダ)	1956-4	Tosashimizu	♀	32.2	19.6	13.3	0.53	18.6	trace		0.59	23.7	0.27	7.9	1.86	44.1	—	
	Albacore (ビンナガ)	1957-3	15°-27° E 87°-102° E	♂	106	115.0	125.5	0.13	3.8	0	0	0	0	0.09	2.3	0	0	—	—
	Yellowfin tuna (キハダ)	1956-3	5°N 90° E	♀	130	260	460	—	—	—	—	0.09	3.2	trace		—	—	0.16	5.6
	Yellowfin tuna (キハダ)	1956-9	6° S 47°5′ E	♀	123	—	—	0	0	0.12	3.1	—	—	—	—	—	—	—	—

Table 39.--Young tunas from stomachs of vertebrates (Klawe 1963).

Position Lat. N	Long. W	Date	From stomach of	Species	No.	Size mm.
Posición Lat. N	Long. W	Fecha	En el estómago de	Especie	No.	Tamaño en mm.
8°45	83°55	June 1938	*Pelamis platurus*	*N. macropterus*	8	approx. 50
21°06	106°45	March 1956	*Katsuwonus pelamis*	*A. thazard*	7	—
7°30	80°00	April 1958	*Neothunnus macropterus*	*A. thazard*	3	—
7°00	84°00	May 11 1958	*Neothunnus macropterus*	*A. thazard*	4	91
7°10	81°50	May 20 1958	*Neothunnus macropterus*	*A. thazard*	2	65, 75
15°55	95°50	Feb. 3 1959	*Euthynnus lineatus*	*A. thazard*	16	75-125
14°30	98°30	March 1959	*Neothunnus macropterus*	*A. thazard*	1	60
6°30	77°40	April 1959	*Neothunnus macropterus*	*A. thazard*	1	78
10°25	85°55	May 1959	*Neothunnus macropterus*	*N. macropterus*	2	35, 40
18°30	104°30	May 1959	*Neothunnus macropterus*	*A. thazard*	32	approx. 90
19°30	110°30	May 1959	*Neothunnus macropterus*	*A. thazard*	2	90

Table 40.--Size-frequency distribution of Auxis found in the stomachs of tunas and marlins (Watanabe 1964).

Area*	B. L. Cm. / Period	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
A	Jan. '53	7	14	25	28	17	15	6	8	4	1	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—
B	Feb. '53	—	—	—	—	—	—	—	—	—	—	—	—	—	8	1	2	8	—	14	1	—	—	—	—	—	—
C	Nov.—Dec. '56	—	7	—	18	1	7	—	1	1	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
D	Dec. '51—Mar. '52	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	2	1	—	—	—	1

A - Banda. Sea.

B - Sawu Sea.

C - Off the coast of Queensland, Australia.

D - Off the southern coast of Shikoku, Japan.

Table 43.--Constants calculated by various investigators for the expression of the length-weight relationship of *Auxis thazard*, *A. rochei*, and *Auxis* sp. species in which $W = aL^n$.

Investigators	*Auxis thazard*		*Auxis rochei*		*Auxis* sp.	
	a	n	a	n	a	n
Ishida (1971)						
(Mikomoto)	6.05×10^{-3}	3.300	4.13×10^{-3}	3.384	--	--
(Shionomisaki)	7.70×10^{-2}	2.509	4.64×10^{-3}	3.362	--	--
Lenarz (1974)	--	--	--	--	2.80×10^{-7}	4.13514
Rodriguez-Roda (1966)	1.00538×10^{-5}	3.129871	--	--	--	--
Sivasubramaniam (1966)	1.780×10^{-4}	3.3338	2.598×10^{-6}	4.6315	--	--
Yasui (1975)	--	--	1.549×10^{-3}	3.65705	--	--

Table 45.--Weights in grams calculated for a frigate mackerel 30 cm in length, using constants of the length-weight relationship provided by various investigators.

Investigators	*Auxis thazard* (g)	*Auxis rochei* (g)	*Auxis* sp. (g)
Ishida (1971)	[illegible]	[illegible]	
(Mikomoto)	453	412	--
(Shionomisaki)	391	429	--
Lenarz (1974)	--	--	359
Rodriguez-Roda (1966)	422	--	--
Sivasubramaniam (1966)	424	511	--
Yasui (1975)	--	391	--

Table 46.--Worldwide catches of frigate mackerel, 1953-73 (in units of 1,000 MT)

Year	Angola	Cyprus	Ghana	Greece[1/]	Italy	Japan	Maldive	Malta	Morocco[2/]	Philippine Islands	Spain[3/]	Sri Lanka	Taiwan	Venezuela[4/]	Yugoslavia	Other
1953	6.4	-	-	0.8	-	15.6	-	-	4.0	-	2.0	-	-	1.2	-	-
1954	7.3	-	-	0.6	-	20.6	-	-	1.4	-	4.0	-	-	1.3	0.1	-
1955	5.2	-	-	1.2	-	23.4	-	-	4.0	-	4.8	-	-	1.3	0.2	-
1956	1.8	-	-	0.9	-	25.9	-	-	2.4	-	3.4	-	-	1.1	0.1	-
1957	1.1	-	-	0.5	-	20.4	-	-	2.5	-	5.4	-	-	1.0	-	-
1958	2.5	-	-	0.7	0.4	23.3	-	-	3.0	-	10.0	-	-	1.2	0.1	-
1959	1.9	-	-	0.7	0.7	19.9	-	-	1.0	-	3.8	-	-	1.7	0.1	-
1960	1.9	-	-	-	0.6	15.8	-	-	1.8	-	5.2	-	-	1.3	0.0	-
1961	2.7	-	-	-	1.0	18.2	-	-	0.2	-	3.4	-	0.7	0.8	0.0	-
1962	1.6	-	-	-	0.7	21.1	-	-	0.6	-	4.4	-	0.8	1.0	0.0	-
1963	1.3	-	-	-	0.8	48.3	-	-	1.6	-	3.1	-	0.6	1.0	0.0	-
1964	0.9	-	-	0.6	0.5	26.9	-	-	1.5	-	2.5	4.0	1.1	1.4	0.0	-
1965	1.7	0.0	2.0	0.7	0.7	30.7	2.5	0.0	1.8	-	2.5	4.5	0.8	1.8	0.0	0.8
1966	1.4	0.0	2.0	0.5	0.9	29.7	3.0	0.0	0.8	-	2.3	4.5	1.2	1.4	0.0	1.2
1967	1.2	0.0	2.0	0.6	1.2	29.3	3.0	0.0	1.2	-	3.5	5.0	0.8	1.1	0.0	0.8

Table 46.--Continued.

Year	Angola	Cyprus	Ghana	Greece 1/	Italy	Japan	Maldive	Malta	Morocco 2/	Philippine Islands	Spain 3/	Sri Lanka	Taiwan	Venezuela 4/	Yugoslavia	Other
1968	0.6	0.0	1.8	0.5	1.2	22.6	3.0	0.0	0.9	-	1.7	5.0	1.2	0.4	0.0	1.2
1969	0.8	0.0	3.0	-	1.1	27.3	3.0	0.0	0.6	-	2.0	5.5	-	0.4	0.1	1.3
1970	0.5	0.0	3.0	-	1.1	29.0	1.7	0.0	1.0	-	2.2	5.0	-	0.7	0.0	0.8
1971	1.1	0.0	2.7	-	1.6	20.1	1.8	0.0	0.3	-	3.8	3.2	-	0.5	0.0	1.8
1972	1.6	0.0	5.3	-	1.7	31.1	3.1	0.0	0.5	19.8	1.9	4.1	-	0.6	0.0	-
1973	1.1	0.0	1.6	-	1.2	34.7	6.2	0.0	1.6	3.8	1.9	3.8	-	0.7	0.0	-
Mean	2.1	0.0	2.6	0.7	1.0	25.4	3.0	0.0	1.6	11.8	3.5	4.5	0.9	1.0	0.0	1.1

- Data not available

0.0 Magnitude negligible or insignificant

1/ Includes bluefin tuna

2/ Includes Atlantic bonito

3/ Includes catches from Ceuta in 1954-58

4/ Includes Atlantic bonito in 1965-67

Data compiled from FAO (1959; 1964; 1969; 1974), Miyake and Tibbo (1972), Miyake, De Boisset, and Manning (1974), Lamboeuf (1972), Sivasubramaniam (1974)

Table 47.--Annual regional catches (in metric tons) of frigate mackerel from Japanese waters, 1952-56 (differences between the sum of the regional catches and the grand total are due to rounding off during conversion from Kan to metric tons; adapted from Okachi 1958).

Region	1952	1953	1954	1955	1956
Hokkaido	41	34	38	53	38
North Pacific	574	746	345	773	1,703
Middle Pacific	5,713	2,941	3,545	4,580	7,581
South Pacific	16,262	9,517	13,407	14,165	14,094
East China Sea	551	960	1,077	1,714	1,020
West Japan Sea	405	705	1,527	1,763	833
North Japan Sea	446	615	608	360	630
Grand total	24,075	15,583	20,609	23,445	25,932

Table 48.--Japanese landing of frigate mackerel, 1963-70 (data supplied by Dr. Shoji Kikawa, Far Seas Fisheries Research Laboratory, Shimizu 424, Japan, (1975).

Year	Total	Hokkaido	Pacific	Japan Sea	East China Sea	Seto Inland Sea
1960	15,756	14	9,172	4,934	1,567	68
1961	18,260	10	13,886	2,070	2,195	96
1962	21,064	12	17,306	1,646	2,009	90
1963	48,339	18	40,518	3,340	4,378	84
1964	26,900	0	20,900	3,500	2,000	100
1965	30,735	23	25,374	2,260	3,038	41
1966	29,740	3	23,424	3,673	2,600	41
1967	29,310	0	21,375	4,570	3,341	45
1968	22,552	3	15,653	4,382	2,439	76
1969	27,334	-	23,481	1,844	1,967	42
1970	28,995	3	25,395	1,525	1,902	70
1971	20,112	-	17,082	1,349	1,649	32
1972	31,110	-	26,044	2,729	2,288	49
1973	34,553	-	29,300	2,917	2,243	93

Metric tons.

Annual Statistical Report on Fisheries and Aquacultural Production-1973. Statistical and Information Division, Ministry of Agriculture and Forestry, Japan.

Table 49.--The names of the prefectures included in the various fishing regions around Japan.

Region	Prefectures included
North Pacific	Aomori, Iwate, Miyagi, and Fukushima
Middle Pacific	Chiba, Shizuoka, Aichi, and Mie
South Pacific	Wakayama, Kochi, Ehime, and Oita
East China Sea	Fukuoka, Saga, Nagasaki, and Kumamoto
West Japan Sea	Fukui, Kyoto, Tottori, Shimane, and Yamaguchi
North Japan Sea	Niigata and Ishikawa

Table 50.--Mean catch, standard deviation (σ), and coefficient of variation (C. V) of tunalike fishes, Japan (Yamashige 1974).

Period		Total	Pacific coast			Japan Sea coast		East China Sea coast region
			North Pacific region	Middle Pacific region	South Pacific region	North Japan Sea region	West Japan Sea region	
1952-61	Mean catch	20.82	0.58	3.98	12.74	1.06	0.85	1.43
	σ	3.59	0.45	1.65	3.07	0.57	0.78	0.50
	C. V	17.2	77.6	41.5	24.1	53.8	91.8	35.0
1961-71	Mean catch	28.67	0.48	5.74	16.80	1.76	1.09	2.72
	σ	7.90	0.29	2.55	4.56	1.16	0.57	0.94
	C. V	27.6	60.4	44.4	27.1	65.9	52.3	34.6
1952-71	Mean catch	24.75	0.53	4.86	14.77	1.41	0.97	2.08
	σ	7.20	0.37	2.27	4.32	0.96	0.68	0.99
	C. V	29.1	69.8	46.7	29.2	68.1	70.1	47.6

Table 51.--Mean catch (in metric tons) of frigate mackerel by month and prefecture, calculated from catches made in January 1952 - July 1957 (adapted from Okachi 1958).

Prefecture	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aomori	-	-	-	-	-	0.38	3.38	6.38	2.62	11.63	2.25	-
Akita	-	-	-	-	-	0.38	2.25	4.13	4.88	6.38	1.50	-
Yamagata	-	-	-	-	-	-	-	0.38	0.38	1.88	0.38	-
Niigata	0.75	0.38	-	-	0.38	-	13.13	11.63	16.88	28.88	67.15	2.62
Toyama	7.50	0.75	-	-	-	0.38	1.50	1.50	1.88	138.42	377.00	226.20
Ishikawa	1.12	-	0.38	0.38	-	-	9.38	4.50	15.38	20.63	39.39	21.38
Fukui	1.12	1.12	0.75	0.75	1.50	1.50	13.13	65.65	18.38	20.63	25.13	7.13
Kyoto	1.12	-	0.38	0.75	-	1.12	1.12	0.75	1.88	19.13	40.89	28.88
Hyogo	0.38	-	-	-	0.75	0.38	-	0.38	1.12	1.12	2.62	1.88
Tottori	0.75	0.75	-	-	0.38	-	0.38	2.25	8.63	19.13	4.88	1.12
Shimane	1.12	0.38	0.75	0.75	1.12	1.12	1.12	3.00	5.63	10.88	28.13	1.88
Yamaguchi	7.13	3.00	1.88	1.12	0.75	-	1.12	6.75	26.63	30.01	79.15	47.64
Fukuoka	0.38	-	-	-	-	0.38	0.38	0.38	5.63	1.12	4.88	0.75
Saga	2.25	0.38	0.38	-	-	-	-	0.38	-	0.38	3.00	1.88
Nagasaki	25.9	2.62	2.62	0.75	1.12	1.88	5.63	8.63	19.13	64.15	109.91	103.91
Kumamoto	-	4.50	0.38	9.00	4.13	0.38	1.12	1.50	1.12	2.25	0.75	0.75
Kagoshima	19.9	15.8	20.63	63.8	72.02	90.78	143.30	64.90	42.39	45.39	52.89	55.89

Table 52.--Fishing areas and seasons for frigate mackerel in the Philippine Islands (Philippine Bureau of Fisheries 1973).

Fishing areas	Fishing seasons
Northern and northwestern Zambales Coast	January to May
Sulu Archipelago	January to May
Manila Bay	December to May
Batangas Bay	November to May
Balayan Bay	November to May

Table 53.--Total landings and percentages of tunas caught on voyage 3 by the purse seiners Royal Venture and Southward Ho in Philippine waters (Rosenberg and Simpson 1975).

Species	Kilos	Pounds	Percent (by weight)
Yellowfin	8,585	18,931	6.8
Skipjack	84,148	185,546	67.2
Little tuna	6,658	14,681	5.3
"Tulingan"[1/] (Frigate mackerel)	10,279	22,665	8.2
Mixed[2/]	15,604	34,406	12.5
	125,274	276,229	100.0

1/ These fish were recorded as "tulingan" by the buyer, and are probably frigate mackerel (Auxis sp.) but their identification has not yet been checked.

2/ Mixed little tuna and "tulingan."

Table 54.--Total landings and percentages of tunas caught on voyage 4 by the purse seiners Royal Venture and Southward Ho in Philippine waters (Rosenberg, Simpson, and Renwick 1975).

Species	Kilos	Pounds	Percent (by weight)
Yellowfin	69,625	153,523	24.4
Skipjack	181,616	400,463	63.8
Tulingan 1/	30,900	68,135	10.8
Reject 2/	2,951	6,507	1.0
	235,092	628,628	100.0

1/ Most of the fish in this group are frigate mackerel (Auxis sp.). The term Tulingan is the common local name for this species.

2/ The fish in this heading were judged not good enough for human consumption and will have to be sold for reduction. The damage occurred during the unloading and grading operations at the local cold storage where the fish was stored.

Table 55.--Estimated catch of tuna and tuna-like fishes in the South China Sea area, by countries, 1970 or 1971 (Kume 1973).

Countries	Bigeye tuna	Yellow-fin tuna	Bill-fish	Skip-jack	Little tuna and frigate mackerel	Spanish mackerel	Main source of data
Hong Kong	-a/	-	-	-	-	1 849	Fisheries Research Station, 1971
Japan	962	2 132	204	n.a.b/	-	-	Annual Report, Tuna Longline, 1971
Philippines	-	3 775c/	-	226	4 246	5 143	Fisheries Statistics, 1971
Sabah	-	-	-	-	2 600	1 700d/	Annual Report, 1971
Sarawak	-	-	-	-	4 414	6 292	Annual Report, 1971
Singapore	-	-	-	-	-	73	Primary Production Department, 1971
China (Province of Taiwan)e/	2 800		2 000	604	14 985	2 541	Fisheries Yearbook, 1970
Thailand	-	-	-	-	6 548f/	9 201	Department of Fisheries, 1971
West Malaysia	-	-	-	-	4 295f/	6 988	Annual Fisheries Statistics, 1971

a/ - = none or negligible
b/ n.a. = not available
c/ Substantial amounts of yellowfin tuna were reportedly caught by municipal fisheries conducted by fishing craft smaller than three tons; these are not included here.
d/ Other types of scombroids are included here.
e/ Tuna and billfish production was obtained by prorating proportions from older data, and other species production probably includes the catch from the coastal area of Taiwan Province.
f/ *Thunnus tonggol* production is included here.

Table 56.--Catch of little tunas and Spanish mackerel in West Malaysia, 1958-71, in MT (Kume 1973).

Year	Little tunas	Spanish mackerel
1958	1 147	7 042
1959	789	4 642
1960	1 712	4 890
1961	1 917	5 125
1962	2 246	6 308
1963	3 355	5 039
1964	2 633	5 425
1965	3 114	6 829
1966	4 455	7 634
1967	5 578	6 161
1968	4 465	6 860
1969	3 430	5 856
1970	4 703	6 982
1971	4 295	6 998

Table 57.--The effort in man-hours and the catch in Minicoy during the 1960-61 fishing season (Thomas 1967).

Month	Effort in man-hours	*Katsuwonus pelamis* (kg)	*Neothunnus macropterus* (kg)	Other fishes (kg)	Total catch (kg)	Catch-per man-hour-effort (kg)
December 1960	630,979	324,740.85	7,023.33	405.17	332,169.35	0.526
January 1961	674,417	530,295.54	11,951.45	623.00	542,869.99	0.805
February 1961	217,521	126,455.19	4,292.02	660.20	131,407.41	0.604
March 1961	192,796	73,789.97	604.17	847.20	75,241.34	0.390
April 1961	141,296	65,941.48	1,457.69	66.07	67,465.24	0.477
Season	1,857,009	1,121,223.03	25,328.66	2,601.64	1,149,153.33	0.619

Table 58.--Estimated catches, in 1,000 MT, of tuna and tuna-like fishes in the pole-and-line and drift-net fisheries on the west and east coasts of India (Sivasubramaniam 1974).

Variety		1971	1972	1973
Yellowfin	W -	0.2	0.2	0.2
	E -	0.04	0.04	0.04
Skipjack	W -	4.4	4.1	4.1
	E -	0.7	0.7	0.7
Little Tuna	W -	0.3	0.3	0.3
	E -	0.04	0.04	0.04
Frigate Mackerel	W -	0.2	0.2	0.2
	E.-	0.04	0.04	0.04
Total	W -	5.1	4.8	4.8
	E -	0.87	0.82	0.82

YF 5%
SkJ 85%
L.tuna 5%
FM 5%

Pole and line, driftnets.

Traditional Crafts and small mechanised boats.

Table 59.--The range in length and average weight of several species of tuna caught by purse seining in Indian waters (Silas 1969).

Species	No.of specimens	Fork length Range in mm	Average weight in kg
Auxis rochei	141	191 - 290	0.168
Auxis thazard	153	201 - 510	0.750
Euthynnus a. affinis	238	281 - 620	2.232
Sarda orientalis	21	281 - 520	1.309
Katsuwonus pelamis	38	421 - 650	3.347
Kishinoella tonggol	1	447	-
Thunnus albacares macropterus	7	500 - 650	3.500

Table 60.--Estimated catches, in 1,000 MT, of tuna and tuna-like fishes in the pole-and-line and surface trolling fisheries of the Maldive Islands (Sivasubramaniam 1974).

Variety	1970	1971
Yellowfin	1.2	1.3
Skipjack	26.1	27.4
L. Tuna	0.2	0.2
Frigate M.	1.7	1.8
Total	29.2	30.7

YF	4.2%
SkJ	89.2%
L.T	0.7%
FM	5.8%

Pole and Line
Troll

Traditional Crafts only

Table 61.--Landings of tuna and tuna-like fishes in the Maldive Islands, 1969-73 (data from a project report--Tuna Canning Plant--prepared by India for the Government of the Republic of Maldive in 1974).

SPECIES		WEIGHT IN METRIC TONS				
COMMON NAME	LOCAL NAME	1969	1970	1971	1972	1973
Small Skipjack	KALIBILA	14,832	22,220	21,577	13,768	18,201
Large Skipjack	Goda	3,477	5,072	7,344	2,281	1,752
Yellowfin	Kennoli	1,819	2,181	1,317	4,974	5,224
Little tuna	Latti	581	577	443	577	1,027
Frigate mackerel	Raagodi	2,994	3,094	26,871	3,085	6,209
Miscellaneous	Faruman and Vehimas	8,546	-	1,371	7,500	1,267
	Total	32,299	33,144	58,923	32,185	33,680

Table 62.--The number of days fished and the number of tuna caught, in thousands of fish, by months and type of gear, 1965 (Hiebert and Alverson 1971).

(a) skipjack and yellowfin tuna;
(b) large skipjack;
(c) little tuna and frigate mackerel.

	Large boat (live-bait fishing)				Small boat (sailing trolling)			
	Days** fishing	(a)	(b)	(c)	Days** fishing	(a)	(b)	(c)
January	18,908	1,156	66	1,083	11,915	49	3	72
February	16,949	933	21	492	12,232	28	1	91
March	15,341	715	3	291	9,262	20	1	32
April	13,322	464	6	166	10,062	14	*	29
May	11,301	553	10	92	11,585	32	1	32
June	14,145	616	4	126	11,994	58	1	51
July	15,067	460	13	74	11,870	22	2	29
August	13,184	452	21	114	10,408	53	2	32
September	11,664	274	40	84	10,190	15	*	25
October	14,444	364	62	294	10,568	22	5	42
November	15,730	333	47	347	10,412	36	1	32
December	17,295	597	76	125	13,667	69	4	50
Total	177,350	6,917	369	3,288	134,165	418	21	517

* less than 500.

** minor discrepancies are due to rounding.

Table 63.--Estimated catches, in 1,000 MT, of tuna and tuna-like fishes in the pole-and-line, surface trolling, and drift-net fisheries operating in the inshore waters of Sri Lanka (Sivasubramaniam 1974).

Variety	1964	65	66	67	68	69	70	71	72	73
Bigeye Tuna	-	-	-	-	-	-	Neg.	Neg.	Neg.	Neg.
Yellowfin (*T. albacares*)	2.0	1.7	2.0	2.6	4.1	3.8	4.0	3.8	5.1	5.0
Skipjack (*K. pelamis*)	2.0	2.5	3.0	3.7	6.0	10.0	11.0	9.8	12.4	10.2
Little Tuna (E. affinis)	3.0	3.0	3.0	3.5	4.0	4.0	4.0	2.4	2.3	2.0
Frigate Mackerel (*A. thazard* + *rochei*)	4.0	4.5	4.5	5.0	5.0	5.5	5.0	3.2	4.1	3.8
Total	11.0	11.7	12.5	14.8	19.1	23.3	24.0	19.2	23.9	21.0

Neg. - Less than 10 Tons.

Drift Net, Pole & line, Troll methods.

Traditional crafts, 3.1/2 Ton and 11 Ton Classes of Vessels

Surface fishery changes commenced. ↑

Table 64.--Estimated catches, in 1,000 MT, of tuna and tuna-like fishes in the pole-and-line fishery operating in the offshore waters of Sri Lanka (Sivasubramaniam 1974).

Variety	1973
Yellowfin	0.10
Skipjack	0.35
Little Tuna	Neg.
Frigate Mackerel	Neg.

Neg. - Less than 10 Tons
Pole and line (live bait).
250 Ton Class vessels.

Table 65.--Catches of mackerel, bonito, frigate mackerel, and bluefin tuna by ring net and trap net along the Mediterranean Spanish coast (Bas 1967).

Species	Type of gear	
	Ring net (MT)	Trap net (No.)
Mackerel (*Scomber scombrus*)	3,000	-
Bonito (*Pelamys sarda*)	500	60,000 - 140,000
Frigate mackerel (*Auxis thazard*)	274 - 2,500	500,000 - 2,250,000
Bluefin tuna (*Thunnus thynnus*)	500	2,000 - 12,000

Table 66.--Average annual production of the tuna trap fishery in Spain and the months of capture of three species of small tunas. Principal months of capture are underlined (adapted from Rodriguez-Roda 1966, 1967).

Species	Barbate		Tarifa		La Linea	
	Catch (MT)	Season	Catch (MT)	Season	Catch (MT)	Season
Euthynnus alleteratus	6.8	May, June, July	1.4	May, June	0.7	August, September
Sarda sarda	2.4	May, June, July	2.2	May, June	5.0	August, September, October
Auxis thazard	15.6	May, June, July	67.1	May, June	216.0	August, September, October

Table 67.--Annual catches of frigate mackerel in the Atlantic Ocean, by country and type of gear, 1960-74.

		1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
FRIGATE MACKEREL - AUXIDE - MELVA																
TOTAL		9.0	8.1	8.3	7.9	6.8	9.3	7.1	9.2	9.5	11.0	12.3	10.7	12.8	9.3	[illegible]
Sub-total by gear, Sous total par engin de pêche, Sub-total por arte de pesca																
Total surface, Total engin de superficie, Total arte de surface		4.2	2.8	4.3	4.3	2.5	5.1	3.4	5.8	4.7	5.5	6.2	1.1	1.5	4.3	[illegible]
Baitboats, Canneurs, Barcos-cebo		—	—	—	1.3	0.9	2.6	1.8	1.8	2.2	4.0	3.1	0.2	0.2	1.2	[illegible]
Purse seiners, Senneurs, Barcos de cerco		—	—	—	—	—	—	—	0.4	1.3	0.2	0.7	0.8	1.2	1.3	—
Unspecified, Non specifié, Sin especificar		4.2	2.8	4.3	3.0	1.7	2.5	1.5	3.6	1.2	1.3	2.4	0.1	[illegible]	[illegible]	[illegible]
Total traps, Total madragues, Total almadrabas		1.0	0.8	0.7	1.8	2.3	1.7	1.4	1.1	1.4	0.9	1.1	0.7	[illegible]	0.3	[illegible]
Total unclassified, Total sans catégorie, Total sin categoría		3.8	4.5	3.3	1.8	1.9	2.5	2.3	2.3	3.4	4.5	5.0	9.9	10.2	[illegible]	[illegible]
Sub-total by country, Sous total par pays, Sub-total por país																
Ghana, Ghana, Ghana	PS 3/	—	—	—	—	—	—	—	—	—	—	—	—	—	1.3	
	UNCL	...	...	...	...	...	...	...	...	1.8	3.0	3.0	2.7	5.3	—	
Japan, Japon, Japón	PS	—	—	—	—	—	—	—	0.4	1.3	0.2	0.7	0.7	1.2	0.2	[illegible]
	BB	—	—	—	—	—	0.9	0.4	0.6	1.6	3.2	3.1	—	0.0	1.2	[illegible]
Morocco, Maroc, Marruecos 1/	Tra	1.8	0.2	0.6	1.2	1.4	1.2	0.6	0.6	0.8	0.1	0.5	0.2	0.4	0.3	[illegible]
	Sur				0.5	0.1	0.5	0.1	0.6	0.1	0.1	0.5	0.1	0.1	1.3	[illegible]
Portugal (Angola), Portugal (Angola), Portugal (Angola)	Tra	—	—	—	—	—	—	—	—	—	—	0.3	0.4	0.4	...	-
	BB	1.9	2.7	1.6	1.3	0.9	1.7	1.4	1.2	0.6	0.8	0.0	0.2	0.2	...	-
	UNCL (Sur)	—	—	—	—	—	—	—	—	—	—	0.2	0.5	1.0	1.6	1.6
Spain, Espagne, España 2/	Tra	1.0	0.8	0.7	0.6	0.9	0.5	0.8	0.5	0.5	0.8	0.3	0.1	0.3	—	0.5
	UNCL	4.2	2.6	3.7	2.5	1.6	2.0	1.5	3.0	1.1	1.2	1.9	3.6	1.6	1.3	—
	PS												0.1	—	—	—

1/ Catch in 1960 includes bonito.
2/ Catches in 1960 and 1961 include a small amount of little tuna.

3/ Types of gear:

PS	Purse seine
BB	Baitboat
Tra	Traps
Sur	Surface gear
UNCL	Unclassified

Data for 1960-62 from Miyake and Tibbo 1972
Data for 1963-73 from Miyake, De Boisset, and Manning 1974.
Data for 1974 from Miyake, personal communication with Mr. Richard S. Shomura.

Table 68.--Percentage composition of the catches, by species, of the Atlantic and Mediterranean trap fishery of Morocco (Lamboeuf 1972).

Traps	*Bluefin*	*Frigate mackerel*	*Bonito*
Atlantic	90 %	3 %	7 %
Mediterranean	1 %	98 %	—

Table 69.--Tuna catches and percentage composition of the catch in Morocco in 1963-69 (adapted from Lamboeuf 1972).

	1963		1964		1965		1966		1967		1968		1969	
	Catch (MT)	%	Catch (MT)	%	Catch (MT)	%	Catch (MT)	%	Catch (MT)	%	Catch (MT)	%	Catch (MT)	%
Bluefin	4,456	43.1	4,484	51.8	2,962	34.5	3,393	50.5	3,425	53.2	1,092	29.8	736	33.7
Skipjack	3,261	31.6	2,141	24.7	3,149	36.7	1,475	22.0	940	14.6	850	23.2	145	6.6
Little tuna	913	8.8	466	5.4	552	6.4	1,042	15.5	884	13.7	801	21.8	718	32.8
Frigate mackerel	1,601	15.5	1,537	17.7	1,762	20.5	787	11.7	1,187	18.5	925	25.2	588	26.9
Bonito	108	1.0	33	0.4	161	1.9	18	0.3	-	-	-	-	-	-
Total	10,339		8,661		8,586		6,715		6,436		3,668		2.187	

Table 70.--Catches of tuna, tuna-like fishes, and broadbill swordfish, in MT, in Morocco, 1971 (Lamboeuf 1973).

Year	*Area*	*Gear*	*Total*	*Blue-fin*	*Skip-jack*	*Broadbill swordfish*	*Atlan-tic bonito*	*Frigate mackerel*	*Atlantic little tuna*	*Plain bonito*
1971	Mediterranean	Vessels . . .	140	42	2	—	37	16	36	7
		Traps	212	37	—	1	17	156	1	—
		Total . .	352	79	2	1	54	172	37	7
	Atlantic	Vessels . . .	1,928	30	118	347	159	59	582	633
		Traps	234	63	—	12	118	26	15	—
		Total . .	2,162	93	118	359	277	85	597	633
	Moroccan total	Vessels . . .	2,068	72	120	347	196	75	618	640
		Traps	446	100	—	13	135	182	16	—
		Total . .	2,514	172	120	360	331	257	634	640

Table 71.--Number of Japanese purse-seine and pole-and-line vessels operated in the Atlantic Ocean, 1962-1963 and 1967-72 (adapted from Hayasi 1973, 1974).

Type of fishery		*Size class* *	*1962*	1963	*1967*	*1968*	*1969*	*1970*	1971	1972**
PURSE SEINE	Single-boat seiner	TOTAL	—	—	—	3	3	1	3	2
		- 50	—	—	—	1	1	—	—	—
		51-100	—	—	—	—	—	—	—	—
		101-200	—	—	—	1	1	—	1	—
		201-400	—	—	—	1	1	1	1	1
		401-	—	—	—	—	—	—	1	1
	Double-boat seiner ***	TOTAL	—	—	4	4	4	3	3	3
		51-150	—	—	4	4	4	3	3	3
Pole-and-line boat		TOTAL	5	5	6	6	6	6	7	14
		151-	5	5	6	6	6	6	7	14

Source of data: Statistics and Information Department, for longline and pole-and-line fisheries; and Fishery Agency and Far Seas Fisheries Research Laboratory, for purse seine fishery.

* Size is given in gross tonnages for all fisheries except the single-boat purse seiner whose size is expressed in carrying capacity.

** Preliminary estimates.

*** Double-boat purse seiners are given in number of units, each of which comprises two net-boats and several carriers.

Table 72.--Catch and percentages (in parentheses) of tunas and tuna-like fishes taken by purse-seine and pole-and-line vessels in the Japanese Atlantic fisheries, 1962-63 and 1967-72 (adapted from Hayasi 1973, 1974).

	1962	1963	1967	1968	1969	1970	1971	1972 1/
Single-boat seiner	-	-	-	1,582 (6)	1,442 (9)	875 (5)	1,983 (8)	2,399 (10)
Double-boat seiner	-	-	8,005 (52)	14,279 (52)	5,547 (34)	4,674 (27)	7,457 (31)	5,352 (24)
Pole-and-line vessels	2,746 (100)	5,568 (100)	7,515 (48)	11,699 (42)	9,390 (57)	11,624 (68)	14,972 (61)	14,959 (66)

1/ Preliminary estimate

Source of data: Statistics and Information Department, for landings of longline and pole-and-line fisheries; and Fishery Agency and Far Seas Fisheries Research Laboratory, for catch of purse seine fishery.

Table 73.--Landings (in metric tons) and percentages (in parentheses) of tunas and tunalike fishes taken by the Japanese Atlantic purse seine fishery, 1964 and 1967-72 (Hayasi 1973, 1974).

	1964	1967	1968	1969	1970	1971	1972[1/]
Yellowfin tuna	455 (93)	5,246 (66)	7,463 (47)	5,805 (83)	1,318 (23)	2,232 (24)	2,827 (36)
Bigeye tuna	- -	82 (1)	413 (3)	161 (2)	92 (2)	249 (3)	308 (4)
Skipjack	32 (7)	2,171 (27)	6,256 (39)	679 (10)	3,519 (62)	6,222 (66)	3,386 (44)
Bonito	- -	2 (0)	- -	- -	- -	- -	- -
Frigate mackerel	- -	443 (6)	1,256 (8)	177 (3)	687 (12)	685 (7)	1,189 (15)
Unclassified and others	1 (0)	63 (1)	476 (3)	166 (2)	23 (0)	52 (1)	40 (1)
Total	488	8,005	15,861	6,989	5,639	9,440	7,750

1/ Preliminary estimates

Table 74.--Landings (in metric tons) and percentages (in parentheses) of tunas and tuna-like fishes taken by the Japanese Atlantic pole-and-line fishery, 1962-63 and 1967-72 (Hayasi 1973,1974).

	1962	1963	1967	1968	1969	1970	1971	1972[1/]
Albacore	-	-	-	38	-	-	-	-
	-	-	-	(0)	-	-	-	-
Bigeye tuna	26	15	381	646	312	32	-	-
	(1)	(0)	(5)	(6)	(3)	(0)	-	-
Yellowfin tuna	1,164	877	1,303	2,151	944	994	2,475	4,425
	(42)	(16)	(17)	(18)	(10)	(8)	(17)	(30)
Skipjack	1,542	4,599	3,735	7,306	4,926	7,481	11,730	10,149
	(56)	(83)	(50)	(62)	(52)	(64)	(78)	(68)
Frigate mackerel	-	-	625	1,558	3,208	3,117	-	25
	-	-	(8)	(13)	(34)	(27)	-	(0)
Unclassified and others	14	77	1,471	38	-	-	765	362
	(1)	(1)	(20)	(0)	-	-	(5)	(2)
Total	2,746	5,568	7,515	11,699	9,390	11,624	14,970	14,961

1/ Preliminary estimates

Table 75.--Catches and value of scombroids of actual or potential commercial interest (Griffiths 1971).

YEAR	CABAÑA (Sarda, Auxis)		CARITE (Scomberomorus)		CACHORRETA (Scomber)	
	Metric tons	Bolivars (1000's)	Metric tons	Bolivars (1000's)	Metric tons	Bolivars (1000's)
1963	1 002	784	2 989	4 409	209	177
1964	1 353	1 209	3 897	5 606	217	166
1965	1 763	1 498	3 225	4 954	406	385
1966	1 434	1 198	3 462	5 591	269	234
1967	1 070	880	3 028	5 035	372	286

Table 76.--Catches of tunas and billfishes, in MT, in the Brazilian fishery, 1969-70 (Paiva 1972).

Species	*1969*	*1970*
Tunas (1)	445	686
Bonito (2)	432	419
Marlins (3)	41	92
Sailfish	27	21
Swordfish	151	135
Others (4)	3,032	3,397
Total	4,126	4,750

Sources: Equipo Técnico de Estadísticas Agrícolas. Ministerio de Agricultura.
(1) Bluefin, yellowfin, albacore, bigeye and blackfin tuna.
(2) Atlantic little tunny and skipjack.
(3) Black marlin, blue marlin and white marlin.
(4) Bonito, frigate mackerel, wahoo and king mackerel.

Table 77.--Catch of *Auxis thazard* off the middle Atlantic states of the United States in 1940-51.

Year	Catch (metric tons		
	New York	New Jersey	Total
[1]1940	5.0	27.5	32.5
1941	--	--	--
[2]1942	20.0	71.8	91.8
[2]1943	73.2	34.5	107.7
[2]1944	14.1	77.1	91.2
1945	--	--	--
1946	--	--	--
1947	--	--	--
[2]1948	30.2	3.9	34.1
[3]1949	11.7	29.4	41.1
[3]1950	--	27.4	27.4
[3]1951	--	0.4	0.4

[1]Data for 1940 are from Fiedler (1945).

[2]Data for 1942-48 are from Anderson and Power (1946, 1947, 1948, and 1951).

[3]Data for 1949-51 are from Anderson and Peterson (1952, 1953, and 1954).

Table 79.--Chi-square values and their probabilities in tests of the ratio of the number of males to females in catches of A. thazard made at Barbate, Tarifa, and La Linea, by month and year (Rodriguez-Roda 1966).

Year	Month	Locality	Males	Females	χ^2	P
1958	June	Barbate	8	12	0.8	0.80-0.70
1961	August	La Linea	73	74	--	--
1961	September	La Linea	70	46	4.96	0.05-0.02
1963	June	Tarifa	10	12	--	--
1964	May	Barbate and Tarifa	71	70	--	--
1964	June	Barbate	16	9	1.96	0.20-0.10
1964	July	Barbate	30	20	1.00	0.50-0.30

Table 80.--Result of starch gel electrophoresis of muscle protein of long-corseleted frigate mackerels (*Auxis rochei*) (Hamada et al. 1974).

Date	Area	No. of specimens	A-gene frequency	Observed values			Theoretical values			Sampling error	χ^2	Confidence interval
				A	AB	B	A	AB	B			
1972												
4/10	Yakushima	45	0.133	0	12	33	0.80	10.38	33.83	0.036	1.073	0.50>P>0.25
4/13	do	47	0.106	0	10	37	0.53	8.91	37.56	0.032	0.671	0.50>P>0.25
4/19	Tosa-shimizu	49	0.102	0	10	39	0.51	8.98	39.51	0.030	0.633	0.50>P>0.25
4/26	do	37	0.149	1	9	27	0.82	9.38	26.80	0.041	0.056	0.90>P>0.75
4/26	Kubotsu (set net)	50	0.100	0	10	40	0.50	9.00	40.50	0.030	0.617	0.50>P>0.25
5/ 9	Sukumo	47	0.053	0	5	42	0.13	4.72	42.15	0.023	0.147	0.75>P>0.50
5/11	Kubotsu (set net)	47	0.160	1	13	33	1.20	12.63	33.16	0.038	0.042	0.90>P>0.75
5/11	Tosa-shimizu	48	0.156	2	11	35	1.17	12.64	34.19	0.037	0.821	0.50>P>0.25
5/31	Kubotsu (set net)	49	0.102	2	6	41	0.51	8.98	39.51	0.030	5.398	0.025>P>0.010
6/11	off Ashizuri I	49	0.143	2	10	37	1.00	12.01	35.99	0.035	1.364	0.25>P>0.10
6/11	off Ashizuri II	50	0.140	0	14	36	0.98	12.04	36.98	0.035	1.325	0.25>P>0.10
6/22	Tosa-shimizu	49	0.152	1	12	36	1.13	12.62	35.24	0.034	0.316	0.75>P>0.50
7/ 3	do	50	0.120	1	10	39	0.72	10.56	38.72	0.032	0.143	0.75>P>0.50
7/29	off Ashizuri	50	0.110	1	9	40	0.60	9.79	39.61	0.031	0.328	0.75>P>0.50
8/11	off Usa	45	0.067	1	4	40	0.20	5.63	39.15	0.026	3.687	0.10>P>0.05
8/25	Sukumo-wan	50	0.120	3	6	41	0.72	10.55	39.80	0.032	9.325	0.005>P
8/26	Luzon	128	0.129	2	29	97	2.12	28.75	97.10	0.020	0.011	P>0.90
8/31	off Usa	44	0.102	0	9	35	0.44	8.05	35.48	0.032	0.559	0.50>P>0.25
9/ 2	off Ito	48	0.125	2	8	38	0.75	10.49	36.75	0.034	2.742	0.10>P>0.05
9/15	Satamisaki	50	0.170	1	15	34	1.45	14.11	34.45	0.038	0.254	0.75>P>0.50
9/17	Koshikishima	31	0.129	1	6	24	0.51	6.96	23.52	0.043	0.613	0.50>P>0.25
9/18	do	47	0.138	0	12	35	0.89	11.18	34.92	0.034	0.982	0.50>P>0.25
10/11	Kubotsu (set net)	50	0.180	3	12	35	1.62	14.76	33.62	0.038	1.994	0.25>P>0.10
11/ 1	Murotomisaki	50	0.080	0	8	42	0.32	7.36	42.32	0.027	0.378	0.75>P>0.50
11/ 2	Tosa-shimizu	50	0.140	2	10	38	0.98	12.00	37.00	0.035	1.352	0.25>P>0.10
12/ 8	do	50	0.120	0	12	38	0.72	10.56	38.72	0.032	0.929	0.50>P>0.25
12/15	Murotomisaki	50	0.160	1	14	35	1.25	13.17	34.57	0.037	0.108	0.75>P>0.50
12/27	Tosa-shimizu	50	0.100	0	10	40	0.50	9.00	40.50	0.030	0.617	0.50>P>0.25

Table 81.--Data on release and recovery of A. rochei that showed long-distance movement in 1965, 1970, and 1972 (Yamashige 1974).

No.	Date of release	Location (release)		Date of recapture	Location (recapture)
1	8/26/65	36°02' N	141°02'E	9/20/65	Uchiura-wan, Numazu, Shizuoka Pref.
2	9/15/65	34°38'	138°58'	9/18/65	Katsuura, Chiba Pref.
3	9/22/65	34°41'	139°27'	11/28/65	Asagawa 5M, Tokushima Pref.
4	9/25/65	33°29'	135°58'	10/17/65	Off Susaki, Kochi Pref.
5	11/7/65	33°25'	135°49'	12/3/65	Ashizuri S W 12M
6	9/5/70	Off Yatabe saki, Tasamachi, Kochi Pref.		9/14/70	Off Hiraiwa, Hyuga, Miyazaki Pref.
7	9/13-15/70	Off Ito		10/26/70	Ashizuri NE 1.5M
8	9/13-15/70	Off Ito		10/26/70	Ashizuri SSW 4.5M
9	9/29/70	Off Hamashima, Mie Pref.		10/26/70	Off Shimoda, Shizuoka Pref.
10	9/3/72	34°59'N	139°09'E	9/13/72	Off Esaki, Wakayama Pref.

Table 82.--Data on release and recovery of *A. rochei* during the 1970 and 1971 fishing season off Japan (adapted from Morita (1972) and Hamada, Ishida, Morita, Takezawa, Okabayashi, and Ishii 1973.

Date of release	Area (release)	Location (release)	No. of fish released	Body length (release) (cm)	Date of recapture	Location (recapture)	Fishing method (recapture)	(Recapture) BL (cm)	(Recapture) BW (g)	Release and recapture Days	Release and recapture Distance
1970					1970						
9/5	Tosa-wan	Off Yatabezaki (E)	299	19-21	(1) 9/14	Off Hiraiwa, Hyuga-shi		20.7		9	220
9/13-15	Izu	Off Ito (A)	691	20-23	(1) 9/15	Uchiura-wan, Shizuoka Pref.	Purse			2	70
				28-29	(2) 10/26	Ashizurimisaki NE 1.5M	Pole-and-line			13	380
					(3) 11/9	Ashizurimisaki SSW 4.5M	Pole-and-line			26	380
					(1) 9/18	Off Shimoda	Purse			2	
					(2) 9/23	Off Tateyama, Chiba Pref.	Purse			7	50
9/16-17	Izu	Off Shimoda (B)	2327	21-31	(3) 10/2	Off Ose, Numazu-shi	Purse			16	45
					(4) 10/2	Off Ose, Numazu-shi	Purse			16	45
					(5) 10/4	Uchiura-wan, Shizuoka Pref.	Purse			18	50
9/19	Kumanonada	Hamashima (C)	207	21	Not available	Off Shimoda-machi	-	-	-	-	-
9/20	Kumanonada	Off Owase (D)	319	27	(1) 10/2	Off Mie Pref.	Purse			12	3
					(1) 12/4	Off Ashizurimisaki	Pole-and-line	25		9	48
1970					1970						
11/25	Tosa-wan	Off Susaki (E)	40	25.4	(2) 12/4	Off Ashizurimisaki	Pole-and-line			9	48
					(3) 12/18	Off Ashizurimisaki	Pole-and-line	25	160	23	48
1971											
3/21	Ashizuri	Ashizurimisaki SW 10M (F)	60	23-28	(1) 3/22	Ashizurimisaki SSE 6M	Pole-and-line			1	
					(1) 11/22	Ashizurimisaki S 18M	Pole-and-line			11	
11/9	Ashizuri	Ashizurimisaki SSE 10M	307	24	(2) 11/23	Ashizurimisaki SSE 8.5M	Pole-and-line			12	
					(3) 11/30	Off Ashizurimisaki 8M	Pole-and-line			21	
1972					1972						
3/26-27	Satsunan	Yakushima S 10-15M	409	25.8	4/10-11 11 fish	Off southern Yakushima	Pole-and-line			15	

Table 83.--Data on release and recovery of *A. rochei* during the 1972 fishing season off Japan (Hamada et al. 1974).

Date of release	Time	Area	Location (release)	No. of fish released	Tag no. (No. of tags)	Mean fork length (cm)	Date of recapture	Area (recapture)	Reporter	Fishing method	Tag no.	(Recapture) FL	(Recapture) BW	Remarks
1972 6/11	0740-1420	Off Ashizuri	32° 36.7' N 132° 54.9' E to 32° 36.7' N 132° 49.4' E	403	1-100 (89) 101-200 (99) 201-300 (100) 401-500 (100) 801-820 (16)	29								No recapture
8/31	0915-1135	Tosa-wan	Susaki 0.5M	430	1401-1800 (400) 106-209 (30)	21	9/1/72 (3 fish)	Nakadosa-machi Kaminokae Yatabe	Mr. Shizutoshi Matsumura	Set net	1417 1650 1716			Abundant small fish were caught (late Aug).
9/15	0930-1300	Satsunan (off southern Kyushu)	Satamisaki 0.5M	5	1901-2000 (5)	23								No recapture in Satsunan area.
9/18	0900-1030	Koshiki Islands	Kami-Koshikishima	53	1600-1620 1340-1360 1901-2000 (53)	24								No recapture in Satsunan area.
9/19	1310-1315	Satsunan	Bono-misaki	2	1955 1956 (2)	24								No recapture in Satsunan area.

Table 84.--Observations made during the aerial survey of waters around Sri Lanka (Sivasubramaniam 1971).

Observations	*South-West*	*West*	*North-West*	*North*	*North-East*	*East*	*South-East*	*South*
Tuna schools	Two. One small probably mackerel tuna or frigate mackerel	One. Small M. tuna or F. mackerel	Nil	Nil	Nil	Two large foamers Skipjack or M. tuna	Three. One large probably Skipjack	Nil
Dolphin/Porpoise Schools	Nil	Nil	Nil	Nil	Nil	One. sparsely scattered, moving northerly	Two. Very large ahead of tuna shoals	Nil
Whales	One	Nil	Nil	Nil	Nil	Nil	One	Nil
Birds	Nil	Nil	Nil	Nil	Nil	Few over one school	V. few over one school	Nil
Plankton patches	Nil	Dense greenish yellow	Nil	Yellowish streaks	Dence yellow streaks over a mile long	V. light yellowish streaks	Nil	Nil
Colour of water surface	Blue-turbid	Bluish-turbid	Greenish clear	Green to Blue clear	Blue turbid	Blue-turbid	Blue to Green mild turbidity	Dark turbid poor visibility
Fishing vessels	Nil	Mech. boats and out-trigger canoes	Nil	Nil	Nil	Mech. boats	Nil	Mech. boat (one)
Others	Nil		Heavy blowing N. easterly	Nil	Nil	Easterly wind	Manta ray with school Sharks around school	Poor visibility heavy wind and rain

Table 85.--Average catch per operation, in kg, of skipjack, yellowfin, mackerel tuna, and frigate mackerel from various regions around Sri Lanka, 1970 (Sivasubramaniam 1971).

			Average catch per operation (in kg)			
Date	Region	Station	Skipjack	Yellowfin	Mackerel tuna	Frigate mackerel
7/27	West	Colombo	1,049	88	36	12
7/27	Southwest	Beruwala-Galle	1,092	39	4	13
7/29	South	Tangalle	136	42	-	-
7/29	East	Trinco-Batticaloa	170	33	-	-

Table 86.--Summary of potential catches from oceanic resources (MT) (Gulland 1971).

Whales etc.	Large baleen	1,900 BWU	=	1,640,000
	Sperm whales:	25,000 animals	=	500,000
	Small whales			500,000
	Dolphins, porpoises			?
Salmon		North Pacific		500,000
		Atlantic		15,000
Tunas	Large tunas:	Pacific		350–450,000
		Atlantic		200–250,000
		Indian Ocean		100–150,000
	Skipjack	Pacific		500–800,000
		Atlantic		250–300,000
		Indian Ocean		160–300,000
	Other small tunas:	Frigate mackerel		(1,000,000)
		Bonito		(500,000)
		Little tuna		?
		Thynnus tonggol		?
Sharks				(500,000)
Coryphaenids				(1,000,000)
Squids				10–100 million
Myctophids, etc.				hundreds of millions
Red crab				(1,000,000)

Note: Salmon are included here because most of their growth is put on in the open oceans, though their potential is discussed in detail elsewhere.

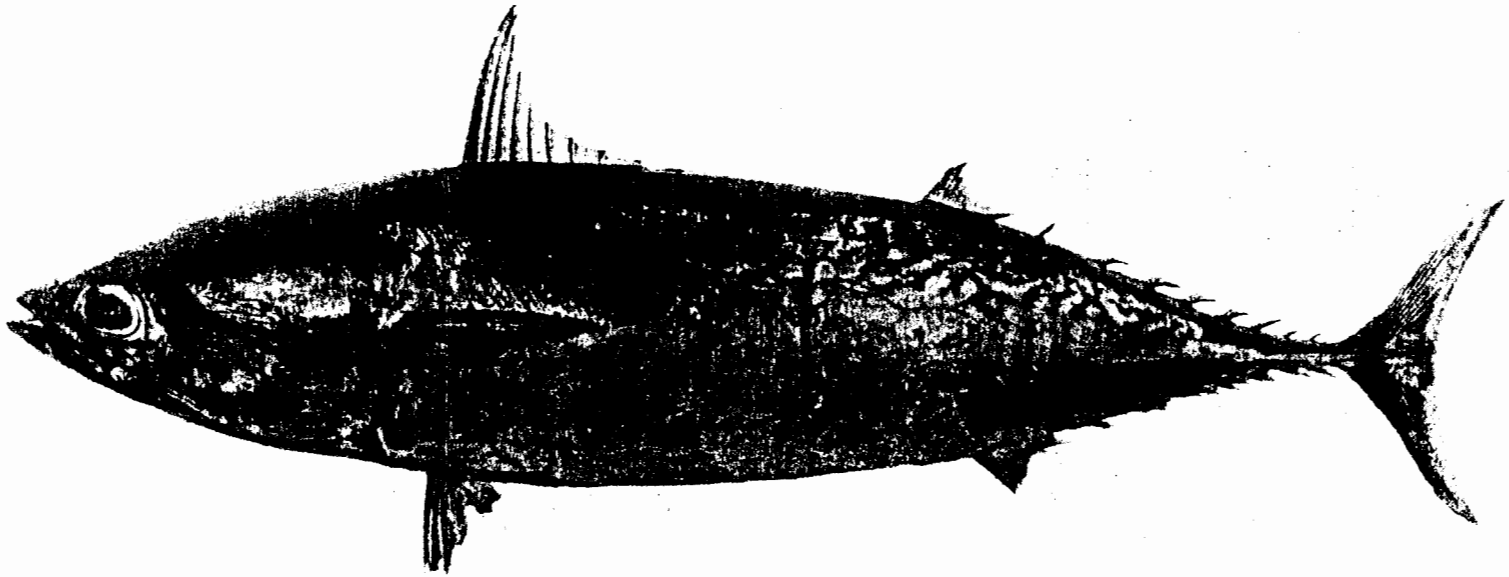


Figure 1.--*Auxis thazard* from the eastern Pacific. Collected at Morgan Bank, Baja California, October 6, 1949 (Fitch and Roedel 1963).

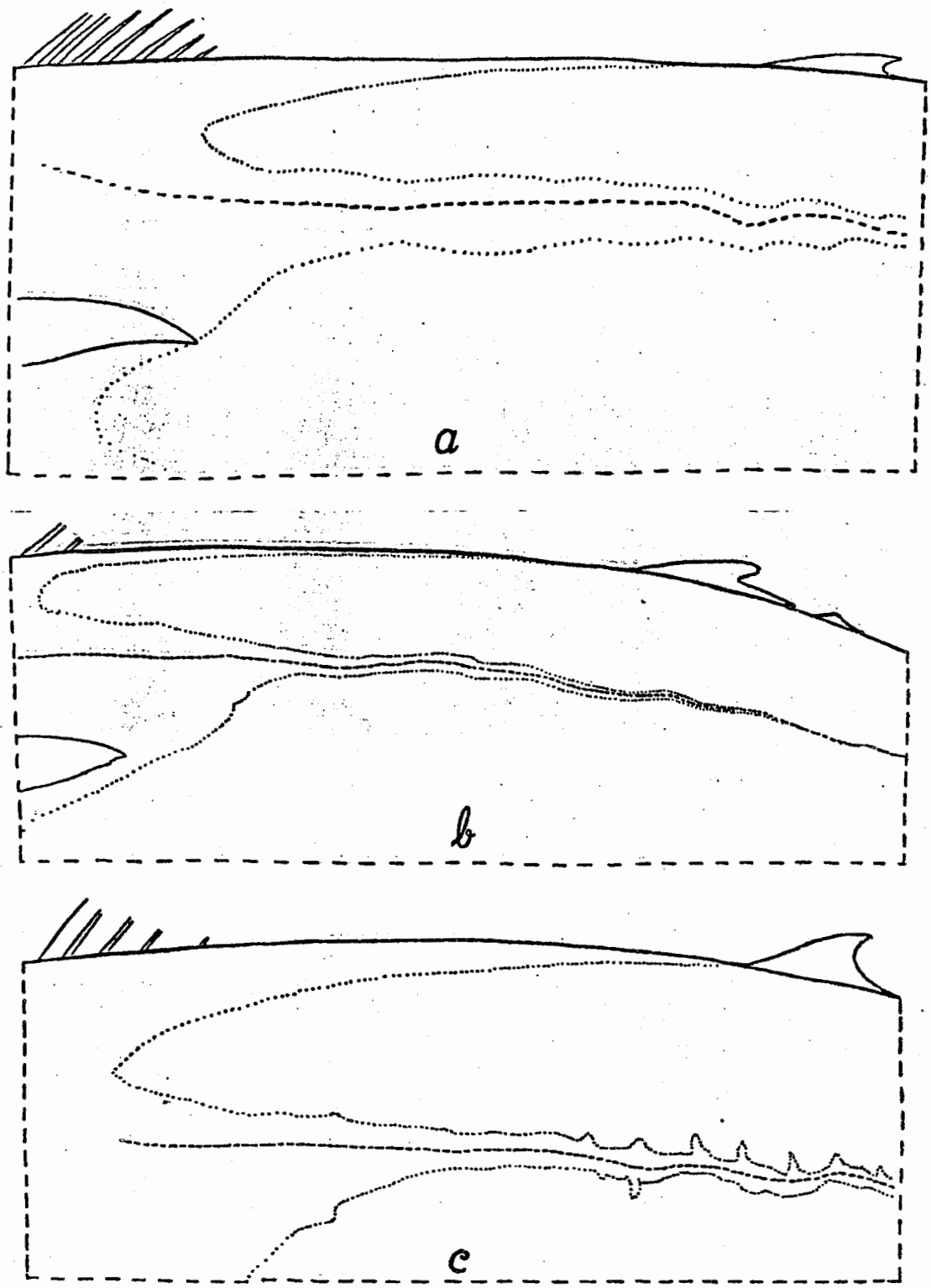


Figure 2.--Outlines of corselets drawn from actual specimens (Jones 1963). a. A. thynnoides; b. A. thazard - typical short-corseletted condition; c. A. thazard - intermediate condition.

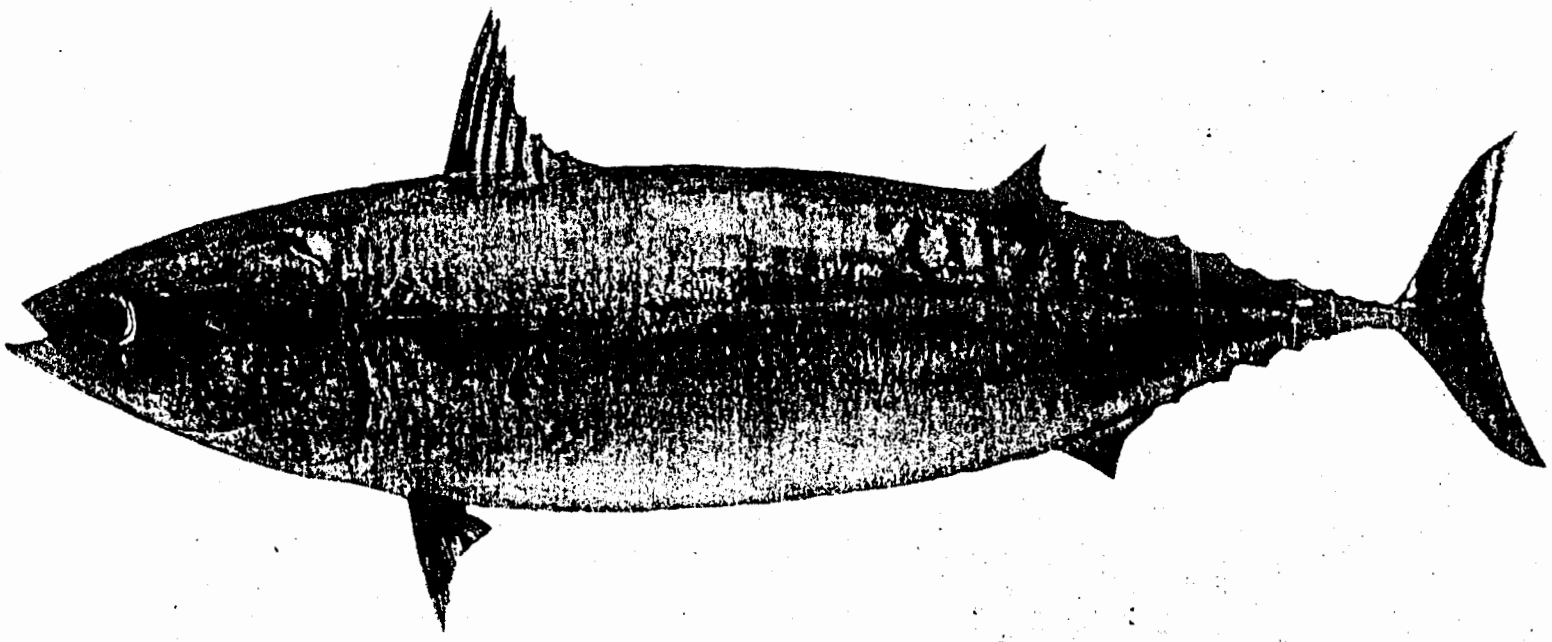


Figure 3.--*A. rochei* from near Santa Catalina Island, California, November, 1935 (Fitch and Roedel 1963). Photo by D. H. Fry, Jr.

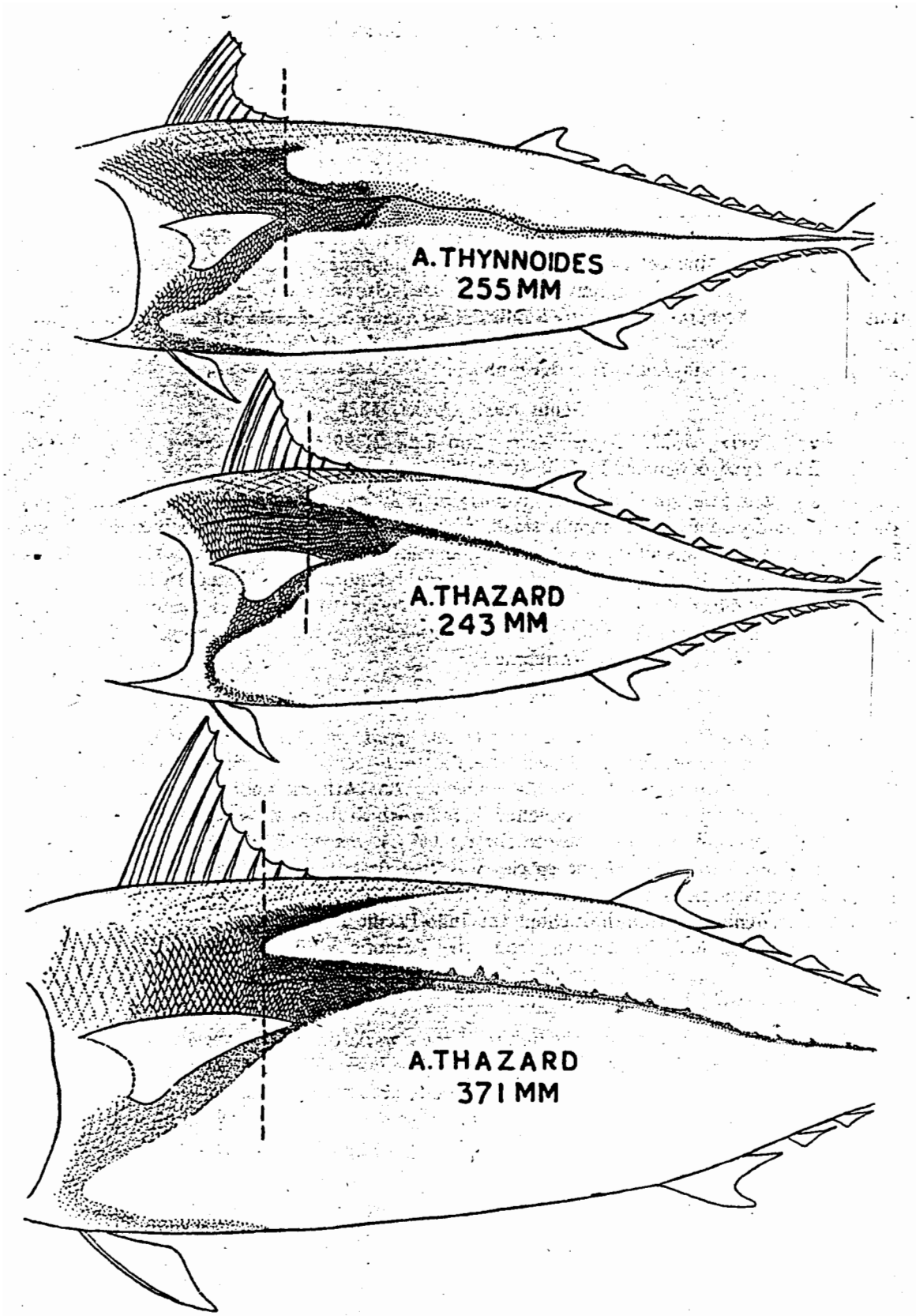


Figure 4.--Forward extent of the scaleless portions above lateral line in relation to pectoral fin in specimens of A. thazard and A. thynnoides (Jones and Silas 1964).

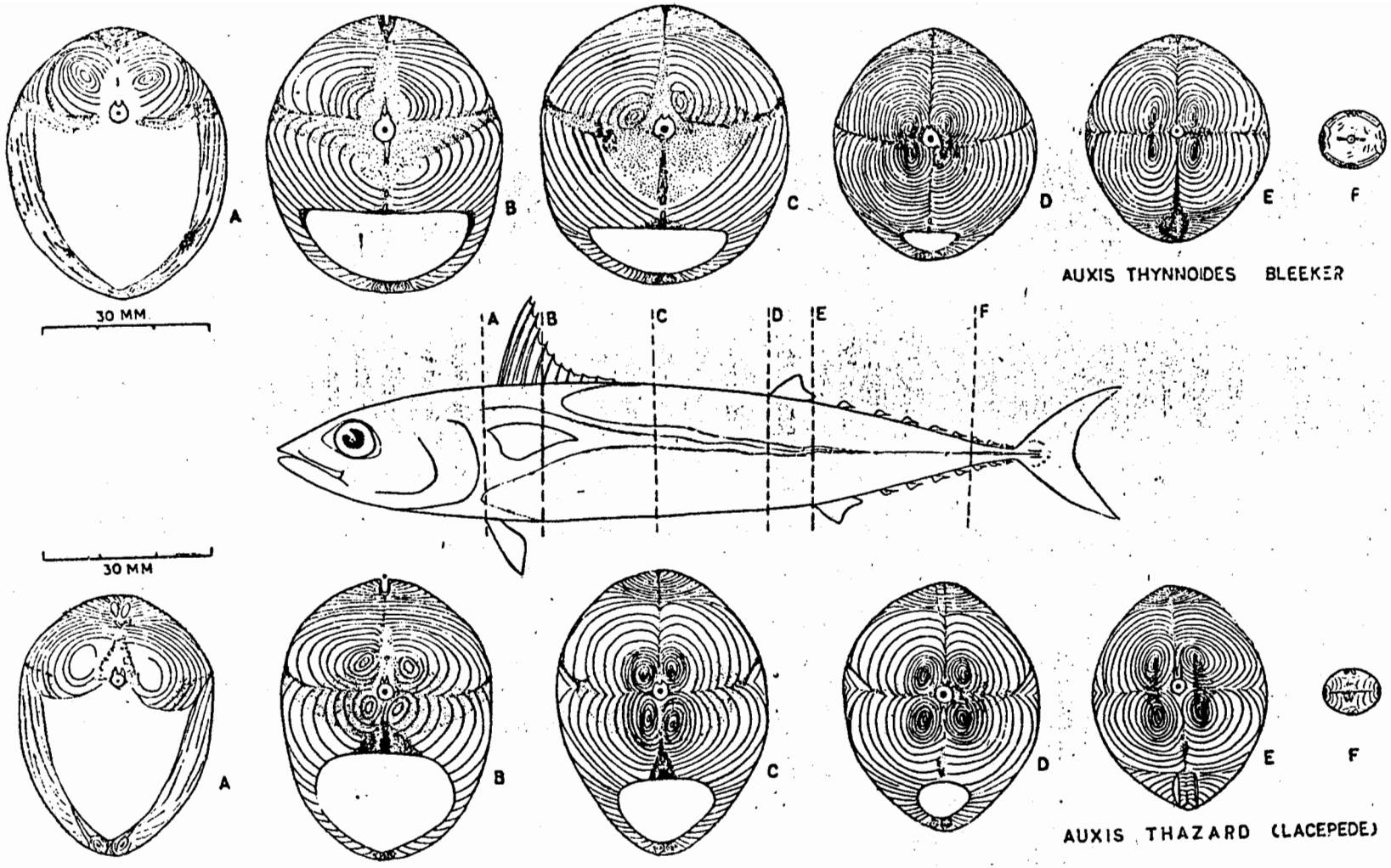


Figure 5.--Schematic drawing of Auxis (central figure) indicating locations from where 6 cross sections of the body were made in A. thynnoides and A. thazard and illustrating the differences in shape of the body and abdominal cavity (Jones and Silas, 1964).

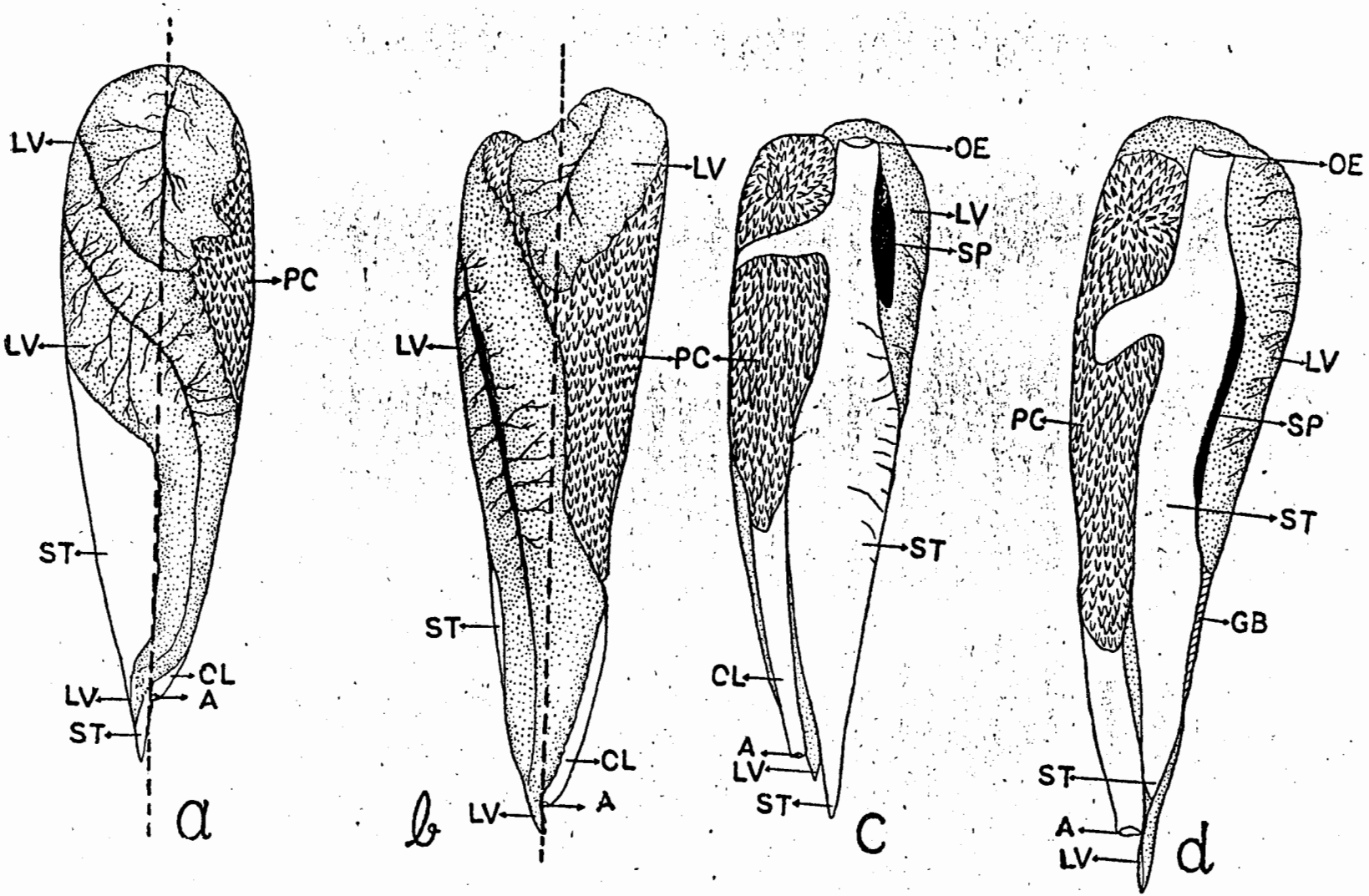


Figure 6.--Ventral and lateral views of viscera *in situ* in a 24.3-cm *A. thazard* (a and c) and a 25.5-cm *A. thynnoides* (b and d). Legend: A=anal opening; CL=colon; GB=gall bladder; LV=liver; OE=oesophageal end; PC=caecal mass; SP=spleen; and ST=stomach (Jones and Silas 1964).

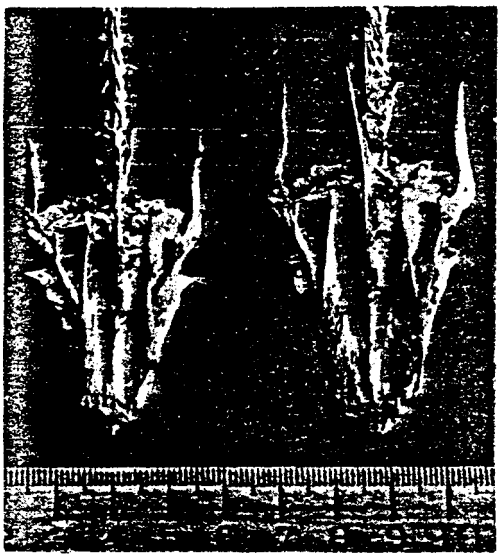


Figure 7.--Dorsal view of skull of A. rochei (left) and A. thazard (right) (Yoshida and Nakamura 1965).

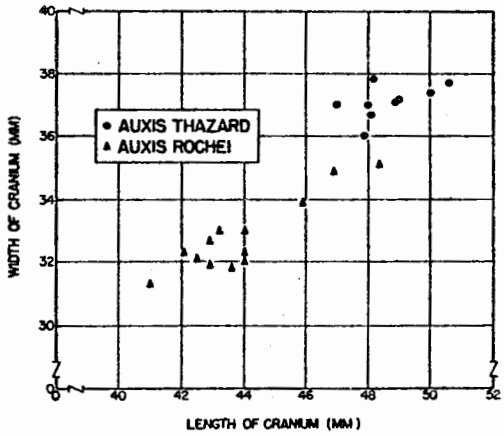


Figure 8.--Relation between the width and length of the cranium of A. thazard and A. rochei. Width: distance between widest points of pterotic processes. Length: distance from anterior margin of vomer to concave ventral tip of aperature of myodome (Yoshida and Nakamura 1965).

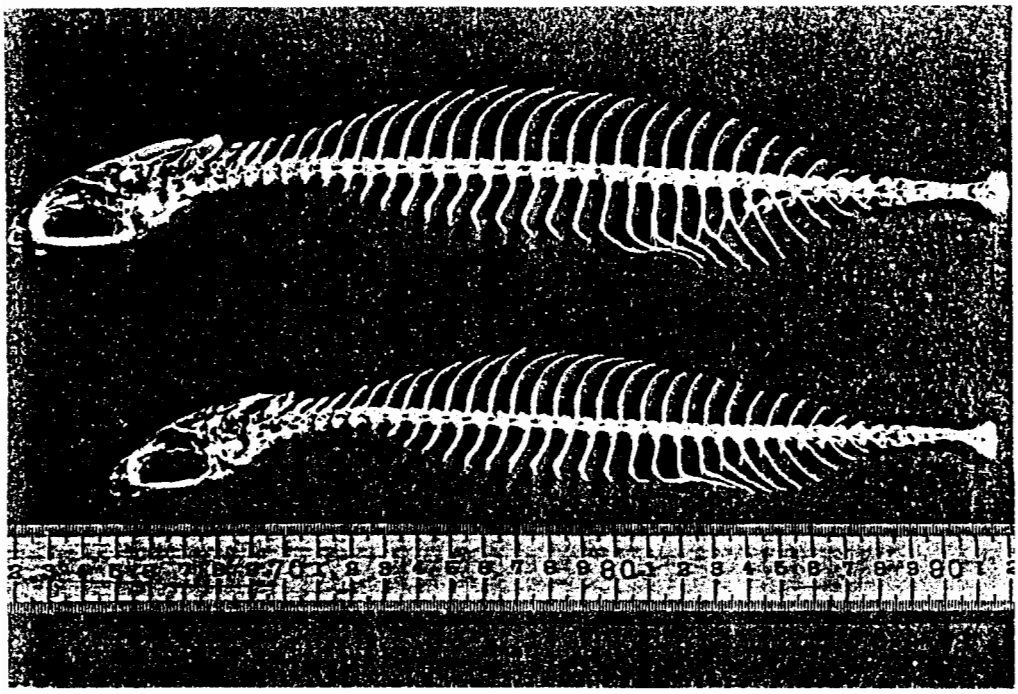


Figure 9.--Lateral view of skeleton of A. thazard (top) and A. rochei (bottom) (Yoshida and Nakamura 1965).

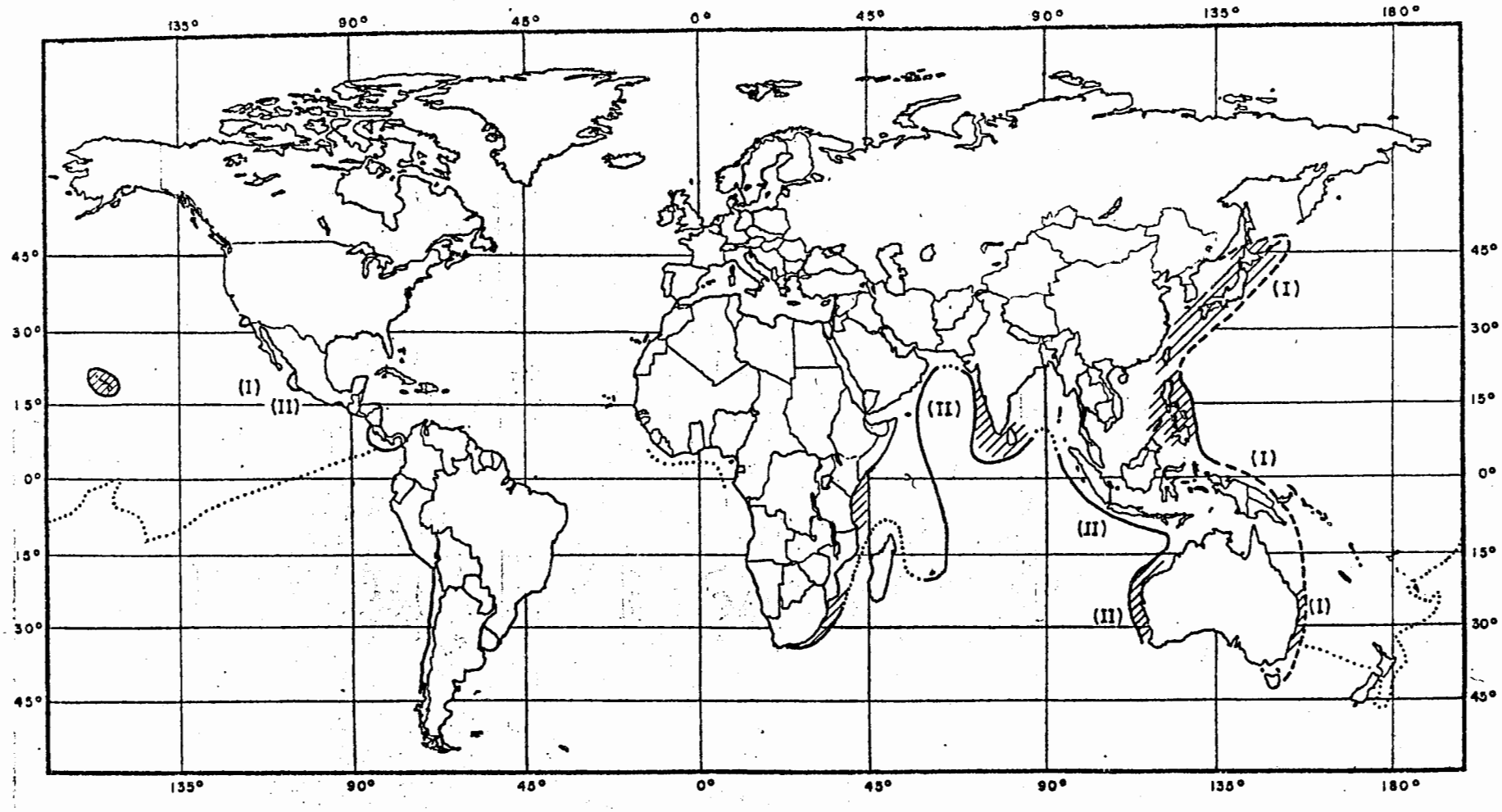


Figure 10.--Distribution and fishing areas of frigate mackerel (I) A. thazard and (II) A. rochei (Laevastu and Rosa 1963).

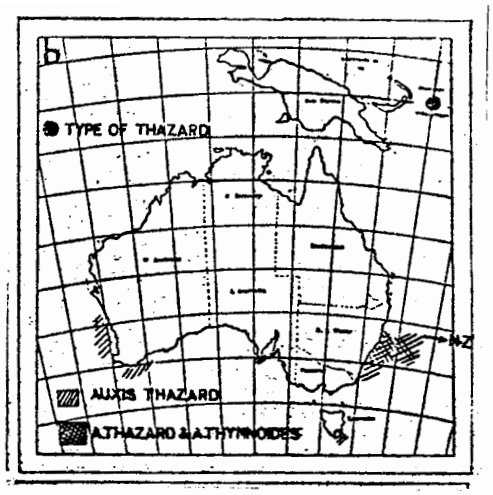


Figure 11.--Distribution of A. thazard and A. rochei off the coast of Australia (Whitley 1964).

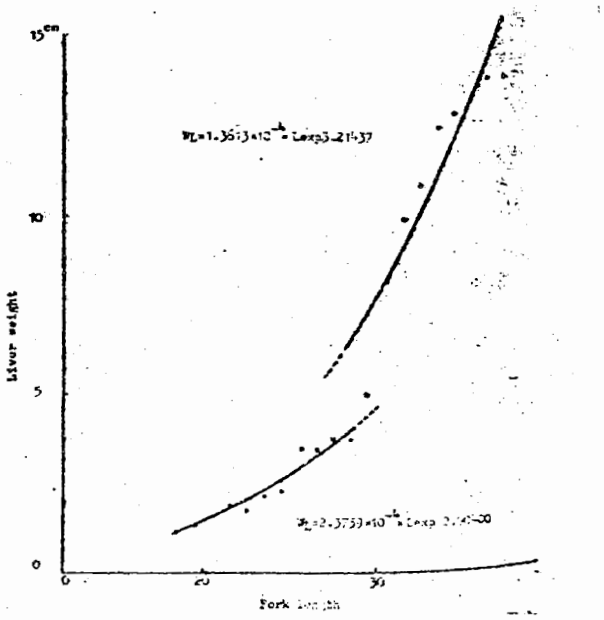


Figure 12.--The relationship between liver weight and body length of A. rochei from Japanese waters (Yasui 1975).

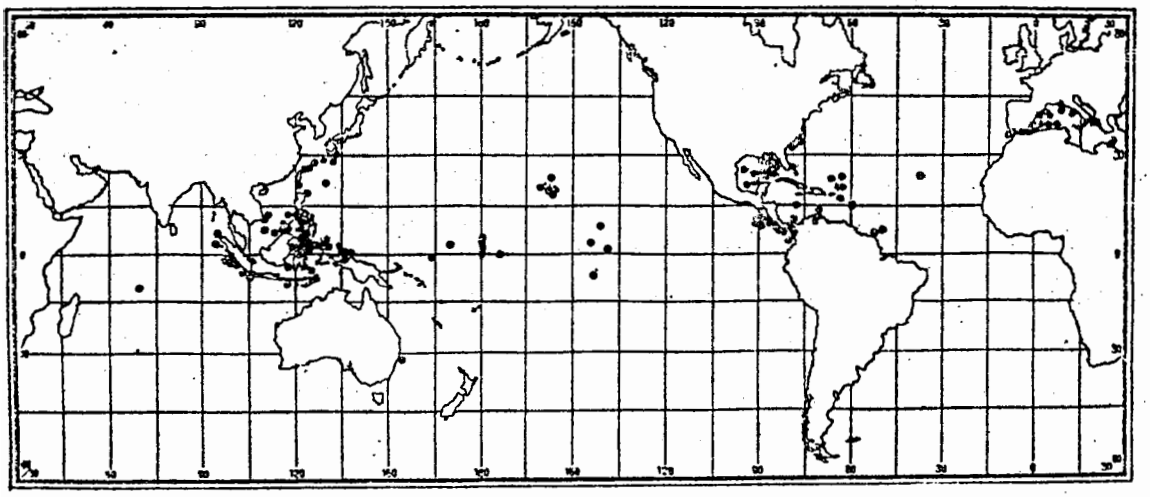


Figure 13.--Localities of capture of frigate mackerel larvae (Yabe et al. 1963).

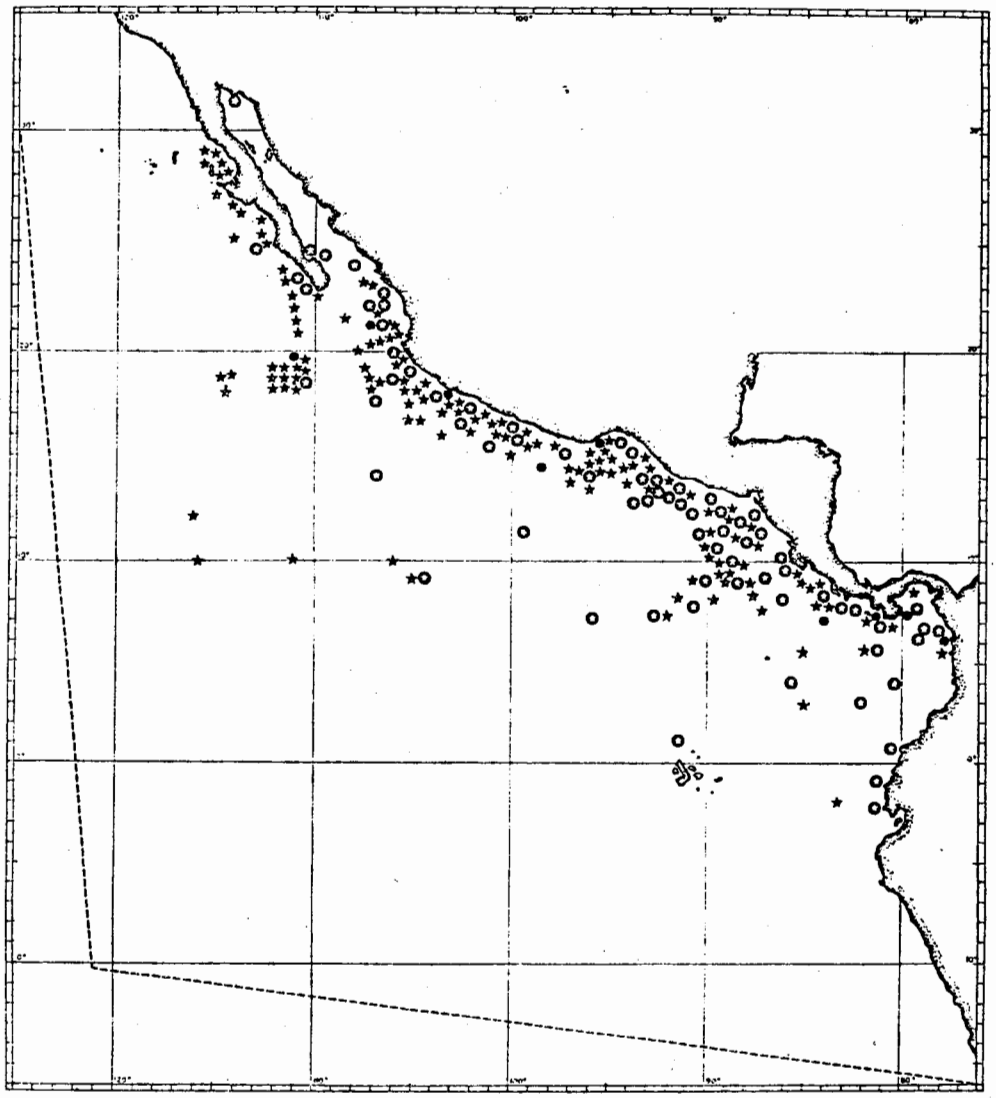


Figure 14.--Locations of capture of larvae and juveniles of A. thazard. Localities of capture are denoted by appropriate symbols (solid star, larvae from plankton tows; circle with a star, juveniles from night-light collections; and solid circle, juveniles from stomachs of vertebrates) (Klawe 1963).

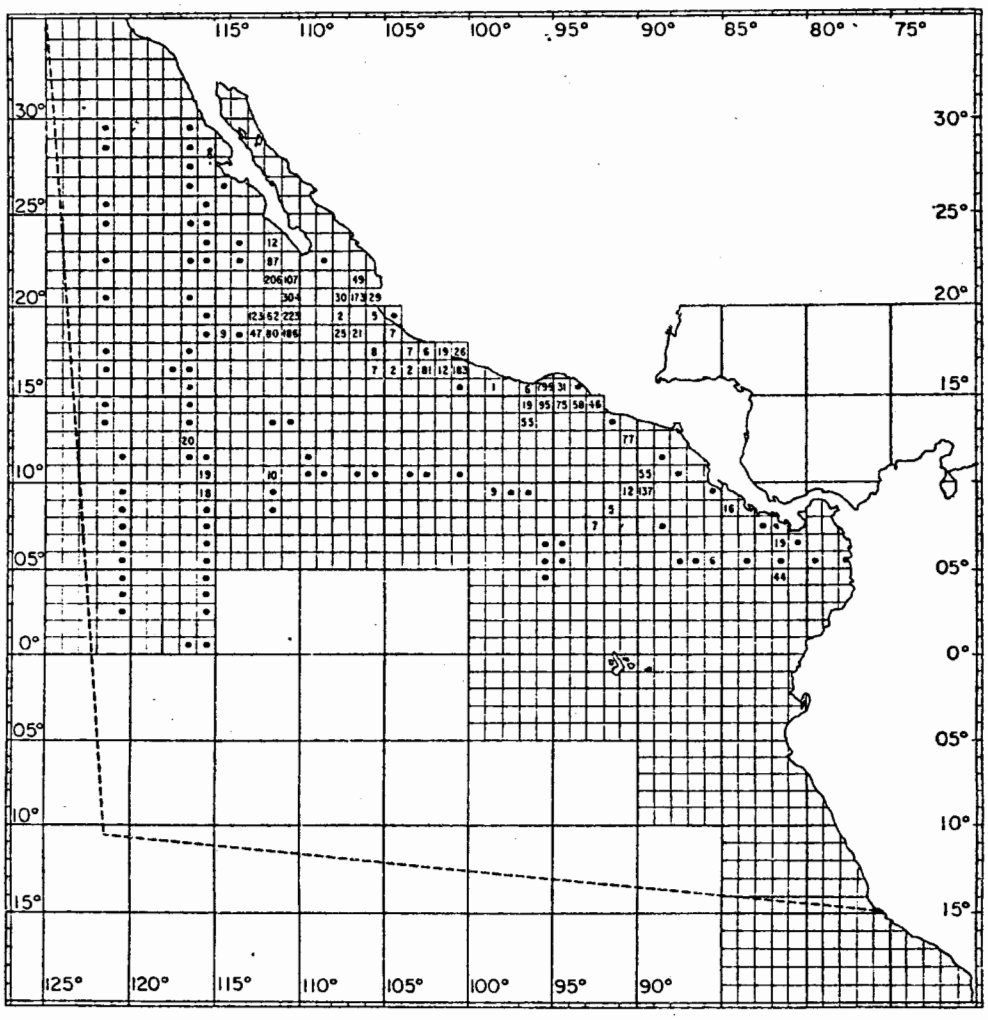


Figure 15.--Abundance of larvae of A. thazard by one-degree areas, for the months May to October, based on plankton collections (Klawe 1963).

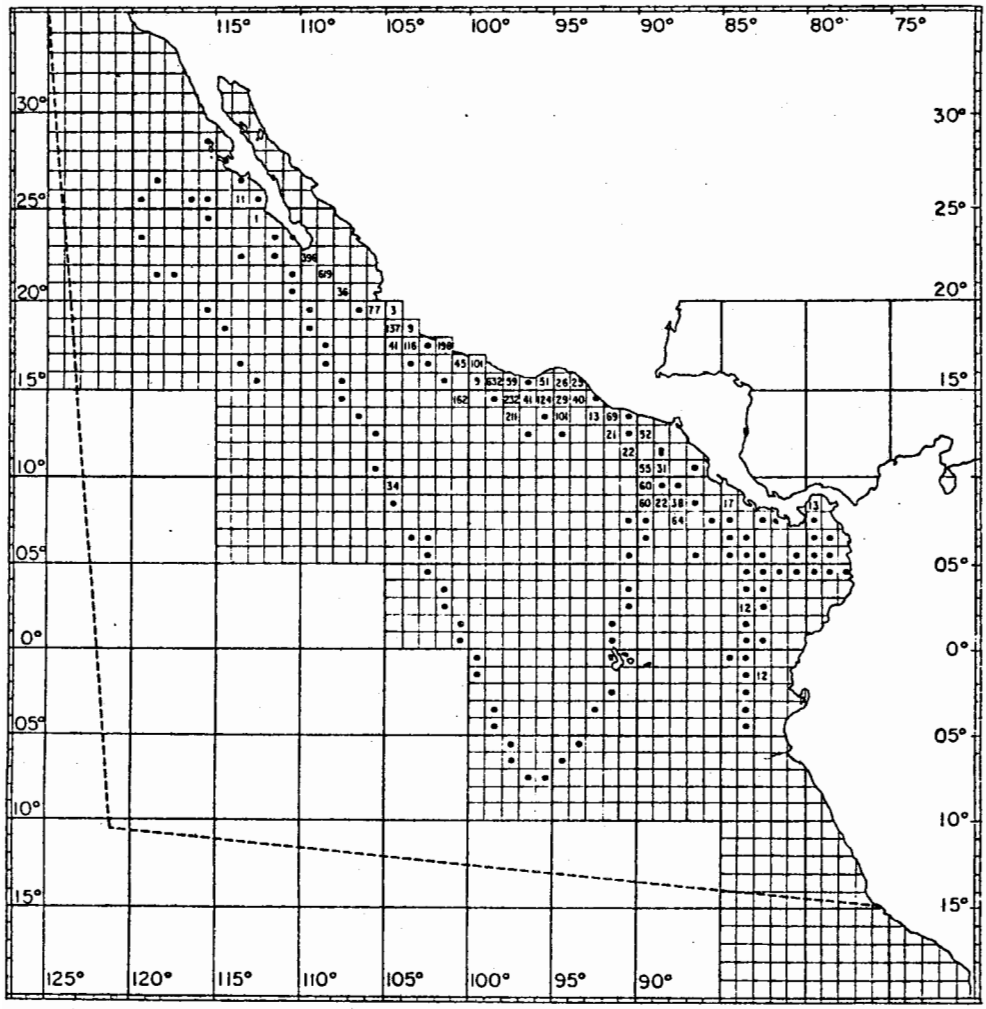


Figure 16.--Abundance of larvae of A. thazard by one-degree areas, for the months November to April, based on plankton collections (Klawe 1963).

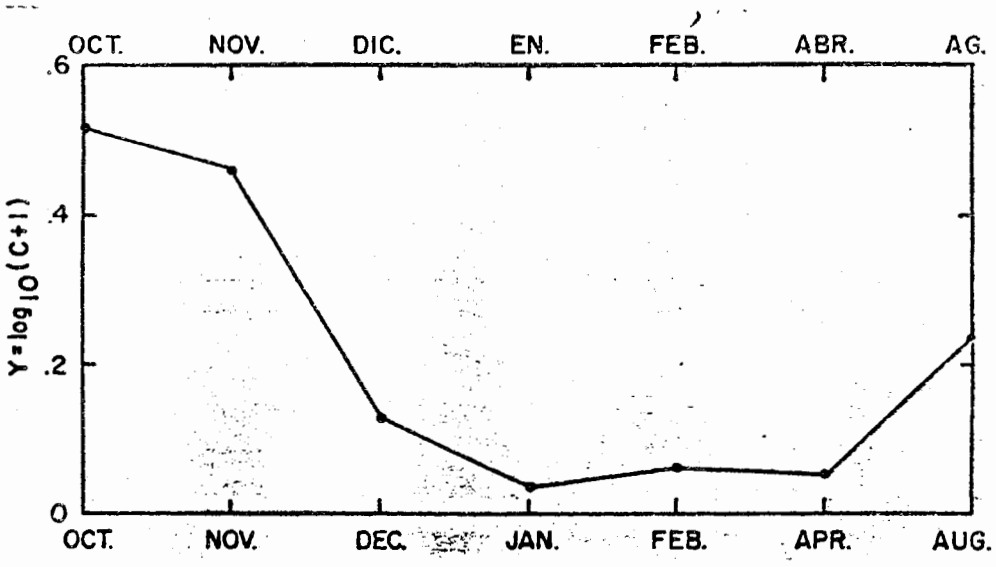


Figure 17.--Average catches of larval Auxis during cruises to the entrance of the Gulf of California (Klawe et al 1970).

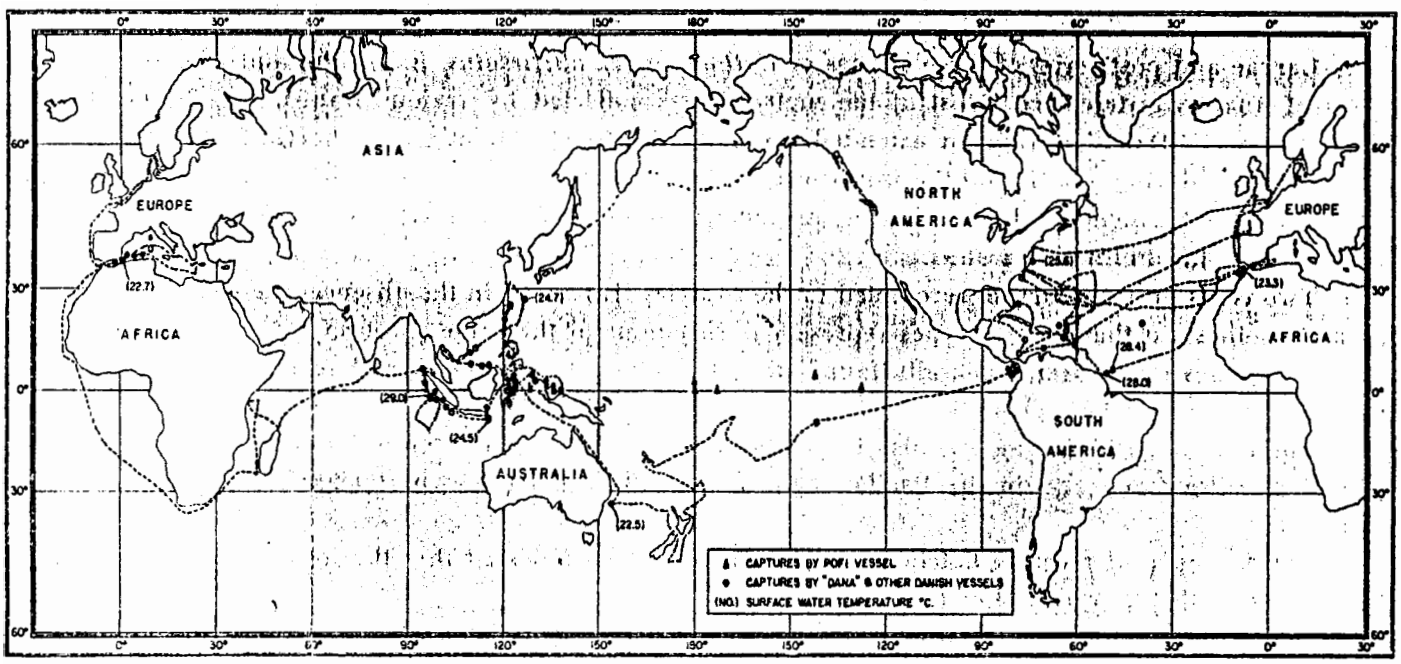


Figure 18.--Localities of capture of Auxis larvae by the Dana and POFI research vessels (Matsumoto 1959).

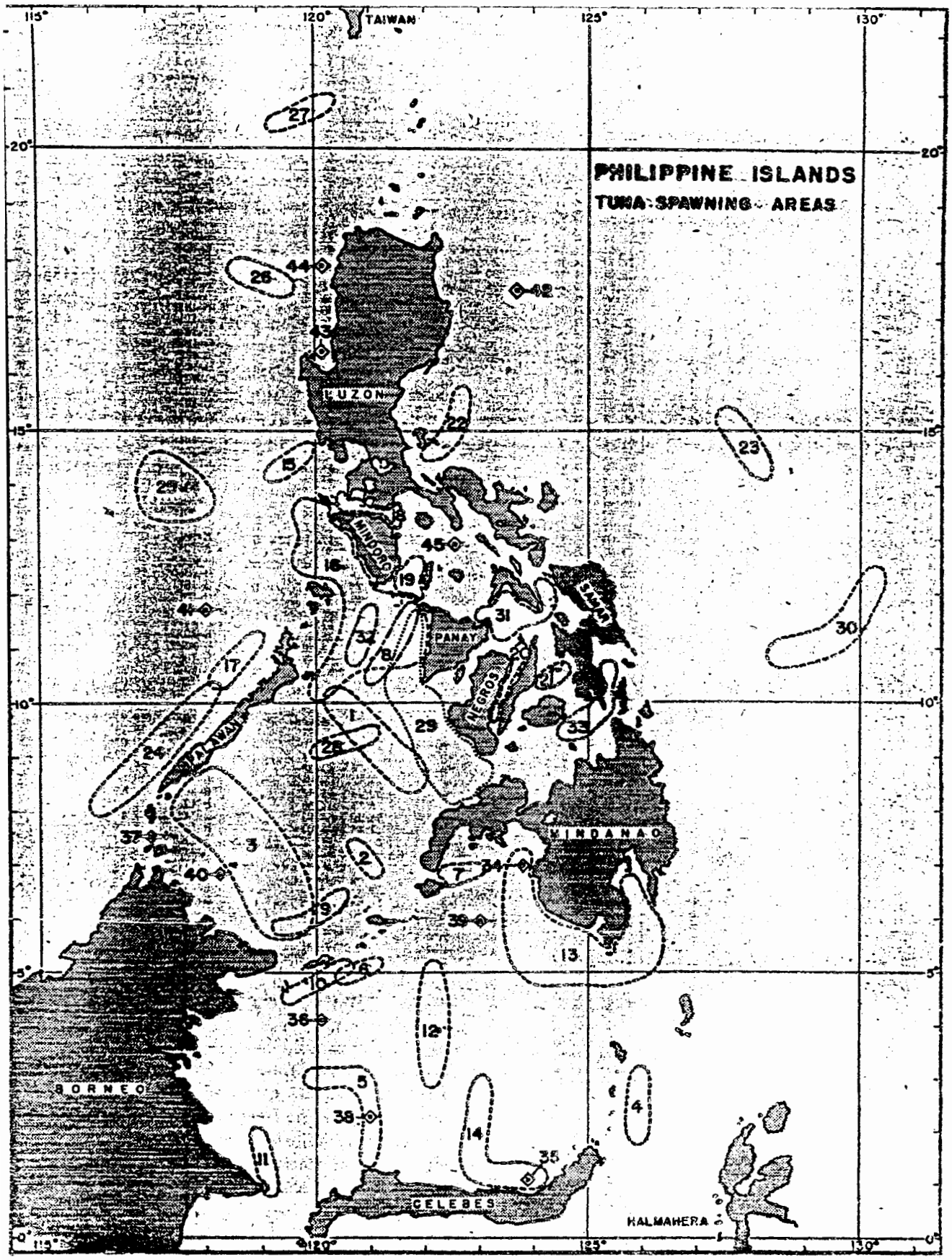


Figure 19.--Tuna spawning areas in Philippine waters (Wade 1951).

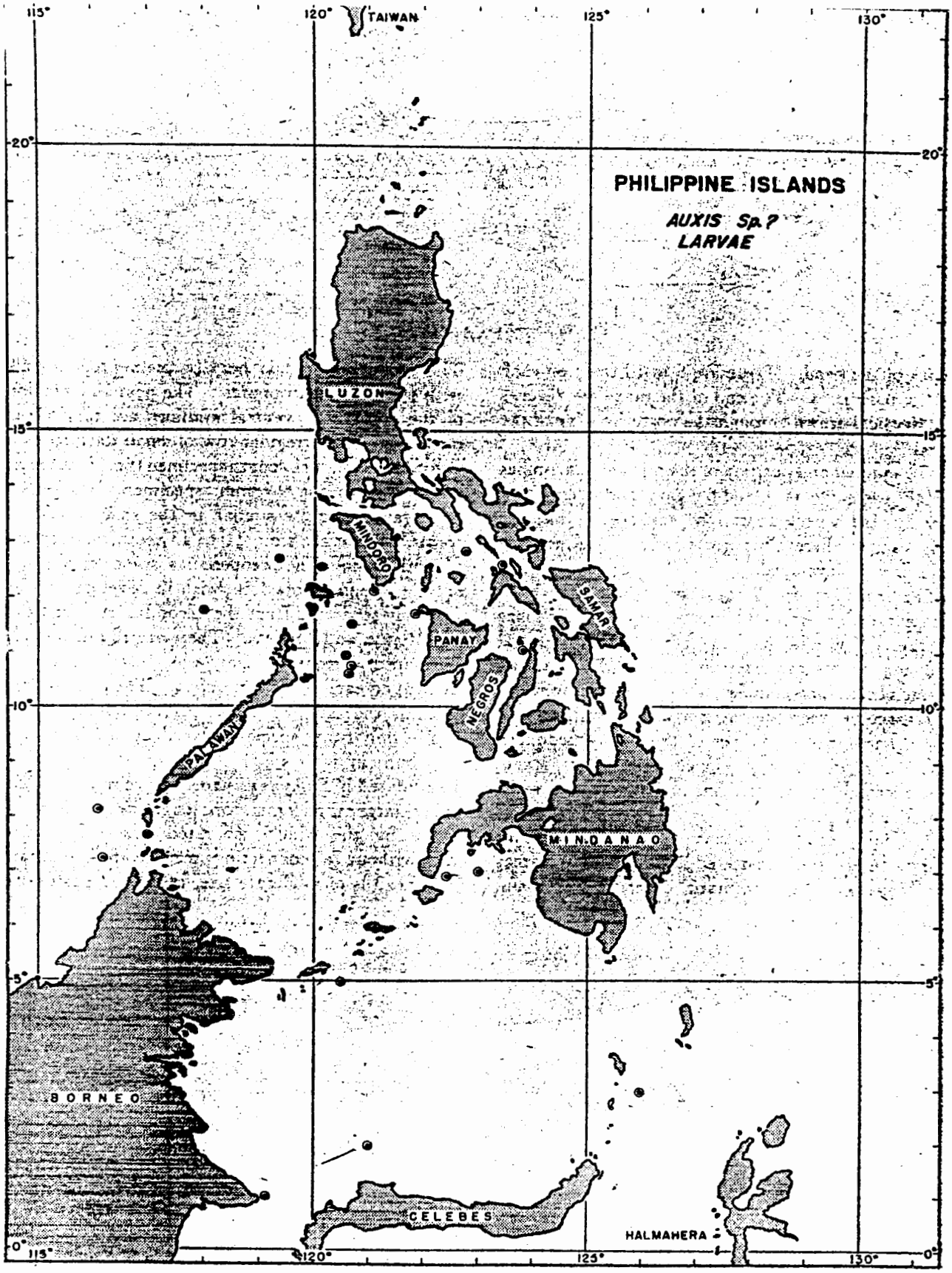


Figure 20.--Localities of capture of Auxis larvae in Philippine waters (Wade 1951).

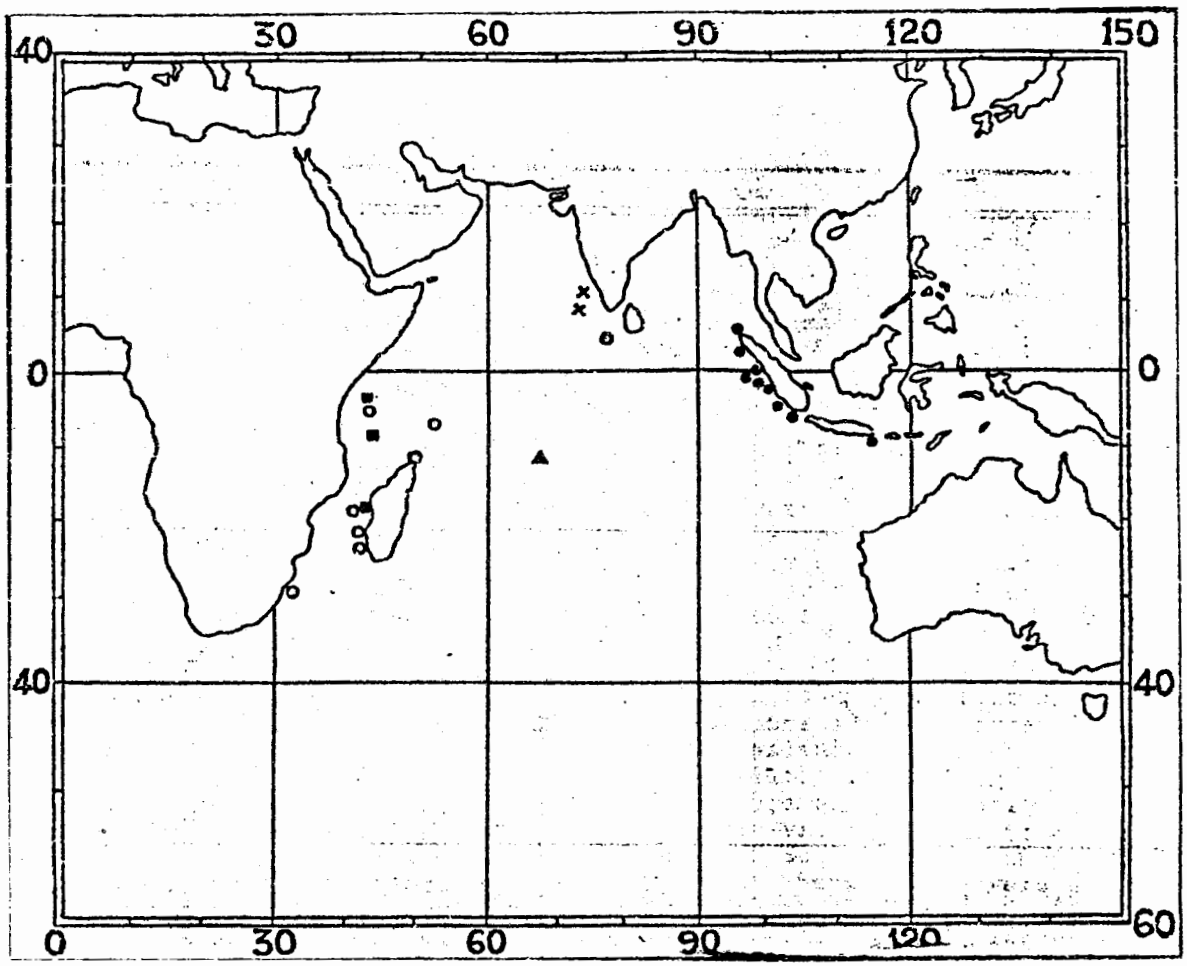


Figure 21.--Localities of capture of Auxis larvae in Indian waters (Jones and Kumaran 1963).

○ Dana collection (A. thazard); ✕ Indian collection (A. thazard); ■ Dana collection (A. rochei); ▲ Japanese collection (A. rochei); ● Dana collection (Auxis spp., after Matsumoto 1959).

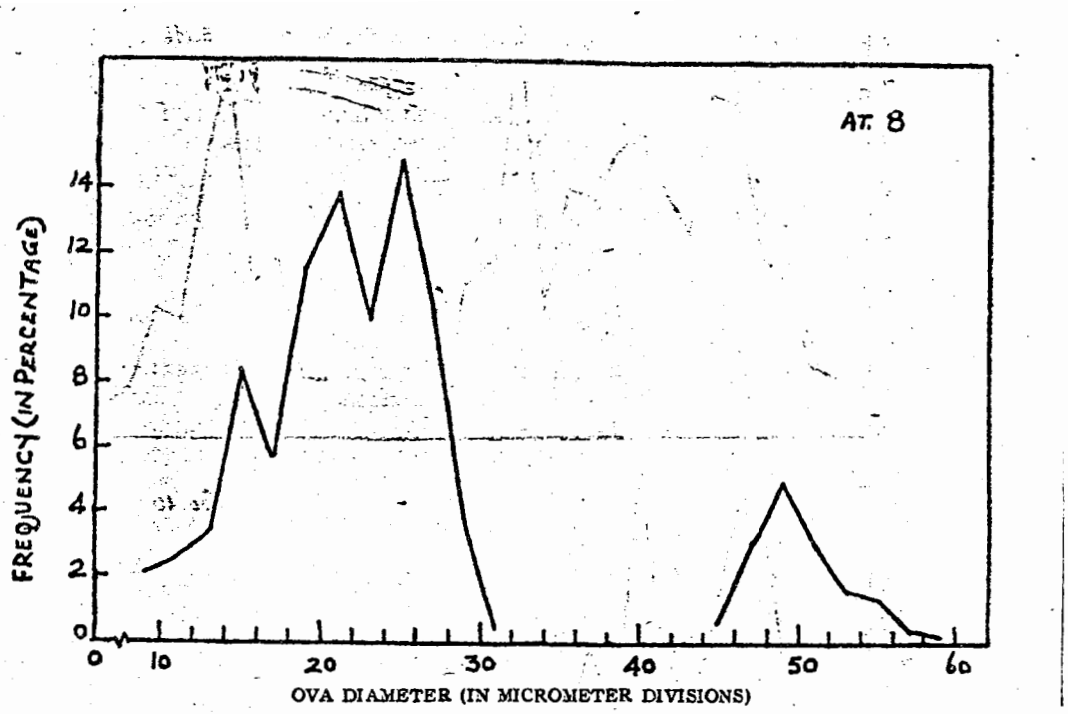


Figure 22.--Ova diameter frequency polygon of ripe ovary from A. thazard (Rao 1964).

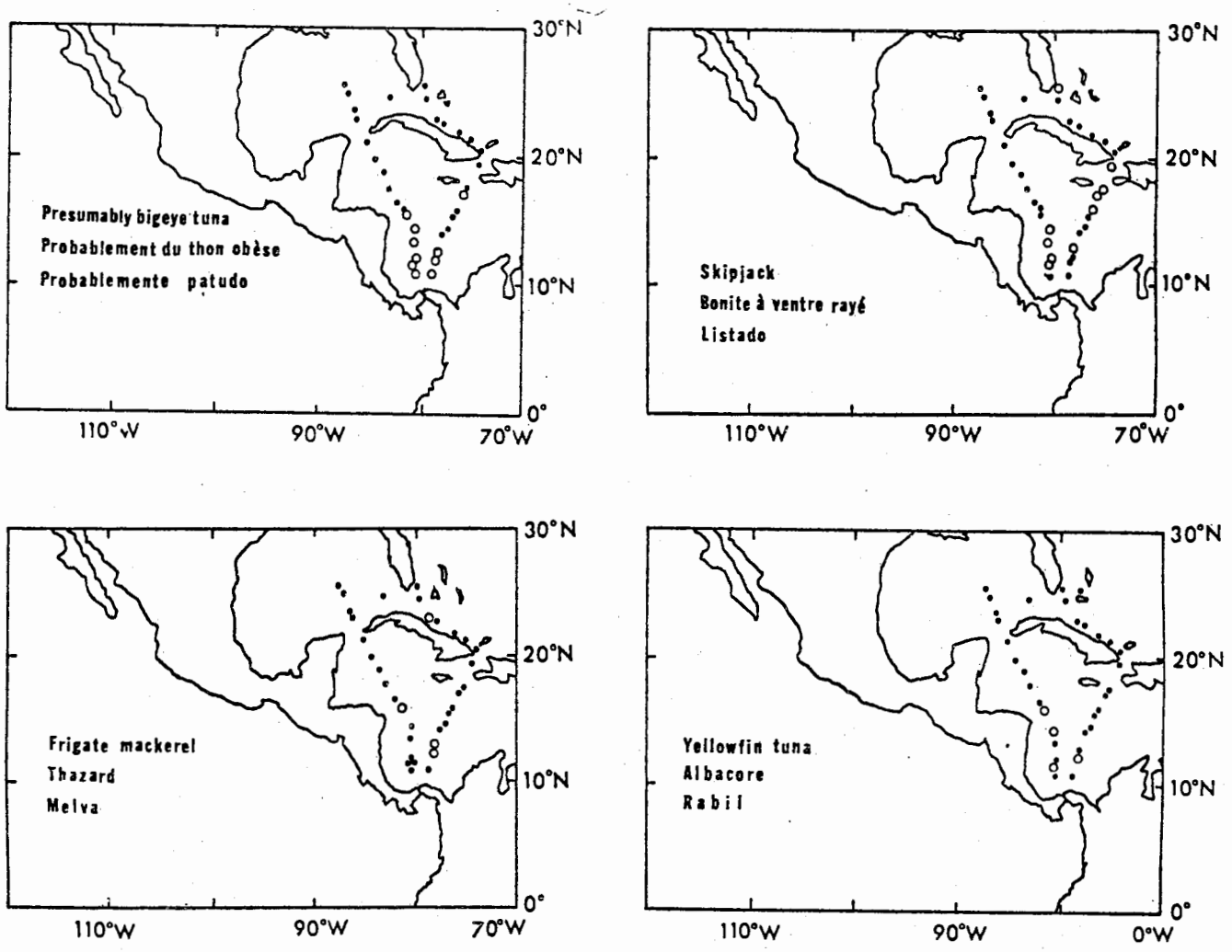
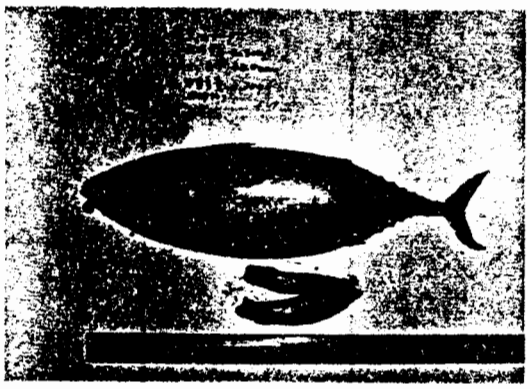


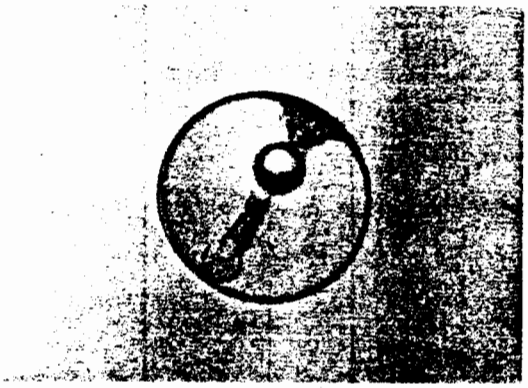
Figure 23.--Successful stations for collecting tuna larvae (bold dots) during cruises of R/V Shoyo Maru, 1969-70 (Hayasi 1972).

Plate 1



Mature *Auxis thazard* (hirasôda) and its ovary.

Fertilized egg of *Auxis thazard* (hirasôda) in morula stage, 0.95mm in diameter.



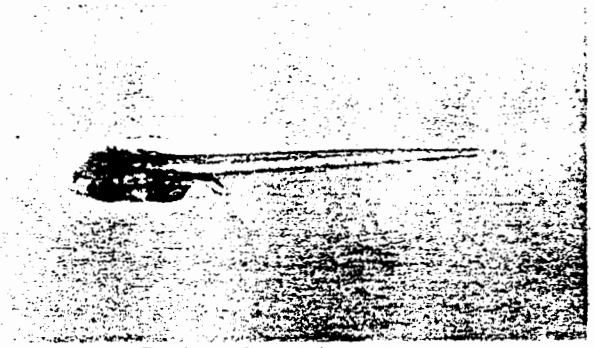
20 hours after fertilization.

Just before hatching, 40 hours.

Larva about 1 day old, 3.4mm in total length.

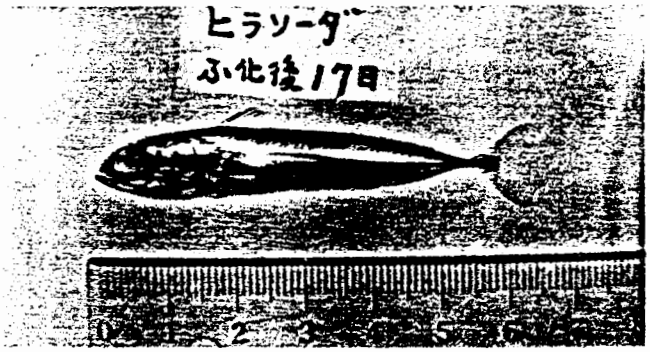
Figure 24.--Various stages of development of egg and larva of A. thazard (Harada, Murata, and Miyashita 1973, plates 1 and 2).

Plate 2

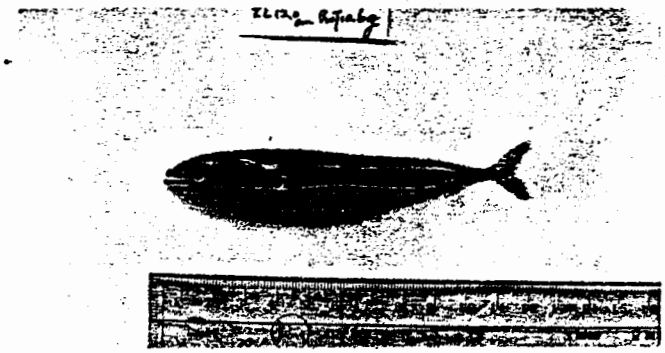


Postlarva about 5 days old.

Postlarva about 10 days old.



Young fish about 17 days old, 64mm in total length.



Young fish about 40 days old, 120mm in total length.

Figure 24.--Continued.

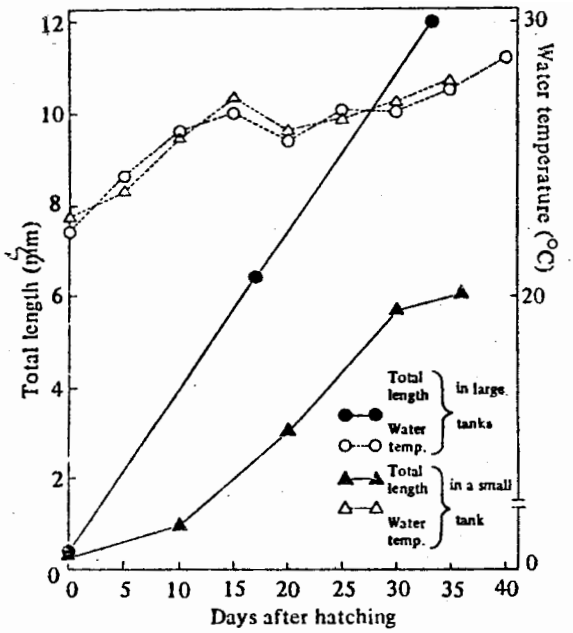
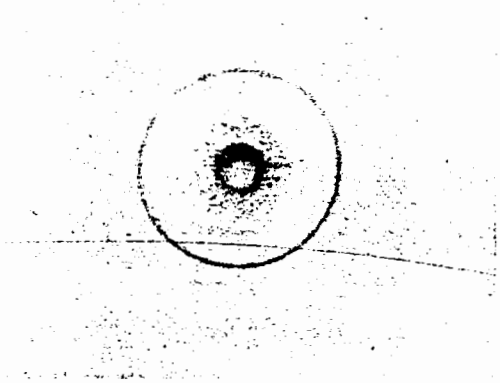
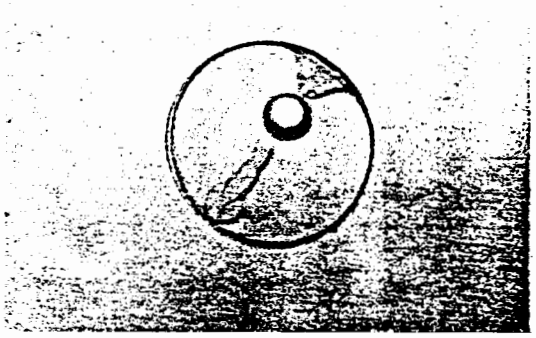


Figure 25.--Growth curves of A. thazard larvae reared in tanks (Harada, Murata, and Miyashita 1973).

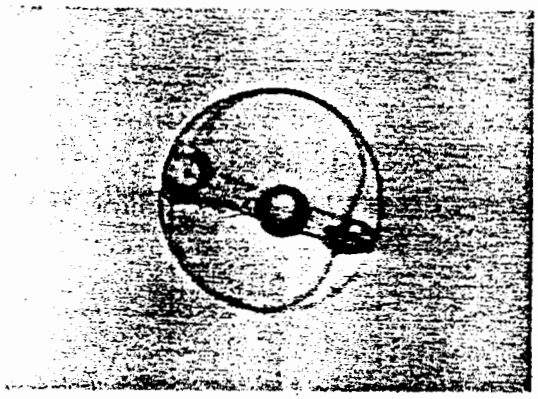
Plate 1



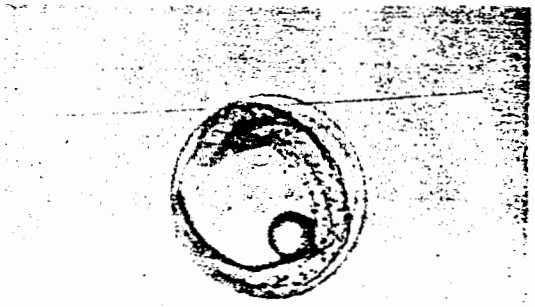
Fertilized egg of Auxis rochei (marusōda) in morula stage, 0.98 mm in diameter.



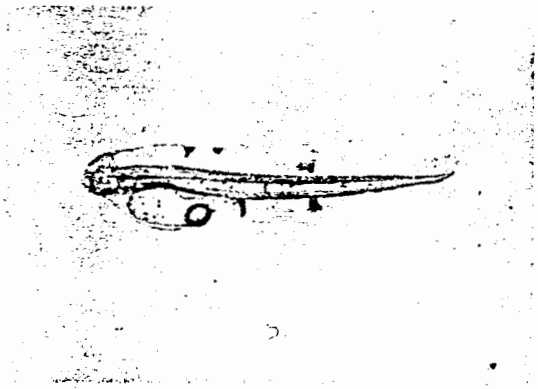
20 hours after fertilization.



28 hours after fertilization.



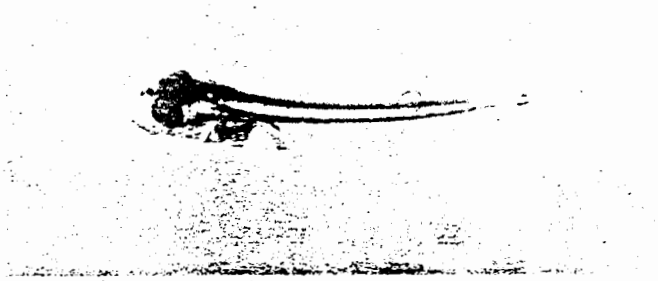
Just before hatching, 38 hours.



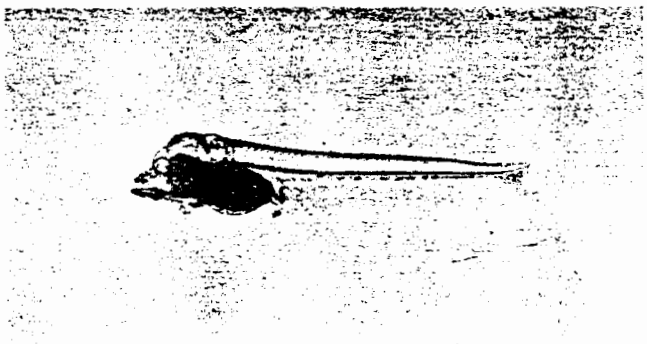
Larva about 1 day old, 3.5mm in total length.

Figure 26.--Various stages of development of egg and larva of A. rochei (Harada, Murata, and Furutani 1973, plates 1 and 2).

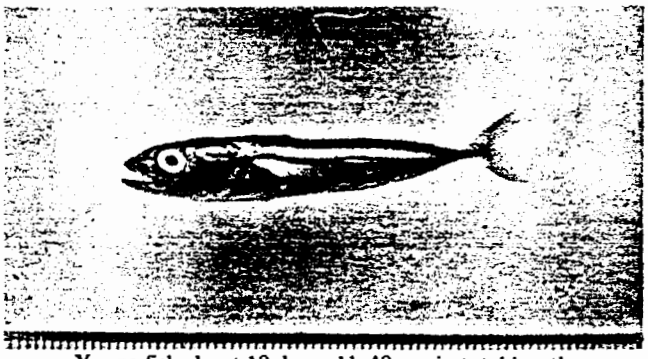
Plate 2



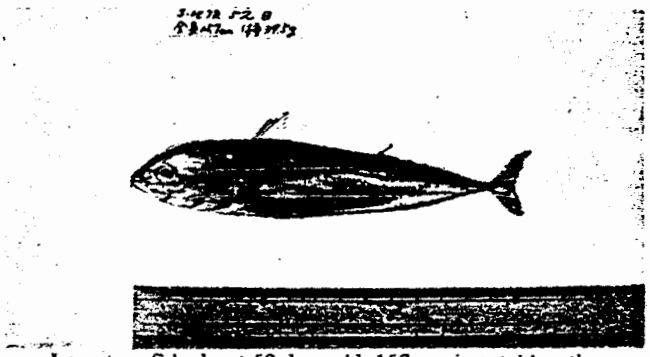
Postlarva about 5 days old.



Postlarva about 10 days old.



Young fish about 19 days old, 49mm in total length.



Immature fish about 52 days old, 157mm in total length.

Figure 26.--Continued.

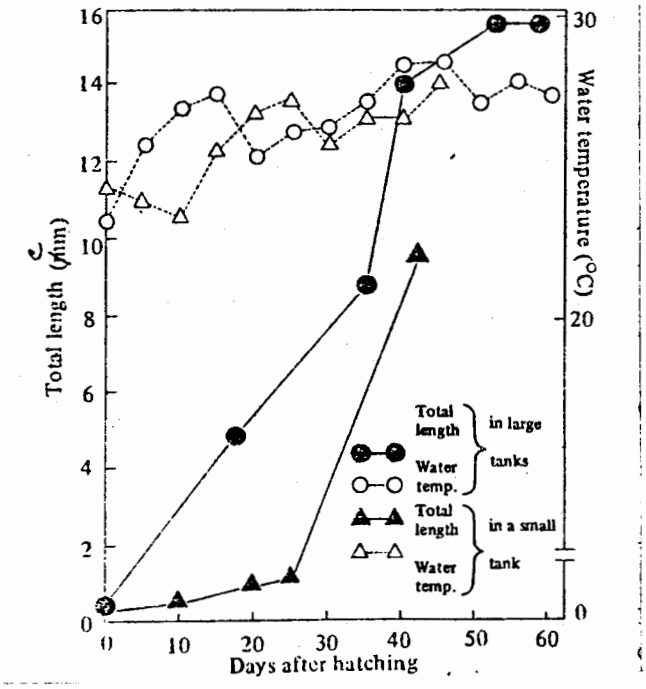


Figure 27.--Growth curves of A. rochei larvae reared in tanks (Harada, Murata, and Furutani 1973).

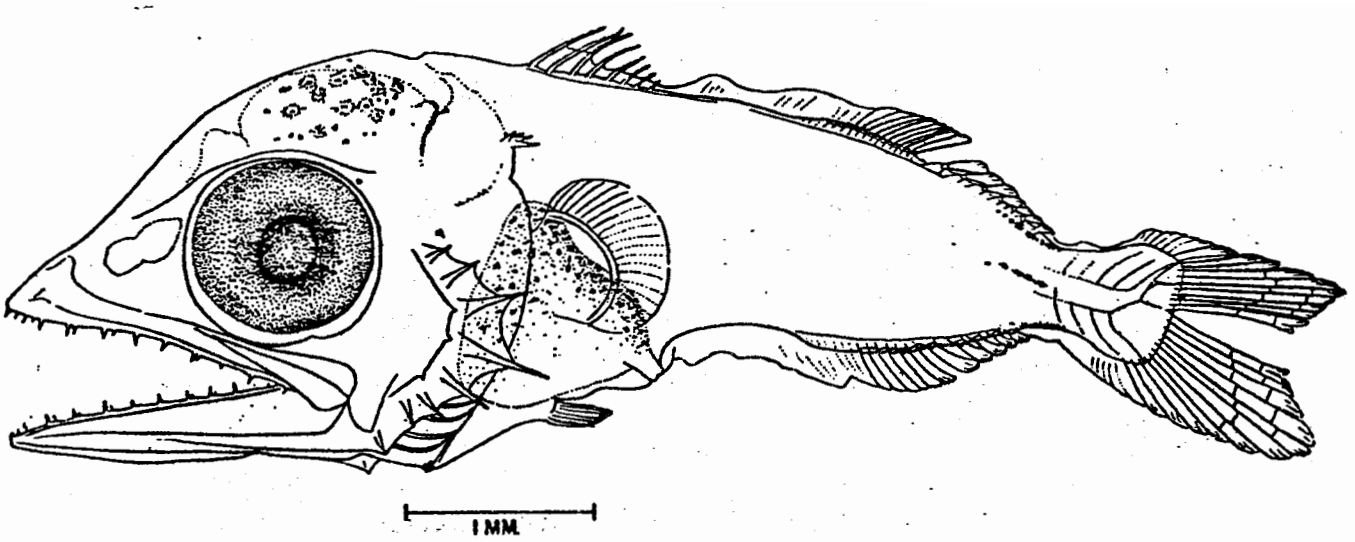


Figure 28.--Auxis larva type I, 7.05 mm (Matsumoto 1959).

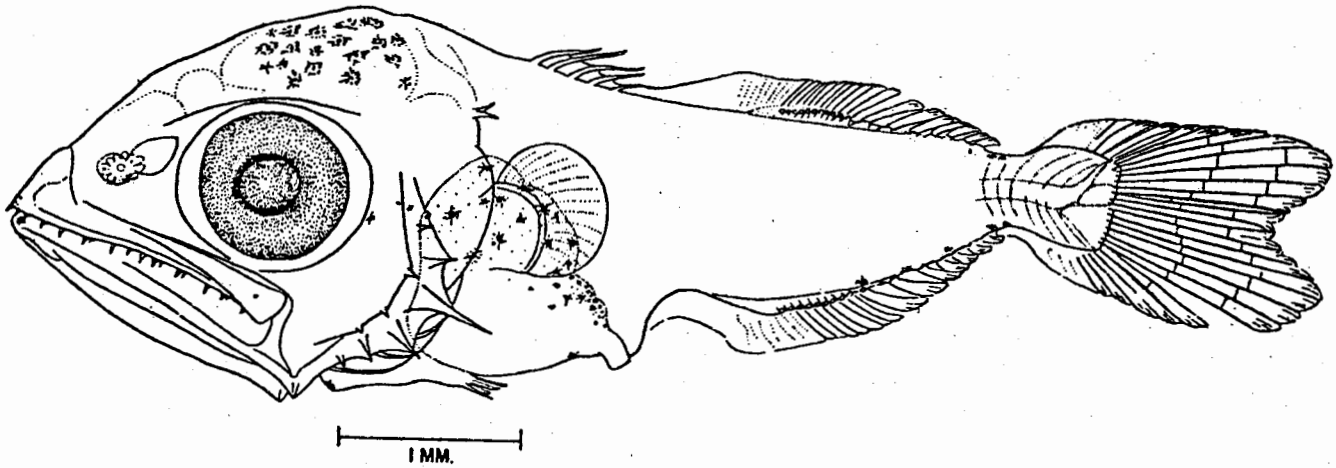


Figure 29.--Auxis larva type II, 7.2 mm (Matsumoto 1959).

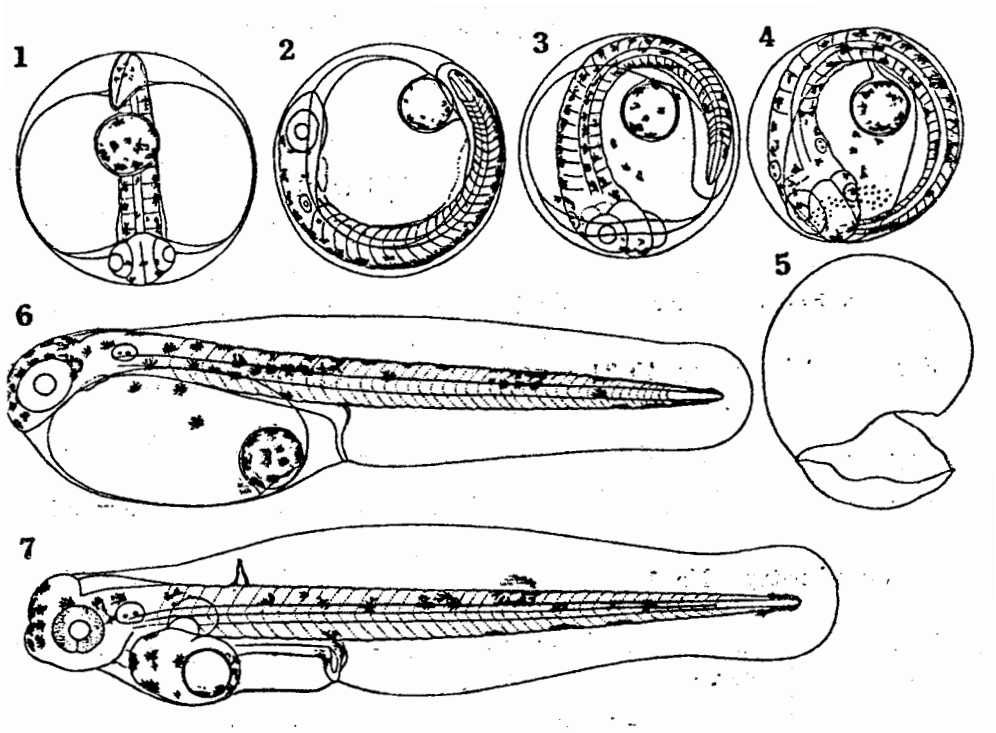


Figure 30.--Various stages of development of egg and larva of

Auxis (Mito 1961).

1. Pelagic egg, 7h 30m after collecting, 1.04mm in diameter, oil globule 0.26mm.
2. 29-myotome stage, 9h 30m after.
3. 10h 30m after.
4. 14h 30m after, shortly before hatching (24—27°C).
5. Empty egg capsule.
6. Larva just hatched, 2.70mm in total length, myotomes 11+32=43.
7. Larva 16h 30m after hatching, 3.68mm in total length, myotomes 9+31=40.

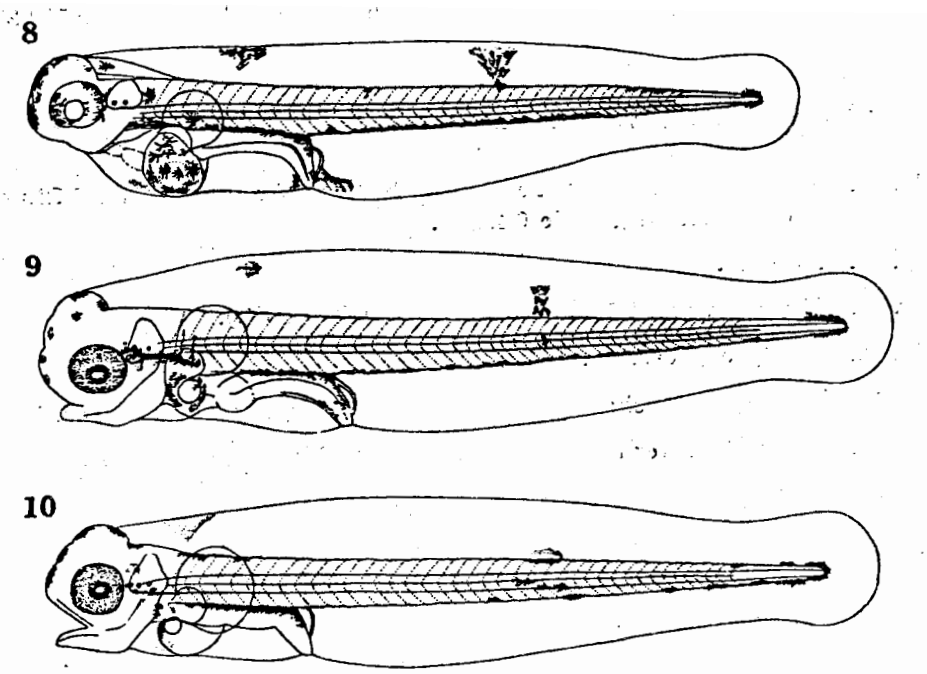


Figure 30.--Continued.

8. Larva 30h after, 3.58mm in total length, myotomes 9+31=40.
9. Larva 42h 30m after, 3.92mm in total length, myotomes 9+32=41.
10. Larva 55h after, 3.75mm in total length, myotomes 8+31=39.

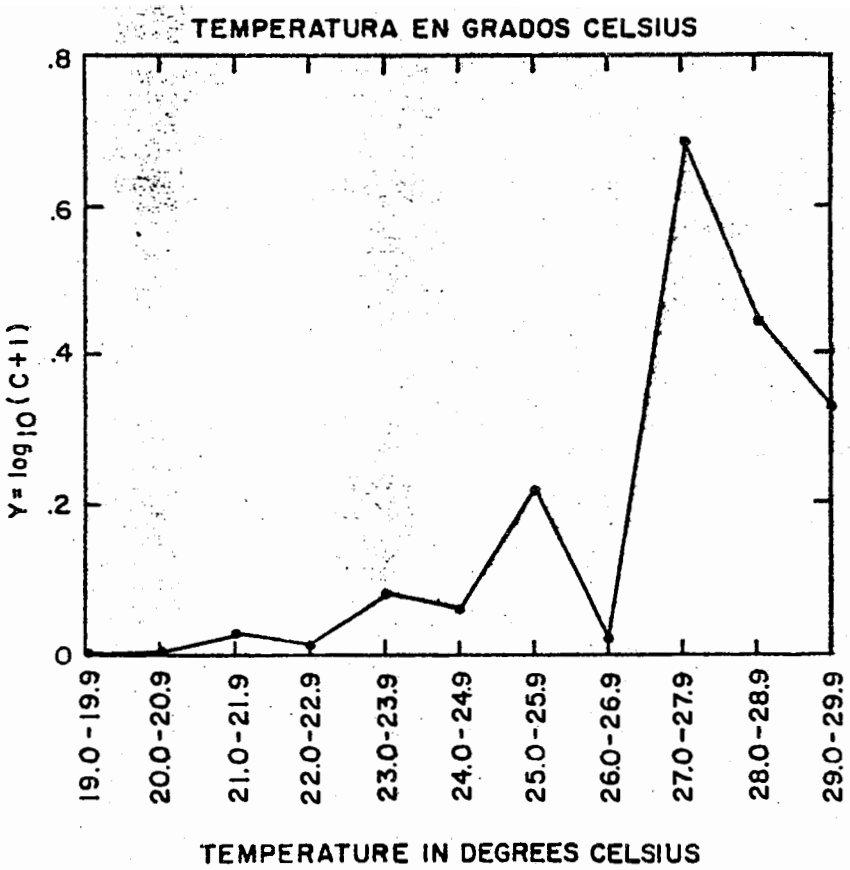


Figure 31.--Average catches of larval Auxis grouped according to surface temperatures prevailing at the time of capture (Klawe, et al. 1970).

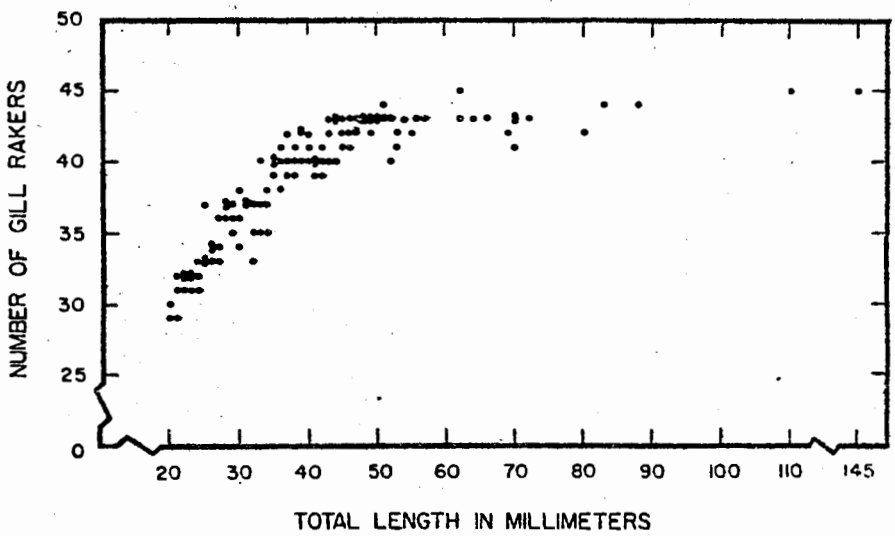


Figure 32.--Gill-raker counts of young A. thazard plotted against total length (Klawe and Shimada 1959).

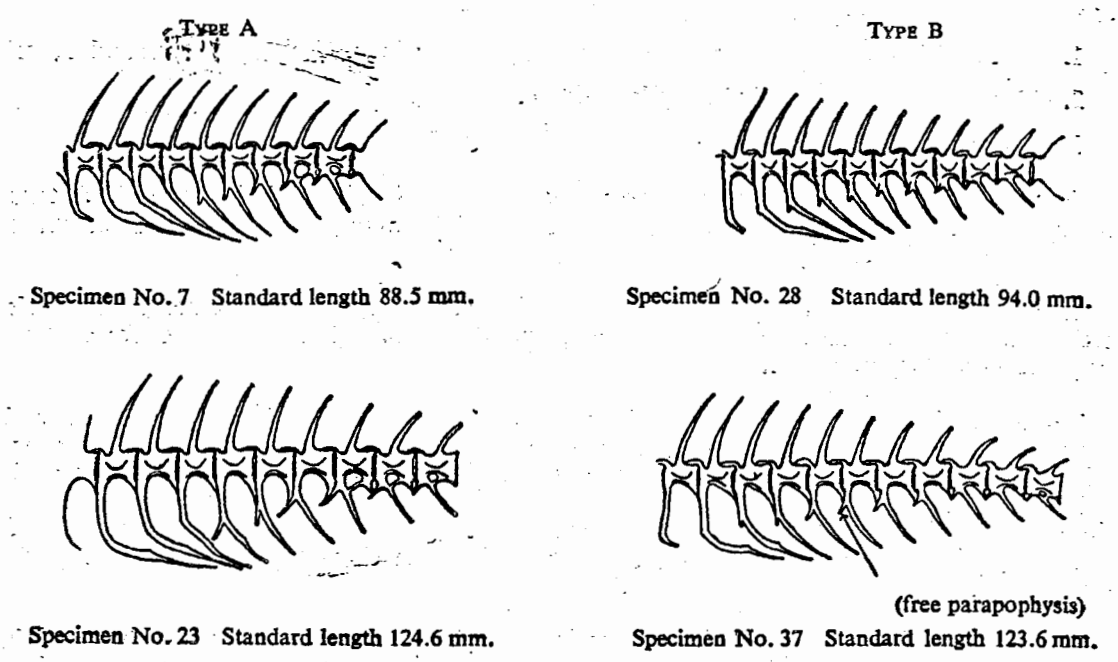


Figure 33.--Two types (A and B) of caudal vertebrae of Auxis (Watanabe 1964).

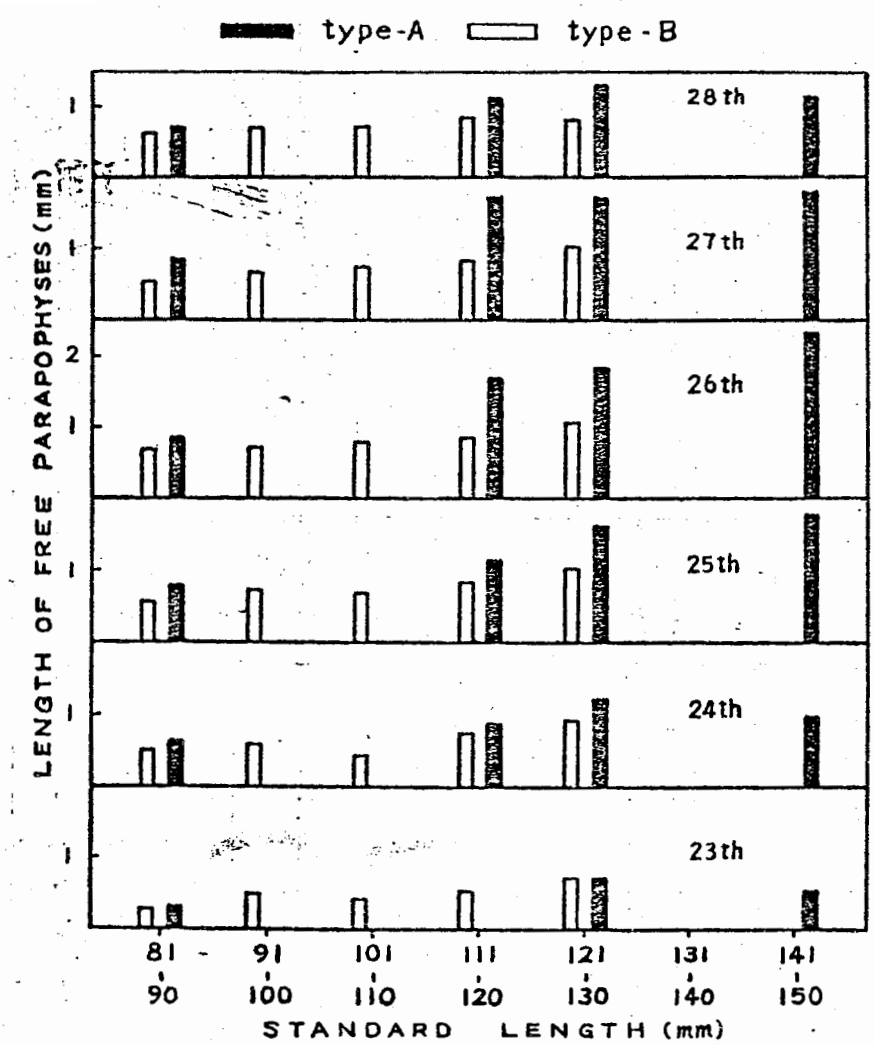


Figure 34.--Comparison of the length of free parapophyses of caudal vertebrae between types A and B (Watanabe (1964).

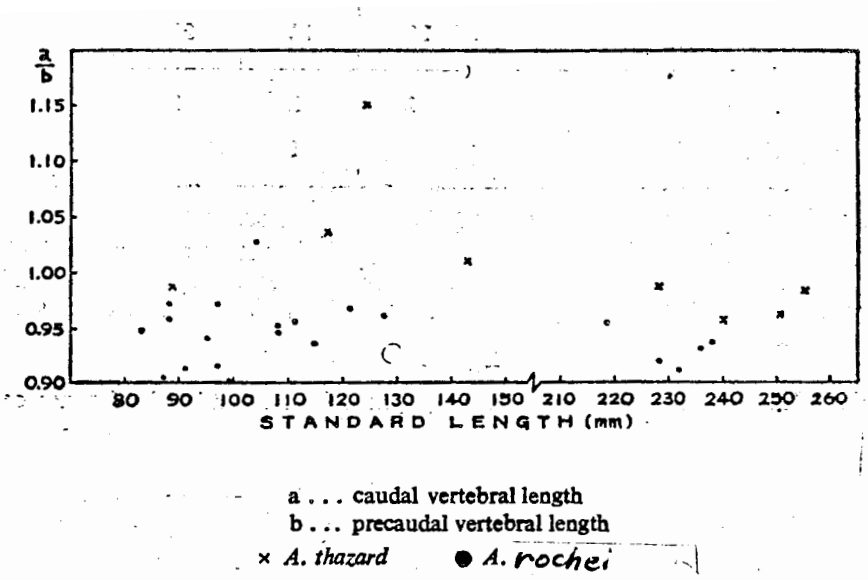
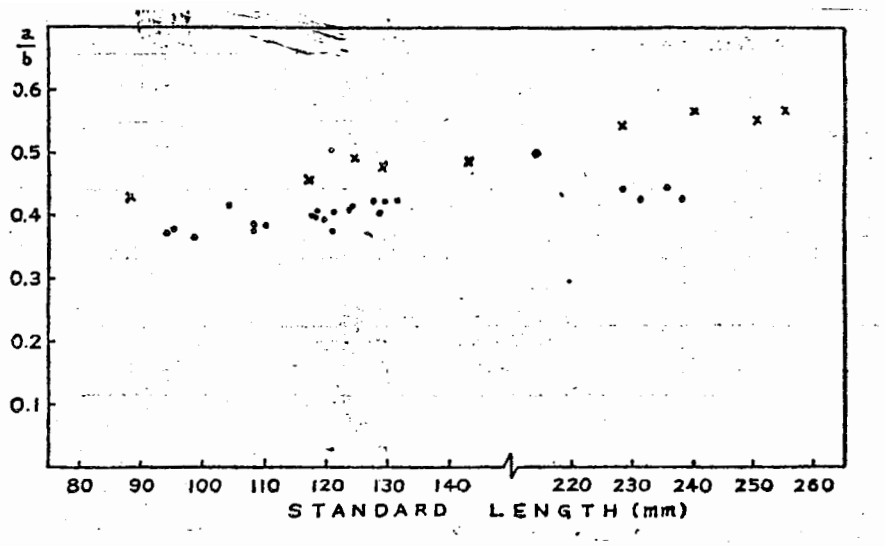


Figure 35.--Comparison of the value (a/b) between A. rochei and A. thazard (Watanabe 1964).



a . . . body height at anal origin
b . . . length of first dorsal to second dorsal origin
× *A. thazard* ● A. rochei

Figure 36.--Comparison of the value (a/b) between A. rochei and A. thazard (Watanabe 1964).

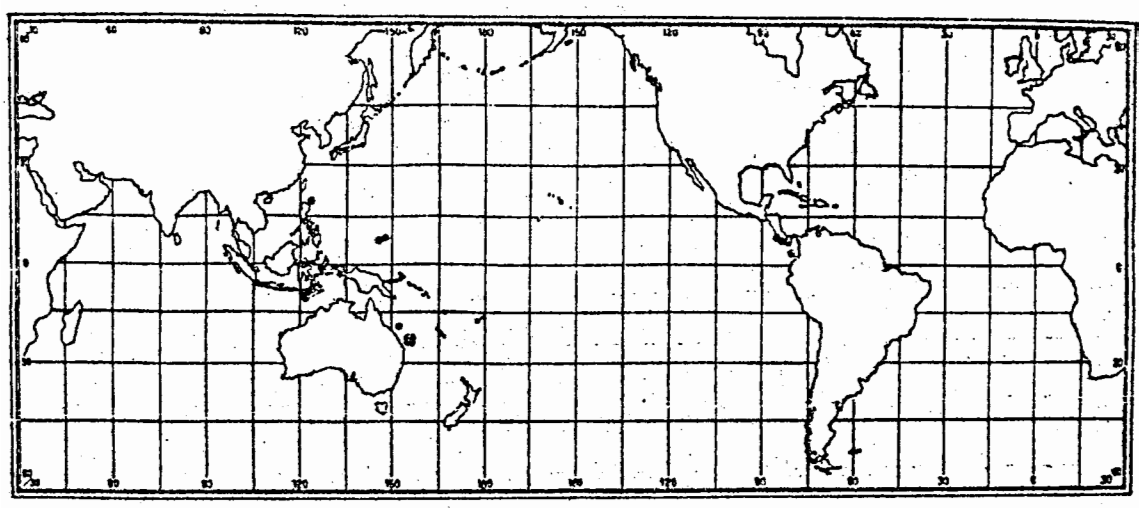


Figure 37.--Localities of capture of juvenile frigate mackerel (Yabe, et al. 1963).

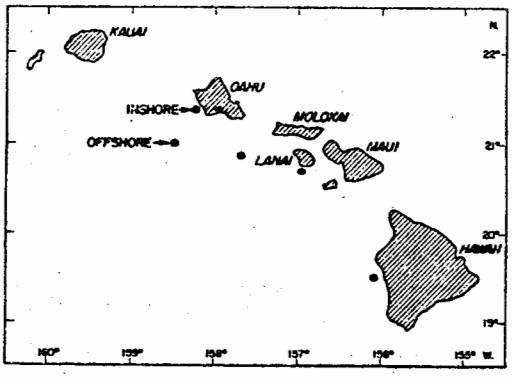


Figure 38.--Areas of midwater trawling, R/V Townsend Cromwell cruise 32, 12 July to 25 September 1967 (Higgins 1970).

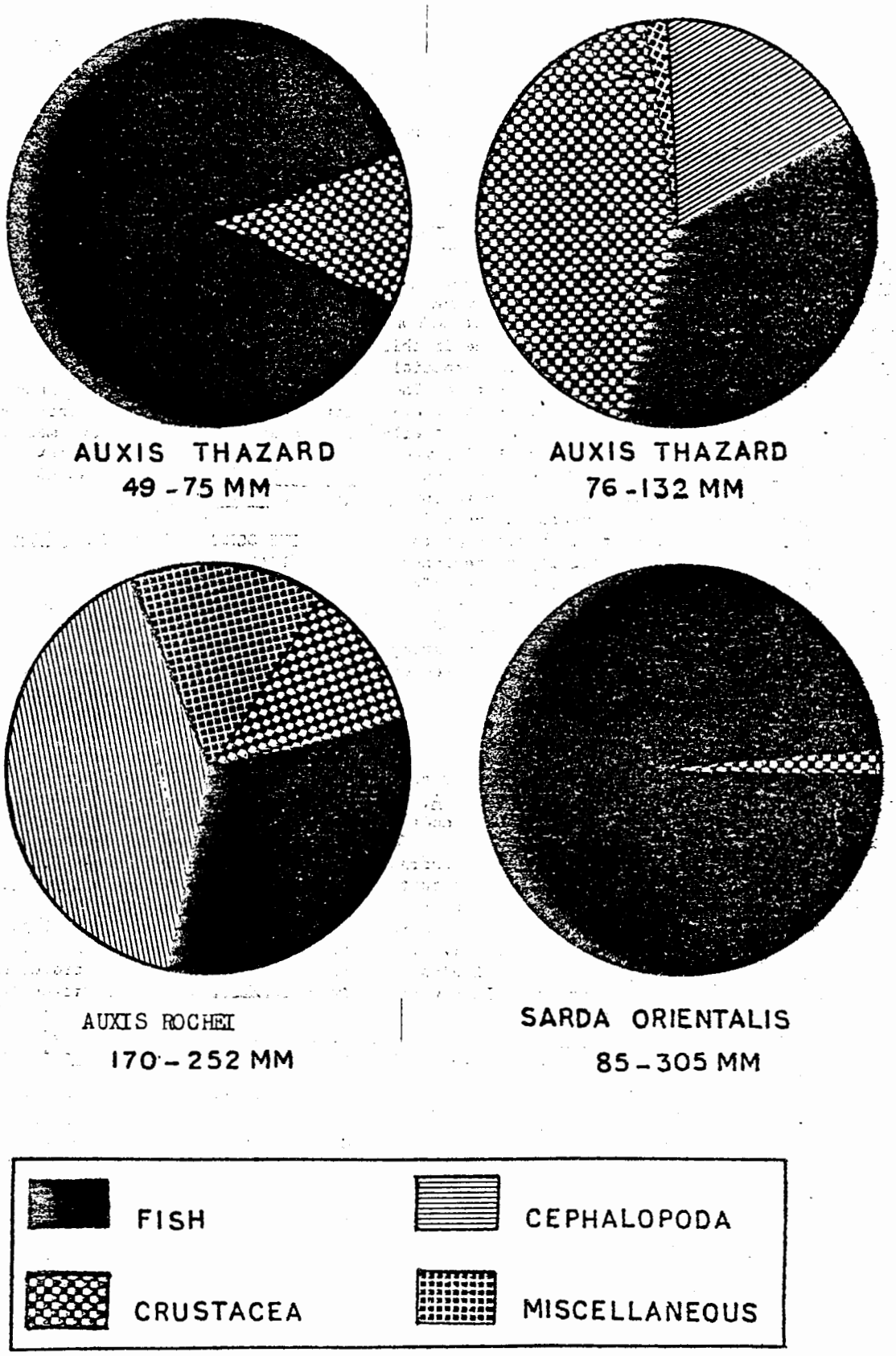


Figure 39.--Diagrams illustrating the composition by volume of the stomach contents of A. thazard, A. rochei, and Sarda orientalis (Thomas and Kumaran 1963).

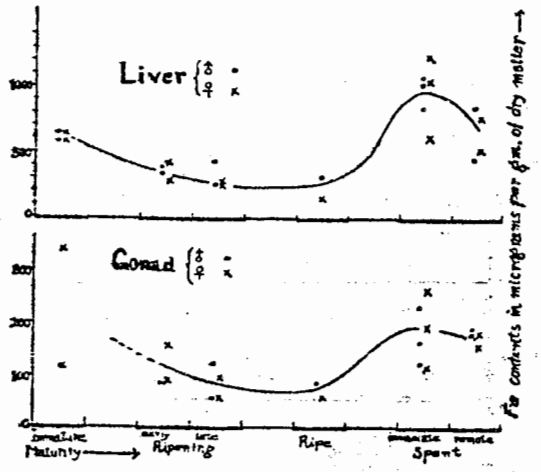


Figure 40.--Correlation between the stage of maturation and the contents of iron in the liver and gonad of A. rochei (Suzuki and Morio 1957).

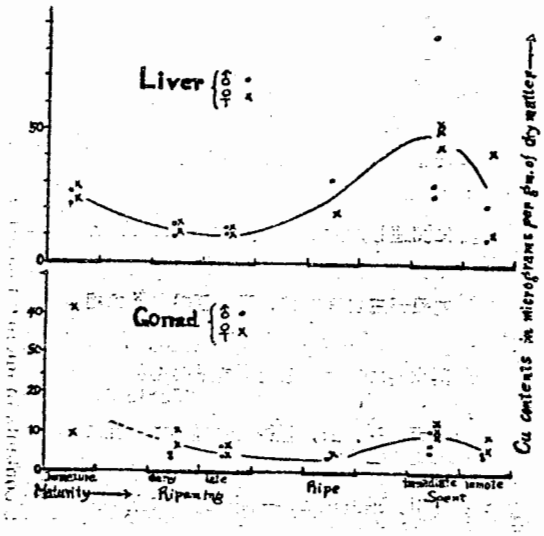


Figure 41.--Correlation between the stage of maturation and the contents of copper in the liver and gonad of A. rochei (Suzuki and Morio 1957).

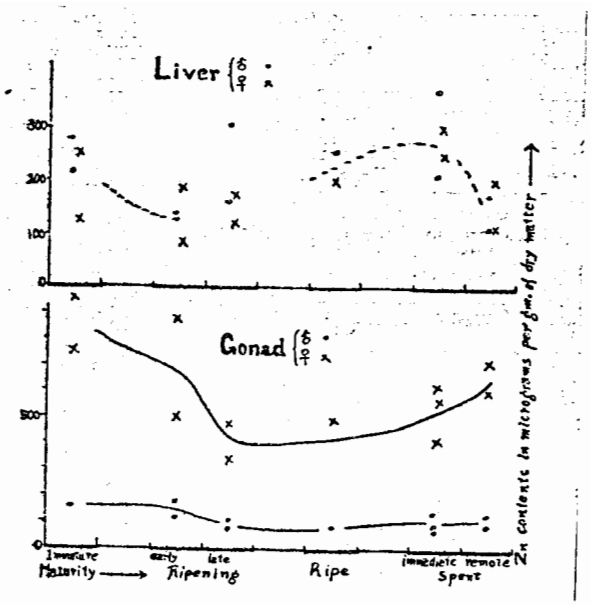


Figure 42.-- Correlation between the stage of maturation and the contents of zinc in the liver and gonad of A. rochei (Suzuki and Morio 1957).

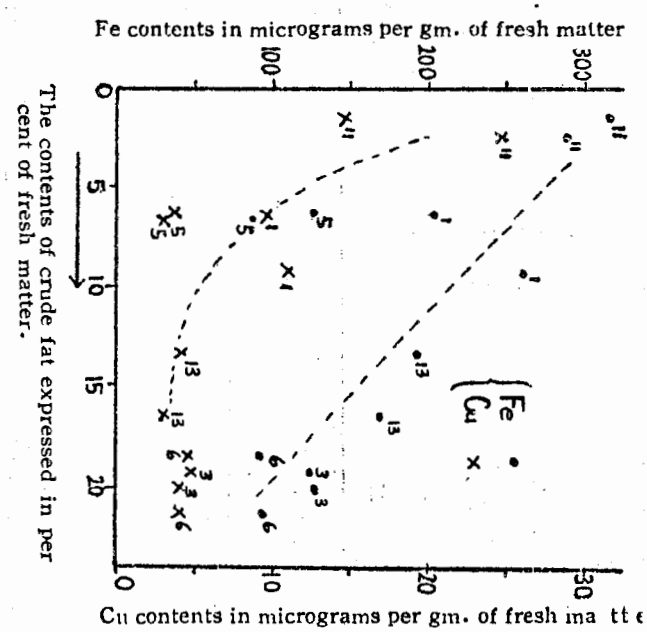


Figure 43.--The relationship between the amounts of crude fat and of iron and copper in the liver of A. rochei (Suzuki and Morio 1957).

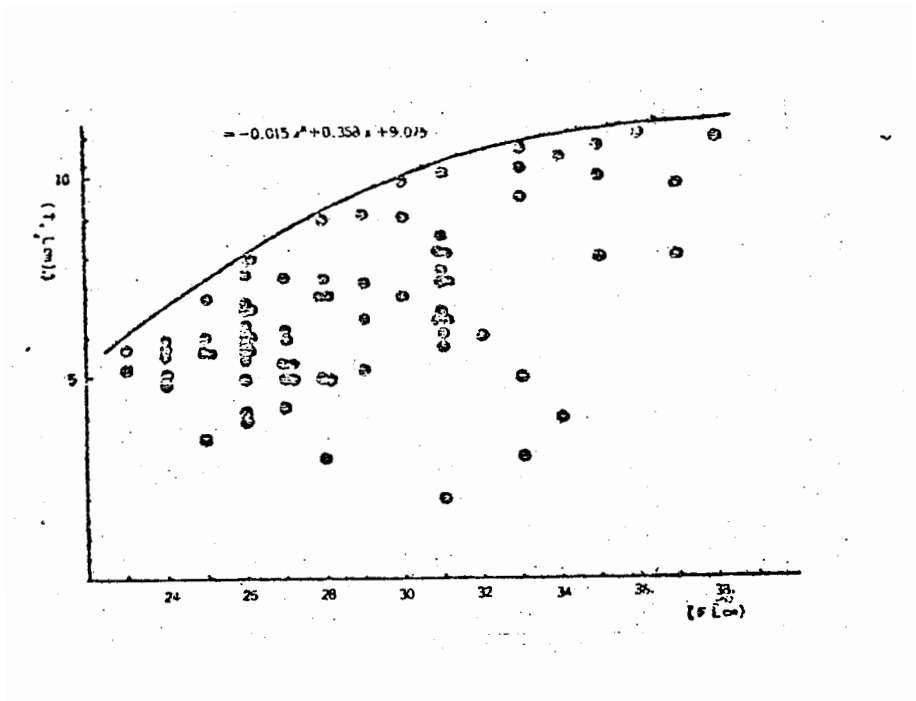


Figure 44.--Relationship between body length of A. rochei and length of fish prey consumed (Morita 1972).

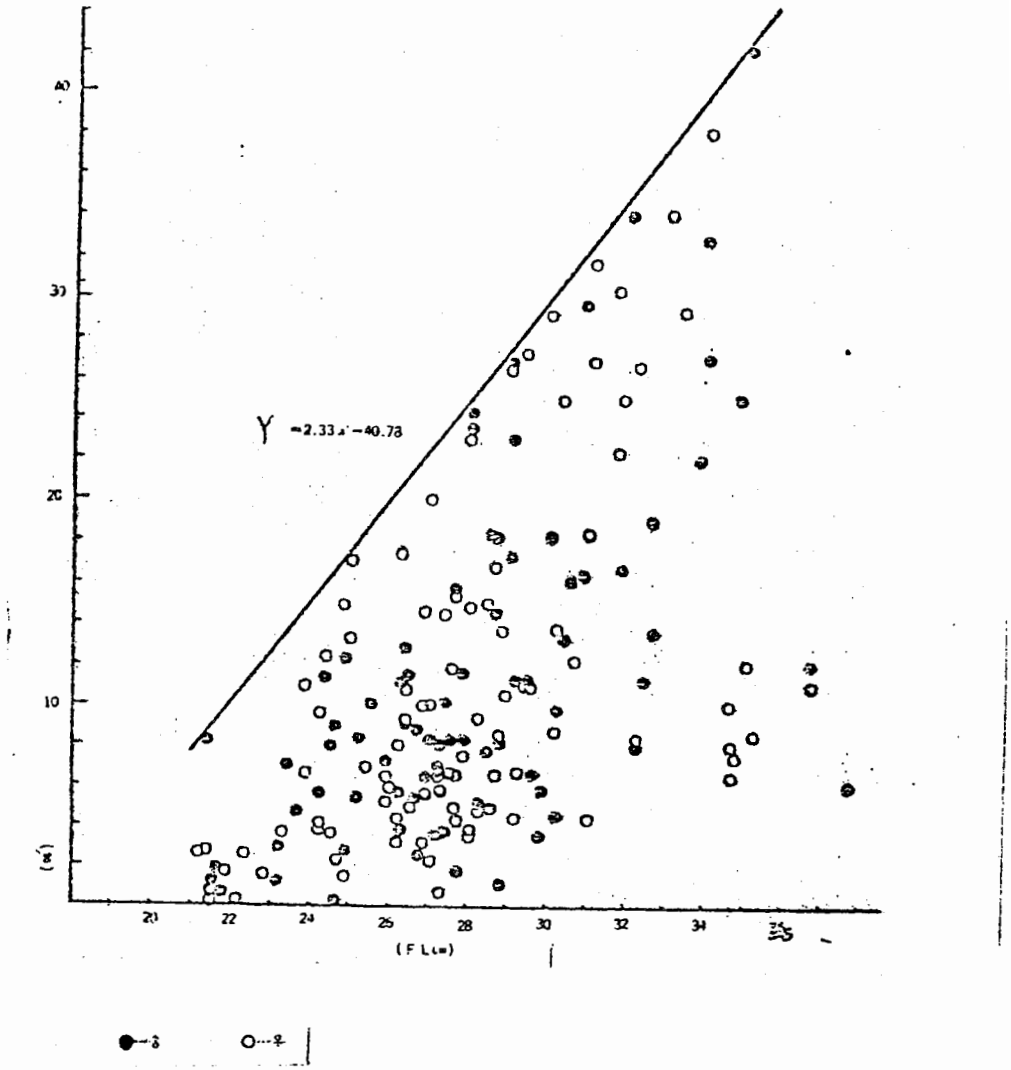


Figure 45.--Relationship between body length of A. rochei and weight of stomach contents (Morita 1972).

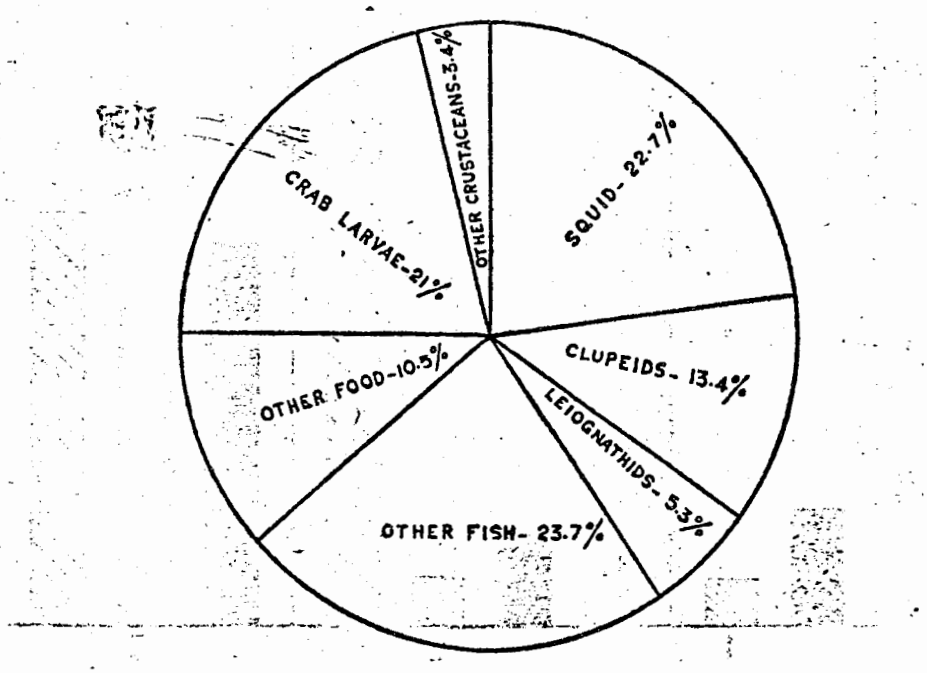


Figure 46.--Percentage, by volume, of the types of food consumed by A. rochei (Kumaran 1964).

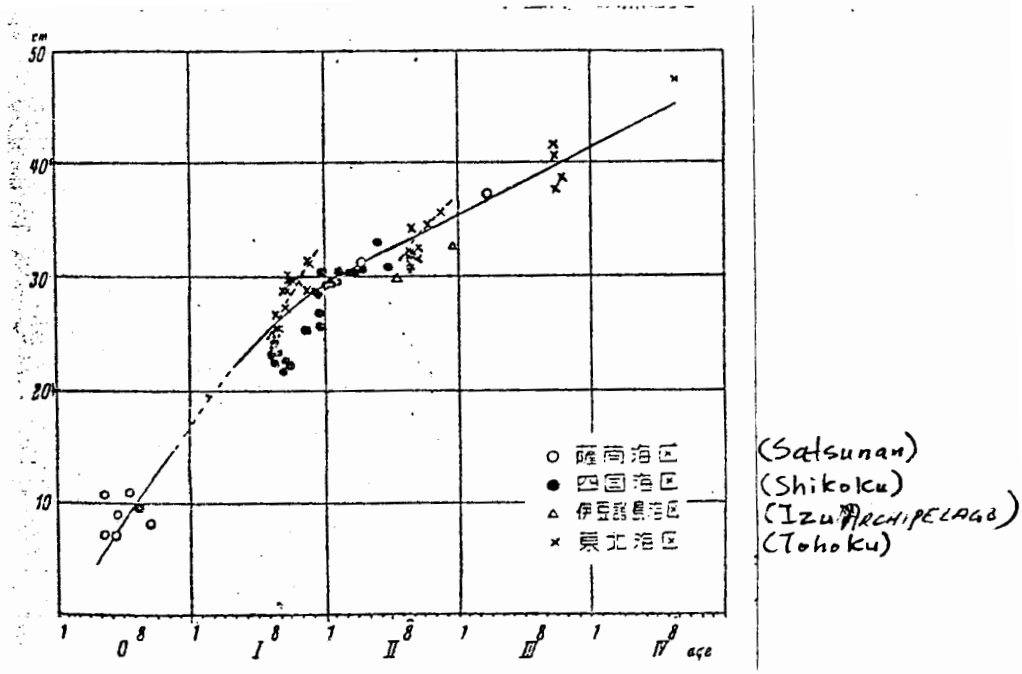


Figure 47.--Growth curve of A. rochei (Hotta 1955).

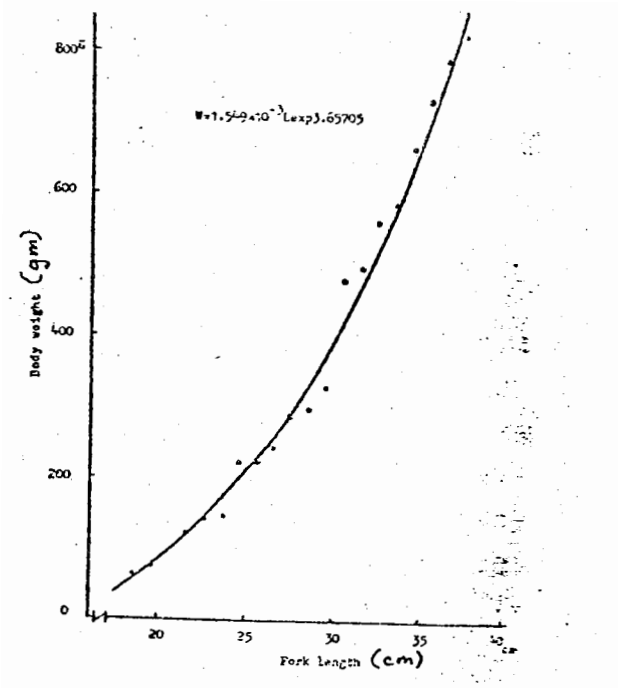


Figure 48.--Length-weight relationship of A. rochei caught in Japanese waters (Yasui 1975).

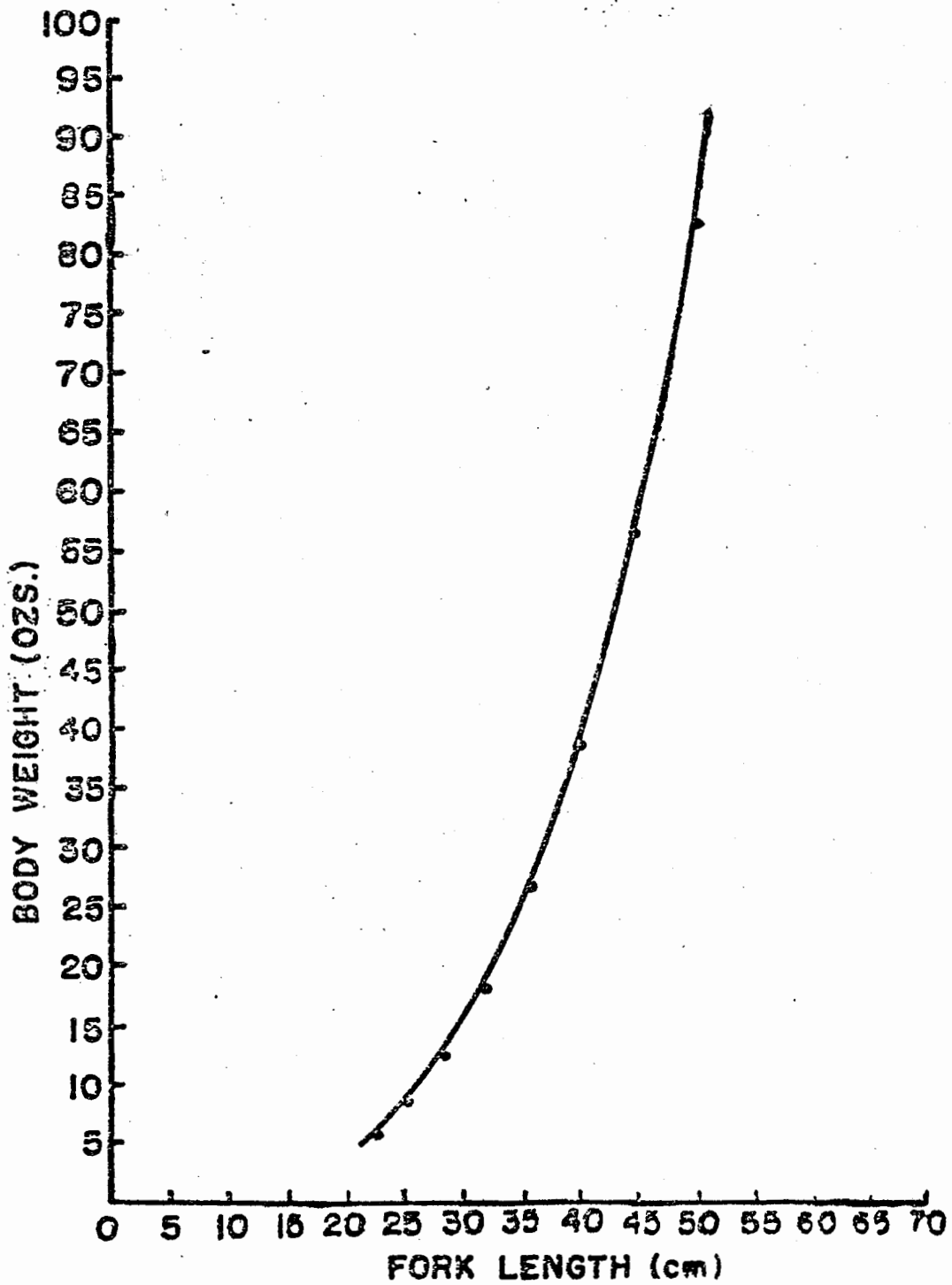


Figure 49.--Length-weight relationship of A. thazard caught off Sri Lanka (Sivasubramaniam 1966).

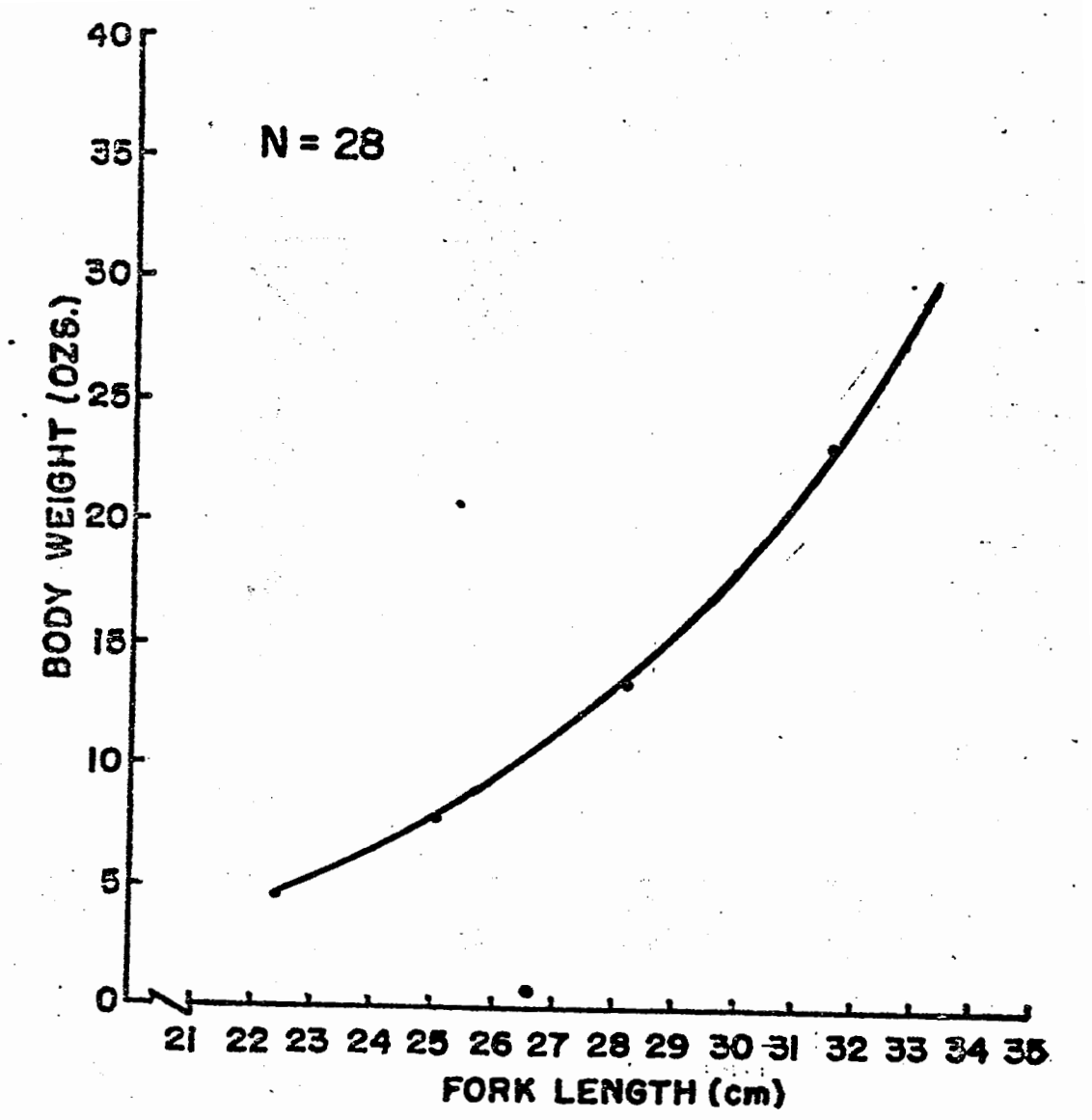


Figure 50.--Length-weight relationship of A. rochei caught off Sri Lanka (Sivasubramaniam 1966).

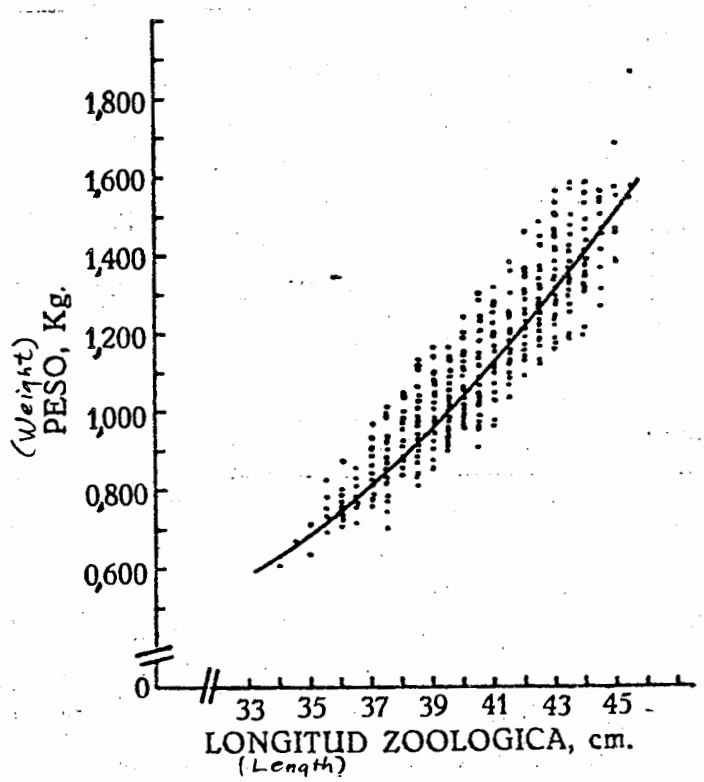


Figure 51.--Length-weight relationship of A. thazard caught at Barbate, Tarifa, and La Linea in 1958, 1961, 1963, and 1964 combined (Rodriguez-Roda 1966).

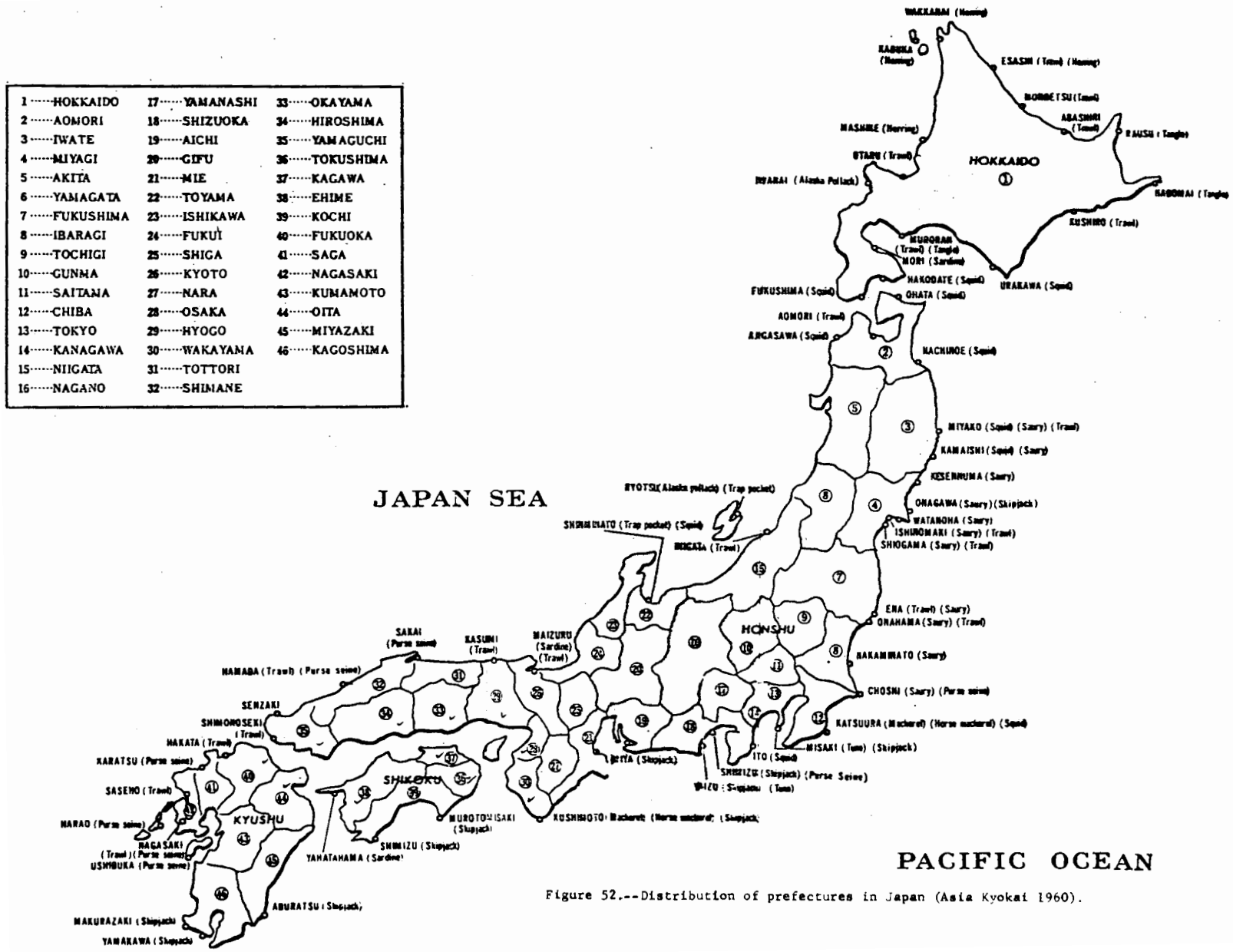


Figure 52.--Distribution of prefectures in Japan (Asia Kyokai 1960).

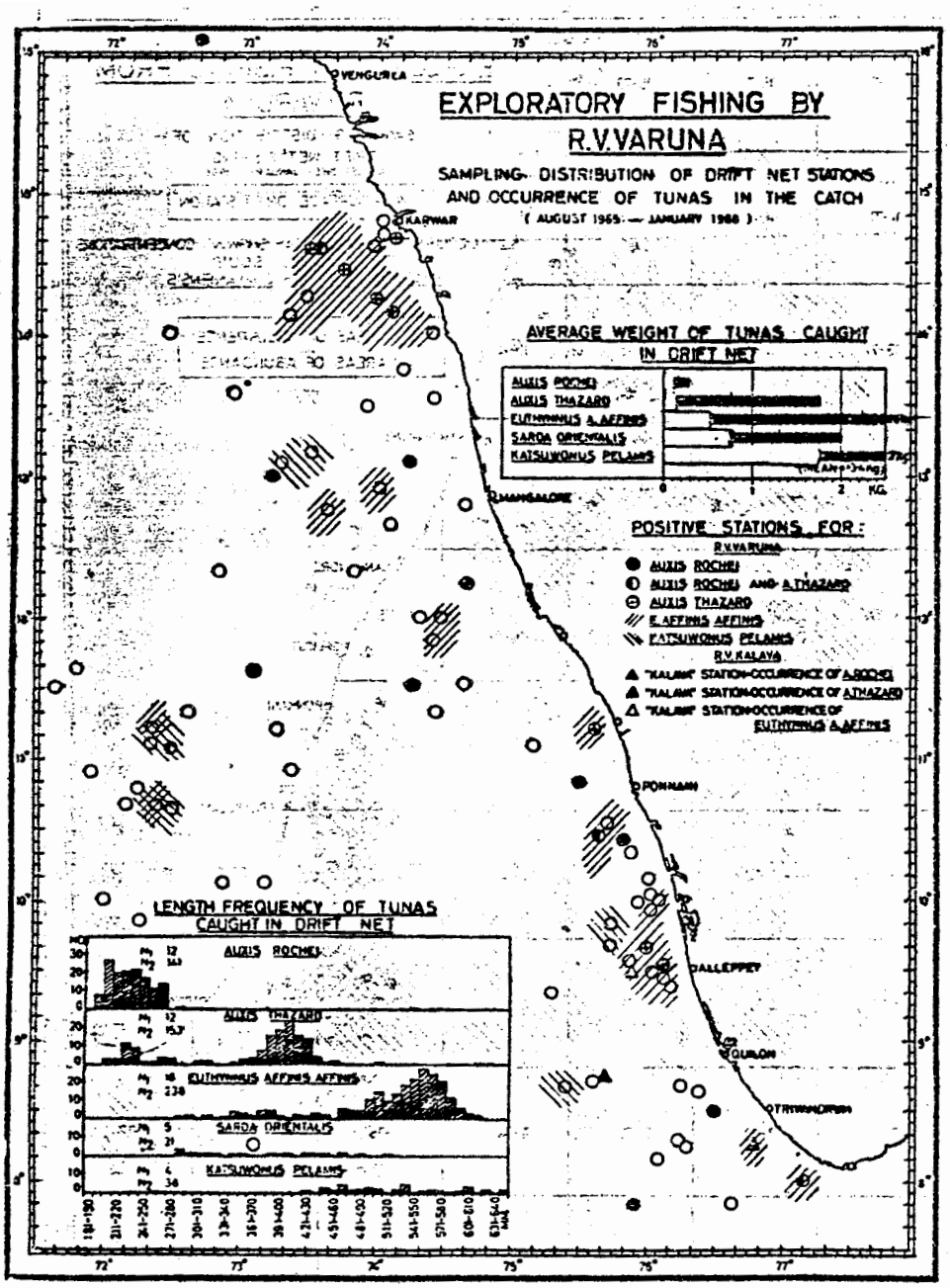


Figure 53.--Sampling distribution of exploratory drift-net stations. Details of occurrence of tunas in the catch, length and weight of tunas caught are also indicated. N_1 = No. of fishing operations; N_2 = No. of specimens (Silas 1969).

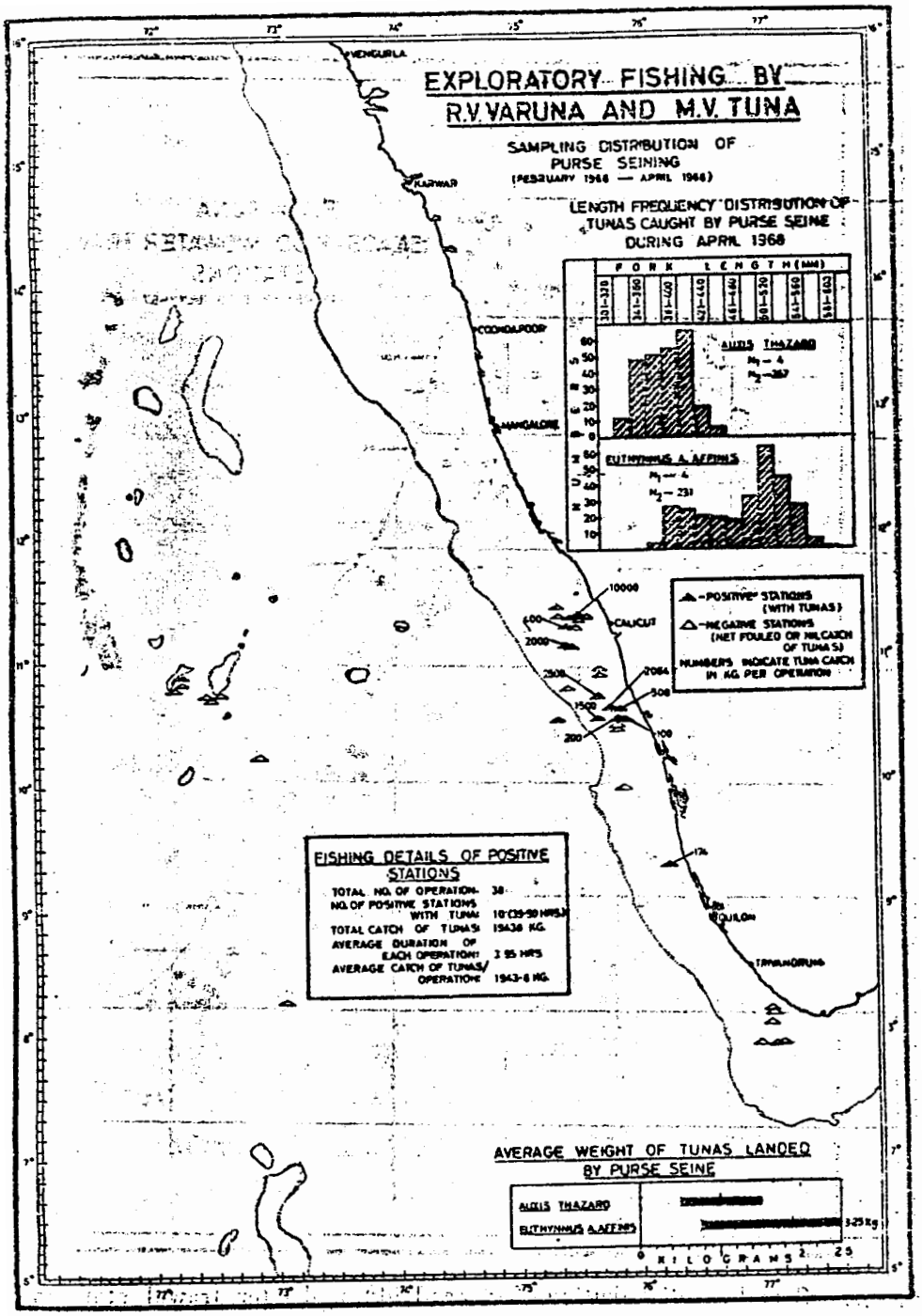


Figure 54.--Exploratory purse seining for tunas from the southwest coast and the Laccadive Sea carried out by R/V Varuna and M/V Tuna. Details of length and weight of the tunas caught as well as catch in kg/per operation are also indicated (Silas 1969).

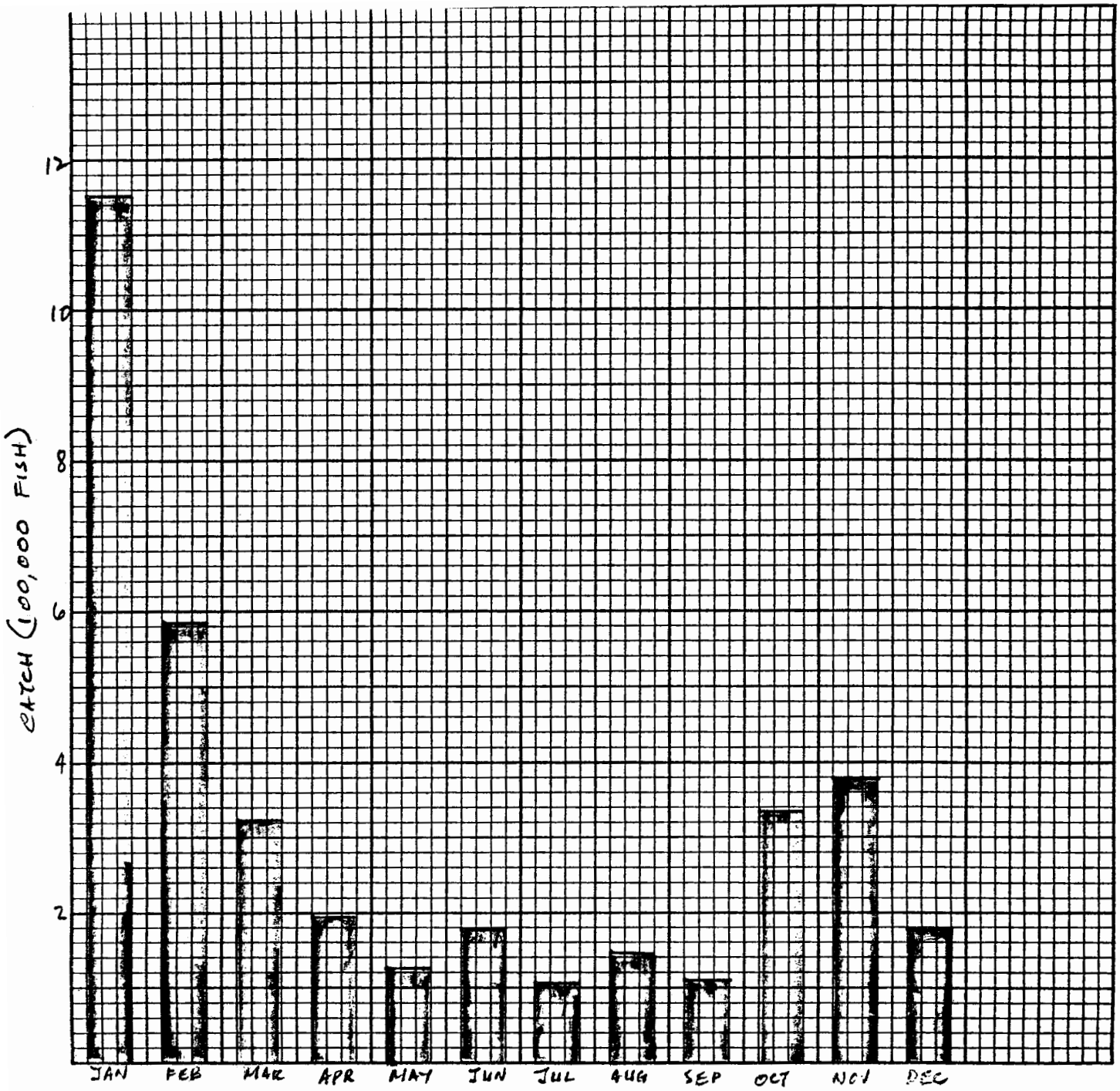


Figure 55.--Catch of little tuna and frigate mackerel, by month, in the Maldive Islands in 1965 (Hiebert and Alverson 1971).

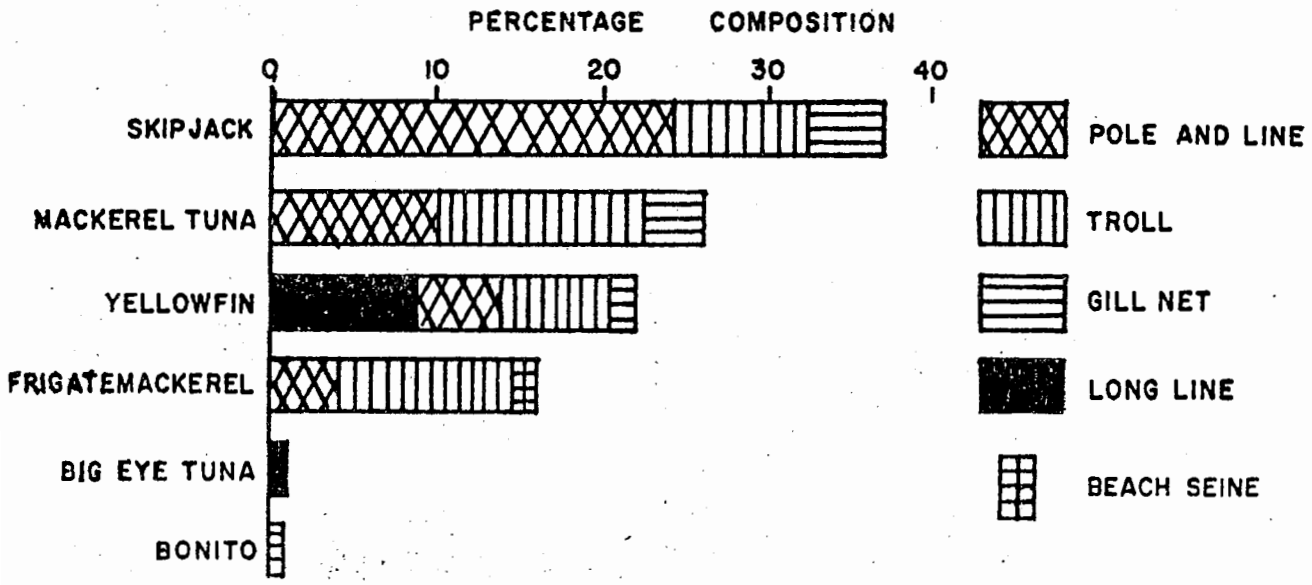


Figure 56.--Percentage composition of tuna species caught by various types of gear from the coastal waters of Sri Lanka (Sivasubramaniam 1965).

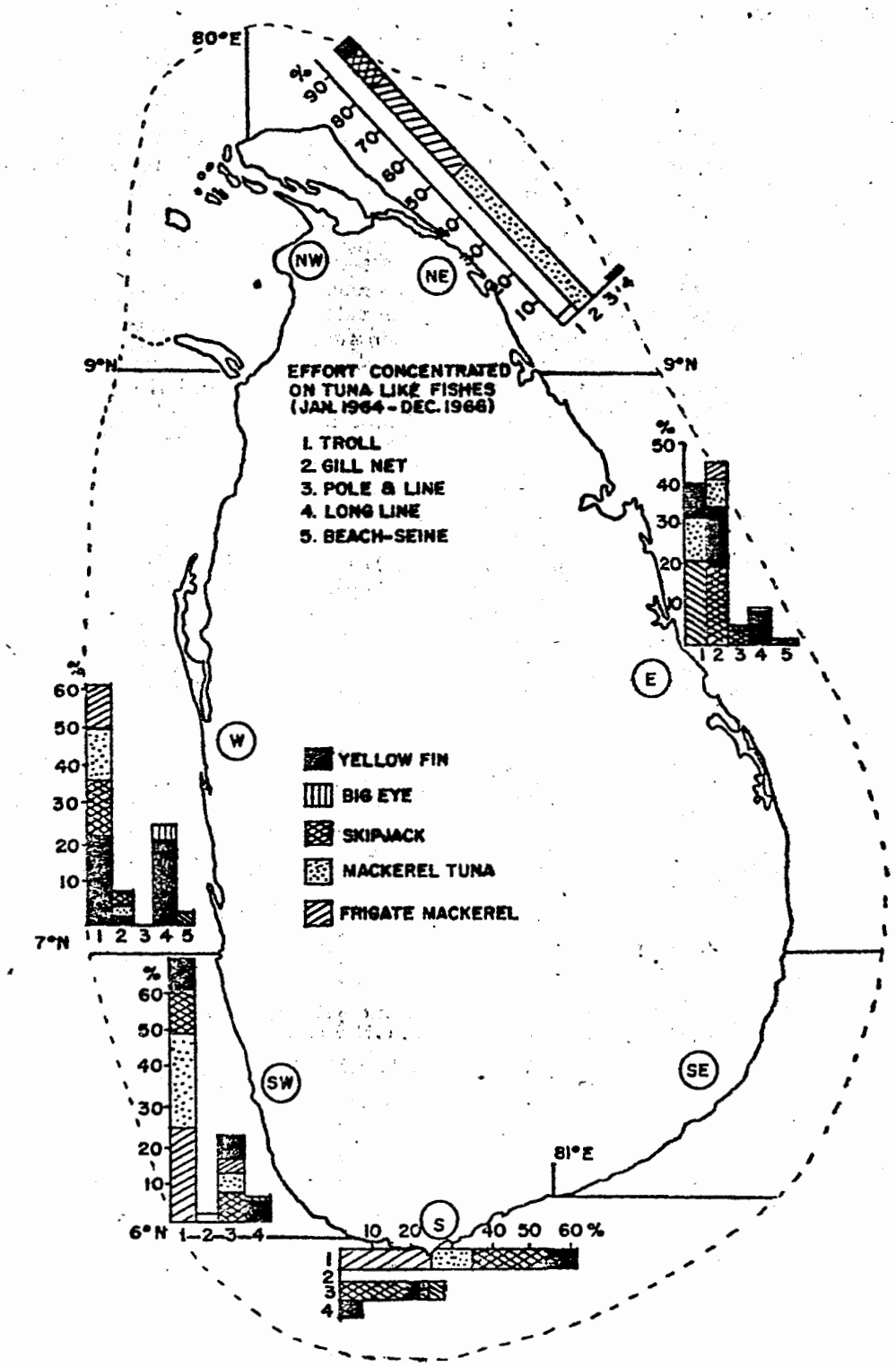


Figure 57.--Distribution of effort on tuna and tuna-like fishes around Sri Lanka (Sivasubramaniam 1966).

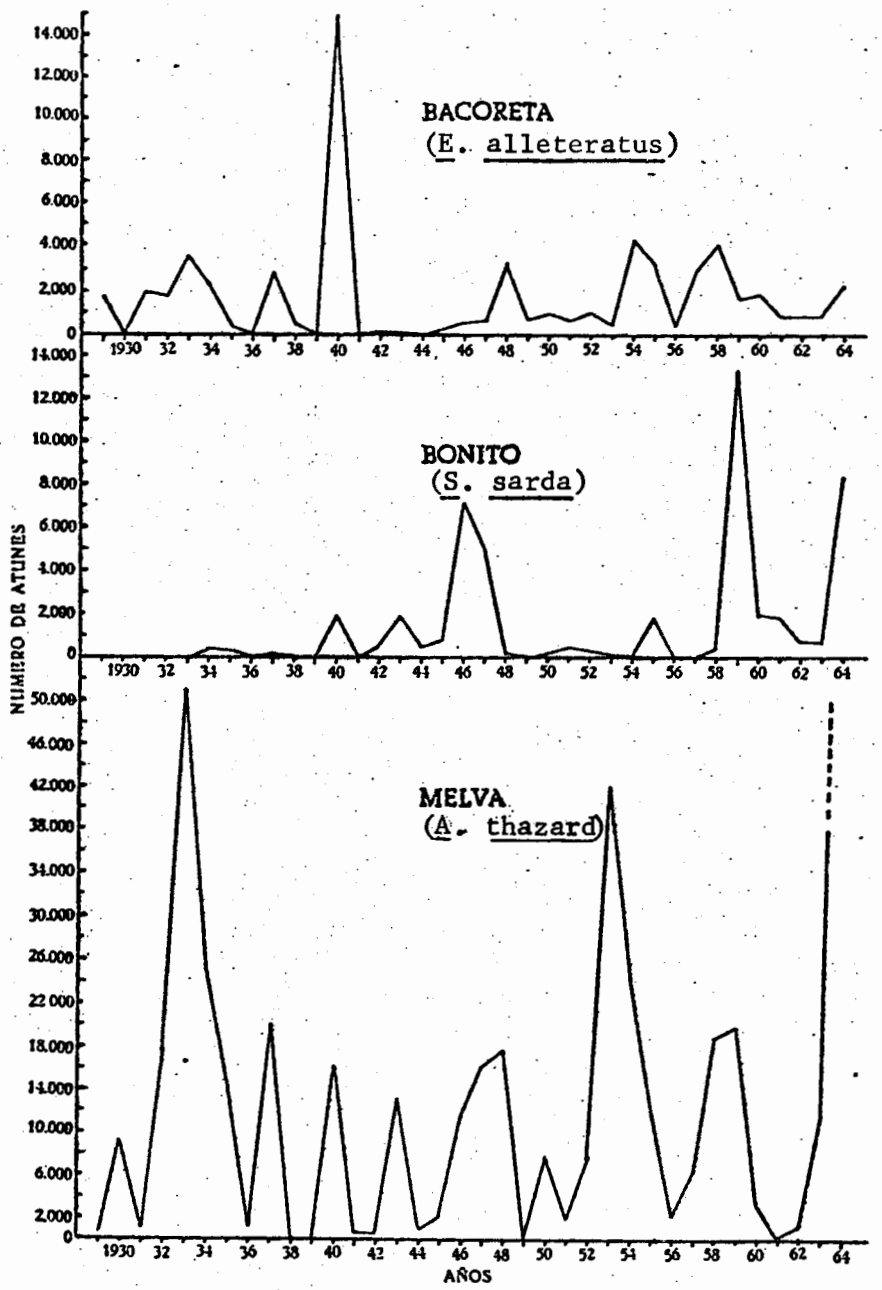


Figure 58.--The annual production of tuna, in numbers of fish, in the trap-net fishery operating at Barbate (Rodriguez-Roda 1966).

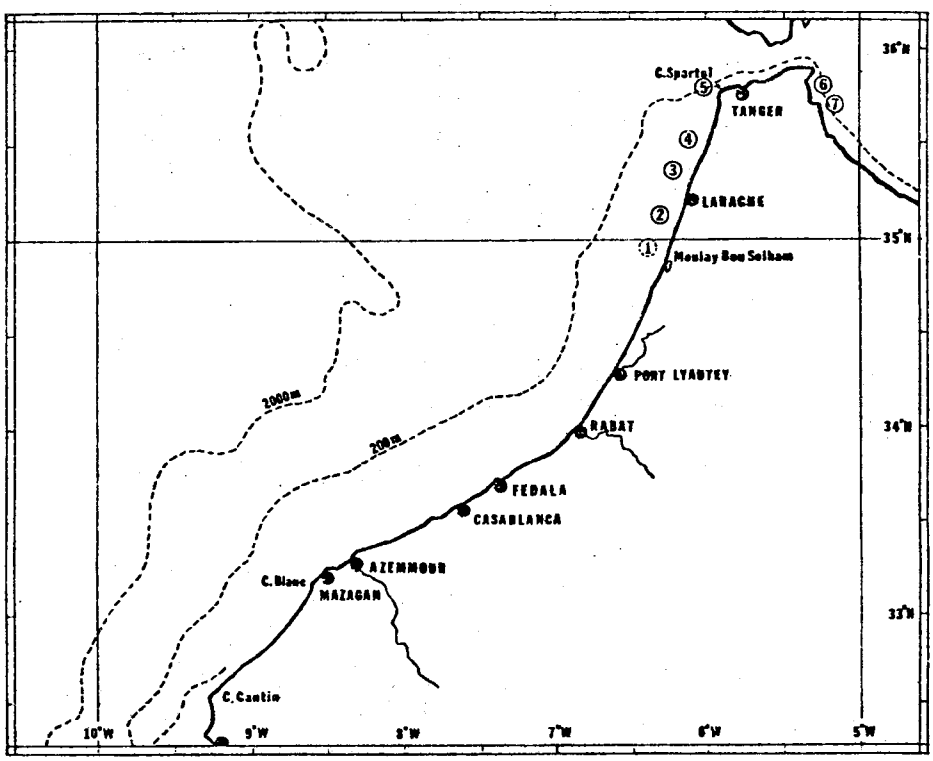


Figure 59.--Location of traps in northern Morocco (Lamboeuf 1972).

1. Kenitra (closed in 1966).
2. Punta Negra.
3. Los Cenizosos.
4. Garifa.
5. Cape Spartel.
6. Principe.
7. Cabo-Negro.

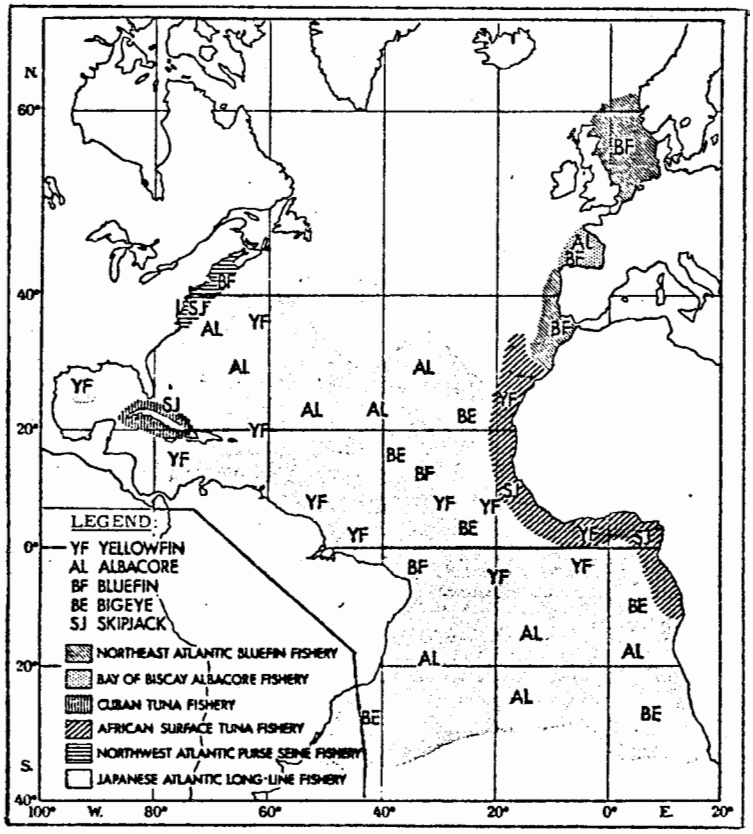


Figure 60.--Location of Atlantic tuna fishing grounds (Shomura 1966).

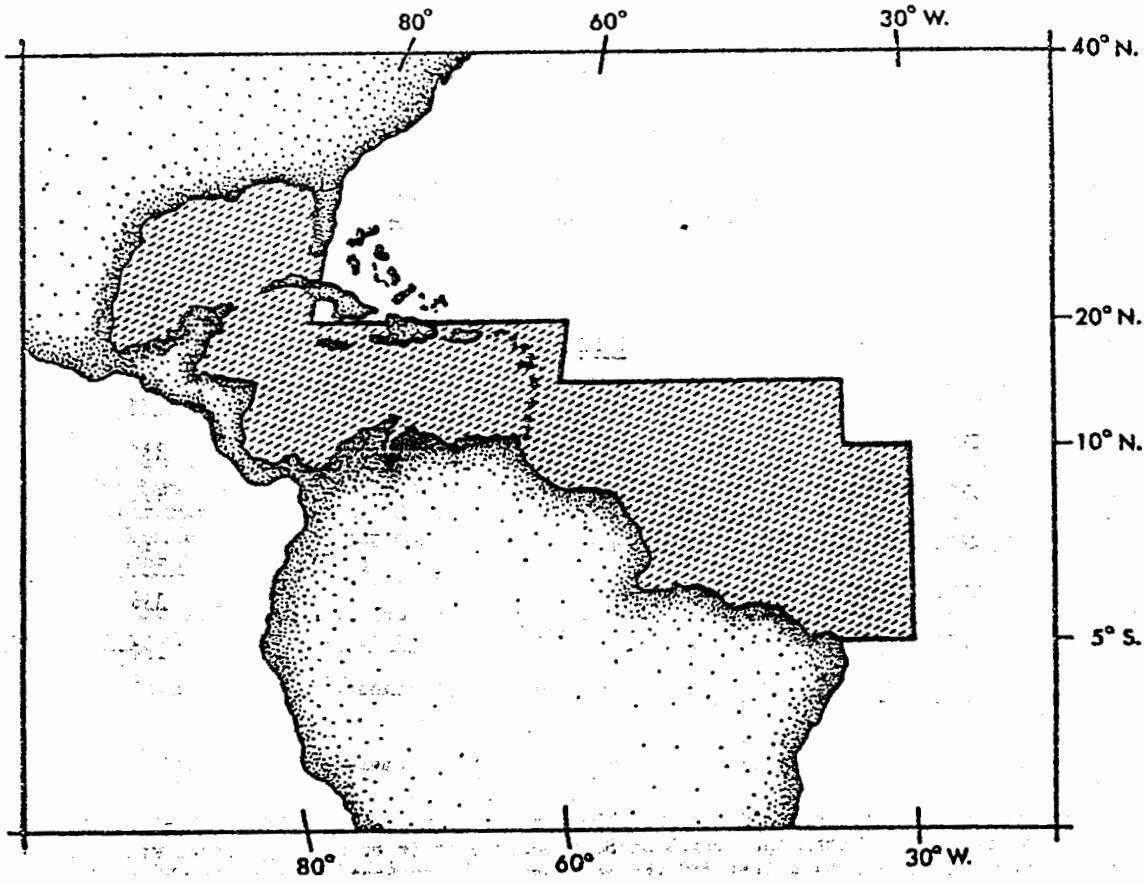


Figure 61.--The fishing ground for tuna and tuna-like fishes in the Caribbean region (shaded area) (Wise and Jones 1971).

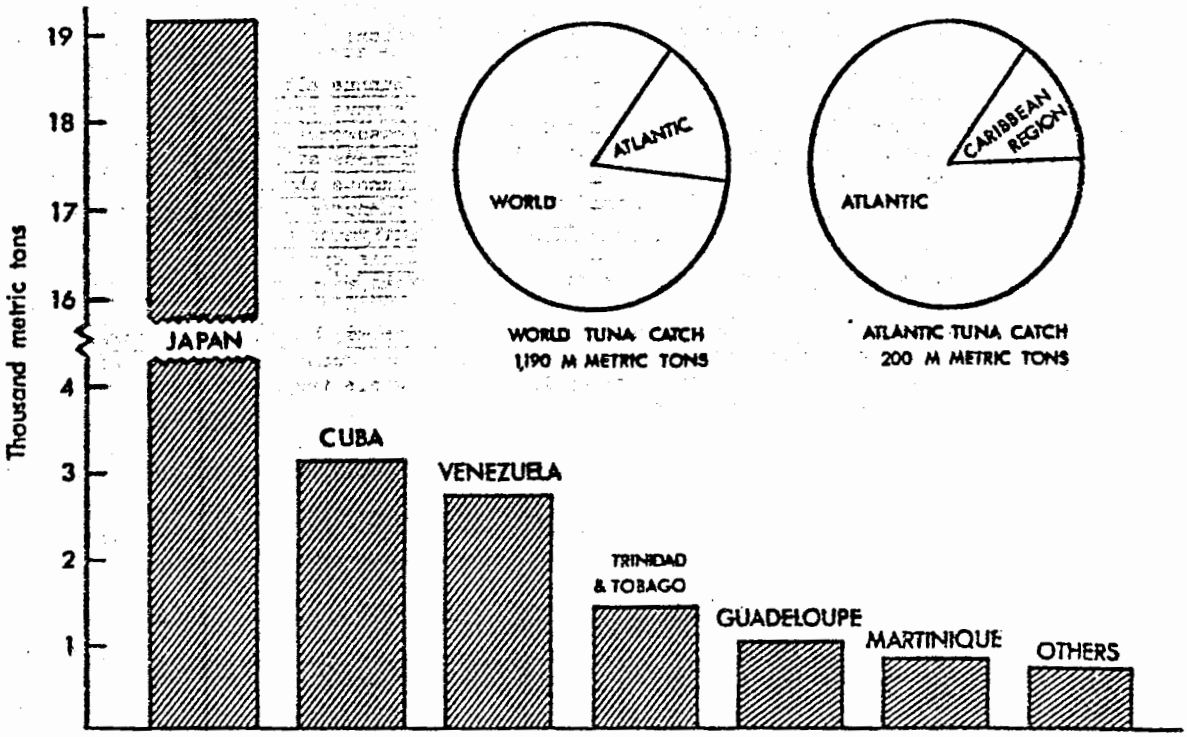


Figure 62.--Catches of tuna and tuna-like fishes in the Caribbean region, by countries (Wise and Jones 1971).

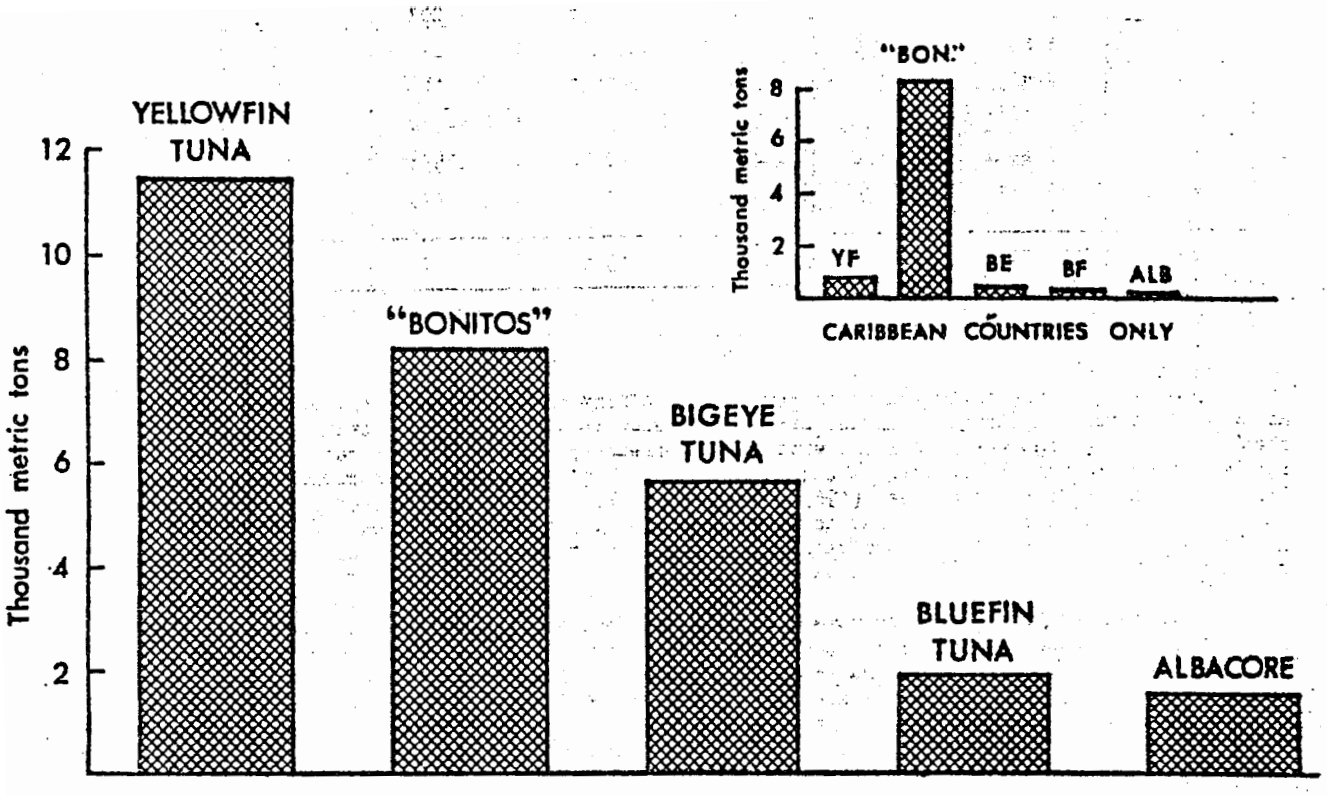


Figure 63.--Catches of tuna and tuna-like fishes in the Caribbean region, by species (Wise and Jones 1971).

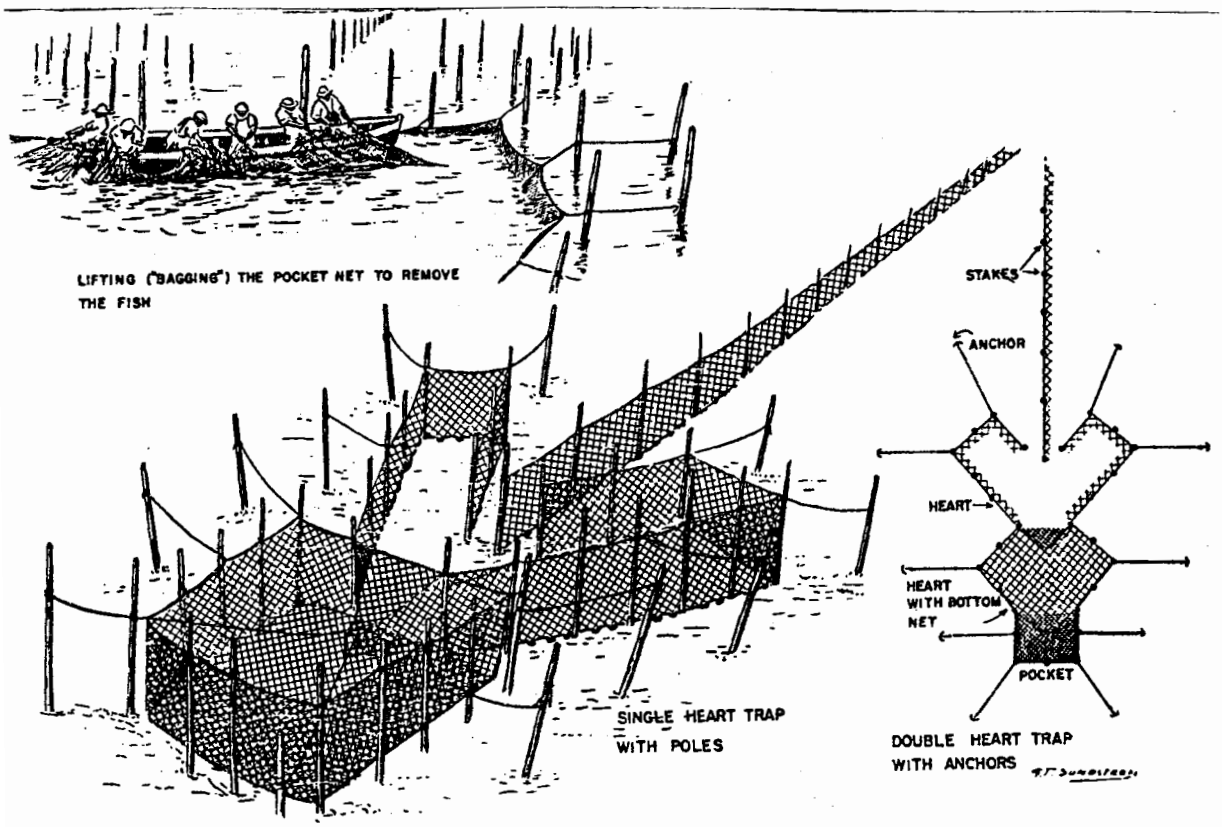


Figure 64.--Detailed sketch of a pound net used along the Atlantic coast of the United States (Sundstrom 1957).

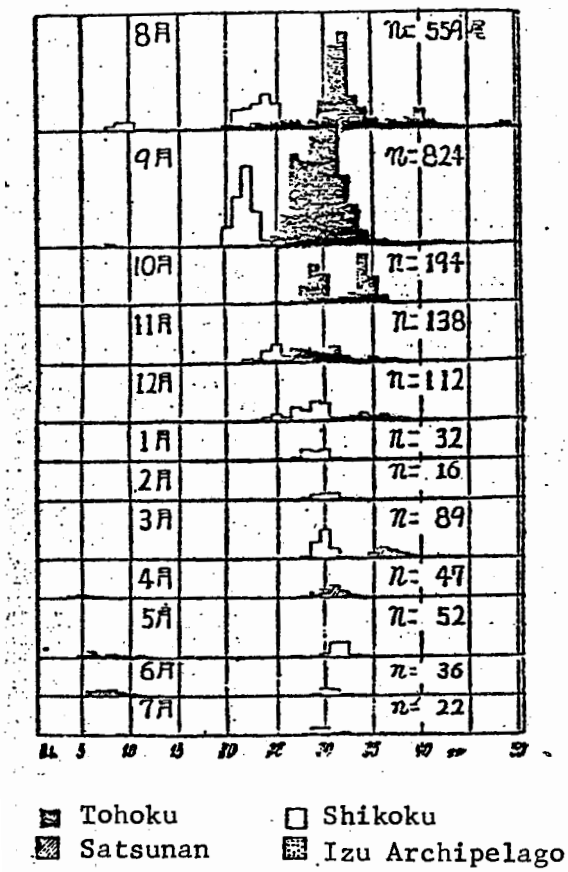


Figure 65.--Length-frequency distribution of A. rochei caught in various sea regions around Japan (Hotta 1955).

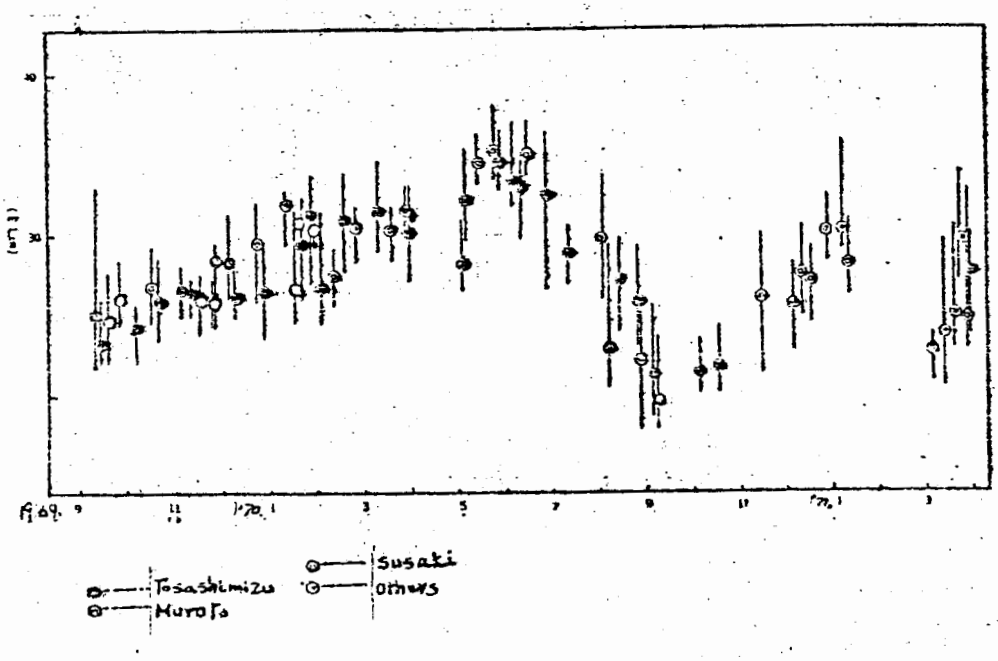


Figure 66.--Mean and range of body lengths, by months, of A. rochei caught at various localities off Kochi Prefecture, Japan (Morita 1972).

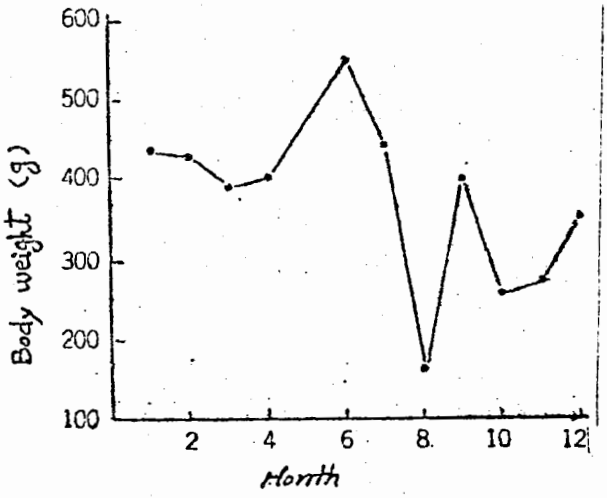


Figure 67.--Monthly average weights of frigate mackerel caught in the pole-and-line fishery off Ashizurimisaki, Kochi Prefecture, Japan (Ishida 1972a).

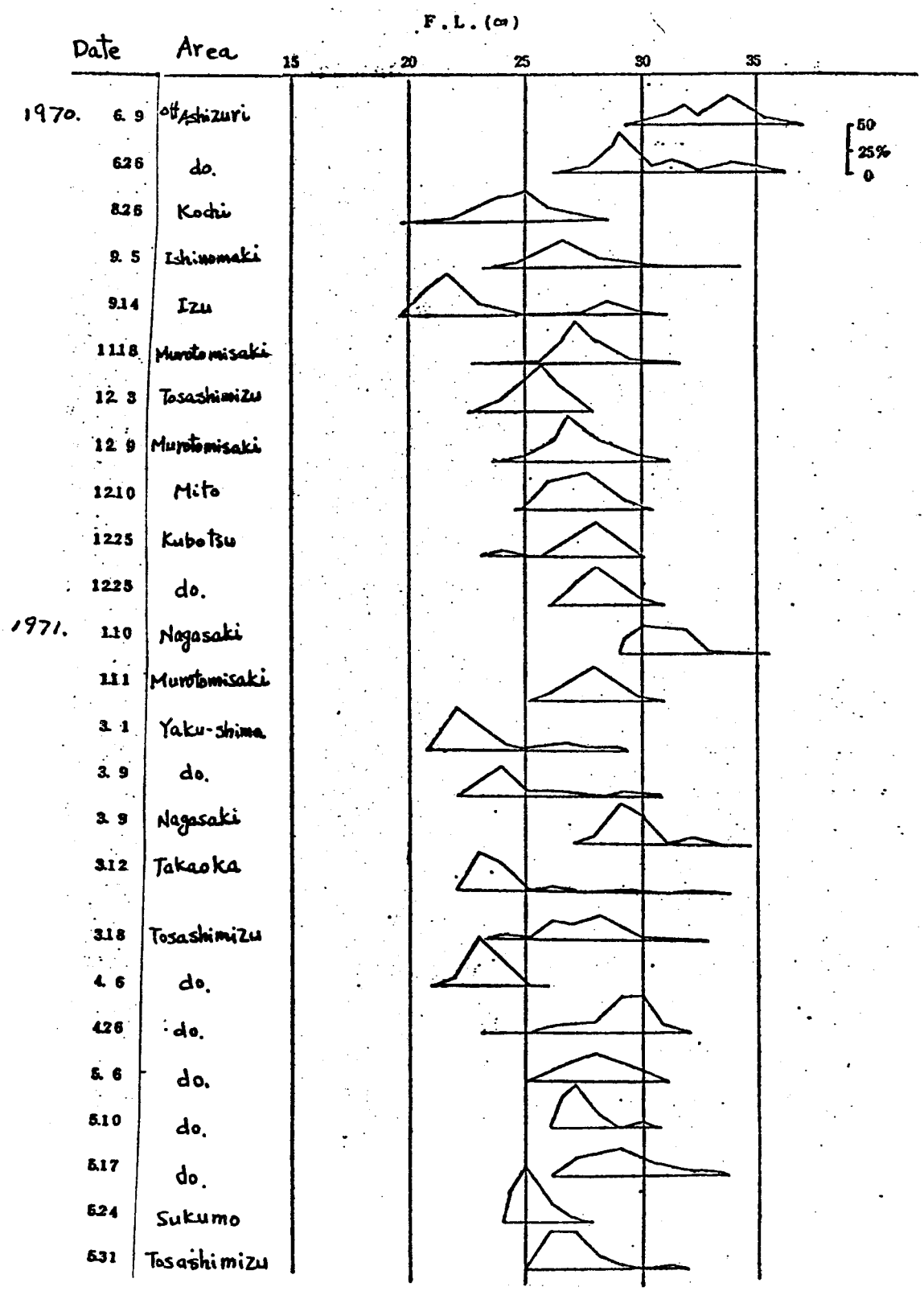


Figure 68.--Percentage frequency distribution of lengths of A. rochei, by date and area of capture, Japan (Hamada et al., 1973b).

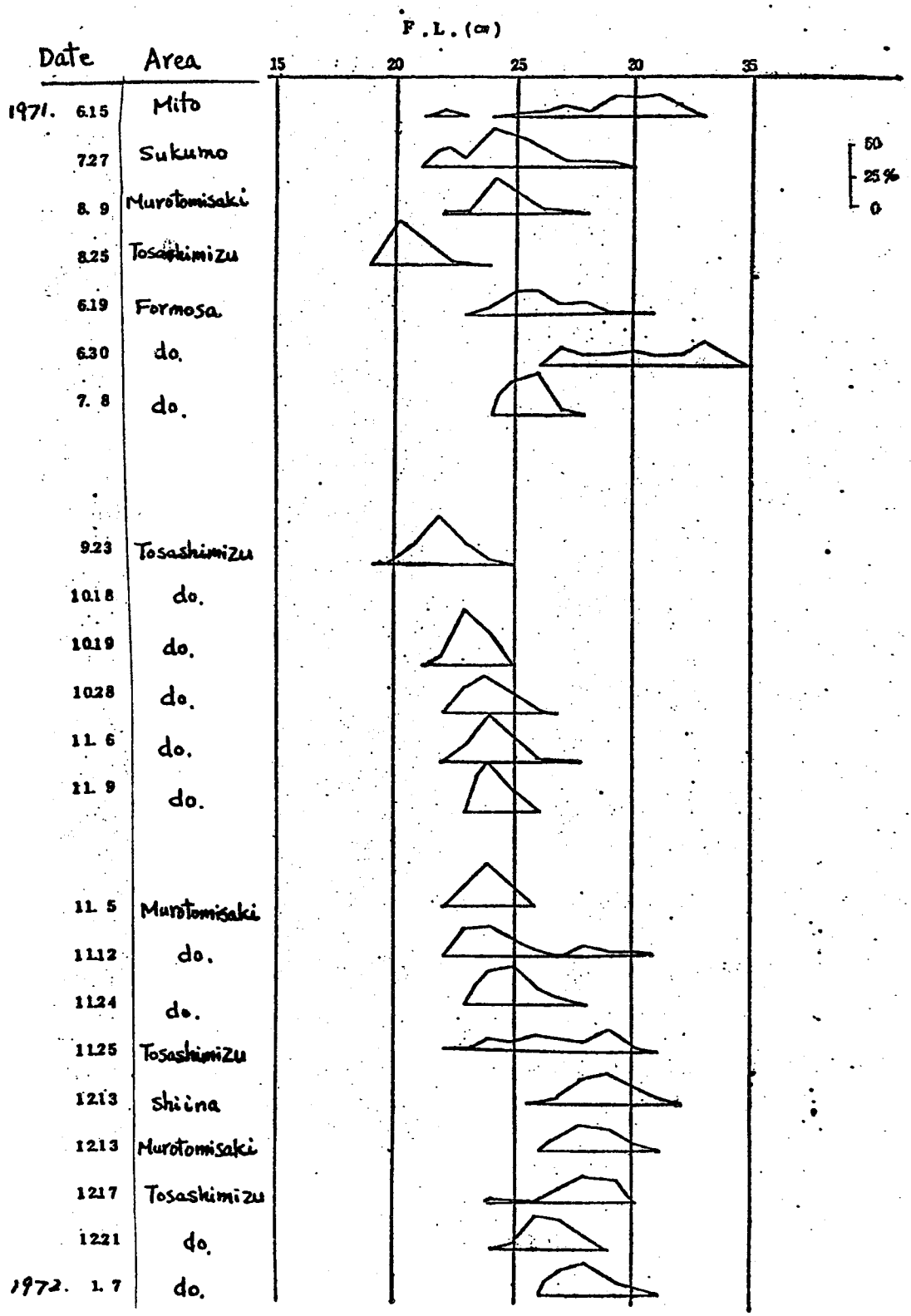


Figure 68.--Continued.

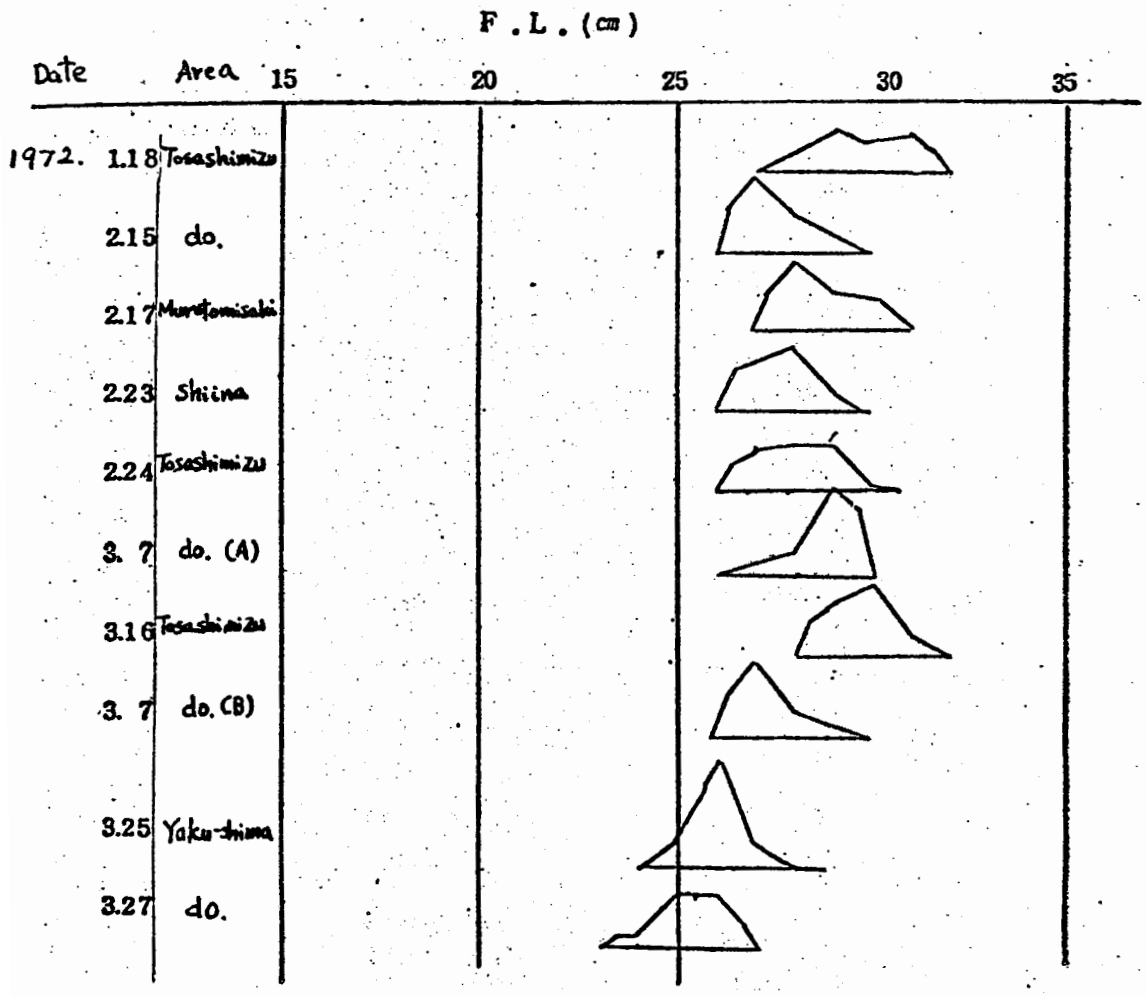


Figure 68.--Continued.

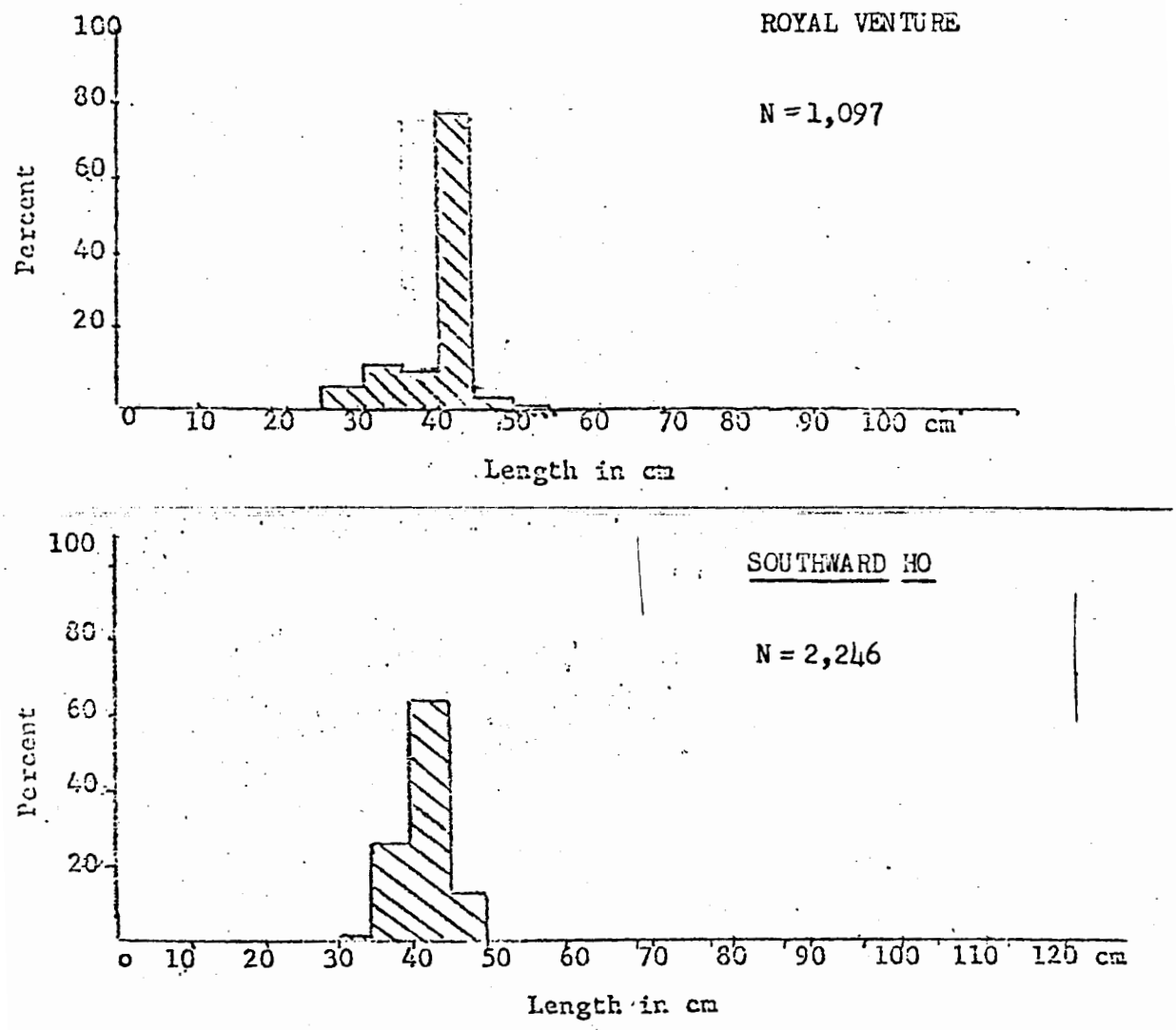


Figure 69.--Length-frequency distribution of frigate mackerel caught by the Royal Venture and Southward Ho on Trip 4, April-May 1975 (Rosenberg, Simpson and Renwick 1975).

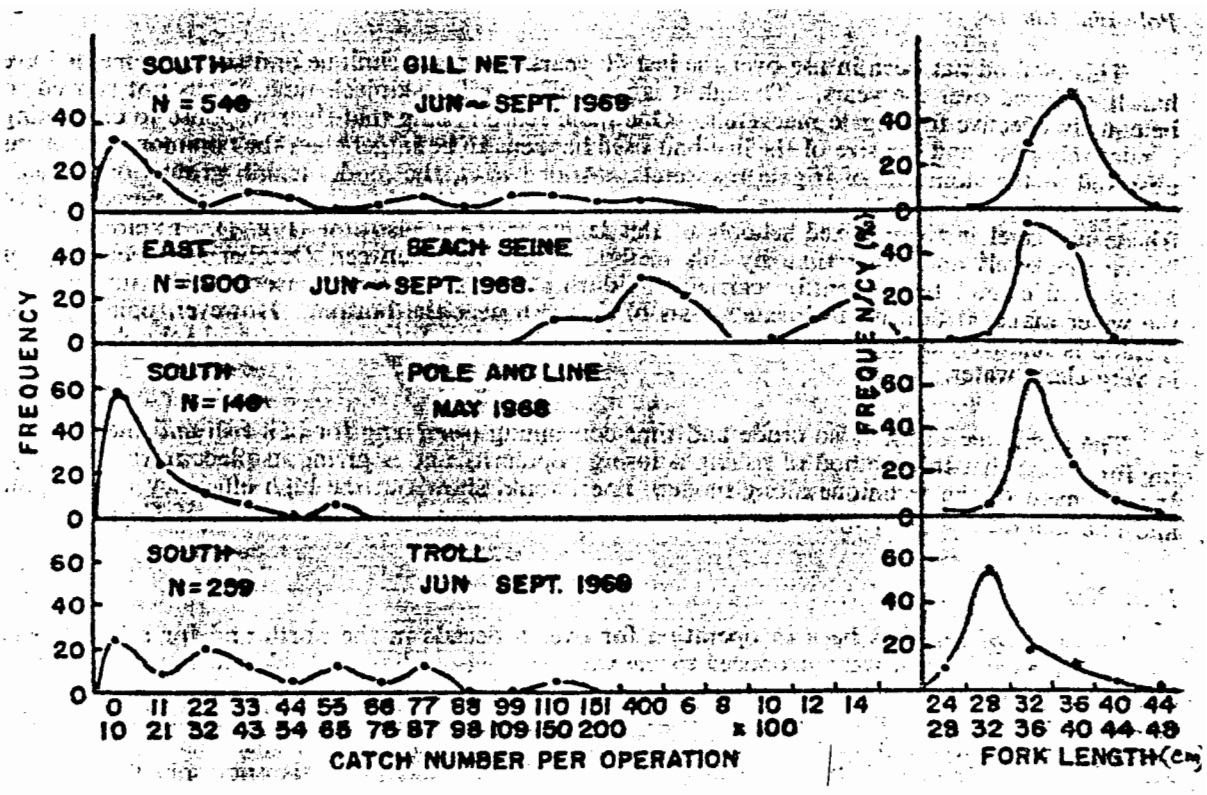


Figure 70.--Catch and length frequencies of A. thazard caught off Sri Lanka, by type of gear (Sivasubramaniam 1968).

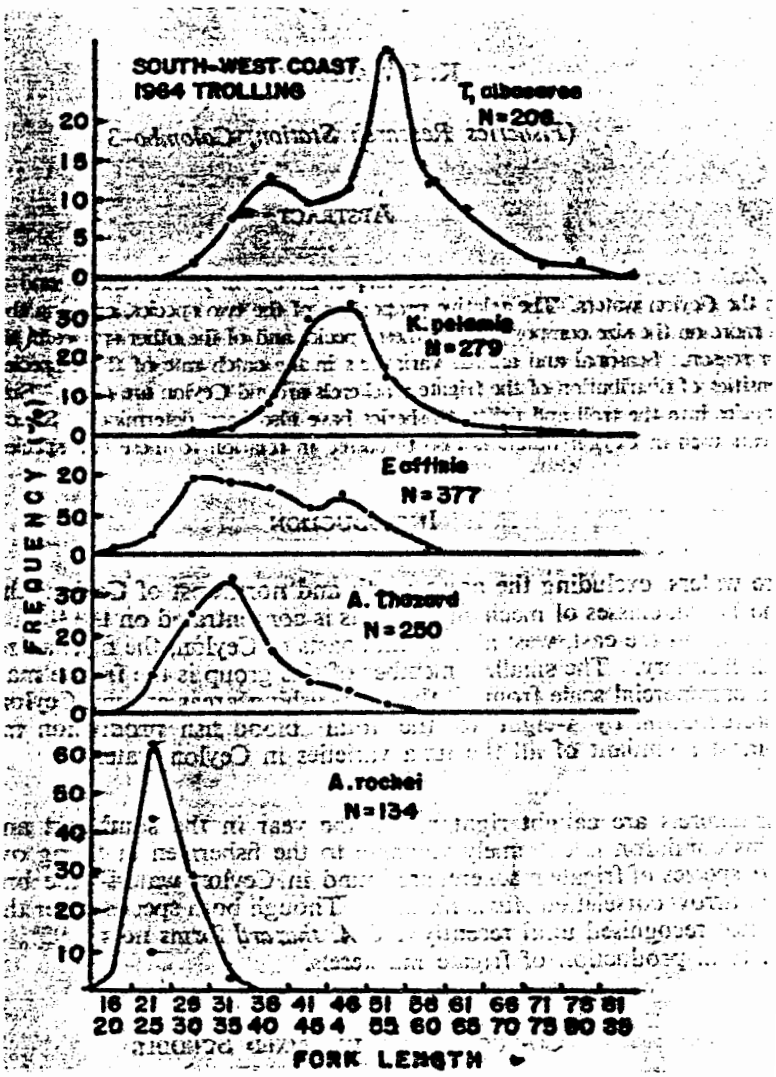


Figure 71.--Length-frequency distributions of tunas caught by trolling gear off the south-west coast of Sri Lanka (Sivasubramaniam 1968).

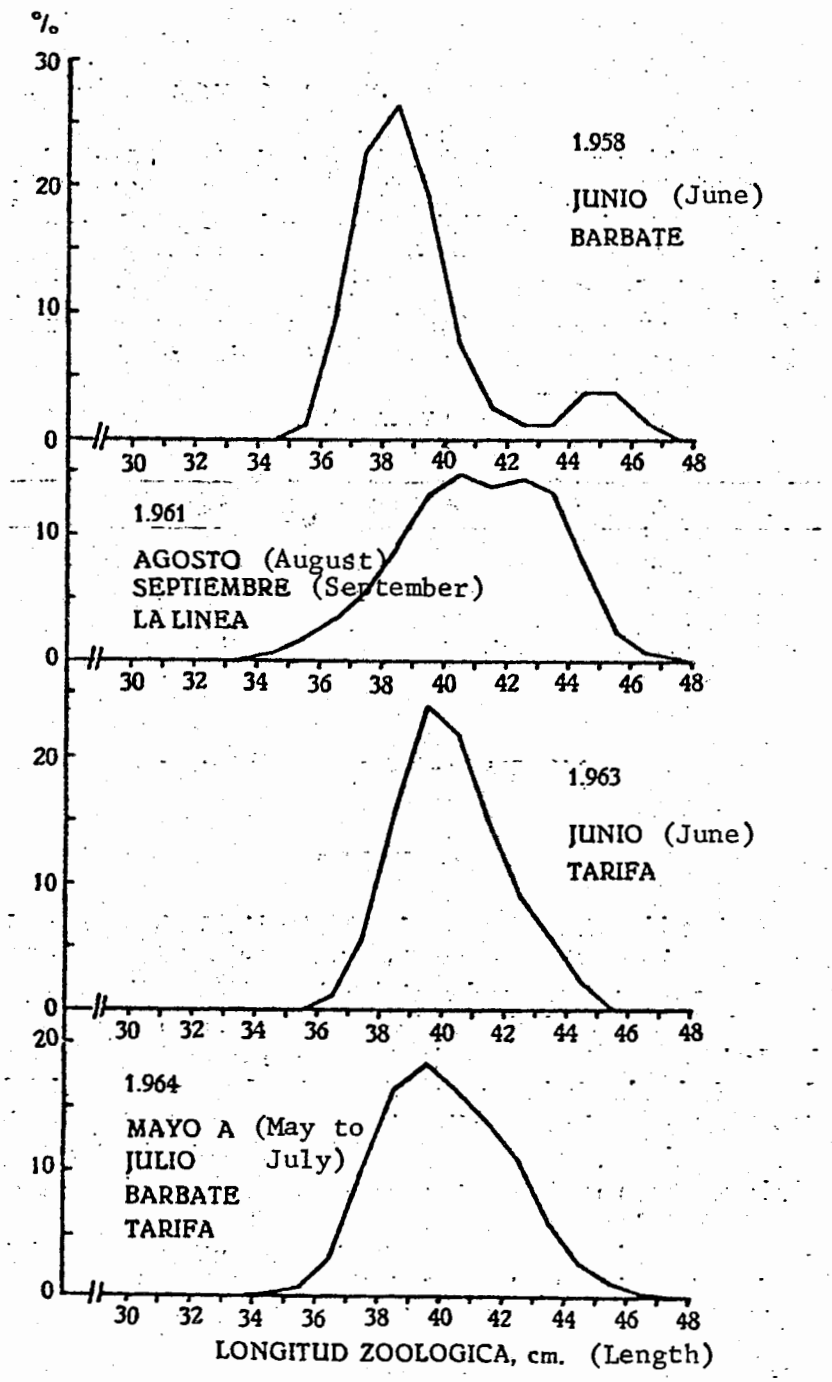


Figure 72.--Length-frequency distributions of A. thazard caught by traps at Barbate, Tarifa, and La Linea, by month and year (Rodriguez-Roda 1966).

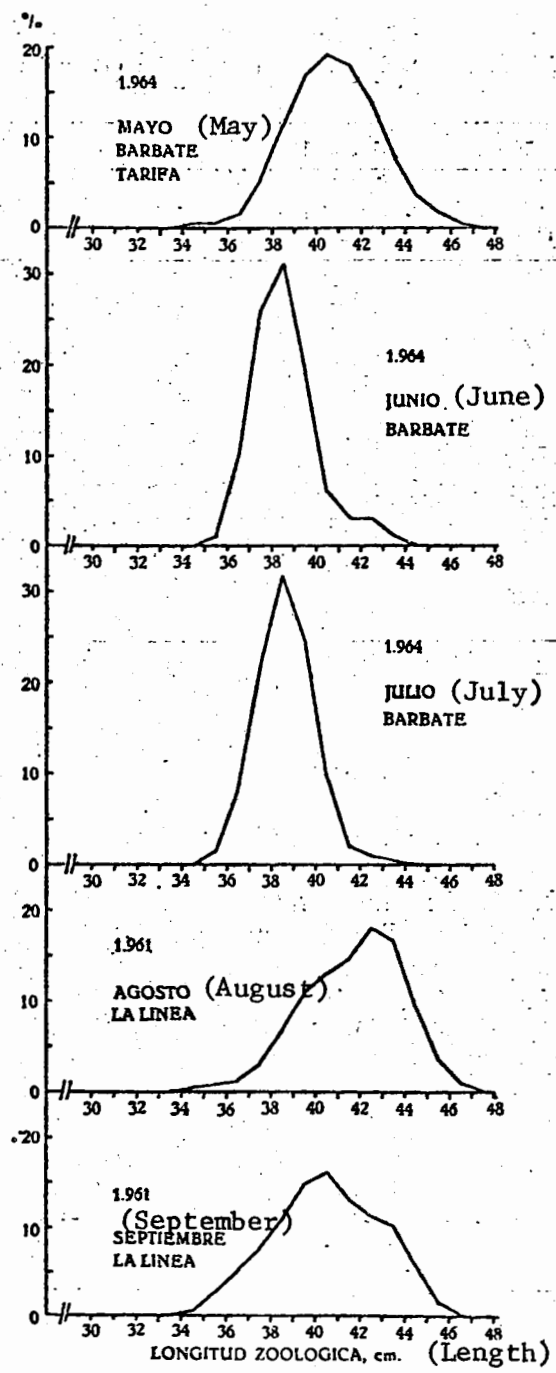


Figure 73.--Length-frequency distributions of A. thazard caught by traps at Barbate, Tarifa, and La Linea, in May-July 1964 and August-September 1961 (Rodriguez-Roda 1966).

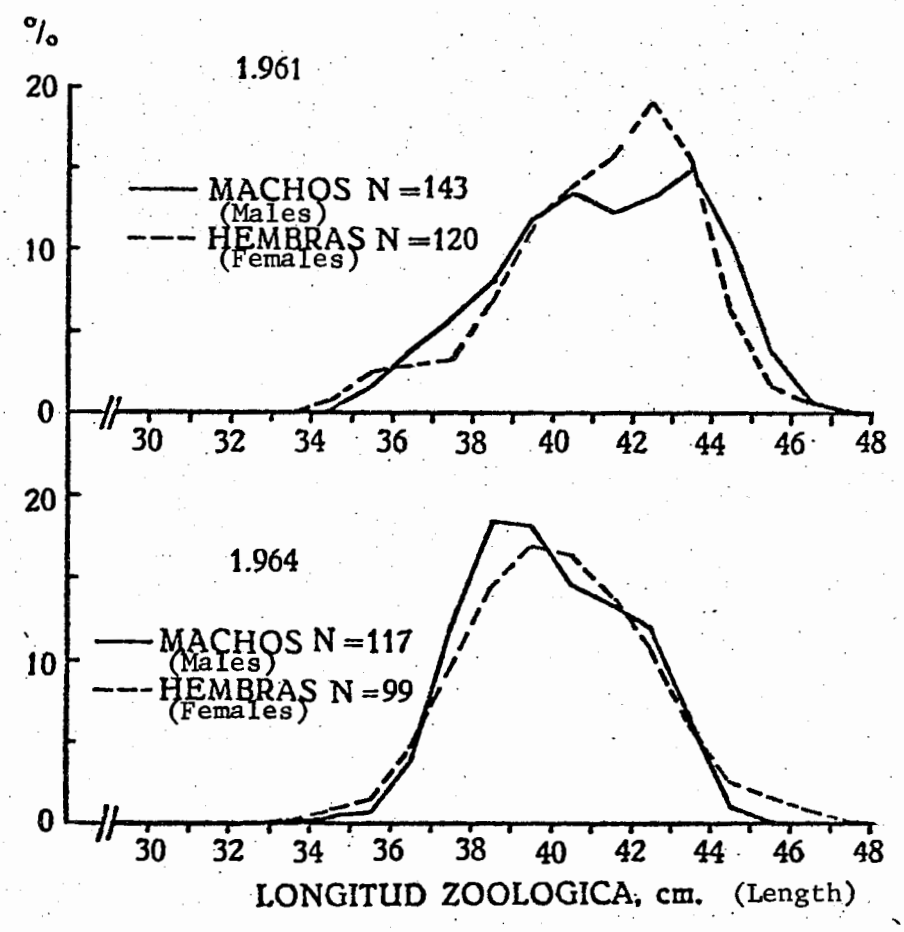
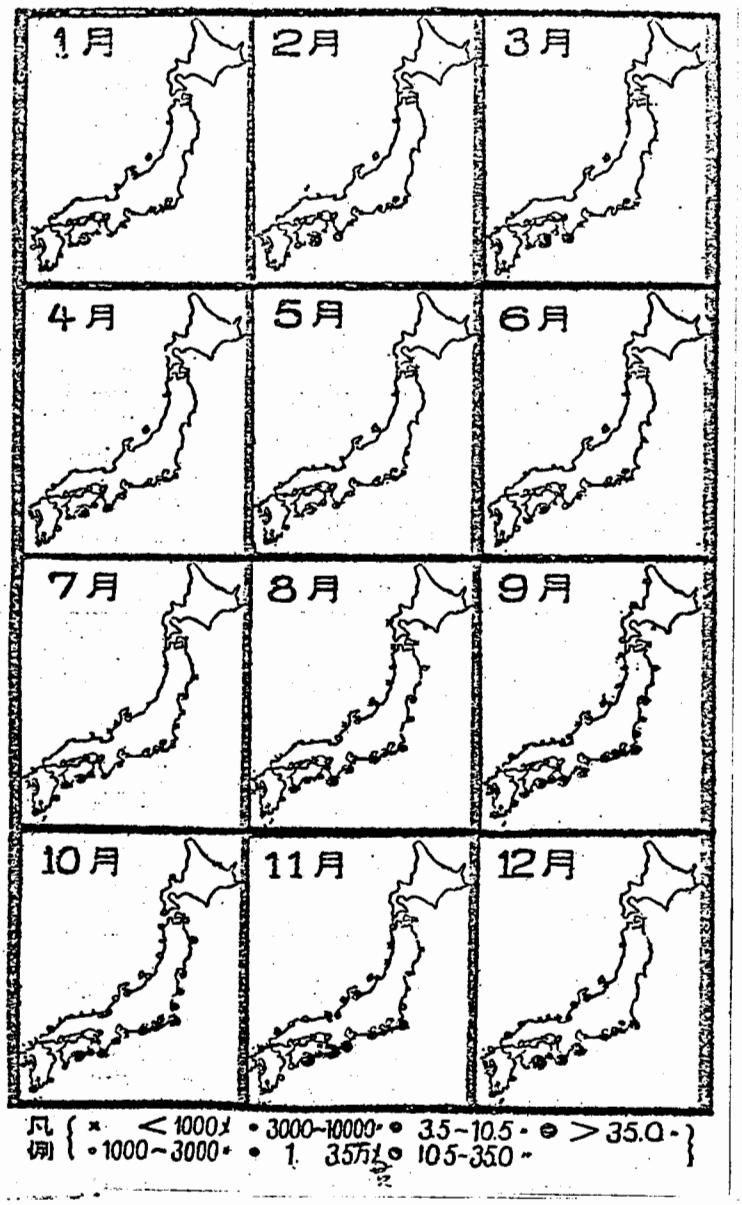


Figure 74.--Length-frequency distribution of male and female A. thazard caught by traps at Barbate, Tarifa, and La Linea in 1961 and 1964 (Rodriguez-Roda 1966).



Legend:	Kan (8.27 lb)	MT
×	1,000	3.75
∘	1,000-3,000	3.75-11.25
•	3,000-10,000	11.25-37.51
•	10,000-35,000	37.51-131.29
•	35,000-105,000	131.29-393.88
•	105,000-350,000	393.88-1,312.94
•	350,000	1,312.95

Figure 75.--Landings of frigate mackerel off Japan, by month (Hotta 1955).

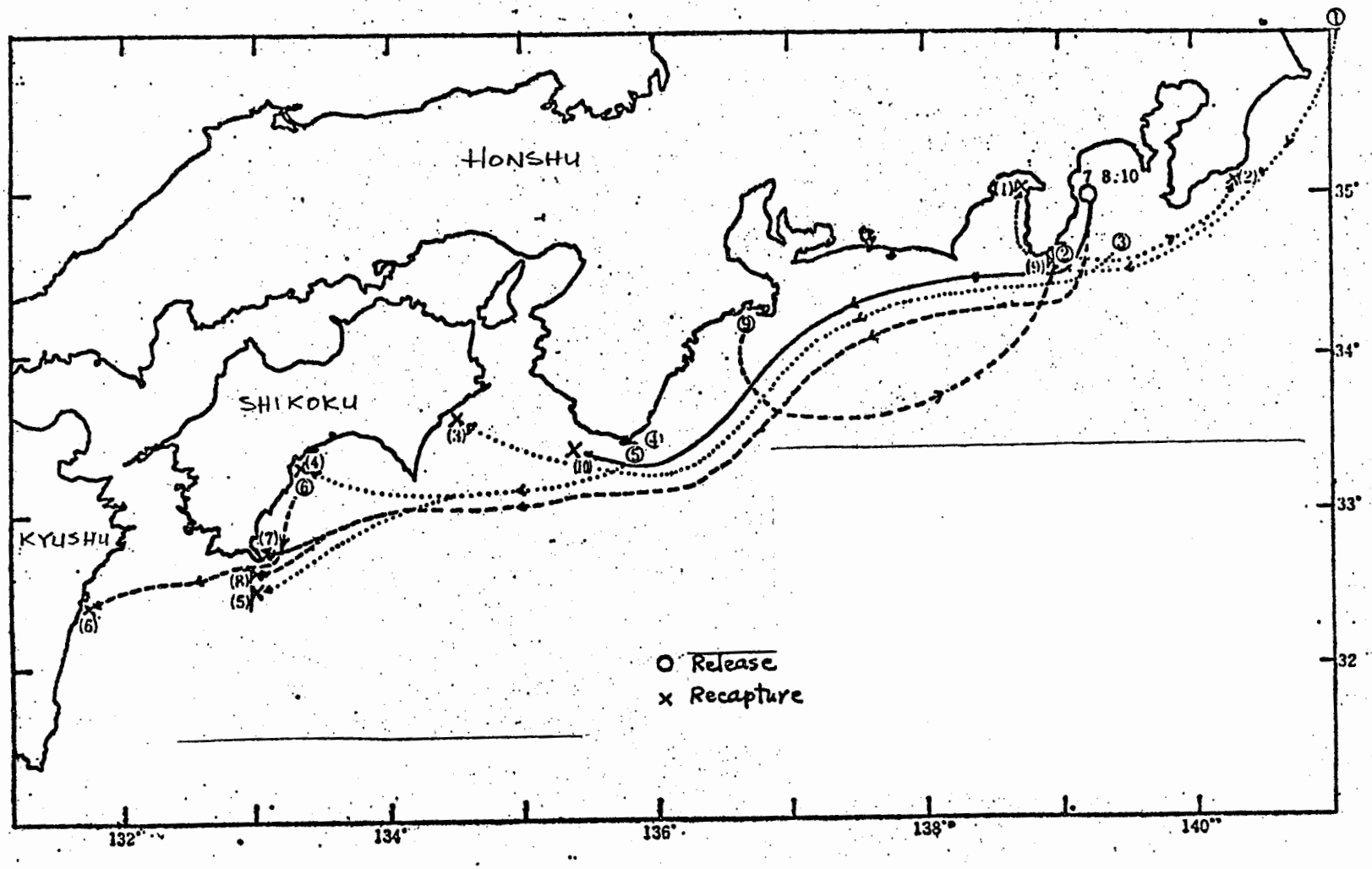


Figure 76.--Long-distance movement of A. rochei tagged in 1965, 1970, and 1972 (Yamashige 1974).

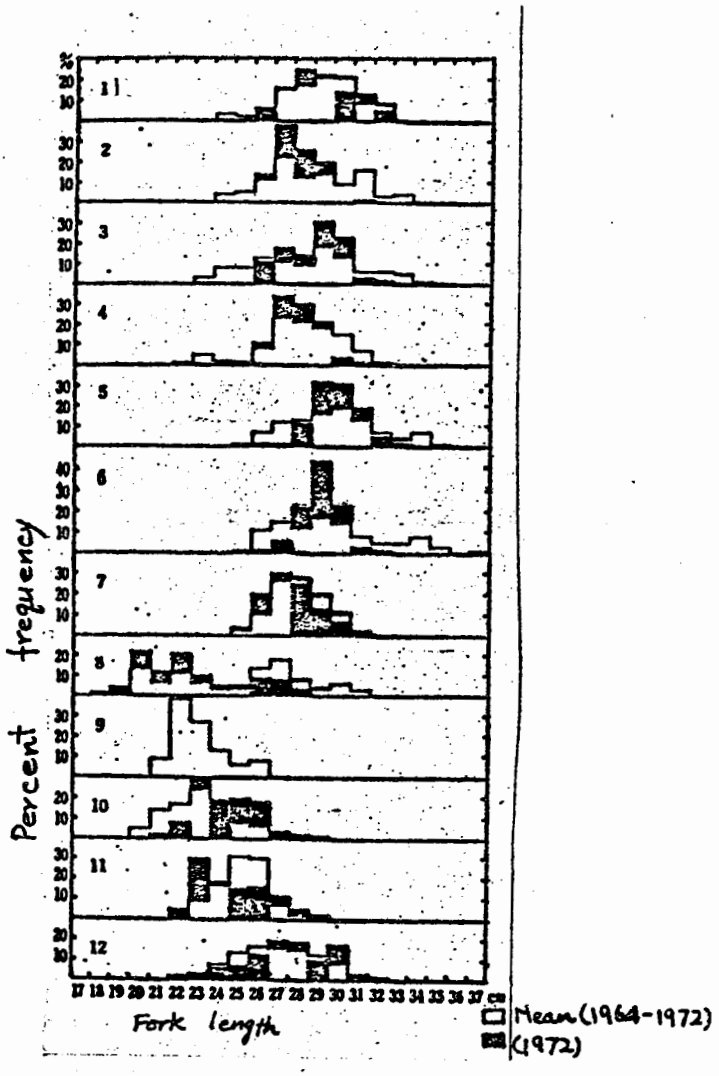


Figure 77.--Percentage length-frequency distributions, by month, of frigate mackerel taken in Japanese waters, 1964-72 (Yamashige 1974).

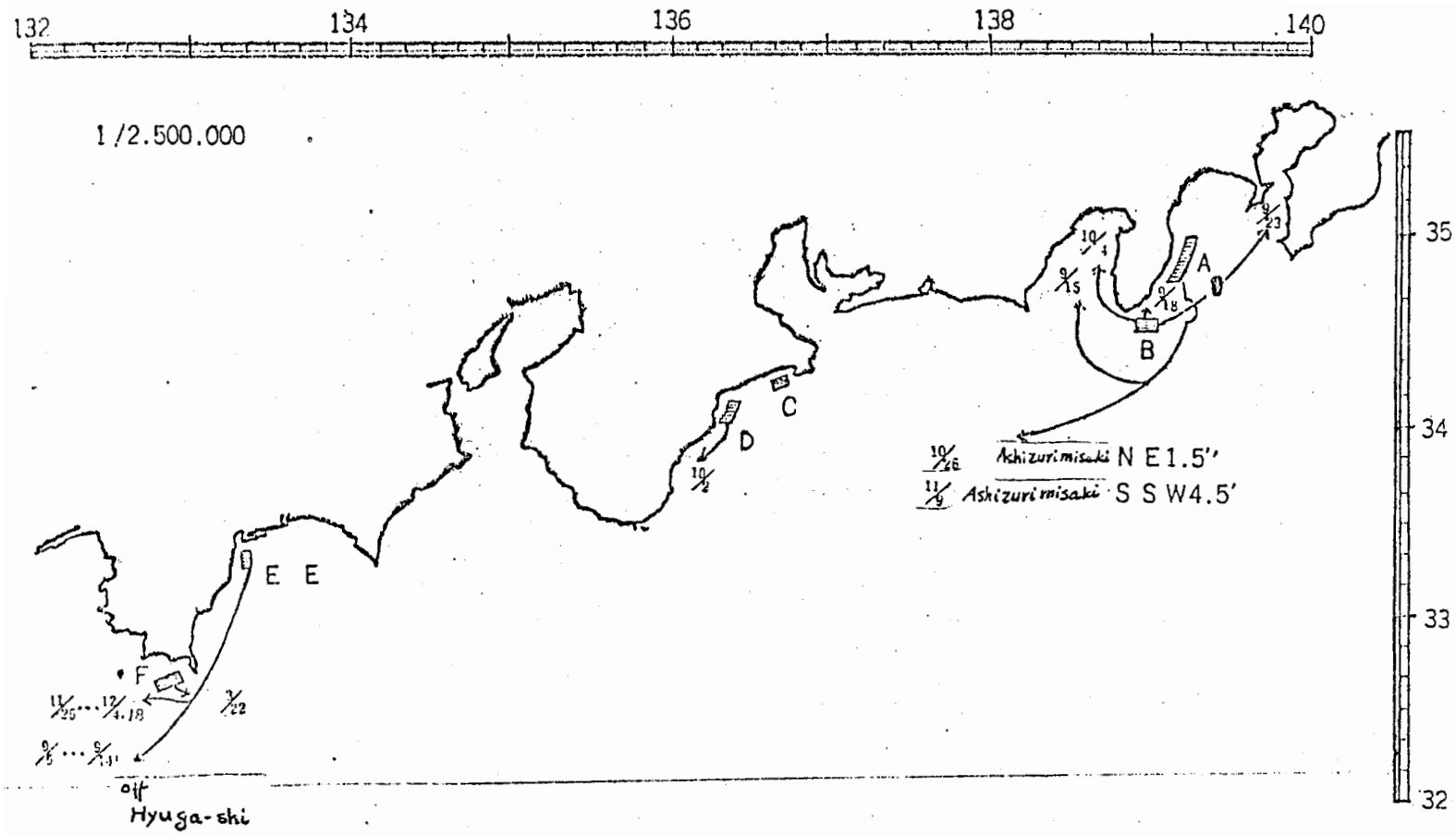


Figure 78.--Movement of A. rochei tagged in Japanese waters (Morita 1972).

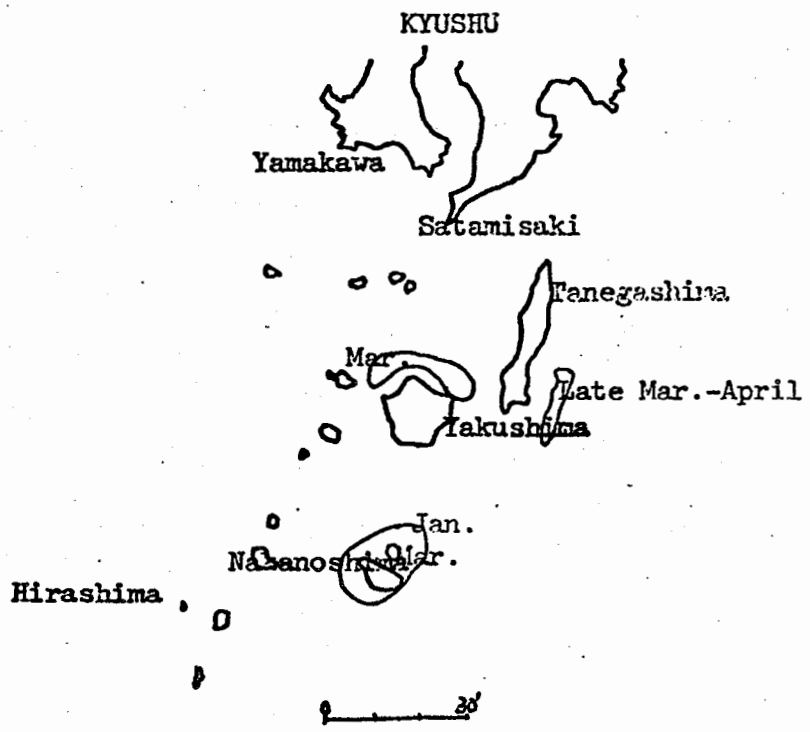


Figure 79.--Movement of A. rochei tagged off Yakushima in 1971 (Hamada, Ishida, Morita, Takezawa, Okabayashi and Ishii 1973).

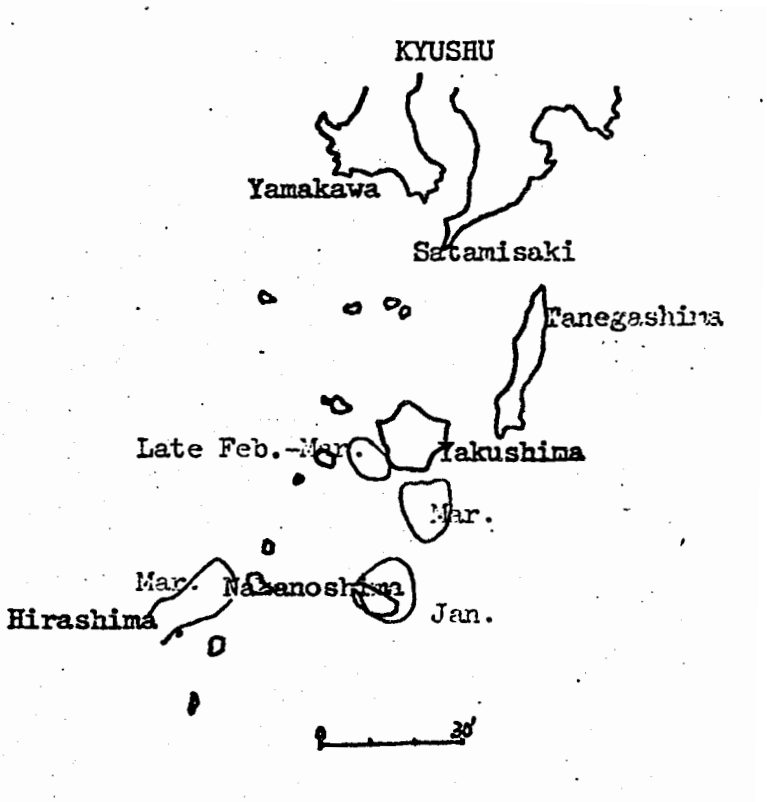


Figure 80.--Movement of A. rochei tagged off Yakushima in 1972 (Hamada, Ishida, Morita, Takezawa, Okabayashi and Ishii 1973).

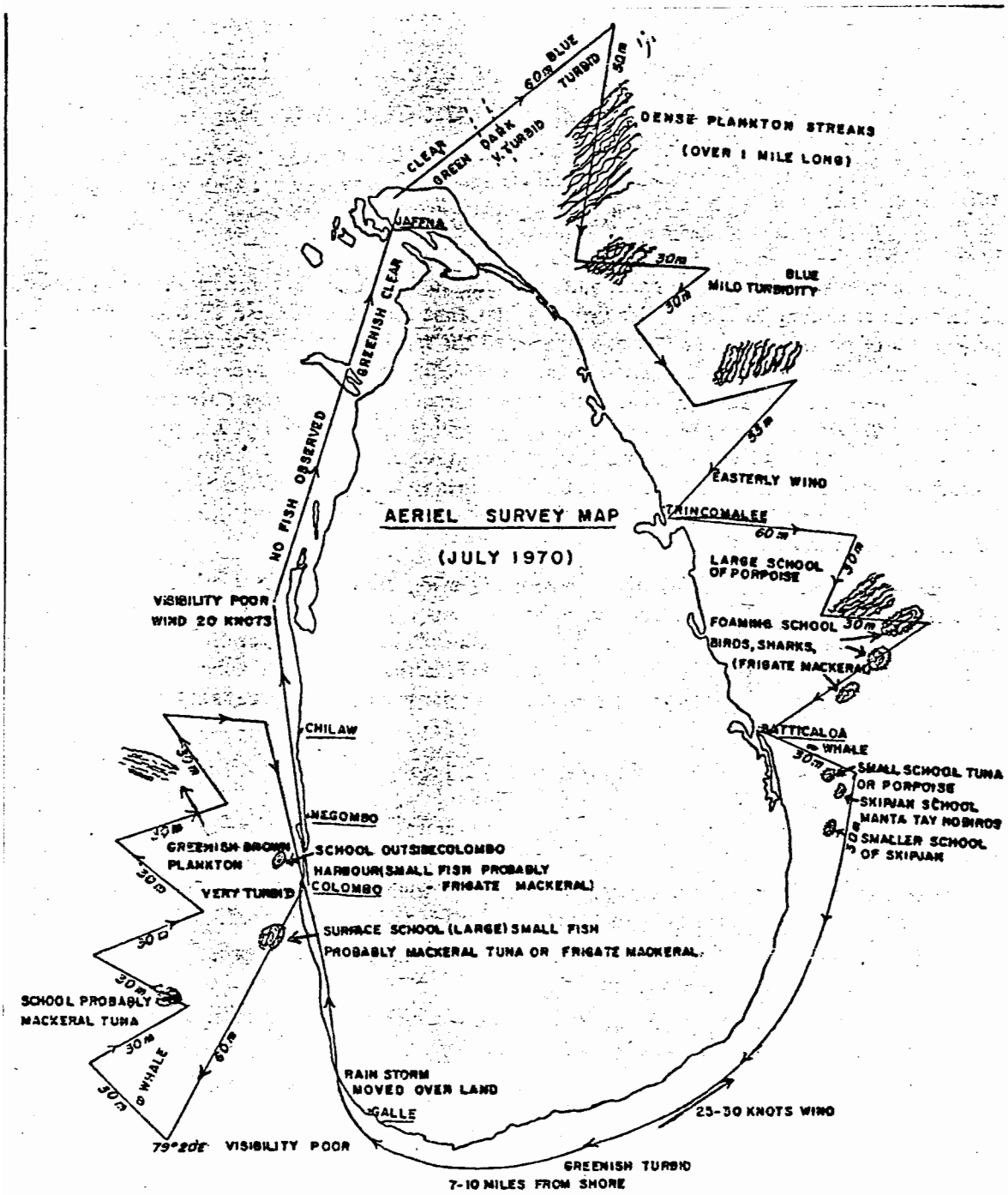


Figure 81.--Flight plan and positions of fish schools sighted during the aerial survey of the waters around Sri Lanka (Sivasubramaniam 1971).

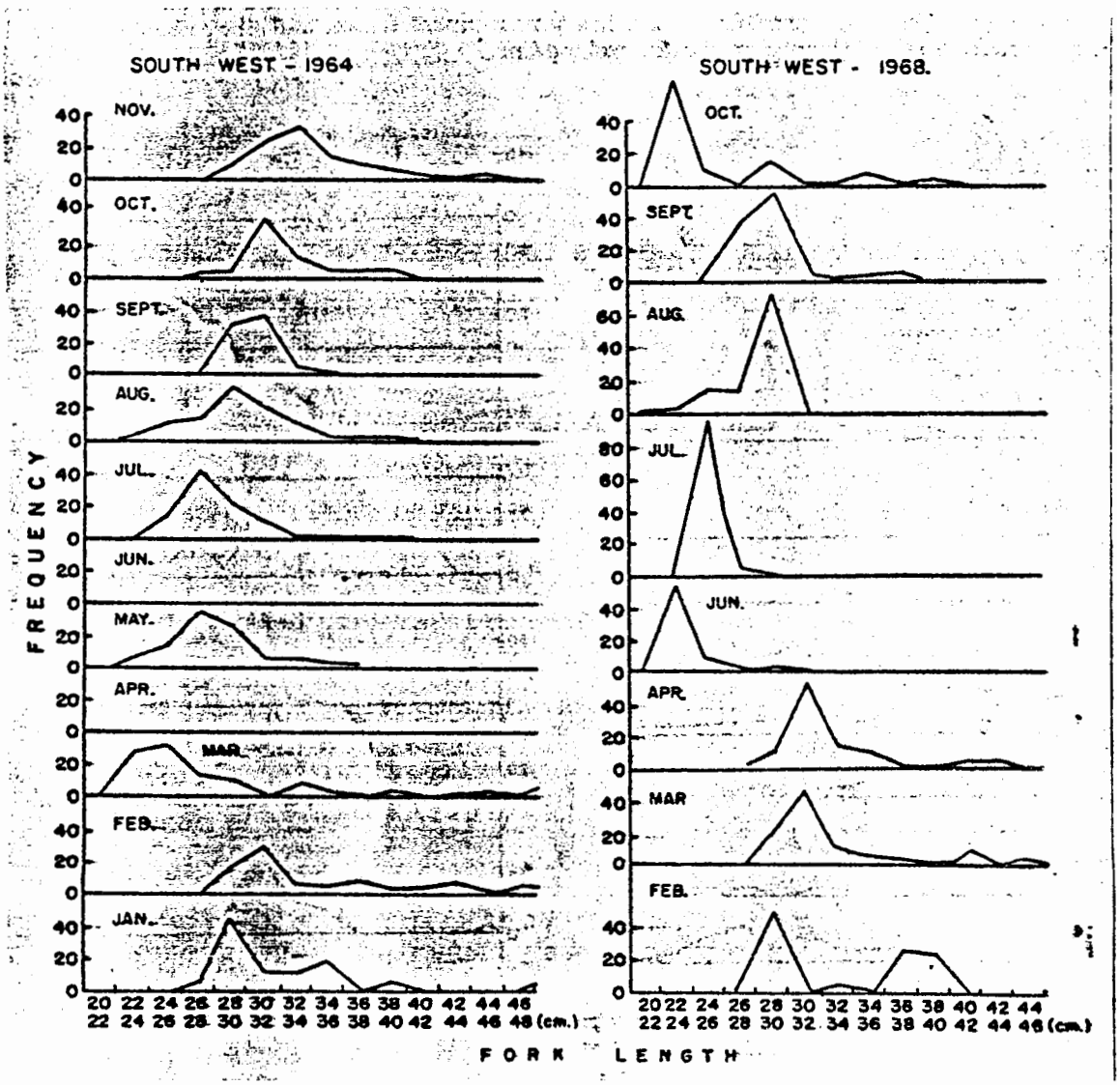


Figure 82.--Length-frequency distributions of A. thazard caught along the southwest coast of Sri Lanka, by months (Sivasubramaniam 1968).

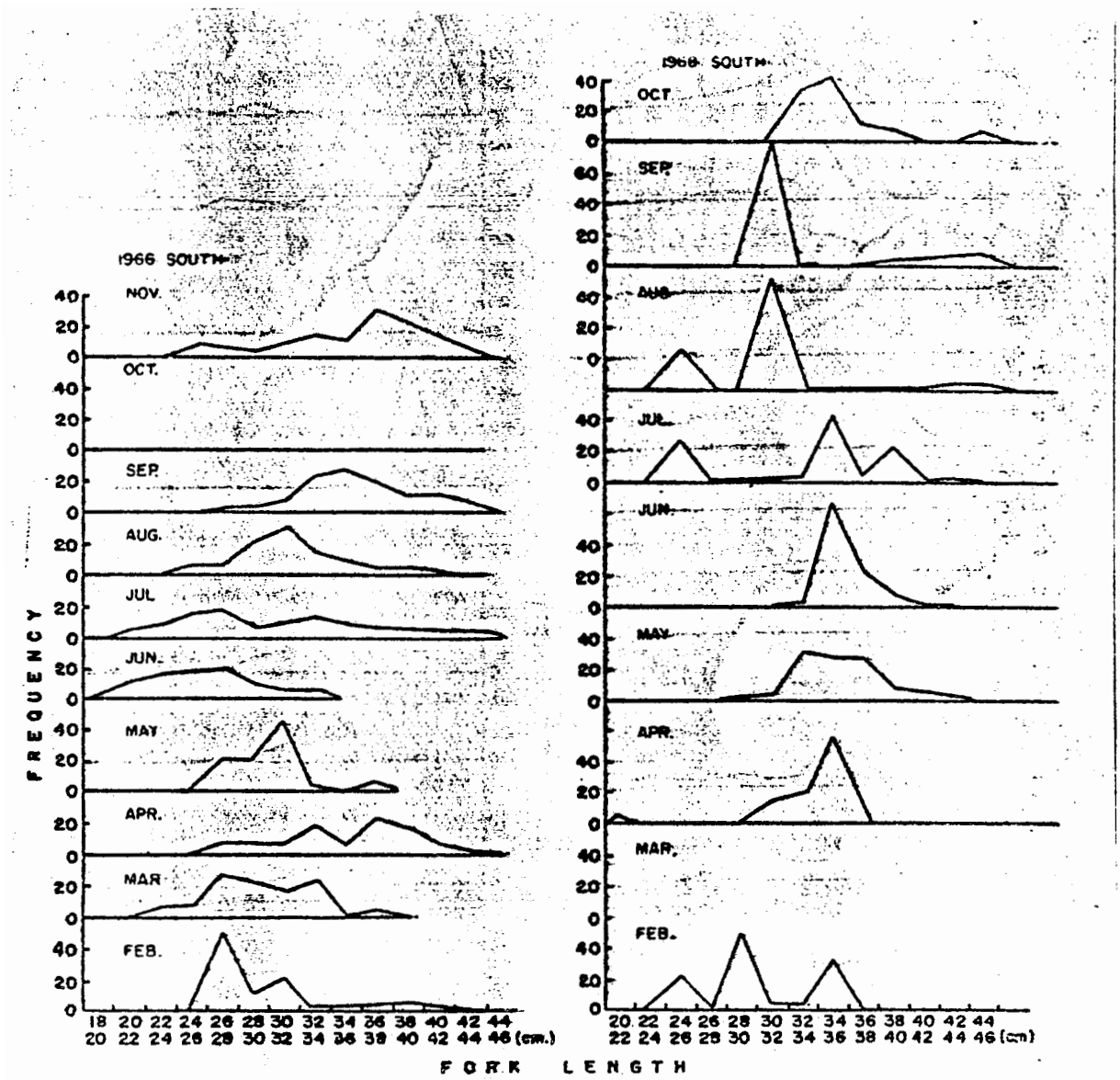


Figure 83.--Length frequency distributions of A. thazard caught along the south coast of Sri Lanka, by months (Sivasubramaniam 1968).

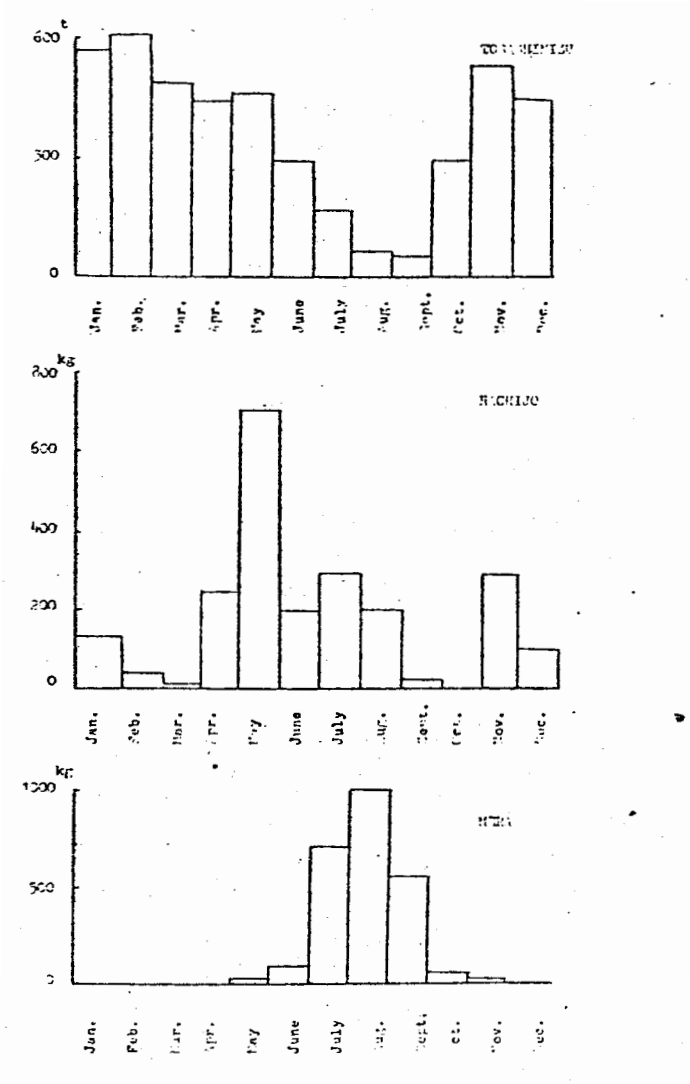


Figure 84.--Average landings of frigate mackerel, by months, at Tosa-Shimizu, Hachijo, and Mera, Japan (Yasui 1975).

	Jan.-Mar.	Sept.-Dec.
1954	O	×
55	O	
56	×	
57	×	
58		O
59	O	
60	×	×
61		×
62	O	O
63		O
64	×	
65		O
66		
67		
68	O	×
69		
70		
71	×	
72		×
73	×	×

O - Good fishing
X - Poor fishing

Figure 85.--Good and poor fishing conditions recorded at Tosa-Shimizu, Kochi Prefecture, Japan (Yasui 1975).

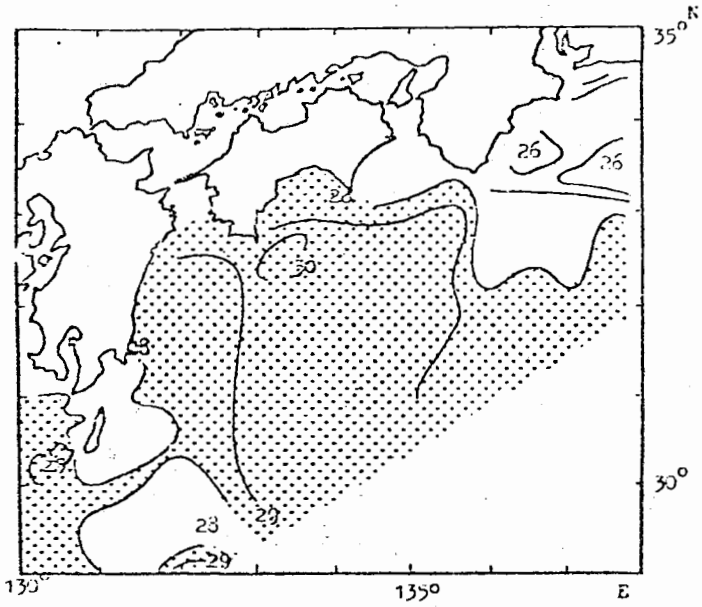


Figure 86.--Distribution of surface temperatures in July-September in a year of good fishing at Tosa-Shimizu, Kochi Prefecture, Japan (Yasui 1975).

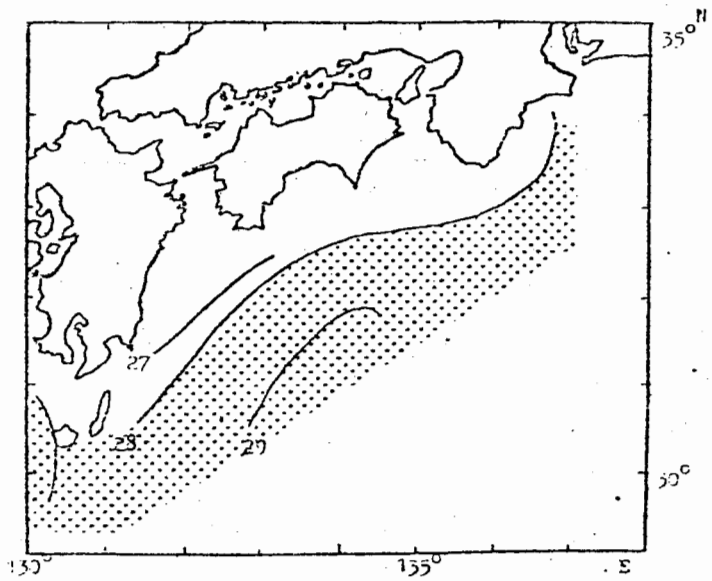


Figure 87.--Distribution of surface temperatures in July-September in a year of poor fishing at Tosa-Shimizu, Kochi Prefecture, Japan (Yasui 1975).

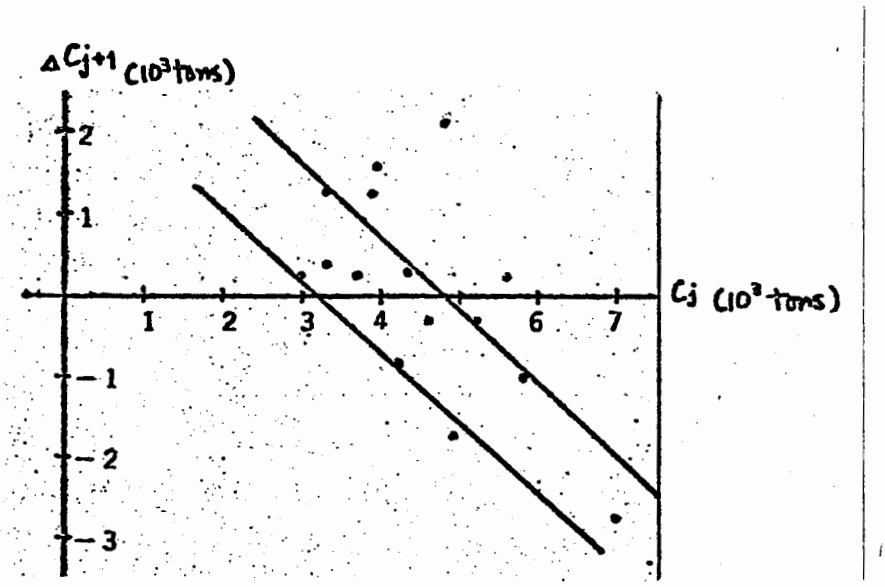


Figure 88.--The relationship of ΔC_{j+1} on Cj (Ishida 1972b).

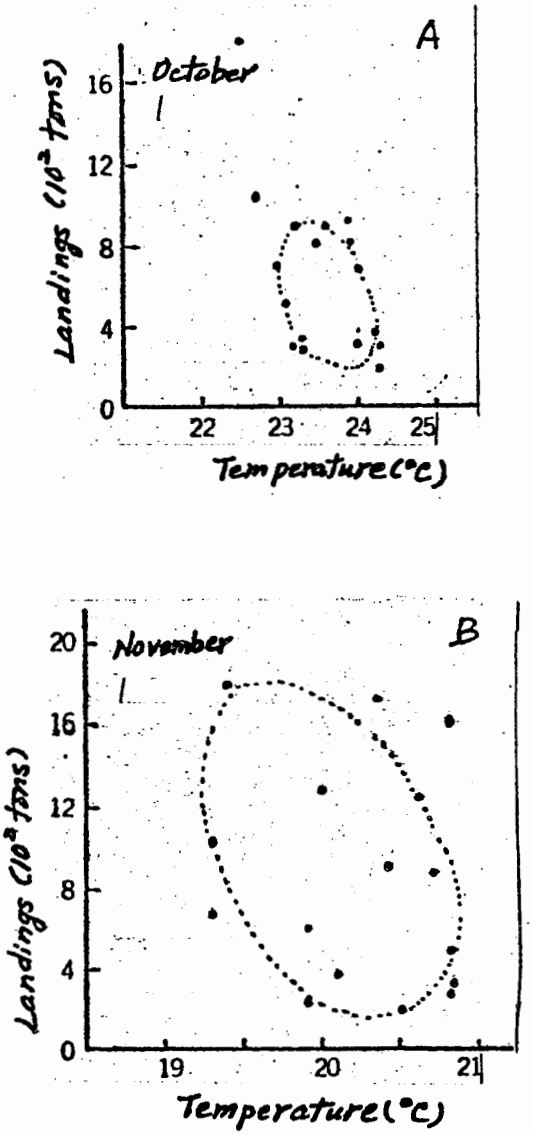
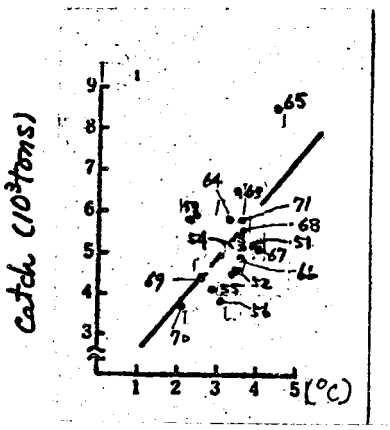


Figure 89.--The relationship between landings at Tosa-Shimizu and surface temperature at Susaki-wan in October and November (Ishida 1972b).



Temperature difference

Figure 90.--Relationship between the August-July catch at Ashizurimisaki and the difference in mean water temperature in August and October (Yamashige 1974).

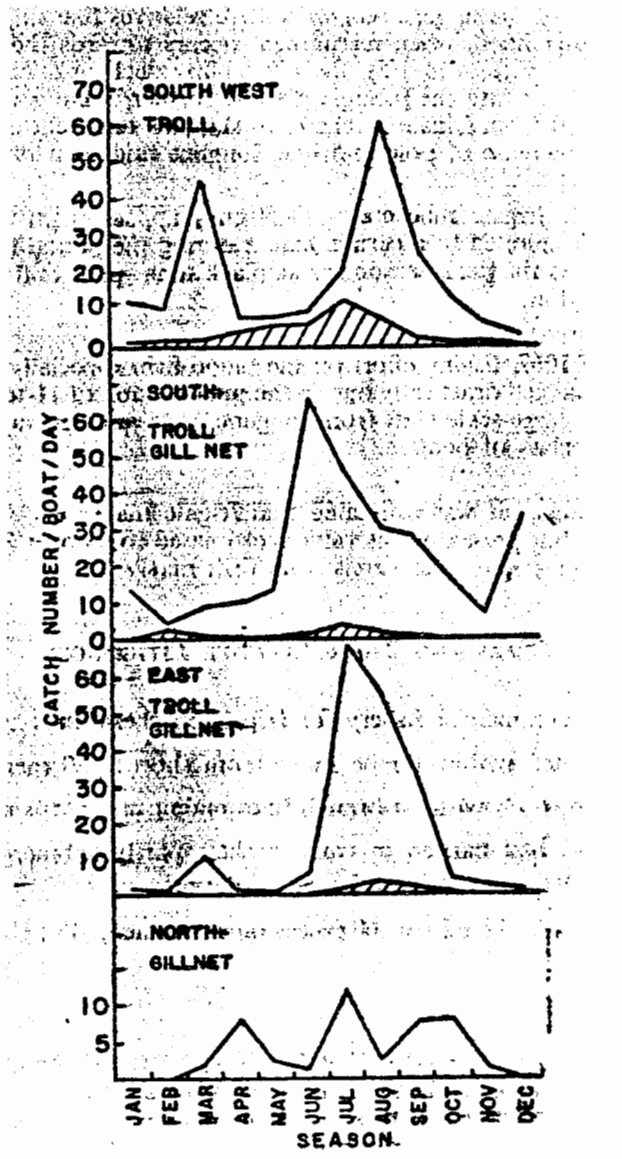


Figure 91.--Seasonal variations in the catch rates of A. thazard and A. rochei (shaded area) (Sivasubramaniam 1968).

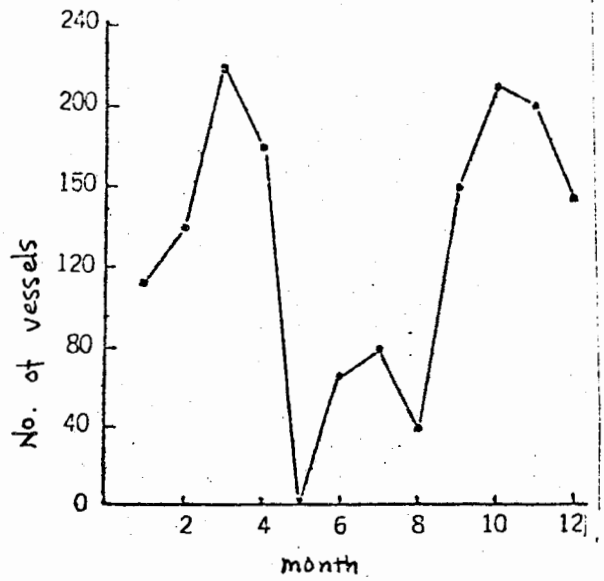


Figure 92.--Number of vessels operating per day in the frigate mackerel fishery off Ashizurimisaki, Japan, by month (Ishida 1972a).

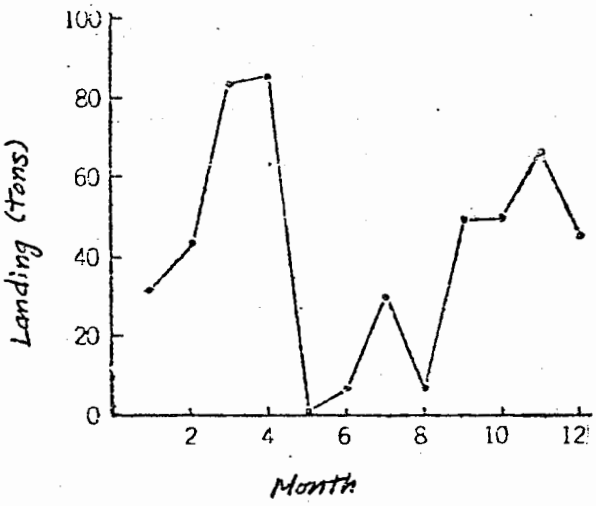


Figure 93.--Landings of frigate mackerel per day in the fishery off Ashizurimisaki, Japan, by month (Ishida 1972a).

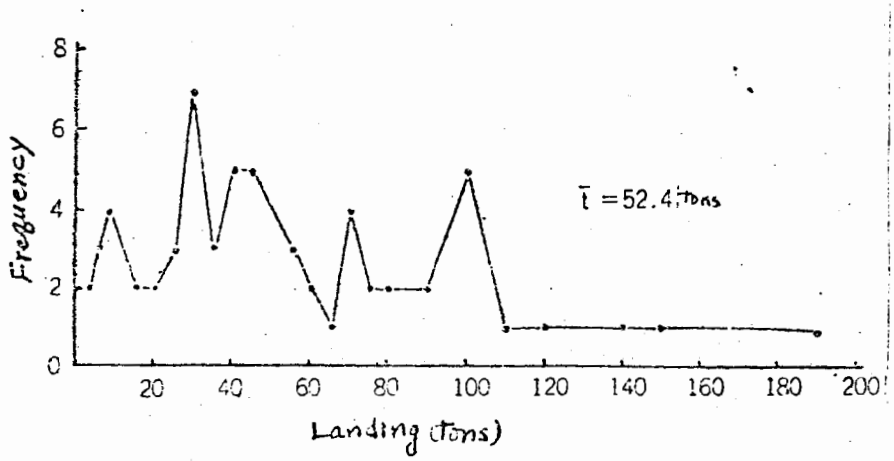


Figure 94.--Frequency distribution of the number of landings per day in the frigate mackerel fishery off Ashizurimisaki, Japan (Ishida 1972a).

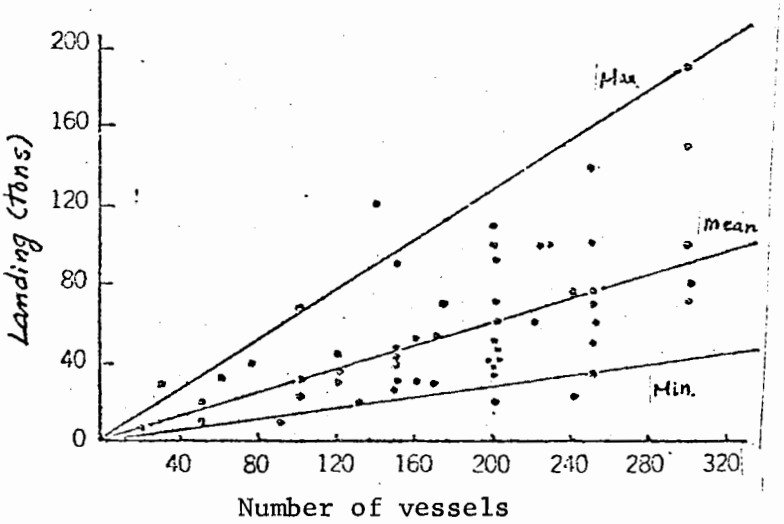


Figure 95.--Relationship between the number of vessels operating per day and landings per day in the frigate mackerel fishery off Ashizurimisaki, Japan (Ishida 1972a).

TEXT FOOTNOTES

2. Roedel, P. M., and J. R. Fitch. Taxonomy and nomenclature of the Pacific tunas. Manuscript presented for discussion at the Pacific Tuna Biology Conference, Honolulu, Hawaii, August 1961. Paper (VI-2):1-19.

3. Presently Honolulu Laboratory, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, Hawaii.

4. Applicable to larvae under about 8 mm in total length.

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SYNOPSIS OF BIOLOGICAL DATA ON FRIGATE TUNA, *AUXIS THAZARD*, AND BULLET TUNA, *A. ROCHEI*

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