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THE BIOLOGY AND RESOURCES OF THE BONITOS, GENUS *SARDA*

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INTRODUCTION

In response to a growing demand for tuna, increased effort has been expended over the years to harvest the commercially important large tunas throughout the world's oceans. The effort has increased to such an extent that some of the tunas are in danger of being over exploited. Examples of these are the yellowfin tuna, *Thunnus albacares*, in the eastern tropical Pacific which has been under management now for a number of years and the albacore, *T. alalunga*, of the South Pacific Ocean (Skillman 1975). To meet the demand for tuna and at the same time avoid the over-exploitation of important resources, attention has been focused on tuna resources that are relatively underutilized, such as the skipjack tuna, *Katsuwonus pelamis*. In addition, some of the smaller tunas or tunalike species like the bonitos, *Sarda*, spp., which up to now has had mixed acceptance in the marketplace, are gaining more attention.

The bonitos are not an entirely unutilized resource. The total world catch of bonitos has ranged from about 92,200 metric tons (MT) to 140,500 MT in the 10-year period from 1964 to 1973 (FAO 1970, 1974) (Figure 1). As indicated above, however, bonitos have varying acceptance throughout the world. In the Mediterranean and Black Sea countries *Sarda sarda* is of great importance and has been the object of a fishery for many years (Demir 1963). In Chile, in contrast to earlier years when *S. chiliensis* contributed insignificant amounts to the total fish processed, more and more bonito have been processed into canned products in recent years (Barrett 1971). In California

Fig. 1

waters S. chiliensis has been exploited since the beginning of the century. It does not have much commercial value, however, and the California tuna industry has accepted bonito more from necessity than by choice (Frey 1971). The flesh of S. orientalis is considered rather soft and inferior in quality and except in Kyushyu, where it is caught as an adjunct to the mackerel and other pelagic species, bonitos are not especially sought after in Japan (Kikawa and staff 1963). And in Australia, the edible qualities of S. australis are not highly regarded (Grant 1972).

The purpose of this report is to review and analyze all the information available on the biology and resources of the bonitos throughout the world. This is being done in anticipation of the expected greater interest in these species. The source of the material for this report is from published papers, in general, and the FAO Species Synopses on the bonitos (Demir 1963; Idyll and de Sylva 1963; Kikawa and staff 1963; and Silas 1963) were heavily relied on.

IDENTITY

The confusion on the number of valid species in the genus *Sarda* has been cleared and basically, four allopatric species are now recognized. These are the southeast Australian *Sarda australis* (Macleay), the eastern temperate Pacific *Sarda chiliensis* (Cuvier), the tropical Indo-Pacific *Sarda orientalis* (Temminck and Schlegel) and the Atlantic *Sarda sarda* (Bloch) (Collette and Chao 1975). The classification of *Sarda* within the family Scombridae as given by Collette and Chao is shown below:

Family Scombridae
  Subfamily Scombrinae
    Tribe Sardini
      Genus *Sarda*
        Species *Sarda australis*
          Sarda chiliensis
          Sarda orientalis
          Sarda sarda

Descriptions of the genus *Sarda* and the species therein and the synonyms for the four species are given below. The synonymies are shortened versions of the complete versions given by Collette and Chao (1975). The synonymy for *S. chiliensis* was split by Collette and Chao for the northeast Pacific *S. chiliensis lineolata* and the southeast Pacific *S. chiliensis chiliensis*. They point out that the data are not convincing that these two populations are subspecies. However, they further point out that certain factors make it practical to use the subspecific designations in the formal synonymy. They also split the synonymy for S. orientalis geographically into Indo-West Pacific (including Hawaii) and the tropical eastern Pacific to facilitate entry into the literature. The synonymies given below follow Collette and Chao.

- Genus Sarda Cuvier 1829

Body elongate, moderately compressed; head large, pointed, compressed, naked; mouth large, terminal, somewhat oblique; maxillary not concealed by preorbital; jaws with a single row of rather strong, conic and slighly compressed teeth; similar teeth on palatines, none on vomer and tongue; eyes rounded, adipose eyelids little developed; gill openings very wide, membranes not united, free from isthmus; gills 4, slit behind fourth; gill rakers strong, few in number; pseudobranchiae present, large; branchiostegals 7; trunk covered with minute cycloid scales, those of pectoral region somewhat larger and forming a distinct corselet; lateral line present, slightly undulated; caudal peduncle extremely slender, with distinct median lateral keel; two dorsals; first dorsal long, reaches or nearly reaches to second dorsal rather low, sloping backwards, contractible in a groove, with 18 to 24 rather strong spines; second dorsal smaller than first dorsal, followed by from 6 to 10 detached finlets; anal similar to second dorsal, followed by from 6 to 9 separate finlets; ventrals and pectorals small, the latter inserted below level of pupils; caudal widely forked; no air bladder; pyloric appendages very numerous and dentritical.

Fig. 2

Sarda australis (Macleay) (Figure 2a)

"D.19 + D.2 + 12 + VIII; A.2 + 11 + VI; V.1 + 5; P.25;

$C.\frac{18}{22}$?"

"Greatest height of body about 4-1/2 in the length of body without caudal fin, or five times including it. Length of head one-fourth of total length. Diameter of eye twice in length of muzzle, and three times to edge of operculum behind; slightly less than one-sixth the length of the head. The posterior end of maxillary does not quite reach the vertical of posterior edge of eye. Nine compressed, slightly inarched teeth on dentary bone, and two large ones on each side of front of lower jaw. The row of small palatine teeth, about 14 on each side. Teeth of upper jaw much smaller than those of lower jaw. Pre-operculum with numerous thick, wavy longitudinal ridges; corselet not exceeding the tip of the pectoral in length. Lateral line with an upward, angular flexure under the sixth ray of dorsal, thence with slight undulations, largest under anal, to keel at middle of side of tail. Pectoral triangular, moderately pointed, rather less than one-eighth the length of the body, reaching as far as eighth spine of dorsal. Ventrals small, with a pointed scale at inner base of each. First dorsal commencing over anterior base of pectoral, second and third rays longest, gradually decreasing to anterior base of second dorsal. The last ray of the dorsal as counted above resembles one of the succeeding pinnules. Color: Back purplish-lavender-grey, becoming paler and silvery on sides of head; body, and belly, with about 11 longitudinal dark streaks running nearly lengthwise; 5 under second dorsal and dorsal finlets, turning upwards obliquely to dorsal edge. Fins with blackish membranes and lighter rays; the edges of the second dorsal, anal, and tips of the caudal lobes slightly yellowish. Iris pale yellow. Measurements: Total length from tip of snout to end of body, excluding caudal fin, 1 ft. 8 in. Proportional measurements to length as 100: Depth of body, $\frac{22}{100}$; from tip of snout to end of operculum, $\frac{25}{100}$; to anterior edge of orbit, $\frac{8}{100}$; to posterior edge of orbit, $\frac{12}{100}$; to end of maxillary, $\frac{12\text{-}1/2}{100}$; to base of first dorsal, $\frac{27}{100}$; to base of ventral, $\frac{31}{100}$; to base of pectoral, $\frac{26}{100}$; to end of corselet, $\frac{38}{100}$; to anal fin, $\frac{70}{100}$; to second dorsal, $\frac{58}{100}$; highest spine of first dorsal, $\frac{10}{100}$; length of pectoral, $\frac{12}{100}$; longest ventral ray, $\frac{7}{100}$; longest ray of second dorsal, $\frac{8}{100}$; longest ray of anal, $\frac{8}{100}$; longest ray of caudal lobes, $\frac{17}{100}$. Twelve scales in three lines under middle of first dorsal." (McCoy 1888).

<u>Pelamys</u> <u>australis</u> Macleay 1880

<u>Pelamys</u> <u>schlegeli</u> McCoy 1888

<u>Pelamys</u> <u>chilensis</u> (not of Cuvier 1931). Ogilby 1893

<u>Sarda</u> <u>chilensis</u> (not of Cuvier 1931). Waite 1904

<u>Sarda</u> <u>chiliensis</u> (not of Cuvier 1831). McCulloch 1922

<u>Sarda</u> <u>orientalis</u> (not of Temminck and Schlegel 1844). Lord 1927

<u>Sarda</u> <u>australis</u>. Walford 1936

<u>Sarda</u> <u>chiliensis</u> <u>australis</u>. Roughley 1951

<u>Sarda</u> <u>chilensis</u> <u>australis</u>. Silas 1964

Sarda chiliensis (Cuvier) (Fig. 2b)

"Head 3.25 to 3.4; depth 4.2 to 4.9; D. XVIII–13 to 15–VII or VIII; A. II, 10 to 13—VI or VII; P. 23 or 24; vertebrae 44 (one specimen dissected).

"Body moderately robust, its greatest thickness about two-thirds its depth, tapering rather abruptly posteriorly; caudal peduncle depressed, with a prominent lateral keel and two smaller ones on base of fin, depth of peduncle 11 to 14 in head; head compressed, convex above; snout long, pointed, 2.9 to 3.1 in head; eye 6.4 to 7.5 in head; interorbital 3.3 to 3.9; mouth moderately large, slightly oblique, terminal; maxillary about half width of eye, scarcely reaching vertical from posterior margin of eye, 2.05 to 2.15 in head; teeth in jaws in a single series, compressed at base, curved inward, pointed, generally a pair of somewhat enlarged teeth on lower jaw anteriorly, palatines with a series of small teeth; gill rakers moderately slender, a little shorter than eye, 16 to 18 on lower and 6 to 8 on upper limb of first arch; lateral line wavy; scales minute, somewhat enlarged, though embedded, in region of pectoral, forming a more or less definite corselet; first dorsal composed of very slender spines, the anterior ones moderately elevated, the posterior ones extending little above dorsal groove, the second or third the longest, equal to or a little longer than snout, origin of fin a little in advance of pectoral, its distance from tip of snout 2.9 to 3.0 in length; second dorsal moderately elevated anteriorly, the last ray enlarged, origin of fin about equidistant from origin of first dorsal and sixth finlet; anal origin about under last ray of second dorsal; ventral moderately small, 3.0 to 3.5 in head; pectoral moderately pointed, reaching margin of corselet to rather more than an eye's diameter beyond it in some specimens, 1.85 to 2.2 in head.

"Color dark blue above, generally with metallic reflections; the color of back gradually merging along middle of side, into the silvery gray of the lower parts; upper part of side with four to six more or less definite oblique black stripes running upward and backward, the stripes rarely nearly horizontal, not always uniform in position and slope on both sides of the same fish; fins more or less dusky; ventral and anal notably lighter than the other fins; ventral often white, at least at base, with an area of a similar color surrounding them." (Hildebrand 1946)

Sarda chiliensis lineolata (Girard)

Pelamys lineolata Girard 1859

Pelamys chilensis, Günther 1860

Sarda chilensis, Jordan and Gilbert 1882

Sarda lineolata, Walford 1936

Sarda stockii David 1943

Sarda chiliensis, Chabanaud 1944

Sarda chiliensis lineolata, Kuo 1970

Sarda chiliensis chiliensis (Cuvier)

Pelamys chiliensis Cuvier *in* Cuvier and Valenciennes 1831

Pelamys chilensis, Günther 1860

Sarda chilensis, Starks 1906

Sarda chiliensis, Walford 1936

Sarda sarda chiliensis, Buen 1958

Sarda chilensis chilensis, Vildoso 1963

Sarda sarda chilensis, Sánchez and Lam 1970

Sarda chiliensis chiliensis, Kuo 1970

Sarda orientalis (Temminck and Schlegel) (Fig. 2c)

"D. 19, 15, 7-8. A. 15, 5-6. Gill rakers 4 + 9, vertebrae 25 + 20, body elongated fusiform in adult specimens, but rather short and compressed in young specimens. Mouth wide, maxillary reaching beyond the orbit, with large curved and compressed teeth. Teeth in jaws are more or less unequal in size. About 16 in the upper, and 10-13 in the lower jaw. Groove in the skin from the corner of the mouth is present, as in the tunnies. Posterior nostril is a mere slit. Scales minute. Lateral line undulating slightly, and has a peculiar, wave-like bend over the pectoral fin.

Stomach long, with more than 20 longitudinal folds. Intestine nearly straight, boundary of therectum indistinct. Pylorus descending with a few longitudinal folds inside, and rather narrow.

Liver consists of three slender lobes, of which the two lateral lobes are very long and nearly equal in length, while the middle one is short.

Myotomes are strongly folded, so that in the cross-section of the lateral muscle we count nearly as many rings as in the same of tunnies. The median wedge-shaped portion of the lateral muscle is reddish, and the red portion becomes thicker towards the tail. On the surface of the last myotome we cannot find a tendon.

Skeleton porous and rather weak, and much resembling to the type of the Cybiidae. The vertebrae of the caudal peduncle are provided with lateral keels, each of which is divided into two, anterior and posterior portions. Two auxiliary intermuscular bones are found on the exoccipital, one on the dorsal wall of the foramen magnum, the other a little forward. At the dorsal part of the clavicle the anterior pointed process is widely separated from the posterior lamellar part.

Grows to a length of about 80 cm and to a weight of 1.5-3.0 kg." (Kishinouye 1923).

Indo-West Pacific

Pelamys orientalis Temminck and Schlegel 1844

Pelamys chilensis (not of Cuvier 1831), Day 1878

Sarda chilensis var. *orientalis* Steindachner and Döderlein 1884

Sarda orientalis, Jordan and Snyder 1900

Sarda chilensis (not of Cuvier 1831), Jordan and Snyder 1904

Sarda chiliensis (not of Cuvier 1831), Fowler 1938

Sarda orientalis serventyi Whitley 1945

Eastern Pacific

Sarda chilensis (not of Cuvier 1831), Gilbert and Starks 1904

Sarda chiliensis (not of Cuvier 1831), Herre 1936

Sarda velox Meek and Hildebrand 1923

Sarda orientalis, Fraser-Brunner 1950

Sarda sarda (Bloch) (Fig. 2d)

" Body elongate, fusiform, somewhat compressed, thicker with age; dorsal and ventral outlines evenly curved; head compressed, tapering to a pointed snout; mouth large, slightly oblique; upper jaw very slightly in advance of lower; teeth on jaws curved inward; the second or third anterior teeth on lower jaw somewhat large; maxillary well exposed, rounded posteriorly, reaches nearly to or slightly past posterior margin of eye; front nostril is a small pore, a little behind the middle in snout length, hind nostril is short vertical slit close before eye; interorbital broad, convex; eye small, rounded, centered at about first 3/7 in head; gill rakers strong like blades, the longest raker a little shorter than eye diameter; caudal peduncle very slender, with a well-developed keel on each side; a small keel at base of each lobe of caudal; lateral line slightly undulating, slopes down to caudal peduncle keel; first dorsal long, nearly reaches to second dorsal, sloping backwards, contractible in a deep groove, inserted about opposite pectoral origin or nearer snout tip than second dorsal origin, with stout spines; second dorsal shorter, concave, inserted nearer caudal than eye, followed by similar separate finlets, last finlet smallest; anal like second dorsal, inserted about opposite posterior base of second dorsal; pectoral falciform, short, inserted below level of eye, close to head; a shallow depression on body behind pectoral; ventral short, inserted near posterior end of pectoral base.

" Color steel-blue above, silvery below; back and sides in adults with 7 to 11 dark stripes running obliquely downward and forward; (for coloration in juveniles and young, see section 3.2.1); dorsals and caudal dusky, pectoral pale, other fins more or less silvery.

" Snout 2.8 to 3.5 in head; interorbital 3 to 3.8; maxillary 1.9 to 2.1; eye 5 to 7.

" Depth 4.4 to 5.3 in length to the caudal fork; head 3.9 to 4.6; pre Dl. 4.0 to 4.3;

pre D2. 1.6 to 1.8; pre P. 3.9 to 4.4; pre V. 3.6 to 4.0, pre A. 1.48 to 1.6.

"Teeth from 16 to 26 on upper jaw; from 13 to 23 on lower; gill rakers from 6 to 9 on upper limb, from 11 to 15 on lower, from 17 to 23 in all on first arch."

"D1. XX-XXIII; D2. ii-iv, 9-14+VII-X; A. ii-iv, 11-13+ VI-IX; P. II, 20-24 V. I, 5; C. x+17+x; vert. 52-54 (=25-28+25-27), very rarely 55." (Demir 1963)

Pelamis Belon 1553

Amia Rondelet 1554

Pelamyde rera Rondelet 1554

Pelamyde sarda Rondelet 1554

Thunnus authoris primus Aldrovandi 1613

Pelamys sarda Willughby 1686

Scomber pelamis Brünnich 1768

Bonite Duhamel du Moncean 1769

Thonin sorte de pélamide Duhamel du Moncean 1769

Scomber sarda Bloch 1793

Scomber mediterraneus Bloch and Schneider 1801

Scomber palamitus Rafinesque 1810

Scomber ponticus Pallas 1811

Thynnus pelamis Risso 1826

Thynnus sardus. Risso 1826

Thynnus brachypterus Cuvier 1829

Sarda sarda, Cuvier 1829

Pelamys sarda, Cuvier in Cuvier and Valenciennes 1831

Palamita sarda, Bonaparte 1831

Pelamis sarda, Valenciennes 1844

Sarda pelamys, Gill 1862

Sarda mediterranea, Jordan and Gilbert 1882

Sarda pelamis, Smitt 1892

The four species of Sarda differ from each other in a number of characters including number of fin rays, gill rakers, vertebrae, and teeth. A summary of characters which show the differences and similarities among the species is given in Table 1.

Table 1

The common and vernacular names of the bonitos are given in Table 2.

Table 2

DISTRIBUTION OF THE SPECIES OF SARDA

A detailed description of the distribution of the four species of Sarda is given by Collette and Chao (1975) and the following account is based on their description (Fig. 3).

Fig. 3

Sarda australis. Sarda australis is known only from the east coast of Australia and Norfolk Islnad. Off the east Australia coast is common from about the Capricorns (Queensland) to Sydney or even Gabo Island (Whitley 1964). The western record for the species is at Port Fairy (Serventy 1941a).

Sarda chiliensis. This species is found only in the eastern Pacific where it is separated geographically into north and south temperate populations. As noted earlier, Collette and Chao (1975) found no conclusive evidence that these two populations are subspecies but they stated that the populations are genetically isolated from each other and there were some significant morphological differences between the two populations. Furthermore, they pointed out that there is ample historical precedent for the name *lineolata* for the northeast Pacific bonito population and that there may be a practical value in using the available subspecific names of *Sarda chiliensis lineolata* for the northeastern population and *Sarda chiliensis chiliensis* for the southeastern Pacific population.

The usual range of the northeast population is from about Point Conception, California to Magdalena, Baja California. There is a record of this species from Socorro Island in the Revillagigedos. It is uncommon north of Point Conception but it has been recorded from off the Farallon Islands and Eureka, California; off Puget Sound, Washington; off the east coast of Vancouver Island, British Columbia; and off coastal Alaska near Ketchikan and Copper River.

The range of the southeastern population is along the coast of South America from Mancora, Peru to the north of Valdivia, Chile to the south.

Sarda orientalis. This bonito occurs in widely scattered locations in the Indo-Pacific and Pacific. There is a population of *S. orientalis* in the tropical eastern Pacific that is confined to the coastal areas between Mexico and Ecuador and around the Galapagos Islands. It occurs in Hawaii where it is not common. In Japan the species occurs along both coasts of Honshu and is most abundant along the coasts of Kyushu. The species has been recorded from the coast of China and also from the Philippines.

In the Indian Ocean *S. orientalis* has been recorded from southwest Australia, along both coasts of India and from Sri Lanka, from Muscat at the entrance to the Persian Gulf, in the Seychelles Islands and Aldabra Island, and along the coast of Natal, South Africa south to Durban. It has also been recorded from Eilat at the northern end of the Gulf of Aqaba in the Red Sea.

Sarda sarda. This bonito is found on both sides of the tropical and temperate Atlantic Ocean, in the Gulf of Mexico, and in the Mediterranean and Black Seas. In the western Atlantic off the east coast of the United States its usual northern limit is Cape Ann, Massachusetts. However, *S. sarda* has been recorded from Casco Bay, Maine and from several localities along the outer coast of Nova Scotia. It occurs off Florida but is uncommon off Miami and the Florida Keys.

Off the Atlantic coast of South America the species is recorded from Colombia and Venezuela and between about Rio de Janeiro, Brazil to Buenos Aires, Argentina.

The north-south range of S. sarda is greater in the eastern than in the western Atlantic: from near Oslo, Norway to Port Elizabeth, South Africa. It is recorded from the Azores, Madeira, the Canaries and Cape Verdes Islands.

ECOLOGICAL CHARACTERISTICS OF AREAS

No detailed description of the habitat of the four species of Sarda will be presented here. From all indications the species of Sarda are inhabitants of the coastal or the pelagic neritic province. Sverdrup, Johnson, and Fleming (1942) sets the vertical border separating the neritic from the oceanic province at the edge of the continental shelf. Thus the neritic zone would include all waters of depths less than 200 m and accordingly may extend far seaward where the continental shelf is wide or may extend only a short distance where the shelf is narrow. "The chemical constituents of the sea water in the neritic province are more variable than in the oceanic. Salinities are usually lower, sometimes markedly, and undergo seasonal or sporadic fluctuations such that many of the inhabitants are more or less euryhaline in nature--that is, able to endure wide ranges of salinity." (Sverdrup et al. 1942.)

Laevastu and Rosa (1963) determined the distribution of various species of tuna and the temperature range in which the species were found. For the species of bonitos they gave a general temperature range of 12°-25°C and the temperature range of the fisheries for bonitos as 15°-22°C.

BIOLOGY AND ECOLOGY

REPRODUCTION

The four species of Sarda probably share many similar sexual behavioral characteristics. They are all heterosexual, seemingly promiscuous in shedding eggs and milt (see section of Sarda chiliensis) and the fertilization of the eggs is external.

Sarda australis. The literature contains very little information on *Sarda australis*. Serventy (1941a) reported on three fish caught in January and February 1939 off Wilson's Promontory and Port Albert. The fish weighed between 4 and 5 pounds (1.8 and 2.3 kg) and two, which were females had "relatively large roes." Whitley (1964) noted that *S. australis* sometimes venture into Victoria in the summer (January to April) and that some of these fish had large roe. He also found that fish ready to spawn were found in February and March off New South Wales.

Sarda chiliensis. There are no apparent external anatomical differences between male and female *Sarda chiliensis*; however, Magnuson and Prescott (1966) noted a sexual dimorphism in the behavior of this species in captivity. Magnuson and Prescott noted that some *S. chiliensis* in their observation tank were "wobblers" and that others were "followers." They postulated and subsequently determined that the "wobblers" were females and the "followers" were males. They also determined by their observations that a male bonito was apparently unable to identify the sex of another bonito except by behavioral characteristics. The bonito is normally heterosexual; however, Vildoso (1960) found cases of hermaphroditism in *S. chiliensis* in Peruvian waters. It is of interest that Magnuson and Prescott observed that one fish exhibited both a "wobbling" and "following" behavior. They attributed the anomalous behavior of this particular fish to a possible misidentification and did not speculate on the possibility of hermaphroditism, or other causes for the aberrant behavior.

As Magnuson and Prescott (1966) point out, pelagic schooling fish were assumed to have no discrete courtship behavior and no pairing and that they were believed to shed eggs and sperm promiscuously while gathered in large active schools. To the contrary, Magnuson and Prescott found that S. chiliensis do exhibit courting and pairing behavior, if only temporarily, and observed pairs of fishes in a sequence of behavior leading to a simultaneous and adjacent release of eggs and milt. The pair of bonitos released the gametes during a circle swimming behavior in which the male swam in tandem with the female in a circular path.

Although such behavioral patterns have been observed only in S. chiliensis it would not be unreasonable to expect that the other species of Sarda also behave in a similar manner. It may just be a matter of observing the other species in observation tanks to confirm the existence of these behavioral patterns.

Barrett (1971) determined the gonad index (GI) ($GI = \frac{w}{W} \times 10^2$, where w = weight of both ovaries in grams and W = body weight in grams) of bonitos and found that female S. chiliensis off the coast of Chile initially reached sexual maturity at a length of 51 cm. For the bonitos off the coast of Peru Vildoso (1966) determined that the size at first spawning ranged from 47 to 53 cm. Kuo (1970) stated that in the northern hemisphere population of S. chiliensis the females attained sexual maturity at 51 cm and that the fish was 5 years old at that length.

The spawning season for S. chiliensis in Chilean waters begins in September, is at a maximum in October and November, and is well over before April (Barrett 1971). The spawning season off the coast of Peru is very similar to that off Chile; peak spawning of bonito extends from October to February (Vildoso 1966). According to both authors, larger older bonito mature earlier in the spawning season than do the younger fish (Fig. 4).

Fig. 4

For the northern hemisphere population of S. chiliensis, Kuo (1970) investigated several different approaches to determine the spawning season including the annual cycle in the development of intraovarian oocytes, the annual cycle of frequency distribution of ovum diameters, and the annual change in gonad index. All of the different methods indicated that the spawning season for the northern hemisphere S. chiliensis in southern California is from May through July. Kuo speculated that off southern Baja California spawning may start as early as April and may continue into August. He also indicated that the larger fish tend to spawn earlier in the season and longer than the smaller fish. Frey (1971), however, attributed an early spawning season for S. chiliensis between southern California and northern Baja California waters. He stated that the bonitos spawned between January and May in these waters.

The results of an ichthyoplankton survey off Baja California seems to corroborate the conclusions of Kuo (1970). On the basis of the distribution of fertilized eggs Sokolovskii (1971) showed that

Fig. 5 *S. chiliensis* spawned in a relatively large area near the coast (Fig. 5). In early March the most intensive spawning occurred in the southern area and in early April it occurred in the northern area. The depth of the ocean in the spawning area ranged from 40 to 150 m and practically no bonito eggs were found outside of the 200-m isobath. Larval bonito were captured at only one station during this survey.

Most of these observations tend to support Klawe (1961b) who, on the basis of the capture of larval and juvenile *S. chiliensis*, had stated that the spawning of this species takes place in the warmer season off California, Baja California, Peru, and northern Chile.

Vildoso (1963a) estimated the number of ova spawned by a 600 mm (3 kg) bonito at half a million per spawning season. According to Vildoso spawning is fractionary. Kuo (1970) estimated that the fecundity of the northern *S. chiliensis* ranged from 104,900 to 894,200 eggs for fish from 47.6 to 63.7 cm in fork length. He indicated that the fecundity increased exponentially with size of fish.

Sarda orientalis. The literature contains very little information on *S. orientalis* in the eastern Pacific and around Hawaii. Klawe (1961b) reported on two larval forms of *Sarda* from off Baja California that could not be identified to species. The distribution of the northeast population of *S. chiliensis* overlaps or nearly overlaps that of the population of *S. orientalis* at the location of capture of the larvae. Therefore the larvae could be either of the two species.

Nothing is known about the spawning of *S. orientalis* around Hawaii except that a few juveniles have been found in the stomachs of predators (unpublished data, Honolulu Laboratory) which provides evidence of reproduction.

No formal studies on the spawning of *S. orientalis* in Japanese waters have been made. Kikawa and staff (1963) presumes that spawning occurs in the coastal waters of the tropical zone in the Indo-Pacific. There apparently is some local unrecorded knowledge of bonito spawning in Japan because Harada, Murata, and Miyashita (1974) report that the spawning season is May-June. They caught mature *S. orientalis* on May 15 and June 10, 1973 in traps set near the coast of Oshima Island and used these fish successfully in an artificial fertilization experiment. Mito (1961) gave descriptions of the fertilized eggs of *S. orientalis* found in plankton collections but gave no collection details. Kishinouye (1923) and Yabe, Anraku, and Mori (1953) reported on the capture of juvenile bonito in southern Honshu and Kyushu waters.

Information on the spawning *S. orientalis* in the Indian Ocean is more plentiful. Although the size at first spawning of bonito has not been clearly determined, a 38.6 specimen possessed residual eggs which were presumably remnants from an earlier spawning (Silas 1964). However, Silas indicated that specimens in "ripe running condition or had already spawned, some showing signs of recovery" measured between 480 and 605 mm from samples collected in 1960 and 1961 at Vizhingam, India. The age of these specimens were not determined. Rao (1964) found four specimens ranging in size from 48 to 55 cm with running-ripe ovaries in June, August, and September 1959 also from Vizhingam.

Silas (1964) made fecundity estimates for five mature specimens of _S. orientalis_. He estimated that the females produce 0.08 to 0.15 million eggs per spawning and 0.24 to 0.64 million eggs per spawning season. Rao (1964) estimated that the bonito spawns 0.21 to 0.28 million eggs per spawning and 0.91 to 1.15 million eggs per spawning season.

Off the coast of Vizhingam _S. orientalis_ spawn from April to September and possibly in other months of the year. Ova diameter frequency distributions indicate the possibility that individual females spawn several batches of ova (Fig. 6) during the spawning season (Silas 1964).

Fig. 6

Gorbunova (1963) reported on the larva of _S. orientalis_ from the Indian Ocean off the northwest coast of Australia and generalized that spawning is limited to the autumn-winter period. However, this conclusion is based, apparently, on the capture of one larva of _S. orientalis_ in December. Gorbunova probably has the seasons confused for December off the northwest coast of Australia would be closer to summer in the southern hemisphere.

Sarda sarda. The following account of _S. sarda_ reproduction is based primarily on the report by Demir (1963) who in turn consulted other works in the literature. As is the case with the other species of bonitos, the sexes cannot be distinguished in _S. sarda_. Apparently, however, some Turkish fishermen can distinguish the sexes by rubbing the skin anterior of the anus with a finger tip. The skin is said to be smooth in the females and rough like emery paper in the males.

The bonito in the Sea of Marmara and the Bosporus attain sexual maturity at the end of the second year. In some years the bonito may be sexually mature in a year. Two-year-old fish range from 52 to 57 cm and 1-year-old from 42-48 cm.

In the Black Sea, part of the stock of _S. sarda_ attains sexual maturity in the second year of life. These 2-year-old fish are said to vary from 33 to 50 cm. Off the coast of Dakar in the eastern Atlantic the size at first maturity is 392 mm for the males and 370 mm for the females. These fish are less than a year in age.

Demir (1963) summarized the fecundity determinations for

Table 3 _S. sarda_ made by various investigators (Table 3). The fecundity estimates range from 450,000 to over 3,000,000 eggs.

Demir (1963) states that spawning begins in mid-May, reaches a peak in June and lasts at least to the end of July. He assumes that the spawning season is the same in the Black, Marmara, and Aegean Seas.

Indications are that the spawning season in the Mediterranean is also from May-July. However, Demir (1963) noted that Dieuzeide, Novella, and Roland (1955) found that the spawning season off the coast of Algeria is from March to May.

Rodriguez-Roda (1966) made observations on the sexual development of S. sarda landed in May, June, and July 1963 and 1964 in the Spanish fishery based at the Mediterranean ports of Barbate and Tarifa. By gross examination of the gonads he classified the males and females according to the following stages of sexual maturity:

I. Immature

II. Early maturing

III. Mature

IV. Pre-spawning

V. Spawning

VI. Spent

Data on the monthly percentage distribution of fish in the various stages of sexual maturity as given by Rodrigues-Roda is shown in

Table 4

Table 4. He also computed the gonad index (G.I.) of the fish for his 1964 samples using the equation G.I. = $\frac{w}{W} \cdot 100$, where w is the weight

Tables 5,6

of the gonads and W is the weight of the fish (Table 5). In Table 6 is shown the relation between the stage of sexual maturity and the gonad index. Rodriguez-Roda noted that the smallest fish with pre-spawning and spawning gonads were 39.5 cm for the males and 40.5 cm for females.

In the eastern Atlantic near the coast of Dakar the spawning season extends from December to June with peaks in January and April and June-July in Moroccan waters. Less is known about S. sarda spawning in the western Atlantic. Bigelow and Schroeder (1953) stated that the bonito spawns south of the Gulf of Maine in June. However, Sette (1943) reported the collection of bonito eggs near Martha's Vineyard, Massachusetts in July. Further south off the South Carolina coast Klawe (1961a), based on the capture of a single 34 mm bonito, stated that this species spawns in the winter. The capture of a larval bonito (Gorbunova and Salabarria 1967) off the coast of Cuba and a juvenile specimen in the central Gulf of Mexico (Klawe and Shimada 1959) suggests some spawning activity in these areas.

LIFE HISTORY

Eggs. The fertilized eggs of the bonitos have been described for all the species in the genus except *Sarda australis*. Except for differences in size the fertilized eggs at the various developmental stages appear to be quite similar and it is doubtful that they could be separated by species. As examples of differences in size of the fertilized eggs among the species of *Sarda*, Demir (1963) found that for *S. sarda* in the Sea of Marmara, the eggs, which were measured after preservation in 4% Formalin[2] varied between 1.18 and 1.55 mm in diameter. The fertilized eggs of *S. chiliensis* (= *S. lineolata*) from off the coast of Baja California measured from 1.4 to 1.8 mm in diameter (Sokolovskii, 1971). However, no mention is made of whether the eggs were measured before or after preservation. Harada et al. (1974) reported that the fertilized eggs of *S. orientalis* were from 1.32 to 1.45 mm in diameter. Here again it is not clear whether the eggs were measured fresh or after preservation. These fertilized eggs were the result of a successful experiment in artificial fertilization and is the first record of success in artificial fertilization for this species.

Because the fertilized eggs of the species of Sarda are similar in appearance, as a typical example a descritpion is given below of the eggs (Fig. 7) of *S. sarda*.

Fig. 7

> "The fertilized planktonic eggs are spherical and have a varying number of oil globules of different sizes. They are transparent and colorless (with the exception of the oil globules.) The envelope (capsule) is elastic. On its outer surface can be seen an irregular mesh produced by very fine lines crossing one another. The yolk sac is homogeneous and finely granulated. Oil globules of different diameters are always present at its surface. The number of these globules varies, usually between one and nine, between two and five being most frequent. In some eggs it is difficult to count the oil globules because of their tendency to unite or divide (Fig. 4). Color can be likened to a faded carrot or dried straw colour.
>
> "Pigmentation in the egg begins later when the developing embryo has reached the stage where the blastoporus is closed. The pigments are black and yellow in color. The eggs which were examined at the Hydrobiological Research Institute, Istanbul, however, were preserved, and as the yellow pigment disappears quickly in preservation, only the black pigments (melanophores) have been investigated. They appear on the yolk sac, oil globules and embryo. The melanophores on the yolk are localized on the surface of the yolk sac curve at the side of the embryo (Fig. 5). On the embryo, they first appear on the dorsal sides of the body and later on the head and tail. When expanded they are branched like sticks, and when contracted they appear as irregular stars." (Demir 1963)

The distribution of the fertilized eggs of *S. chiliensis* in the eastern Pacific is not well defined. Barnhart (1927) collected bonito eggs in a plankton net off La Jolla, California. Orton (1953a) described the early embryonic stage of Pacific bonito but gave no capture locality for her samples. Sokolovskii (1971) made a more detailed study of the distribution of fertilized eggs of the Pacific bonito off Baja California. The distribution of the fertilized eggs off Baja California in the spring of 1966 can be seen in Figure 5. As noted by Sokolovskii, *S. chiliensis* spawns only in the shallow waters of the coastal zone. He found very few, if any fertilized eggs outside the 200-m isobath. He also found that the eggs are found only at the surface for no eggs were collected in vertical plankton hauls.

There is hardly any information in other literature on the distribution of the fertilized eggs of *S. orientalis*. Mito (1961) gave generalized descriptions of fertilized eggs of the species in what he termed the Scombrina, including *S. orientalis*. However, Mito gave no capture locality for his samples. Except for this fragmentary bit of information on the planktonic fertilized eggs of *S. orientalis* off Japan there is nothing on the distribution of their eggs in the other areas of the Pacific and Indo-Pacific where this species occurs.

The distribution of fertilized eggs of S. sarda has been studied in greater detail in the Black Sea and the Sea of Marmara. Mayorova and Tkacheva (1959) reported on the distribution of S. sarda

Fig. 8 eggs in the Black Sea in 1956 and 1957 (Fig. 8). They noted that in 1956 bonito eggs were found in great numbers in the surface layer, the maximum catch amounting to 12,000 eggs per "10 minute catch," presumably made using a plankton net. At a depth of 5 m the number of eggs taken did not exceed 5,000 eggs per 10-minute tow. In 1957 the overall abundance of fertilized eggs was less than in 1956 and the vertical distribution was also different in that the 5 m depth produced more eggs than the surface layer. Demir (1963) noted that available data indicate that S. sarda eggs have been found everywhere in the Black Sea, the locations varying from year to year.

The fertilized eggs of S. sarda have also been found in the

Fig. 9 Sea of Marmara (Fig. 9) (Demir 1963). It can be seen from Figure 9 that in June and July of 1959 most of the fertilized eggs were found in the eastern portion of the Sea of Marmara.

It is of interest that very little is known of the distribution of fertilized S. sarda eggs in the Mediterranean Sea. Demir and Demir (1961) noted that planktonic fertilized eggs of S. sarda were unknown from the Mediterranean Sea. They pointed out that the eggs reported on by Sanzo (1932) were eggs which were extracted from a female gonad and artifically fertilized and reared. More recently, however, Duclerc et al. (1973) reported on the collection of fertilized S. sarda eggs near the Balearic Islands in the Mediterranean Sea. Thus, as far as can be determined from the literature the distribution of fertilized eggs of bonito is not very well defined in the Mediterranean Sea.

Except for the report of the collection of the fertilized eggs of S. sarda off the coast of Massachusetts by Sette (1943) nothing is known of their distribution in the Atlantic Ocean.

LARVAE, JUVENILES, AND PRE-ADULTS

The size of newly-hatched larva of S. chiliensis is given by Barnhart (1927) as 3.75 mm. Newly hatched larvae of S. orientalis measured 4.1 to 4.3 mm (Harada, et al.,1974). As a typical example of the development of the larvae of bonitos, a description of the larval and postlarval development of S. sarda is given below. The description is taken from a translation of Padoa (1956).

"The embryonic development is completed rapidly and the larva hatches only a day after the closing of the blastopore. On top and along the length of the trunk of the embryo and around the oil droplet there are rare small, branched melanophores, which later are joined by small xanthophores, especially abundant on the distal curve of the yolk sac.

"The larva at hatching is little advanced in development, with the mouth not yet open, and the eye without pigment. Its length however

Fig. 10 is remarkable, over 4 mm. In the example illustrated in Fig. 309 [Fig. 10] the total length is 4.32 mm. of which 1.90 mm. is taken up by the pre-anal region. The yolk sac is large, the oil droplets are in a posterior position, and not fused together. The fin fold is large, and the anus opens at a distinct distance from the yolk sac, which permits the existence of a distinct border to the pre-anal region. The pectorals are barely outlined. The pigmentation is characterized by rather large spots of yellow pigment on the margin of the anterior two-thirds of the dorsal and ventral borders of the fin fold. Two yellow spots on the caudal trunk are at the posterior end of the series of spots on the fin fold. Other yellow points are distributed on the dorsal profile of the head and of the abdominal trunk, and on the distal curve of the yolk sac. A few thin melanophores may be seen on the oil droplet and on the trunk, especially on the ventral margin of its caudal portion. There are 15 pre-anal segments, 38 post-anal, in all about 50, corresponding to the adult vertebrae (Fig. 309) [Fig. 10].

"Two days after hatching, the total length has increased to 4.6 mm., and the yolk is reduced to less than half. The height of the head has increased as has the lateral flattening of the body, and the organization has progressed considerably. The mouth is open, the eye, still slightly oval, is pigmented and iridescent. The middle intestine ends in a strong valve, followed by the terminal intestine, as an ample sac. The anus has moved forward; the pre-anal segments are decreased from 15 to 11 and the pre-anal increased to 39. The pectorals are well developed and membranous. Hypurals are absent. The yellow pigmentation is practically unchanged; the melanophores of the trunk are now limited to the ventral margin of its caudal portion. Other black elements are present in the curve of the peritoneal cavity with a few on the profile of the snout (Fig. 310) [Fig. 10].

"On the 4th day, the length is slightly augmented, to 4.68 mm. The yolk is nearly used up. The snout has lengthened considerably, and there are well defined teeth, at a stage when they are absent in other Thunnidae. The visceral cranium is by now well differentiated; the preopercular margin has a triangular spine directed to the rear. The anus is displaced even farther forward, to the level of the 9th segment, and the abdominal cavity is rather high, as in Scomber. The pectorals are sample and membranous; hypurals are still absent. The yellow pigment on the border of the fin fold is diminising and tending to disappear. The melanophores persist on the ventral margin of the caudal trunk; those of the dorsl peritoneal walls and of the head are augmented in number and size. Others align themselves on the thoracic girdle, and "the location of pigment is characteristic ... of the larvae of similar species of Scomberoidei" (Sanzo [1931]).

"On the 6th day the larva has exhausted its yolk and has diminished a little in length (4.20 mm.). "The head has the snout a little more distinctly pointed, and is conspicuously raised at its juncture with the trunk. It is changing to the subconical form, characteristic, however early, development in similar species of Scomberoidi" (Sanzo [1932]). The preopercular spine is pointed and evident. The dorsal extremities of the thoracic girdle again jut out in front, at the level of the 6th or 7th segment. As this stage, the pre-anal distance, which can be measured from Fig. 311, represents about 34% of the total length. The pectorals are membranous, with their sample rounded margin reaching about the level of the anus. The hypurals are still absent. The yellow pigment at the edge of the fin fold has broken down to minute granules, and is close to disappearing. There are a few melanophores on the ventral margin of the trunk, irregularly spaced; one or two elements have an abundant brnching. Some go along the fin fold to the caudal extremity. The melanophores persist on the peritoneal curve, along the course of the thoracic girdle and on the upper profile of the head. Finally, some melanophores are present at the apex of the snout and in the middle of the mandible (Fig. 311) [Fig. 10].

Fig. 11 "Post-larval stages. An example of 7.2 mm. (Fig. 312)[Fig. 11] described by Ehrenbaum [1924], corresponds well to the preceding stage. There is pigment at the apex of the snout, on the profile of the head, on the peritoneal curve and along the thoracic girdle. Chromatophores are almost completely lacking on the caudal trunk, limited to a few dispersed elements, as in the preceding stage, along the ventral margin. At this stage a system of preopercular spines has developed considerably, arranged in two series, an anterior of three, and a posterior of six, of which the two central ones are very long. Two other spines are on the posterior margin of the otocysts. The maxillary and the mandible have about ten pointed teeth on each side. The point of the maxillary arch precedes the mandible somewhat....The urostyle is still straight, with outlines of the hypurals. Corresponding with the future second dorsal and anal fins, outlines of about 13 days can be counted (a few less than the definitive number). There is a considerable distance between the anus and the origin of the anal fin. At this stage, in fact, the pre-anal distance represents 42% of the total length; from the point of the snout, to the insertion of the anal fin is 65% (calculated on the figure); and the post-anal region includes about 20 segments. Whereas during the resorption of the yolk in the very youngest larvae, we have been a progressive displacement of the anus forward, at the present stage an opposing phenomenon has started. There is enlargement of the visceral cavity and alteration of its posterior wall in the cranial-caudal direction and also of the anus, a modification which will continue in successive stages, until finally the anus comes close to the anal fin. The pectorals are very large and their margin reaches the level of the anus; also the ventrals are relatively ample.

"...At the 26.5 mm. stage, the pre-opercular spines are always well evident although still small. The body height is contained about four times in the total length, a little greater than in the adult, in which is relation decreases to 1/5. The caudal is already clearly forked; the pectorals and ventrals are relatively small, about the smae proportions as in the adult. The finlets are still united by a membrane continuous with the second dorsal and anal. The anal aperture, at least insofar as can be deduced from the figure, must open at a short distance from the anterior insertion of the anal fin.

The ventrals and the base of the caudal are densely pigmented. The first dorsal is intensely black with a clear space at the base of the tenth to thirteenth rays; the other fins are transparent. There is a fine spotting of pigment on the snout, on the nape and on the dorsal region of the trunk, where six vertical bands begin to appear, descending from the dorsal to about the middle of the flanks. A dark horizontal stripe, quite evident, marks the limit between the pigmented dorsal portion of the trunk and the ventral, which is not pigmented. At 32 mm. total length the preopercular spines being to decrease in size, but are still evident. The finlets are still united by a continuous membrane. The fin coloration remains about the same. On the head the pigment is augmented, and the six bands which traverse the trunk are by now quite evident."

Illustration of larval and postlarval S. sarda given by de Buen (1932) and Vodianitskii and Kazanova (1954) are also shown in Figure 11.

Klawe (1961b) and Pinkas (1961) gave descriptions of post-larval S. chiliensis and Jones (1960), Gorbunova (1963), and Harada et al. (1974) described larval and postlarval S. orientalis (Figs. 12 and 13).

Figs. 12, 13

Except for S. chiliensis and S. orientalis in the eastern Pacific where there may be some overlap in the distribution of these two species, the problem of identifying and separating the larval and juvenile species within the genus has not occurred. As for the larval forms of S. chiliensis and S. orientalis in the eastern Pacific Klawe (1961b) states that it would be impossible to separate the two species without a complete developmental series of both species. Klawe further notes that it should be possible to distinguish juvenile S. chiliensis and S. orientalis from each other based on gill raker counts even at a relatively small size. Pinkas (1961) pointed out other characters (number of teeth on lower jaw and presence or absence of posterior gill teeth) that could be used to separate S. chiliensis larger than 24 mm from similar sized S. velox (= S. orientalis).

Once the juveniles acquire the full adult complement of certain characters, which seems to be at a relatively small size (Klawe 1961b; Pinkas 1961), the summary of distinguishing characters for the four species of Sarda compiled by Collette and Chao (1975) indicates that the juveniles could be separated without difficulty. S. australis, S. chiliensis, and S. orientalis can be separated from each other on the basis of gill raker counts while S. sarda can be distinguished from all the others by the number of vertebrae.

The distribution of the larvae and juveniles of Sarda is shown in Figure 14. The capture of the larvae and juveniles of S. australis has yet to be recorded in the literature. Whitley (1964) noted that the smallest S. australis in the Australian Museum was 19.8 cm and was caught off New South Wales.

Records of capture of juvenile S. chiliensis is shown in Table 7. Table 7 includes a record of two larvae 2.9 and 3.5 mm long which Klawe (1961b) could not determine whether they were S. chiliensis or S. orientalis. Other than the pre-larval stages which Barnhart (1927) and Orton (1953a, 1953b) reported on, and the two larvae recorded by Klawe, the only other larvae of Sarda reported from the eastern Pacific are those by Sokolovskii (1971). Sokolovskii reported the capture of six larvae ranging from 7 to 13.8 mm at an ichthyoplankton station in the waters off Baja California. It can be seen from Table 7 that juvenile S. chiliensis in the northern hemisphere has been found off Baja California between lat. 22° and 26°N. In the southern hemisphere they have been found along the coast of Chile and Peru between lat. 13° and 25°C.

Table 7

Records of larval S. orientalis are even fewer. Gorbunova (1963) recorded the capture of a larva 11.56 mm long from off the northwest coast of Australia in the Indian Ocean. Elsewhere in the Indian Ocean Jones (1960) reported specimens 80, 89, 174, and 262 mm in total length from Vizhingam on the west coast of India. In the Pacific Ocean juveniles ranging in length between 75 and 100 mm are reportedly caught in waters adjacent to southern Kyushu (Yabe et al. 1953) and Kishinouye (1923) reported a specimen 170 mm taken off Wakayama Prefecture, Japan. Juveniles from the stomachs of predators have been recorded from Hawaii (unpublished data, Honolulu Laboratory).

Mayorova and Tkacheva (1959) state that S. sarda pre-larvae and larvae occur in the same regions as the fertilized eggs in the Black Sea. Figure 8 shows that fertilized eggs of S. sarda are widely distributed in the Black Sea thus indicating that larval bonito are also widely distributed. The larvae were more abundant at a depth of 5 m than at the surface. Mayorova and Tkacheva also noted that juvenile S. sarda 10-95 mm long were distributed over a vast area of the Black Sea in waters from 80 to 100 miles from the coast. In the Sea of Marmara, however, plankton tows did not reveal any S. sarda larvae although fertilized eggs in all stages of development were plentiful (Demir 1963).

Elsewhere, larvae of *S. sarda* have been reported from the Mediterranean Sea northwest of Oran by Ehrenbaum (1924), in the Alboran Sea by de Buen (1932) and more recently freshly-hatched pre-larvae were collected near the Balearic Islands by Duclerc et al. (1973). In the Atlantic Ocean larvae have been found off Cuba (Gorbunova and Salabarria 1967), and a juvenile measuring 34 mm has been recorded off the South Carolina coast (Klawe 1961a). Two juvenile *S. sarda* 64 and 67 mm in total length were also captured in the Gulf of Mexico (Klawe and Shimada 1959).

Information on the pre-adults of *Sarda* is fragmentary for most of the species. The smallest *S. australis* on record is a specimen 19.8 cm deposited in the Australian Museum (Whitley 1964). Specimens of *S. chiliensis* ranging up to 20 cm have been captured by various methods along the coastline in the eastern Pacific in both the northern
Table 7 and southern hemisphere (Table 7). Vildoso (1966) sampled bonito from the Peruvian fishery ranging upward from 20 cm and Barrett (1971) reported bonito of about 15 cm taken with anchovy catches at Arica, Chile. In southern California pre-adult *S. chiliensis* 15.2 to 25.4 cm (6-10 in.) are first seen by the bait fishermen in the early summer (Frey, 1971).

Yabe et al. (1953) reported that 75 to 100 mm *S. orientalis* are caught in waters around southern Kyushu. They also reported on *S. orientalis* landed at the port of Aburatsu, Japan ranging in size from 161 to 348 mm. Pre-adult *S. orientalis* occasionally appears in large numbers in the Indian Ocean. Jones (1960) reported large catches of fish ranging in length from 160 to 200 mm off the west coast of India between Trivandrum and Cape Comorin. Gnanamuttu (1966) recorded the occurrence of S. orientalis ranging from 240 to 260 mm in total length off the northeast coast of India. In the waters around Sri Lanka the commercial fishery lands fish ranging upwards from 20 cm (Sivasubramaniam 1969).

S. sarda from 6 to 18 cm long are captured in varying numbers in the Dardanelles, the Bosporus, the Sea of Marmara, and the Black Sea nearly every year in July-August (Demir 1963). The abundance of pre-adults in this size range apparently is a good indicator of the future abundance of fish 25 to 38 cm long which are the basis of an important Turkish fishery that takes place starting in September in the same areas. Pre-adults 8-12 cm long have been captured in large numbers in the Aegean Sea (Serbetis 1955) and Belloc (1954) discussed the occurrence of S. sarda 7.5 to 20 cm long caught in the Gulf of Naples and the Gulf of Catania and 15-25 cm long fish in the Bay of Biscay.

The capture of pre-adults 20-30 cm long has been reported from the Atlantic coast of France (De la Tourrassee 1957), and 25-35 cm fish have been taken commercially together with mackerel in the Miramichi estuary in the Gulf of St. Lawrence (McKenzie 1959). Klawe and Shimada (1959) reported the capture of two specimens 64 and 67 mm long in the Gulf of Mexico. Young S. sarda 5 to 6 in. long (12.7-15.2 cm) have been taken off Orient, New York (Nichols and Breder 1927).

Adults. The general distribution of the four species of Sarda has already been discussed. S. australis is known only from Australia and Norfolk Island. S. chiliensis is widely distributed along the coast of North and South America but is restricted to the eastern Pacific. S. orientalis is known from widely scattered areas in the Pacific Ocean and occurs in the Indian Ocean and the Red Sea. S. sarda occurs on both sides of the Atlantic, in the Gulf of Mexico, the Mediterranean, and the Black Sea. A number of studies has been made on the variability within each of the species except for S. australis.

Godsil (1955) compared specimens of S. orientalis from Japan and specimens from the eastern Pacific population which was then known as S. velox. He concluded that it would be possible to distinguish fish from the two areas but that there was no justification for a specific separation and that more studies should indicate that S. velox should be a synonym of S. orientalis. Silas (1964) summarized meristic counts

Table 8

obtained for S. orientalis from various areas (Table 8) and concluded that the data were not comprehensive enough to show significant differences. Collette and Chao (1975) made a detailed morphometric comparison of specimens from the population in Japanese waters and

Table 9

from the eastern tropical Pacific (Table 9) and concluded that there are some differences in certain characters. They state, however, that based on available material there appear to be no significant anatomical or meristic differences among the populations in different areas.

Collette and Chao (1975) made a thorough summarization and investigation of the variability between the northern and southern hemisphere S. chiliensis. Although these two populations are geographically separated and genetically isolated from each other they are virtually identical with each other anatomically. Walford (1936), Hildebrand (1946), and Kuo (1970) investigated the difference in the corselet length between the southern and northern populations of S. chiliensis. Walford found the character usable in separating the populations but Hildebrand and Kuo concluded that the character was not reliable.

Collette and Chao (1975) found only small morphometric differences between northern and southern S. chiliensis. Meristically, they found that the total number of vertebrae was the best distinguishing character between the two populations: the northern population has more vertebrae than the southern population. The mean number of vertebrae for the northern population has been given as 44.9 by Collette and Chao, 44.8 by Kuo (1970), and 45 ±0.47 by Vildoso (1963b). For the southern population Collette and Chao found the mean vertebral number to be 44.2, Vildoso, 44.15 ±0.40, and 44.21 ±0.40, and Kuo, 43.4.

A detailed analysis of the geographic variation in S. sarda was also done by Collette and Chao (1975). They compared S. sarda occurring in five geographic areas: North and South America, northeast Atlantic (Scandinavia, Atlantic Europe, and the Azores), Mediterranean

Sea (including the Black and Adriatic Seas), and Gulf of Guinea (extending south to South Africa). They found varying meristic and morphometric differences between and among the populations in the five areas.

From all indications it appears that all the species of Sarda are closely associated with the coast where the ocean environment may be subject to rapid changes. Demir (1963) states, however, that S. sarda cannot tolerate sudden changes in environment but they can adapt to gradual changes in temperature ranging from 12° to 27°C and salinities between 14°/₀₀ and 39°/₀₀. S. sarda have been taken in the Miramichi Estuary, Gulf of St. Lawrence, where the conditions must surely be less than oceanic. S. orientalis has been found in waters ranging from 13.5° to 23°C (Kishinouye 1923).

The relationship of S. chiliensis with the other species occupying the same areas off southern California are not clear. However, recent changes in the species composition of pelagic fish stocks off California shores may involve the bonito as well as sardine, Sardinops caeruleus, and anchovies, Engraulis mordax (Frey 1971). Presumably these changes would involve the ability of the various species to compete with one another for food and space. Behavior studies on S. chiliensis indicate that they can compete very well with other species in obtaining food. In a fish tank containing Pacific barracuda, Sphyraena argentea, yellowtail, Seriola dorsalis, and tarpon Megalops atlantica, S. chiliensis was the first species to reach and ingest food tossed onto the surface (Magnuson and Prescott 1966). Magnuson and Prescott note that the high speed of S. chiliensis gave them an advantage over the other species in a "scramble" type of competition.

In the Indian Ocean adult S. orientalis are often caught together with Euthynnus affinis, Auxis thazard, Kishinoella tonggol, and Scomberomorous spp. and presumably compete with these species for food (Silas 1963). Demir (1963) states that all predatory fishes and dolphins are potential competitors of S. sarda including Delphinus delphis ponticus, Tursiops tursio, Scomber scombrus, Trachurus mediterraneus, Temnoden saltatrix in the Black Sea, and additionally, Scomber colias, Auxis thazard, and Euthynnus alletteratus in the Sea of Marmara.

Records of parasitism on bonitos include a trematode, Didymozoon pelamyzis, from the gill lamella of S. sarda from the Black Sea, Sea of Marmara, and the Mediterranean (Dawes 1946; Demir 1963). Larvae of Callitetra rhynchus gracilic have been found in the body cavity of Livoneca sp. from the gill lamella of S. sarda (Postel 1954). Vervoort (1971) found a copepod Ceratocolax euthynni from S. sarda. Silas (1967) and Silas and Ummerkutty (1967) gave a detailed listing of the parasites of scombroid fishes including Sarda (Table 10).

Table 10

Other miscellaneous observations have been made on the bonitos. Cushing (1964) reported on unpublished results of experiments to determine blood factors in S. chiliensis. It was reported that a blood factor in S. chiliensis can be detected by a lectin, Dolichos bifloris. It was further shown that a significant difference exists in the frequencies of fish reacting positively to this lectin in samples of larger and smaller fishes. The reason for this difference has not been determined. Carey et al. (1971) found that S. sarda body temperature was warmer than the surrounding water temperature. They made measurements on three specimens and noted that their body temperatures were 21.0°, 20.5°, and 20.5°C whereas the surface water temperature was 19.2°C. According to Carey et al., the S. sarda possess a countercurrent heat-exchange mechanism for conserving metabolic heat and raising their body temperature. Matsumoto et al. (1969) described a stripeless S. chiliensis. Barrett and Williams (1965) determined the blood hemoglobin level of nine S. chiliensis. The hemoglobin level ranged from 11.2 to 15.3 gm per 100 ml and averaged 12.9 gm per 100 ml.

Magnuson and Heitz (1971) examined the relation between the gill raker morphology and the food habits of scombrid fishes, including S. chiliensis. In the past, the high diversity of food organisms in the stomachs of scombrids gave rise to the opinion that scombrids are nonselective feeders. However, Magnuson and Heitz point out that selectivity does exist in terms of food size in scombrid food habits in that the stomach contents of small and large fish of the same species were dissimilar. They suggest that larger predators have a reduced ability to catch small prey (crustaceans) because of a relatively large gill gap. Among scombrids of the same size *S. chiliensis* and *S. orientalis* had the largest gill gaps (1.8-3.3 mm). The relative unimportance of crustaceans in the food habits of *S. chiliensis* noted by Pinkas, Oliphant, and Iverson (1971) could be related in part to the large gill gaps in this species.

AGE AND GROWTH

There is almost nothing in the literature on the age and growth of *S. australis* except that they grow to 91.4 cm (36 in.) (Ogilby 1954).

In the waters between southern California and northern Baja California *S. chiliensis* spawns between January and May and the pelagic fertilized eggs take about 3 days to hatch. Young *S. chiliensis* are first observed in the early summer when they are 15.7 to 25.4 cm (6-10 in.) and by the following spring they are about 38.1 cm (15 in.) long and weigh from 0.7 to 0.9 kg (1.5 to 2 lb). In the fall these fish may weigh 1.4 kg (3 lb) or more and by the following year in May, they may weigh 2.7 to 3.2 kg (6-7 lb). When they are 4 years old they are 71.1 cm (28 in.) and weigh about 5.4 kg (12 lb) (Frey 1971).

The growth data given above are probably the result of random observations and not a systematic study. Kuo (1970) made a detailed study of the growth of *S. chiliensis* from southern California waters and from Peru based on otoliths (Fig. 15). Kuo fitted the von Bertalanffy growth function to his data and found that the growth rate of bonito from the two areas did not differ for age 1, 2, and 6 fish but that there was a significant difference in growth for fish 3 to 5 years old. Length-age data for northern and southern bonito are given in Table 11. The growth equations obtained for the northern and southern population, respectively, were :

Fig. 15

Table 11

$$L_t = 2661\ [1 - e^{-0.038(t + 0.60)}]$$

and

$$L_t = 1014\ [1 - e^{-0.154\ (t + 0.015)}]$$

where L_t is fork length in millimeters and t is age in years.

The maximum size of *S. chiliensis* in the northern hemisphere is about 101.6 cm (40 in.) and about 11.3 kg (25 lb). There is an unverified record of a 16.8 kg (37 lb) specimen but bonito over 11.3 kg are rare (Frey 1971). In light of these observations the L_∞ of 2,661 mm obtained by Kuo (1970) for the northern hemisphere bonito seems unreasonably large. The age-length data given by Frey (1971) and Kuo (1970) are also quite different. Frey gives the length of a 4-year-old bonito from the northern population as 71.1 cm (28 in.) whereas Kuo's data show that a 4-year-old bonito has a mean length of 43.3 cm.

Barrett (1971) determined the length-weight relationship

Table 12 for the southern S. chiliensis population (Table 12). The relationship was determined from a sample of 595 bonitos from the commercial fishery based at Iquique, Chile. Barrett found no significant difference in the exponent (b) between sexes and therefore combined the data for the sexes.

The maximum size of S. chiliensis in the southern hemisphere is not well defined. Barrett (1971) sampled the fish landed in the Chilean fishery and noted that the maximum size of fish landed was 74 cm. In an earlier study de Buen (1958) found fish as large as 79 cm. Mann (1954) stated that Chilean bonito grows larger than 80 cm.

Very little information is available on the age and growth of S. orientalis. Yabe et al. (1953) presented data on the mean lengths of six samples of S. orientalis ranging in length from 161 to 348 mm that were sampled at Aburatsu, Japan over an irregular period from

Table 13 August 26 to October 17, 1950 (Table 13). The mean lengths of fish

Fig. 16 from the six samples are plotted against sampling date in Figure 16. A straight line was drawn by eye through the data points. If the line is a reasonable representation of the growth of S. orientalis between 161 and 348 mm, it indicates a mean gorwth of about 2.6 mm per day. Harada et al. (1974) made observations on the growth of larval and juvenile S. orientalis in artificial fertilization experiments. They determined that the fertilized eggs hatched in about 50 h in water temperature ranging from 20° to 24°C and that the newly hatched larvae were 4.1 to 4.3 mm in total length. The larvae grew to 14 mm in total length in 10 days to 74 mm in 20 days, to 106 mm in 30 days, to 219 mm in 42 days, and to 290 mm in total length in 99 days after hatching. This growth rate represented the fastest growth under the conditions provided in the experiment. The growth rate of larval and juvenile *S. orientalis* indicated by these experiments was about 2.9 mm per day during the 99-day period. This growth rate compares favorably with that suggested by the data presented by Yabe et al. (1953). Harada, Kumai, and Nakamura (1973) presented some data on the growth of *S. orientalis* kept in artificial enclosures. Thirty-three *S. orientalis* 40 cm long and 675 gr in weight grew to 50 cm and 1,500 gm in about 4 months.

Sivasubramaniam (1966) determined the length-weight relationship for *S. orientalis* from the waters around Sri Lanka (Ceylon) in the Indian Ocean (Table 12). The length-weight relationship is based on a sample of 25 fish and although Sivasubramaniam did not give the size range of the fish, his Figure 14 indicates that the fish ranged from about 24 to 51 cm.

With regard to the maximum size of *S. orientalis*, in the Indian Ocean the large specimens off the southwest coast of India are generally less than 70 mm long (Silas 1964). Smith (1949) states, however, that *S. chiliensis* (= *S. orientalis*) grows to at least 101.6 cm (40 in.). In Japanese waters *S. orientalis* grows to about 80 cm and 1.5-3.0 kg (Kishinouye 1923).

Monthly length data for young S. sarda from the Black Sea

Table 14 are given in Table 14. The data were given as the ranges of lengths sampled during monthly periods. The midpoint of the length ranges were

Fig. 17 plotted in Figure 17 to represent the growth of S. sarda ranging in length from 3 to 42 cm in the Black Sea. As would be expected there is some variation in the data presented by the various investigators, but the variation was relatively small. In gross terms these data suggest that S. sarda grew about 252 mm in 90 days (7.5-11 cm in July to 30.5-38.5 cm in October) or at a growth rate of 2.8 mm per day.

Demir (1963) summarized the age-length relation of S. sarda

Table 15 determined by various authors (Table 15). Subsequent to the publication of Demir's paper Kutaygil (1967) published some data on age-length

Table 16 determinations on S. sarda (Table 16). Kutaygil used otoliths to age the fish and also back calculated the lengths of the fish at various ages. He noted that bonito from different year classes had different growth rates.

Zusser (1954) in contrast to the other investigators gave age-length relations for fish up to 9 years of age. Demir (1963), however, remarked that the age-length relations given by Zusser were probably erroneous. Although several age-length relations for S. sarda are available, as far as is known no one has tried to fit a growth curve to these data.

Rodriguez-Roda (1966) computed the length-weight relation of S. sarda landed at the southern Spanish port of Barbate (Table 12).

The largest *S. sarda* is about 85 cm in the Black Sea. Of *S. sarda* in the western Atlantic, Bigelow and Schroeder (1953) states that they grow to about 91.4 cm (36 in.) and 4.5 to 5.4 kg (10-12 lb). Hammond and Cupka (1975) note that *S. sarda* seldom exceeds 6.8 kg (15 lb).

NUTRITION

Only a few miscellaneous observations are available on the feeding habits of the Australian bonito. Particularly during the winter months *S. australis* occurs commonly in schools in the inshore coastal waters of Queensland and feeds on hardyheads, *Pranesus ogilbyi*, pilchards *Sardinops neopilchardus*, and anchovies, *Engraulis australis* (Grant 1972). Munro (1958) indicated that they also feed on mackerel scad, *Trachurus mccullochi*.

A detailed study of the food habits of *S. chiliensis* was conducted by Pinkas et al. (1971) based on a total of 1,498 stomachs collected in 1968 and 1969 from fish captured in nearshore waters of southern California and Baja California. Their study clearly showed that the northern anchovy, *Engraulis mordax* was the major food item in the diet of *S. chiliensis*. The common squid, *Loligo opalescens* ranked next in importance and miscellaneous fish and a few crustaceans made up the small remainder of the diet of *S. chiliensis*. A summary of the

Table 17 occurrence and volume of the food items is given in Table 17. There was a seasonal variation in the importance of the common squid in the

the diet of S. chiliensis. Squid was most important in the first and second quarter of the year but was less important in the third quarter of the year. This seasonal pattern of the importance of squid in the bonito's diet was related to the seasonal concentrating behavior of squid during its reproductive cycle.

Information on the food and feeding habits of S. orientalis in Japanese waters are fragmentary. Yabe et al. (1953) examined 18 stomachs from juvenile S. orientalis in southern Kyushyu waters. Fifteen of the 18 stomachs were empty, 2 of the stomachs contained Engralis japonicus remains and 1 stomach contained unidentifiable fish remains. Yokota et al. (1961) examined stomachs of 24 S. orientalis caught in about the same area and found a total of five saury, 1 Sphyraena sp., 1 squid, and 1 carangoid in the stomachs.

Kumaran (1964) investigated the food habits of S. orientalis in the Indian Ocean based on 43 specimens ranging in length from 85 to 305 mm. The most important single food item was an anchovy, Anchoviella commersonii. Fishes of lesser importance in the diet were Leiognathus insidiator, Decapturus russelli, and Sardinella sp. Kumaran noted that the variety of food organisms was smaller in the stomachs of S. orientalis as compared with Euthynnus affinis affinis, and Auxis thynnoides. He gave as the reason for this the fact that all the S. orientalis specimens were collected from a single locality. Sivasubramaniam (1969) looked at the stomachs of 11 S. orientalis caught in the waters around Sri Lanka that had food in them. Nearly 60% by volume of the food consisted of a clupeiod fish, 18% cephalopod mollusk (squid and octopus), 15% decapod crustacea and 7% miscellaneous items including unidentified fishes.

More information is available on the food and feeding habits of S. sarda including information on larval and juvenile stages. Larval S. sarda about 5 mm long start active feeding even before the yolk sac is completely absorbed. Larvae larger than 6-7 mm feed on relatively large organisms including fish larvae but prefer copepods. Juveniles larger than 18-20 mm feed on the larvae of anchovy, horse mackerel and S. sarda (Mayorova and Tkacheva 1959). Zusser (1954) reported a Pseudocalanus in the stomach of a 7.2 cm juvenile and a 4.5 cm long anchovy in a 8.7 cm juvenile. Demir (1963) found a single 3.5 cm horse mackerel in 44 stomachs of juvenile S. sarda ranging in length from 6.5 to 16 cm taken in the Black Sea, the Sea of Marmara, and the Bosporus from 1957 to 1959. Because of the predponderance of empty stomachs Demir believes that the juveniles, like the adults, regurgitate their food at the moment of capture.

Demir (1963) states that adult S. sarda is an insatiable predator that feeds diurnally. Feeding in Turkish waters is much more vigorous in the early morning and towards evening. Demir notes that the feeding season is usually from the second half of April to the end of October in Turkish waters. S. sarda adults primarily feed on smaller schooling fishes, the species depending on the locality (Table 18).

Table 18

In the western Atlantic, in the Gulf of Maine S. sarda prey on mackerel, alewives, menhaden, other small fishes such as launce and silversides, and squid (Bigelow and Schroeder 1953). Boschung (1966) examined the stomachs of 52 S. sarda taken during a fishing tournament in the Gulf of Mexico and noted that the fish had fed on a variety of fishes and invertebrates. They included: a clupeid (probably Harengula pensacolae), harvest fish, Peprilus paru; spot, Leiostomus xanthurus; anchovies, Anchoa sp.; mackerel, Scomberomorus sp.; sea robin, Prionotus sp.; squid, Loligo sp.; shrimp, Penaeus sp.; and unidentified fishes.

S. sarda can swallow relatively large prey and the adults and juveniles are both cannibalistic. There is a record of a 38 cm S. sarda from the stomach of a 63 cm fish (Zusser 1954).

BEHAVIOR

A detailed, systematic study on the behavior of captive S. chiliensis in a large fish tank at Marineland of the Pacific, Palos Verdes, California was reported on by Magnuson and Prescott (1966). The courtship and spawning behavior of S. chiliensis as reported on by Magnuson and Prescott was discussed earlier in another section. Further results of their observations are detailed below.

About 25 S. chiliensis, out of 60 that were caught near Marineland of the Pacific became established in the tank and were used in the observational program. Of the 25 survivors, 10 fish lived for 38 months in captivity. The tank used was part of a public display and contained more than 800 other fish of over 40 species. Part of the daily routine included five 15 min shows in which a diver entered the tank to feed the fish. Magnuson and Prescott noted that the S. chiliensis "appeared habituated to show announcements and background music as well as to sounds made by tapping on the tank windows and sides." These observations indicate that S. chiliensis are able to adapt to various environmental conditions.

In the Marineland of the Pacific tank S. chiliensis swam continuously against the current averaging 88.2 cm/sec at a tail-beat frequency of 1.42 beats/sec when not feeding or courting. S. chiliensis apparently are less powerful swimmers than skipjack tuna and yellowfin tuna. In fish about the same length (bonito = 57 cm; skipjack tuna = 57 cm; yellowfin tuna = 52 cm) Magnuson and Prescott noted that at 4 tail beats/sec S. chiliensis traveled only 170 cm/sec whereas K. pelamis averaged 230 cm/sec and T. albacares averaged 240 cm/sec.

Magnuson and Prescott observed nine miscellaneous behavior patterns in S. chiliensis: mouth closure (long), mouth closure (short), snap, yawn, quick swim, lean, bend, jerk, and defecation. They discussed in detail the possible functions of all these miscellaneous behavior patterns. They noted that mouth closure (long) movements could have been associated with olfaction or gill ventilation; snaps following a yawn or a quick swim with a drinking movement; leans may have a function as a social releaser in schooling; and bends and jerks may be associated with food passing through the alimentary canal.

No such detailed behavioral observations have been made on the other species of Sarda. Inoue et al. (1967) were able to maintain S. orientalis up to 438 h in a pool. Inoue et al. (1970) determined that S. orientalis was negatively phototactic to both sunlight and artificial light. The swimming speed of the fish (size not given) ranged from 0.3 to 0.56 m/sec.

As for schooling behavior, all the species of Sarda generally appear to be schooling fish. S. australis occurs commonly in schools in inshore coastal waters of Queensland, Australia (Grant 1972). Frey (1971) states that the S. chiliensis of the northern hemisphere is a pelagic schooling fish. In Japanese waters, however, Tominaga (1943) stated that S. orientalis does not aggregate densely, rarely comes to the surface of the sea, and always swim around reefs or near a cape where the current is strong and that they never go out to the high seas. Conflicting observations are available on the schooling of S. orientalis in the Indian Ocean. Silas (1963) states that schools of adults and young appear along the southwest coast of India. Sivasubramaniam (1969), however, notes that S. orientalis is very seldom seen in surface schools of mixed tunas and when they are caught from mixed schools the catch never exceeded six fish. All of the observations on S. sarda indicate it is a schooling fish. Demir (1963) states that S. sarda gathers in dense schools of many thousands of fish of about the same size. S. sarda in the western Atlantic is a schooling fish, traveling in large aggregations and is usually found at the surface, although occasionally it is caught near the bottom (Idyll and de Sylva 1963). Of S. sarda that occurs in the Gulf of Maine, Bigelow and Schroeder (1953) says, "The bonito is a strong, swift, predaceous inhabitant of the open sea and like its tribe travels in schools."

RESOURCE

The four species of Sarda are the bases of many fisheries throughout the world. Detailed information in the fisheries, however, are available only from a relatively few fisheries. Sarda australis, being found only along the coast of eastern Australia and around Norfolk Island east of Australia, is the object of a small incidental fishery in Australia. According to statistics published by FAO in the Yearbook of Fishery Statistics, the Sarda chiliensis of the northern hemisphere

in the eastern Pacific is the basis of fisheries by Mexico and the United States. The southern hemisphere S. chiliensis is exploited by Chile and Peru. Landings of S. orientalis do not appear in the FAO Yearbook of Fishery Statistics (see FAO 1974). Relatively small amounts of this species are taken throughout its distributional range and it is not the basis of any well-developed fishery. S. sarda on the other hand appears to be exploited throughout its distributional range in fisheries of various sizes. In the Atlantic Ocean the FAO Yearbook lists 18 countries reporting landings of S. sarda. Thirteen countries report landings of S. sarda from the Mediterranean and Black Seas. The total landings of S. chiliensis ranged from 53,300 to 94,100 MT during 1965 to 1973 and was greater than the total landings of S. sarda in each of 9 years. The landings of S. sarda ranged from
Fig. 18 25,000 to 65,700 MT during the same period (Fig. 18) (FAO 1974).

SARDA AUSTRALIS

There apparently is no well-developed fishery for S. australis in Australia. It occurs on the eastern coast of Australia along Queensland, New South Wales and as far south as Port Fairy in Victoria. Serventy (1941b) states that "the bonito appears to be numerous enough to be regarded as a commercially important tuna, and a fishery could be maintained throughout the year on the eastern coast." Marshall (1965) noted that S. australis is destined to be of economic importance in Australia some day. It is of interest that there seems to be a difference of opinion on the food quality of *S. australis*. Grant (1972) states that the flesh of the Australian bonito is dark red and its edible qualities are not highly regarded, whereas Marshall (1965) claims that the flesh is light colored, of delicate flavor and of good canning quality. *S. australis* is generally taken incidentally by trollers who use the fillets as snapper bait or by sports fishermen who use it as bait for billfishes and sharks.

As noted earlier, very little is known about this species. Marshall (1965) says that *S. australis*, along the coasts of Queensland and New South Wales, are found in "great schools throughout the year." Grant (1972) states that this species occurs in schools in Queensland waters expecially during the winter months.

There is no information on the size or age of the fish except for generalized observations. The species grows to about 3 ft (91.4 cm) but the average size of fish caught is about 16 or 18 in. (40.6 or 45.7 cm) (Marshall 1965). Grant (1972) states that the usual size taken is 4-5 lb (1.8-2.3 kg).

The annual landings of *S. australis* from 1955 to 1973 are
Fig. 19 shown in Fig. 19. As can be expected from an incidental type fishery the landings are quite erratic and in some years no fish are landed at all. No information is available on the utilization of the *S. australis* that are landed.

SARDA CHILIENSIS

Fisheries

The northern hemisphere *S. chiliensis* is most abundant in the area from Point Conception, California, to Magdalena Bay, Baja California (Frey 1971) and presumably this is the area in which the California-Mexico fishery for this species is conducted. Although the market for this species is limited, this bonito has been commercially fished in California waters since around 1900. Since 1965 over 90% of the California catch has been made north of the California-Mexico border. The mean monthly landings of *S. chiliensis* in California for the 5-year period from 1968 to 1972 indicate that the fishery may be
Fig. 20 somewhat seasonal (Fig. 20). Although bonito was landed throughout the year in this 5-year period peak landings were experienced in August-October. Only a small quantity of bonito is sold fresh and most of the catch is canned like tuna and for use as pet food.

The California fishery uses various kinds of gear to catch *S. chiliensis* including trolling gear and purse seines. The largest landings are made by the local purse seiners and the trolling fleet lands a lesser amount. The high seas purse seiners may occasionally catch bonito to fill out the loads of other tunas (Frey 1971).

In a study of the California sport fishery it was found that *S. chiliensis* made up the biggest part of the fish catch by a single species (Pinkas, Oliphant, and Haugen 1968). Bonito are taken in party and private boats, from piers and jetties and from the shoreline. They will strike at most bait and lures and fishing techniques for bonito varies from still fishing to trolling.

The southern hemisphere population of S. chiliensis is exploited by the fisheries of Peru and Chile. The Peruvian fishery extends along the coastline from the port of Mancora (ca. 04°S, 81°W) to the port of Ilo (ca. 17°30'S, 71°15'W) and the Chilean fishery extends from Arica (ca. 20°15'S, 70°15'W) to Talcahuano (ca. 37°45'S,
Fig. 21 73°W) (Fig. 21). Bonitos are landed throughout the year in Chile and
Fig. 22 Peru but both fisheries have seasonal peaks (Fig. 22). It is of interest, however, that the seasonal peak is in October-November in Chile whereas it occurs in January in the Peruvian fishery.

The Chilean bonito fishery prior to 1964 was conducted almost entirely on an "artisanal, semi-industrial day-fishery basis" primarily from the ports of Iquique and Antofagasta (Barrett 1971). The vessels used in this fishery is known as "faluchos" and are about 10 m long. They fish principally with floating gill nets or with small purse seines called "bolinches," which are hauled manually. During the period from 1964 to 1964 two modern 36-m tuna/bonito seiners and eight other bonito/tuna seiners entered the fishery. All the new purse seiners in the bonito fishery have power launches and power blocks and use nylon nets 300-400 fathoms (ca. 549-732 m) long and 40-60 fathoms (ca. 73-110 m) deep.

The fishing gear and vessels of the Peruvian fishery have been described by Ancieta (1963).

Population Structure

Kuo (1970) obtained sex ratio data on *S. chiliensis* that were caught from San Diego waters during a 1-year period between 1964 and 1968. The percentage of females in the monthly samples varied from 37.5% to 70.3% and averaged 49.9% for the year. He found that the monthly sex ratios did not differ significantly from 1:1 except for the sample from the month of May.

Fig. 23 Footnote 3 The length-frequency distributions of *S. chiliensis* caught by sport fishermen from southern California waters is shown in Figure 23. The figure was prepared from data provided by Dr. Ching-Ming Kuo[3] and are based on part of the *S. chiliensis* sample he used in his study (Kuo 1970). Kuo measured a total of 929 *S. chiliensis* from southern California waters ranging in length from 331 to 750 mm. Both the male and female length-frequency distributions were similar: a single prominent mode was present between 510 and 540 mm.

Footnote 4 Fig. 24 McCall, Stauffer, and Troadec (MS[4]) presented *S. chiliensis* length-frequency data for the California commercial and party-boat fisheries in 1973 (Fig. 24). They state that various segments of the fishery exploit different parts of the bonito population which suggested an uneven geographical distribution of various age groups. It was indicated that, generally, the older fish were more available near

Mexico and in offshore waters, although large fish were also taken in the fall off Santa Barbara. The party-boat fishery caught bonito smaller than 60 cm but the long-range party boats fishing off Mexico took older fish. The commercial fishery took larger fish. It is of interest that the modal size taken by the party boats during the period 1964 to 1968 was larger than that taken in 1973.

The percentage of female S. chiliensis from eight samples of 100 bonito each obtained from the commercial catch landed at Iquique, Chile varied from 47% to 65% between September 1968 and October 1969 (Barrett 1971). Barrett noted that more females were present in the catch during September-October, the spawning season, but stated that more data were needed to verify this observation.

Barrett (1971) presented bonito length-frequency data from Chilean landings and noted that the larger bonito, in about the 62 cm modal group, made up most of the catch in September-October 1968 (Fig. 24). Most of the bonito in the April, August, September, and October 1969 landings, however, were smaller, 48-52 cm, and the larger fish were present only in July and August. Barrett further noted that the preponderant 72-74 cm modal group in 1953 reported on by de Buen (1958) was almost absent in the 1968 and 1969 samples, which suggested that the older fish were no longer present in the fishery in 1968 and 1969.

Fig. 24

Subpopulations

It appears that the *S.chiliensis* found off northern Mexico and southern California comprise a single homogeneous stock. Tagging experiments conducted by the California Department of Fish and Game indicate that the bonito does not make long migrations. Although some tagged fish have traveled as far as 250 miles, most of the tagged fish have been recaptured in the vicinity of release (Frey 1971).

From all indications it appears that the northern and southern hemisphere populations of *S. chiliensis* are completely separate with little or no interchange. They are geographically separated from each other and there are certain meristic and morphological differences between the two populations. For example, the northern hemisphere population of bonito has more vertebrae than the southern hemisphere population (Vildoso 1963b; Kuo 1970; and Collette and Chao 1975).

Some preliminary work has been done on *S. chiliensis* to determine if protein differences attributable to genetic variation could be useful in identifying population units. Barrett and Williams (1967) experimented with gel-electrophoresis of the soluble eye lens proteins of bonito in an attempt to find such genetically-controlled differences. They did find polymorphism of the soluble lens proteins for the bonito. They also calculated the gene frequencies together with their expected distributions and found conformity to the Hardy-Weinberg principles. However, Barrett and Williams also found that the distribution of the apparent phenotypes were related to the lengths of the bonito. They concluded therefore that ontogenetic factors caused the observed polymorphism and that gel-electrophoresis of the soluble eye lens proteins, under the conditions used in their experiment, was not a useful technique in differentiating population units of bonito.

Smith (1971) examined the electrophoretic patterns of nuclear lens proteins from S. chiliensis and also found polymorphism in the protein patterns. He suggested that there could be another explanation for the observed distribution of phenotypes than that suggested by Barrett and Williams (1967).

It is not clear whether the stocks of S. chiliensis off Peru and Chile are independent of each other or whether they form a single homogeneous population. The center of bonito abundance off Peru is from Chimbote to Pisco (Ancieta 1963) which is centrally located between the north and south borders of Peru. The center of abundance off Chile is closer to the northern boundary of Chile near Arica, Iquique and Antofagasta (Barrett 1971). In other words, the stocks of S. chiliensis off the coasts of Chile and Peru are at least contiguous with each other. In his attempts at determining a stock production model for the Chilean bonito, however, Barrett (1971) apparently considered only the Chilean stock. He listed as one of his recommendations, however, that future studies should include a "determination of relation, if any, with the Peruvian fishery for bonito."

Landings

Fig. 25 Figure 25 shows the landings of *S. chiliensis* in California and Mexico. *S. chiliensis* landed in Mexico makes up only a small proportion of the total landings in the northern hemisphere. From 1965 to 1973 the California landings constituted from about 77% to 100% of the total landings of bonito north of the equator in the eastern Pacific. The annual landings have been erratic and, to some extent reflects the relative availability of the species in southern California and Mexican waters. The landings, however, do not reveal the condition of the stock because the bonito is caught incidentally or in lieu of more desirable species in the California fishery (Frey 1971).

Fig. 26 The California party-boat landings of *S. chiliensis* are shown in Figure 26. Here again the annual landings most likely do not reflect the condition of the bonito stock. The party-boat fishery is a multi-species fishery and many other species of fish in addition to the bonito are taken. Furthermore, the bonito is under a form of management in that sport fishermen may not possess more than 10 bonito per day. There is some indication that water temperature may affect the relative availability of bonito to the party-boat fishery in California waters. It was noted that the party-boat landings of bonito were lower in the 6-year period 1948-1953, which were cold water years in California (Young 1969).

[Page 63a follows]

The landings of S. chiliensis in the southern hemisphere fisheries of Peru and Chile are shown in Figure 27. The bulk of the landings are made in the Peruvian fishery. Chile's share of the southern hemisphere landings of bonito varied from about 2% to 15% of the total annual landings from 1965 to 1973. The annual Peruvian landings except for minor fluctuations increased steadily from 1941 and reached a peak of 104,000 MT in 1961. The landings, with minor fluctuations have been declining since then. Except for 1955 when the landings of bonito amounted to 7,500 MT, the annual landings in Chile were less than 5,000 MT during the period from 1940 to 1963. The landings increased sharply in 1965 and reached a peak in 1966 as the result of the entry of several new, modern purse seiners into the fishery in 1964-66 (Barrett 1971). The landings, however, have declined in subsequent years.

Fig. 27

Abundance

In the Chilean bonito fishery Barrett (1971) examined the relations among fishing effort, yield, and apparent abundance for the period from January 1965 to December 1969. Barrett recognized three different types of vessels, according to species objective, that fish bonito in the Chilean fishery: the anchovy, bonito, and tuna vessels. As the name implies, the anchovy and tuna vessels fished for bonito when anchovy and tunas, respectively, became less available and bonito more available. The bonito vessels fished primarily for bonito although

[Precedes page 63a]

they did also capture other species. Barrett used the data from the bonito vessels for his analysis. The data for the entire monitored fleet, however, showed the same trends as for the bonito fleet after they were standardized to that of the bonito vessels. He noted a steep downward trend in total catch, an upward trend in relative fishing intensity and a corresponding decline in apparent abundance in the fishery (Figs. 28, 29, and 30). The trend appeared to level off in 1969. Barrett stated that the decline has probably resulted from the effects of the fishery and not from fishery-independent factors.

Figs. 28,29, & 30

McCall et al. (MS[4]) related the indices of abundance of the northern hemisphere S. chiliensis obtained by Squire (1972) on aerial surveys with catch per unit of effort (CPUE), in terms of catch in numbers of fish per angler, for the California party-boat fishery. McCall et al. assumed that the aerial survey concentrated on the commercial fishing grounds since the surveys were designed to aid the commercial fishery, and thus reflected changes occurring in the past of the stock exploited by the commercial fishery. And since the length-frequency data showed that the party boats exploited younger bonito than the commercial fishery, they further assumed that the party-boat CPUE provided an index of pre-recruit abundance of fish before they are exploited by the commercial fishery approximated 3 years later. They computed a "combined" party-boat CPUE index which took into consideration mortality and recruitment and related it to the aerial survey day index for the period 1963 to 1972

(Fig. 30a). They concluded that the party-boat CPUE appears to be a valid indicator of recruitment to the commercially exploitable segment of the bonito stock, at least during this period. The party-boat CPUE from 1936 to 1973 indicated recruitment was very low before 1957 after which it increased sharply (Fig. 30b) (McCall et al. MS[4]). McCall et al. further state that S. chiliensis, for unknown reasons unrelated to fishing, became scarce during the early 1940's and that subsequently and until 1956, the party boats were dependent on migratory fish. They noted that after 1956 "large quantities of bonito moved into California waters and became re-established as a locally spawning population."

Stock Production Model

Barrett (1971) was unsuccessful in developing a stock production model, following Schaefer (1954), for the Chilean bonito fishery. He cited as the cause of this the fact that the necessary assumptions for this type of model were unsatisfied. One of the requisite assumptions of the model is a stable age and size distribution in the population. The rapidly occurring changes in the fishery since 1965 have likely made this assumption untenable, according to Barrett. Another factor that affected the development of the model was the apparent discontinuous seasonal availability of some size classes of bonito in the fishery. Barrett concluded that he could not determine whether the fishery was stabilized or in a state of overfishing and therefore recommended an accelerated research program on the Chilean bonito.

McCall et al. developed a surplus production model for the northern hemisphere bonito in California waters (Fig. 30c). They used total catch data and a combination of CPUE for the party-boat fishery and aerial survey index for the period 1963 through 1972 to develop the model. The model indicated that the northern hemisphere bonito is being harvested at or above the maximum sustainable yield. McCall et al. cautioned, however, that the assessment was confounded by the possibility of a density independent decline in recruitment. They noted that the California catch of *S. chiliensis* in 1973 appeared to be greatly in excess of the equilibrium yield. They state, however, that conclusions drawn from the production model must be viewed with caution since bonito fishing in California waters is influenced by ocean temperatures.

Because of the lack of necessary data, McCall et al. did not attempt a yield per recruit analysis.

SARDA ORIENTALIS

Fisheries for this species are not very well developed throughout its distributional range. The most recent FAO Yearbook of Fishery Statistics (FAO 1974) does not show any *S. orientalis* landings. The *S. orientalis* found in the tropical eastern Pacific between central Baja California and Peru is of little commercial importance and when caught may enter the catch statistic grouped with *S. chiliensis* (Pinkas 1961). This species is not very common around Hawaii and when landed the catches are not identified in the statistics published by the State.

In Japan S. orientalis occurs in waters south of central Honshu along both the Pacific and Japan Sea coasts. It is most abundant in the coastal waters of Kyushu (Kikawa and staff 1963). This species is taken by various gear including trolling gear, pole and line, purse seines, and set nets. There is no exclusive fishery for S. orientalis in Japan; it is taken together with species that inhabit or enter the coastal waters of Japan in multi-species fisheries employing various gear. The landings of this species are not identified in the statistics published by the Japanese Government. Apparently, landing records are maintained by prefectural "fishery guidance stations" but these statistics are presumably not published or not readily available.

Fig. 31 Figure 31 shows the mean monthly landings and catch rates for S. orientalis in waters off southern Japan. Both the landings and catch per trip of S. orientalis were relatively higher during the fall-winter months, suggesting that there are seasonal differences in the availability or abundance of S. orientalis off the coast of southern Japan. Table 19 gives the annual landings made at four ports in southern Japan, Tosashimizu, Muroto, Murotomisaki, and Aburatsu, from 1967 to 1974. Data on the size composition of the stock of S. orientalis in Japanese waters are almost non-existent. Yabe et al. (1953) presented measurement data on a small sample of S. orientalis landed at Aburatsu, Japan (Table 13).

Table 19

There apparently is a minor fishery for S. orientalis in the Philippines. Warfel (1950) made a survey of the outlook for the development of a tuna industry in the Philippines. He presented some statistics showing the landings (number of fish) of S. orientalis at three Philippine markets: 369 at Batangas, 2,308 at Iloilo, and 6,762 at Zamboanga. He indicated that most of the fish were taken in traps. In the "Fisheries Statistics of the Philippines" (Philippine Bureau of Fisheries 1970, 1971, and 1972) there is an entry for "bonito;" however, it is not clear what species or species that category refers to.

In the Indian Ocean minor fisheries for S. orientalis have been reported off the southwest tip of India (Silas 1964) in the Gulf of Aden along the coast of Somalia (Laevastu and Rosa 1963) and around Sri Lanka (Sivasubramaniam 1969). The bonitos are taken primarily by drift nets (gill nets) in India and Sri Lanka. In the Indian fishery stray specimens may be taken in April, May, and June; however, the main fishing season appears to be from about July to September (Silas 1963). In nearby Sri Lanka S. orientalis appears in the catches throughout the year off the south coast. Mature fish are taken along the northeast coast from June-August and off the south and southwest coast between September and February. The juveniles appear off the west coast usually during the southwest monsoon in June-August (Sivasubramaniam 1969). Sivasubramaniam presented length data for S. orientalis from the Sri Lanka fishery (Fig. 32). The average size of adult S. orientalis taken off southwest India was about 45 cm (Silas 1963).

Fig. 32

Sivasubramaniam (1969) concluded that the apparent abundance of S. orientalis around Sri Lanka was so low that it was not worth an attempt to develop a fishery for this species. He noted that not more than a few hundred pounds were taken in 1964 and he estimated that the annual catch was about a ton in 1969.

SARDA SARDA

Fisheries

There are commercial fisheries of varying sizes almost throughout the entire distributional range of S. sarda. Countries with fisheries for this species in the eastern and western Atlantic and in the
Table 20 Mediterranean and Black Seas are listed in Table 20. The list was compiled from the FAO Yearbook of Fishery Statistics (FAO 1974).

Demir (1963) summarized the fishing seasons for S. sarda in
Table 21 various areas (Table 21). Rodriguez-Roda (1966) summarized the fishing seasons in the Spanish fishery by various geographical areas in the
Table 22 eastern Atlantic and the western Mediterranean (Table 22). Apparently the fishing seasons in the Black Sea-Aegean Sea areas are related to the migrations of S. sarda. There is disagreement on the exact routes of the migration in certain areas, and the routes are unclear in other areas, but it is certain that S. sarda does migrate back and forth from the Aegean Sea, Sea of Marmara, and the Black Sea. According to Demir (1957) schools of S. sarda spend the summer in the Black Sea and the winter in the Sea of Marmara and the Aegean Sea. Thus, the fishing

season of May-October coincides with the time the migrating S. sarda are in the Black Sea in the summer. The fishing peaks of April-May and September-December in the Sea of Marmara coincides with the spring migrations of the bonitos from the Aegean Sea through the Sea of Marmara to the Black Sea and the fall return migration from the Black Sea to the Aegean Sea.

No information is available on the migration of S. sarda in the other areas of the Mediterranean and in the Atlantic Ocean. The seasonal development of the Spanish fishery in various areas of the western Mediterranean, however, suggests that S. sarda may be migrating to and from the western Mediterranean (see Table 22).

S. sarda are taken by trap net, purse seine, ring net, beach seine, gill net, trammel net, and hook and line (Demir 1963).

Population Structure

Rodriguez-Roda (1966) determined the sex ratio of four samples
Table 23 of S. sarda landed at the ports of Barbate and Tarifa, Spain (Table 23) in 1963 and 1964. The percent of females in the samples ranged from 26% to 57.1%. Postel (1955a) presented data on the monthly sex ratio
Table 24 of S. sarda from the eastern tropical Atlantic (Table 24). In the Gulf of Mexico a sample of 52 S. sarda was composed of 31 males and 21 females.

The length-frequency distribution of S. sarda from the Black Sea in the spring, 1955-58 is shown in Figure 33. It can be seen that the Black Sea landings in 1955 was dominated by a group of fish centered at a length of 45 cm. In the subsequent 2 years the same group of fish (1956 = 55 cm, 1957 = 60 cm, and 1958 = 65 cm) dominated the catch. This group of fish was the result of a strong year-class that originated in 1954 (Mayorova and Tkacheva 1959). Artuz (1959) also noted the same phenomenon. He sampled the landings at the Istanbul Fish Market and found that 3-year-old fish (1954 year class) dominated the landings in May 1957. His sample showed that the May 1957 landings were composed of 10.5% age I fish (1956 year class), 28.7% age II fish (1955 year class), 53.2% age III fish (1954 year class), and 7.6% age IV fish (1953 year class). Mayorova and Tkacheva (1959) also noted that a rich year class in 1938 also dominated the fishery in the Black Sea from 1938 to 1945.

Fig. 33

Length-frequency distributions of S. sarda landed at Barbate and Tarifa, Spain in 1963 and 1964 are shown in Figure 34 (from Rodriguez-Roda 1966). The 1963 sample showed a strong mode centered at around 41 cm and lesser modes between 49 and 59 cm and 59 and 69 cm. The 1964 sample had only two modes: one at about 43 cm and other at about 51 cm. Rodriguez-Roda also presented his data in a weight-frequency distribution (Fig. 35) which showed only two modes for the 1963 sample and only one well-defined mode for the 1964 sample. The 1964 data were also summarized by month (Fig. 36). The length-frequency

Fig. 35

Fig. 36

distribution showed two well-defined modes in May, June, and July whereas the weight-frequency distribution showed only a single mode during those months. It is of interest that the relative proportion of fish in the larger mode in the length-frequency distribution appeared to decrease from May to July. The length-frequency distribution of male and female S. sarda were similar except that the modes were

Fig. 37 displaced (Fig. 37).

Postel (1955a) presented data on the maximum size of S. sarda sampled in monthly periods in the eastern tropical Atlantic. The maximum lengths ranged from 450 to 690 mm for the males and 443 to 714 mm for the females.

Landings

The annual landings of S. sarda in the eastern and western Atlantic and in the Mediterranean-Black Seas during the period from

Fig. 38
Table 25 1965 to 1973 are shown in Figure 38 and Table 25. Except in 1973 when the eastern Atlantic landings exceeded 10,000 MT, the landings in the eastern and western Atlantic never rose above this figure. The fisheries of Spain and Portugal make up the larger part of the landings in the eastern Atlantic. In the western Atlantic the bulk of the landings are made by the fisheries of Argentina and Brazil. The landings in the Mediterranean and Black Seas fluctuated from 10,600 to 55,200 MT during the period from 1965 to 1973. Turkey contributed 71.7% to 91.3% of the annual landings during this period.

Wide fluctuations in the landings of S. sarda in the Black Sea-Mediterranean Sea area are a characteristic of this fishery (Fig. 39) and investigators in this area have been trying to find the causes for the fluctuations. Artuz (1959) noted that the landings at the Istanbul Fish Market showed fluctuations following a 9-year cycle during the period from 1936 to 1958 (Fig. 40). As stated earlier, part of the fluctuations were explained by the entry into the fishery of rich year classes. However, Mayorova and Tkacheva (1959) pointed out that although relatively good year classes develop in certain years, these fish fail to return to the Black Sea. They concluded that "the rich yield of young fish in the Black Sea is not always followed by an increase in the abundance of large pelamid."

Fig. 39

Fig. 40

Artuz (1959) also indicated that there may be an inverse relation between the relative abundance of S. sarda and the mackerel, Scomber scomber in Turkish waters (Fig. 41). In the period from 1940 to 1956 he found that when S. sarda was abundant the mackerel catches were poor and vice versa.

Despite the wide fluctuations in the landings of S. sarda in the Black Sea-Aegean Sea areas the stock of bonito apparently is able to maintain itself. Demir (1963) stated that there were no regulatory measures in effect for the fisheries in the Black, Mediterranean, and adjacent seas or in the Atlantic and that there didn't seem to be a need for any regulations.

Subpopulations and Migrations

As indicated earlier, the seasonal migrations of *S. sarda* from the Aegean Sea through the Sea of Marmara to the Black Sea were well documented. The migration routes were presumably determined by the development of the fisheries in these areas and were verified by tagging experiments (Demir 1963). The migration from the Aegean Sea to the Black Sea starts toward the end of April and lasts to the beginning of June or later. The return migration from the Black Sea to the Aegean Sea usually starts in September and lasts to the end of November. Some of the bonito schools returning from the Black Sea may stay in the Sea of Marmara but others continue on to the Aegean Sea.

The *S. sarda* in the Adriatic Sea apparently makes a north-south migration within that sea down to around the Greek islands (Belloc 1954). The bonitos leave the upper Adriatic in November-December and travel along both shores of the Adriatic and arrive in February-March in Greek waters. The return migration starts around August. In addition there apparently are schools of bonito that remain the whole year round in Greek waters and in waters along the east coast of Sicily.

The relation of the bonitos in the Aegean Sea-Sea of Marmara-Black Sea complex with the Adriatic Sea bonito and with the bonitos in the other parts of the Mediterranean is not clear. Turkish investigators imply that the stock in the Aegean Sea-Sea of Marmara-Black Sea complex originate in the Aegean Sea and the Sea of Marmara (Demir 1957) and remain within this complex.

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Text Footnotes

[2]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

[3]Presently with Oceanic Institute, Makapuu Point, Waimanalo Hawaii 96795.

[4]McCall, Stauffer, and Troadec. Report on CF&G-NMFS cooperative stock assessment, fishery evaluation, and fishery management of southern California recreational and commercial fisheries. Southwest Fisheries Center Administrative Report No. LJ-74-24, August 2, 1974 (Revised April 9, 1975).

Table 1.--Summary of characters showing differences and similarities among the four species of Sarda.

(From Collette and Chao, 1975.)

Character	*S. sarda*	*S. australis*	*S. chiliensis*	*S. orientalis*
Lamellae in nasal rosettes (Table 3)	22-33 (x̄ 26.5)	34-39 (x̄ 37.2)	21-30 (x̄ 25.4)	25-36 (x̄ 31.9)
Vomerine teeth	- - - sometimes	- - -	- - - never	- - -
Upper jaw teeth (Table 5)	- - - 16-26	- - -	18-30 (x̄ 23.5)	12-20 (x̄ 15.5)
Lower jaw teeth (Table 6)	12-24 (x̄ 16.0)	11-20 (x̄ 14.5)	14-25 (x̄ 19.2)	10-17 (x̄ 13.0)
Palatine teeth	8-21 (x̄ 12.3)	7-14 (x̄ 10.7)	9-22 (x̄ 15.2)	8-19 (x̄ 11.9)
Supramaxilla width (Fig. 32)	- - - intermediate	- - -	wide	narrow
Ectopterygoid-dorsal portion (Fig. 36)	- - -	pointed	- - -	slightly expanded
Hyomandibular spine-condyle (Fig. 39)	projects beyond condyle	- - -	short	projects beyond condyle
Angle of hyomandibular spine (Fig. 39)	- - - about 90°	- - -	greater than 90°	less than 90°
Elliptical ceratohyal window (Fig. 42)	- - -	present	- - -	only slight depression
Ventral surface of glossohyal (Fig. 43)	- - -	depression present	- - -	no depression
Gill rakers (Table 7)	16-23	19-21	23-27	8-13
Vertebrae (Table 9)	50-55	- - -	43-46	- - -
Pleural ribs	24	- - -	19-23	- - -
Intermuscular bones	31-45	- - -	32-36	- - -
Keels on vertebrae number	5-10	- - -	5-8	- - -
First closed haemal arch (Fig. 51)	- - - 13-15th vertebra	- - -	- - - 12-14th vertebra	- - -
Length of haemal prezygapophyses and postzygapophyses at precaudal-caudal junction (Fig. 52)	postzygapophyses longer than prezygapophyses	- - -	prezygapophyses longer than postzygapophyses	- - -
Dorsal spines (Table 10)	20-23	- - -	17-19	- - -
Dorsal finlets (Table 11)	modally 8	modally 7	- - - modally 8	- - -
Anal rays (Table 12)	- - - 14-17 (modally 15)	- - -	12-15 (modally 14)	14-16 (modally 15)
Anal finlets (Table 12)	modally 7	modally 6	modally 7	modally 6
Total anal elements (Table 12)	- - - 19-23 (modally 21-22)	- - -	18-22 (modally 20)	20-22 (modally 21)
Supracleithral notch (Fig. 60)	wide angle	almost 90°	- - - wide angle	- - -
Pectoral rays (Table 13)	23-26	25-27 (modally 26)	- - - 22-26 (modally 24-25)	- - -
Vertical wing of pelvic girdle (Fig. 66)	- - -	shorter and wider	- - -	narrower and longer

Table 2.--Common and vernacular names of *Sarda* spp.

Country	Standard common name	Vernacular names
	Sarda australis	
Australia	Australian bonito	Horse mackerel, little bonito
	Sarda chiliensis	
United States	Pacific bonito	
Chile	Bonito	
Peru	Bonito	
	Sarda orientalis	
Australia (Western)	Oriental bonito	
India	Oriental bonito	Vari choara (Malayalam)
Mauritius-Seychelles		Brasse-a-dents (Creole name)
Somali		Sinufa
South Africa, Republic of	Bonito	
Japan	Hagatsuo	Kitsunegatsuo, Hohzan, Sujigatsuo, Sabagatsuo, Shimagatsuo, Tozan
United States	Bonito	
Sri Lanka (Ceylon)		Thora-baleya
	Sarda sarda	
Albania	Palamiti	
Algeria	Bonite	Bonito, Bonite a dos raye Palamita, Rsela
Bulgaria	Palamud, Turuk	Lakerda
Canary Islands	Bonito	Bonite
Denmark	Rygstribet Pelamide	
France	Bonite a dos raye	Pelamide commun, Pelamide, Conite, Pelamido, Pelamida, Palamida, Boniton, Bonicou, Bonnicou, Boussicou, Boussicon

Table 2.--Continued.

Greece	Palamida, Toriki	Pelamyda, Doriki, Touliki, Ternata, Koini
Germany	Pelamide	Bonite, Unechter Bonito, Mittellandischen Bonite, Rygstribed Pelamite
Israel	Sarda	
Italy	Palamita	Palamita sarda, Pelamida, Palamide, Palamida, Palamita, Palamito, Palamitu maiaticus, Palametto, Pilamitu, Palamia, Paamie, Pirantuni, Pisantuni, Tombarello, Parantuni, Strombo, Strumbo, Scurma, Sangulu, Sgamiru, Sgonfietto, Cuvarita, Cavaritu imperiali, Bonnicou, Tunnachiu
Libya	Balamit	Blamto
Madeira Islands	Cerda	
Malta	Palamit	Plamtu, Palamita, Plamitu, Palamia
Monaco	Palamida	Piramida, Paramida
Morocco	Cerda, Bonito	
Portugal	Bonito, Serra	
Rumania	Pelamida	Lacherda
Spain	Bonito	Bonitol, Bonitu, Cerda
South Africa	Bonito	Katankel, Sarrajoa
Sweden	Pelamide	Rygstrimmig Pelamid
Syria	Palamet	
Tunisia	Palamid	Pelamid, Balamit, Toumbrel, Rsela
Turkey	Palamut, Torik	
United Kigdom	Pelamid	Belted bonito, Stripe-backed pelamis
U.S.S.R.	Pelamida	Lacherda
United States	Common Bonito	Atlantic Bonito, Bonito, Boston Mackerel, Bone Jack, Bloater, Skipjack
Yugoslavia	Polanda	Polandra, Palovnic, Pastrica, Sarica, Sargasto, Tombarel, Trup lacherda

Table 3.--Fecundity of *Sarda sarda*.

Area	Size of fish	Fecundity (No. of eggs)	Reference
Black Sea	40-50 cm	700,000-1,000,000	Zusser (1954)
	60-70 cm	1,500,000-2,000,000	
	70 cm	6,000,000	
Black Sea	--	450,000-1,000,000	Slastenenko (1956)
Black Sea	--	700,000-1,000,000	Krotov (1957)
Black Sea	56-65 cm (2-3.8 kg)	732,160-3,233,580	Mayorova and Tkacheva (1959)
Eastern Atlantic	60 cm	900,000	Postel (1955b)

Table 4.--Monthly percentage distribution of *Sarda sarda* in the various stages of sexual development, Barbate and Tarifa, Spain in 1963 and 1964. (From Rodriguez-Roda 1966)

	Stage of sexual development													
	Males							Females						
	I	II	III	IV	V	VI	No. of fish	I	II	III	IV	V	VI	No. of fish
May	7.02	1.75	87.72	3.51	--	--	57	30.00	15.00	55.00	--	--	--	20
June	--	--	73.81	23.81	2.38	--	42	2.38	--	64.29	30.95	--	2.38	42
July	--	--	100.00	--	--	--	18	--	--	54.17	41.67	--	4.17	24
							117							86

Table 5.--Monthly gonad index of Sarda sarda landed at Barbate, Spain in 1964. (From Rodriguez-Roda 1966.)

	Males			Females		
	No. of fish	Mean	Range	No. of fish	Mean	Range
May	9	3.84	2.77-4.41	10	3.34	1.90-5.48
June	11	4.51	2.80-6.17	13	5.44	2.40-12.15
July	6	5.59	4.00-6.41	9	4.79	2.15-9.40

Table 6.--Relation between the stage of sexual maturity and the gonad index for Sarda sarda landed at Barbate, Spain in 1964. (From Rodriguez-Roda 1966.)

Stage of sexual maturity	Males			Females		
	Mean	Range	No. of fish	Mean	Range	No. of fish
I	--	--	--	0.56	0.42-0.69	2
II	0.94	--	1	0.85	--	1
III	4.15	0.96-6.90	30	4.44	1.77-12.15	23
IV	--	--	--	5.39	3.56-9.40	8
V	--	--	--	--	--	--
VI	--	--	--	2.15	--	1

Table 7.--Records of capture of juvenile *Sarda chiliensis* from the eastern Pacific (from Klawe 1961 and Pinkas 1961).

Date	General locality	Latitutde	Longitude	Method of capture	Size range fork length in mm	No. of specimens
			Northern hemisphere			
May 17-18, 1947	Off La Jolla, Calif., United States			Night light, dip net	--	1
Aug. 5, 1951	100 miles N.W. of Cape San Lazaro, Baja Calif., Mexico	25°35'N	113°56'W	Night light, dip net	42	1
Aug. 5, 1951	Off Baja Calif., Mexico	25°35'N	113°56'W	Night light, dip net	42	1
Aug. 12, 1951	Off Ballenas Bay, Baja Calif., Mexico	26°29.5'N	113°29.2'W	Plankton net	2.9, 3.5	2
July 15, 1953	S. of Cape San Lazaro, Baja Calif., Mexico	23°47'N	112°25'W	Night light, dip net	25-41	5
July 18, 1953	S.W. of Cape San Lazaro, Baja Calif., Mexico	23°16'N	112°45'W	Night light, dip net	19-41	8
April 11, 1955	S. of Cape San Lucas, Baja Calif., Mexico	22°52.8'N	109°53.7'W	Night light, dip net	16.7	1
July 11, 1956	S.W. of Cape San Lucas, Baja Calif., Mexico	23°35'N	112°11'W	Night light, dip net	33.0-33.5	2
July 12, 1956	S.W. of Cape San Lucas, Baja Calif., Mexico	22°20'N	112°27'W	Night light, dip net	24-48	8
July 17, 1956	S.W. of Cape San Lucas, Baja Calif., Mexico	22°47'N	112°14'W	Night light, dip net	54.5	1
			Southern hemisphere			
Feb. 20, 1951	Off Pt. Lobos, Peru			?	125-130	3
Jan. 3, 1956	Off Pt. Negra, Peru			Bait net	143-164	3
Dec. 10, 1957	Independencia Bay, Peru	14°14'S	76°12'W	Bait net	128	1
Dec. 13, 1957	Off Ilo, Peru	17°38'S	71°23'W	Bait net	121	1
Dec. 15, 1957	Off Ilo, Peru	17°38'S	71°18'W	Bait net	200.9	1
Dec. 18, 1957	Off Ilo, Peru			Bait net	70-135	3
Dec. 21, 1957	S. of Santa, Peru	09°31'S	78°26'W	Bait net	38.0-51.0	5
Dec. 31, 1957	Off Pt. Pichalo, Chile	19°35'S	70°16'W	Night light, dip net	37	1
Jan. 1, 1958	Off Ilo, Peru	17°47'S	71°30'W	Bait net	86.8	1
Jan. 3, 1958	Off Pt. Dos Reyes, Chile	24°30'S	70°49'W	Night light, dip net	39	1
Jan. 3, 1958	Off Pt. Dos Reyes, Chile	24°36'S	71°01'W	Night light, dip net	36-44	3
Jan. 14, 1958	S.W. off Fraile Pt., Peru	13°14.8'S	77°55.5'W	Night light, dip net	34	1
Feb. 1958	Off Chimbote, Peru			Bait net	89-129	3
May 6, 1958	Almejas Bay, Baja Calif., Mexico			Bait net	103	1
Feb. 1, 1959	Sama Cove, Peru			Bait net	111	1
Mar. 15, 1959	Off Ilo, Peru			?	135-160	3
Mar. 16, 1959	Off Barranca, Peru			?	173, 199	2

* Identity uncertain.

Table 8.--Meristic counts in Sarda orientalis from various parts of the Indo-Pacific (Silas, 1964).

Author and area	D_1	D_2	D_2 finlets	P_1	A	A finlets	Gill rakers
A—Western Indian Ocean							
East coast of S. Africa:							
Barnard (1927) (*S. chilensis*)	XVIII	14–16	(6) 7–9	...	2, 10–12	6–9	...
Smith (1949)	XVII–XIX	14–16	6–9	...	2–3, 10–12	6–9	— + 8
Seychelles Plateau:							
Ommanney (1953)	...	...	8	...	...	7	...
B—Northern Indian Ocean							
Coast of India:							
Day (1878)	XVIII	3, 13	8	24	3, 12	6	...
S. W. coast of India:							
Silas (in this paper)	XVII–XIX	14–16	7–8 (exceptionally 9)	23–25	13–16	5–7	1—4+8—10 (=9—14)
C—Eastern Indian Ocean							
W. Australia:							
Munro (1958)	XVII–XIX	15	7–8	22–27	15	5–6	2—4+7—9
D—Western Pacific							
Philippines:							
Warfel (1950)	XVIII–XIX	14–15	7–9	...	14–15	5–6	3+1+7—10 (= 11—14) Mode 4+9
E—North Western Pacific							
Japan:							
Kishinouye (1923)	XIX	15	7–8	...	15	5–6	4+9 (=13)
Yabe *et al.* (1953)	XVII–XIX	12–14	7–8	...	12–15	...	2—4+7—9 (=10—12)
Godsil (1955)	XVIII	15–16	8	...	15	6–7	2—3+1+8—9 (=11—13)
F—Eastern Pacific							
Meek and Hildebrand (1923) (*S. velox*)	XVIII	16	8	...	2, 12	7	— + 9
Godsil (1954) (*S. velox*)	XVII–XIX	15–16	7–9	...	14–16	6	2—3+1+5—8 (=8—11)
G—General							
Fraser-Brunner (1950)	XVIII (fig.)	...	7–8	...	...	5–6	3—4+7—9
Klawe (1961b)	...	...	...	...	...	...	2—3+6—10

Table 9.--Comparison of morphometric characters in populations of Sarda orientalis from Japan and the eastern tropical Pacific (Collette and Chao 1975).

	Japan			East tropical Pacific		
Character	Range	$\bar{x}$	N	Range	$\bar{x}$	N
Fork length (mm)	342-560	432	7	354-613	472	10
Expressed as thousandths of fork lengths						
Snout — A	674-703	694	5	662-703	678	10
Snout — 2D	596-614	606	5	569-596	582	10
Snout — 1D	273-308	286	7	274-311	288	10
Snout — P_2	293-316	303	5	299-321	310	10
Snout — P_1	272-292	281	7	277-299	290	10
P_1 — P_2	109-118	113	5	105-118	114	10
Head length	268-286	278	7	266-294	284	10
Max. body depth	221-244	234	4	193-236	213	10
Max. body width	143-151	146	4	127-153	144	10
P_1 length	104-125	115	7	119-134	127	10
P_2 length	70- 78	76	5	81- 91	86	10
P_2 insertion - vent	374-419	392	7	353-384	367	10
P_2 tip - vent	305-322	311	3	265-302	280	10
Base 1D	285-327	306	7	282-302	292	10
Height 2D	75- 82	78	7	89-101	94	8
Base 2D	85-111	93	7	88-107	95	9
Height anal	61- 85	73	7	84- 97	89	8
Base anal	66- 78	73	7	73- 83	79	9
Caudal spread	168-234	214	4	192-259	236	5
Snout (fleshy)	86-103	96	7	98-105	101	10
Snout (bony)	80- 97	86	7	83- 91	86	10
Maxilla length	141-149	145	6	146-156	150	10
Post orbital	128-147	139	5	141-151	146	10
Orbit (fleshy)	32- 60	42	7	34- 40	37	10
Orbit (bony)	29- 65	56	7	60- 68	64	10
Interorbital width	67- 73	71	6	65- 79	71	10
Expressed as thousandths of head length						
Snout (fleshy)	306-368	344	7	348-369	357	10
Snout (bony)	288-344	308	7	291-317	303	10
Maxilla length	510-529	522	6	512-557	528	10
Post orbital	476-525	503	5	494-553	512	10
Orbit (fleshy)	102-152	136	7	120-147	130	10
Orbit (bony)	210-234	220	7	210-238	226	10
Interorbital width	251-263	256	6	230-283	251	10

Table 10.--Parasites of *Sarda* (From Silas 1967 and Silas and Ummerkutty 1967).

Host	Parasites			
	Copeopds	Monogenetic Trematodes	Dingenetic Trematodes	Cestodes
Sarda chiliensis	*Caligus bonito* *Caligus mutabilis* *Pseudocycnus appendiculatus*			
Sarda orientalis	*Caligus bonito* *Alicaligus tripartitus*	*Capsala caballerio*	*Bucephalopsis cybii*	
Sarda sarda	*Caligus bonito* *Caligus mutabilis* *Caligus pelamydis* *Caligus productus* *Alebion gracilis* *Pseudocycnus appendiculatus*	*Capsala pelamydis* *Hexostoma pricei* *Hexostoma thynni*	*Aponurus tschugunowi* *Atalostrophion sardae* *Bucephalopsis arcuata* *Dinurus barbatus* *Hirudinella clavata* *Lecithochirum caudiporum* *Lecithochirum texanum* *Nematobothrium pelamydis* *Opecoelides vitellosus* *Rhipidocotyle angusticollis* ?*Tormopsolus orientalis* *Unitubulotestes sardae*	*Grillotia erinaceus* *Lacistorhynchus tenus* *Scolex pleuronectis* *Tentacularia bicolor* *Tentacularia coryphaena* **Tetrarhynchus megabothrium* *?*Tetrarhynchus scomber-pelamys* ***Tetrarhynchus* sp.

? Indicates doubtful record.
* Species incerte sedis
** Forms unidentifiable.

Table 11.--Age-length data for northern and southern hemisphere *Sarda chiliensis*. (From Kuo 1970.)

Age	Species	Mean length, mm.	Standard error	Confidence interval	N
1	*lineolata*	152	0.95	150 - 154	222
	chiliensis	151	1.99	147 - 155	141
2	*lineolata*	252	1.28	249 - 254	219
	chiliensis	256	2.76	250 - 261	137
3	*lineolata*	347	1.70	344 - 351	212
	chiliensis	364	6.02	352 - 376	43
4	*lineolata*	433	2.26	429 - 438	182
	chiliensis	480	7.01	466 - 494	26
5	*lineolata*	509	3.19	503 - 515	133
	chiliensis	550	7.27	535 - 565	25
6	*lineolata*	585	4.79	576 - 595	74
	chiliensis	604	9.18	585 - 623	24
7	*lineolata*	652	13.00	625 - 678	35
	chiliensis	---	---	---	0
8	*lineolata*	756	12.10	728 - 783	9
	chiliensis	---	---	---	0

lineolata = *Sarda chiliensis lineolata*. [Northern hemisphere]

chiliensis = *Sarda chiliensis chiliensis*. [Southern hemisphere]

Table 12.--Length-weight relationships of *Sarda*

Species	No. of fish	Size range of fish: Weight	Size range of fish: Length (cm)	Log a	a	b	Weight unit	Length unit	Source
S. chiliensis	595	--	40-73	-1.9281	0.0118	3.02	gr	cm	Barrett (1971)
S. orientalis	25	--	--	-3.2697	5.375×10^{-4}	2.958	oz	cm	Sivasubramaniam (1968)
S. sarda	165		40.55.5	-4.82796	0.0000158607	2.971925	kg	cm	Rodriguez-Roda (1966)

Table 13.--Lengths of <u>Sarda orientalis</u> landed at Aburatsu, Japan in 1950 (Yabe et al. 1953).

Date	No. of fish	Body length (mm)	
		Range	Mean
Aug. 26	17	205-221	214
Sept. 1	2	241-249	245
Sept. 2	3	233-243	239
Sept. 8	5	161-270	239
Sept. 9	10	254-277	263
Oct. 17	5	333-348	339

Table 14.--Monthly length data for *Sarda sarda* from the Black Sea.

	July	Aug.	Sept.	Oct.
			cm	
Zusser (1954)	--	19-27	27-29.5	25-36
Tkacheva (1958)	--	21-33	27-36	36-40
Mayorova and Tkacheva (1959)	--	21-33	27-37	36-41
Demir (1963)	6-16	12-32	25-38	33-42

Table 15.--Age-length relation in Sarda sarda. (From Demir 1963.)

Age

Author	1	2	3	4	5	6	7	8	9
	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)
Zusser (1954)	25-37	33-50	42-54	50-62	56-67	60-70	63-76	70-78	74-85
	31.5	41.5	48.8	56.2	61.2	66.5	69.5	73.5	76.2
Nümann (1955)	38-41	53-57	60-64	-	-	-	-	-	-
Nikolski (1957)	35.3	55.1	64.2	72.5	-	-	-	-	-
Türgan (1958)	30-40	50-55	55-60	60-65	-	-	-	-	-
Nikolov (1960)	38.85	52.6	60	67	(74-75)	-	-	-	-

Table 16.--Calculated lengths for each age of *Sarda sarda*.

(From Kutaygil 1967)

Sample		No. of fish	Age 1	2	3	4
June 1957	II (1955)	7	44.0	59.1	--	--
	III (1954)	22	45.4	57.9	64.8	--
	IV (1953)	4	47.6	59.2	64.5	68.7
	Grand mean =		45.1	58.3	64.9	
	N =		33	33	26	
Jan. 1958	IV (1954)	5	42.9	53.3	60.6	64.2
Feb. 1958	IV (1954)	18	41.1	52.9	59.2	63.8

Table 17.--Food of Sarda chiliensis, 1968 and 1969. (From Pinkas et al., 1971.)

Food items	Number	Percent number	Volume ml	Percent volume	Frequency of occurrence	Percent frequency of occurrence
Vertebrates						
Fishes						
Engraulidae						
Engraulis mordax	4,159	75.5	11,356.4	75.9	462	56.3
Scomberesocidae						
Cololabis saira	27	0.5	190.8	1.3	16	1.9
Gadidae						
Merluccius productus	24	0.4	6.8	<0.1	15	1.8
Carangidae						
Trachurus symmetricus	16	0.3	185.6	1.2	13	1.6
Sciaenidae						
Genyonemus lineatus	1	<0.1	38.0	0.3	1	0.1+
Seriphus politus	3	<0.1	1.3	<0.1	2	0.2+
Embiotocidae						
Brachyistius frenatus	1	<0.1	10.0	<0.1	1	0.1+
Cymatogaster aggregata	1	<0.1	14.0	0.1	1	0.1+
Zalembius rosaceus	1	<0.1	9.0	<0.1	1	0.1+
Scorpaenidae						
Sebastodes spp.	12	0.2	5.8	<0.1	5	0.6
Stromateidae						
Peprilus simillimus	7	0.1+	195.0	1.3	6	0.7
Bothidae						
Citharichthys sordidus	1	<0.1	0.6	<0.1	1	0.1+
Unidentified fishes	765	13.9	223.8	1.5	185	22.5
Subtotal, fishes other than Engraulidae	859	15.6	880.7	5.9	247	30.1
Subtotal, all fishes	5,018	91.1	12,237.1	81.8	709	80.4
Invertebrates						
Cephalopods						
Loligo opalescens	448	8.1	2,690.7	18.0	207	25.1
Onychoteuthis borealijaponicus	1	<0.1	3.7	0.2	1	0.1+
Unid. cephalopods	17	0.3+	9.9		16	2.0
Crustaceans						
Pleuroncodes planipes	4	<0.1	5.6		4	0.5
Crab megalops larvae	3	<0.1	0.1		1	0.1+
Unidentified animals	19	0.3+	4.7		17	2.0
Subtotal, all invertebrates (except *Loligo opalescens*) and unidentified animals	44	0.8	24.0	0.2	39	4.8
TOTALS	5,510	100.0	14,951.8	100.0	--	--

In the Percent volume column, the value 0.2 is bracketed across the rows from *Onychoteuthis borealijaponicus* to Unidentified animals.

Table 18.--Food of Sarda sarda in the Black Sea, Sea of Marmara, and the eastern Atlantic. (From Berg et al. 1949; Postel 1954; Zusser 1954; Slastenenko 1956; Ionescu, Gadidov, and Stanescu 1958; and Demir 1963.)

Black Sea

Engraulis encrasicholus
Spratella sprattus phalerica
Ammodytes cicerellus
Scomber scombrus
Trachurus mediterraneus
Mullus barbatus
Pomatomus sattatrix (young)
Sarda sarda (young
Mugil spp.
Atherina spp.
Gobiidae

Sea of Marmara

Important food items

Engraulis encrasicholus
Spratella sprattus phalerica
Scomber scombrus
Scomber colias
Clupea pilchardus
Ammodytes cicerellus
Trachurus mediterraneus

Less important food items

Smaris alceda
Trachurus trachurus
Boops boops
Mullus barbatus
Atherina spp.

Atlantic Ocean near Dakar, Senegal

Sardinella sp.
Engraulis sp.
Scomber colias
Ammodytes sp.
Planktonic crustaceans
Caprella
Euphausiid spp.

Table 19.--Annual landings of *Sarda orientalis* in four southern Japan ports. (Data provided by Dr. S. Kikawa, Far Seas Fisheries Research Laboratory and Mr. T. Kato, Nansei Regional Fisheries Research Laboratory, Japan.)

			Landings in kg		
Year	Tosashimizu	Muroto	Murotomisaki	Aburatsu	Total
1967	37,462	No data	No data	No data	37,462
1968	22,171	No data	No data	No data	22,171
1969	30,024	No data	No data	No data	30,024
1970	30,718	No data	No data	25,461	56,179
1971	256,939	42,595	No data	31,732	331,266
1972	229,722	41,220	No data	9,994	280,936
1973	299,621	13,152	11,294	8,426	332,493
1974	No data	No data	11,710	No data	11,710

Table 20.--Countries with fisheries for *Sarda sarda*. (Compiled from FAO Yearbook of Fishery Statistics (FAO 1974.)

Countries exploiting *Sarda sarda* in the eastern Atlantic	
Angola	Morocco
Bulgaria	Portugal
Equatorial Guinea	Romania
German Democratic Republic	Spain
Greece	U.S.S.R.
Countries exploiting *Sarda sarda* in the western Atlantic	
Argentina	Mexico
Brazil	United States
Grenada	Venezuela
Martinique	
Countries exploiting *Sarda sarda* in the Mediterranean and Black Sea	
Algeria	Romania
Bulgaria	Spain
Cyprus	Tunisia
Greece	Turkey
Italy	U.S.S.R.
Malta	Yugoslavia
Morocco	

Table 21.--Fishing seasons for *Sarda sarda*.

Area	Fishing season	Peak months of fishing	Source
Black Sea	May-October	--	Demir (1963)
Bosporus, Sea of Marmara, Dardanelles	Throughout the year	April-May, September-December	Demir (1963)
Aegean Sea (around Greece)	Throughout the year	--	Serbetis (1955)
Eastern Mediterranean (off Spain)	May-June	--	Gruvel (1931)
Mediterranean (off Tunisia)	Throughout the year	May-July	Postel (1956a)
Eastern tropical Atlantic	October-May	--	Postel (1955b)
Eastern Atlantic (off Morocco)	Throughout the year	--	Furnestin et al. (1958)
Eastern Atlantic (Bay of Biscay)	Mid-April-mid-May	--	de la Tourrasse (1957)
Western Atlantic (Gulf of Maine)	June-October	--	Bigelow and Schroeder (1953)

Table 22.--Fishing seasons in the Spanish fishery for *Sarda sarda*

(From Rodriguez-Roda 1966.)

Area	Fishing season	Peak months of fishing
Bay of Bissay (along Spanish coast)	April to November	July to October
Eastern Atlantic (off northwest coast of Spain)	April to December	July and August
Eastern Atlantic (southwest coast of Spain)	January to December	September and October
Western Mediterranean (southeast coast of Spain)	January to December	August to October
Western Mediterranean (east coast of Spain)	January to December	May and September
Western Mediterranean (northeast coast of Spain Spain)	January to December	June to November
Western Mediterranean (Balearie Islands)	January to December	May to September
Eastern Atlantic (Canary Islands)	Januqry to December	August and September

Table 23.--Sex ratio of *Sarda sarda* landed in Spain. (From Rodriguez-Roda 1966.)

Year	Month	Port	Males	Females
1963	June	Tarifa	17	18
1964	May	Barbate	57	20
1964	June	Barbate	25	24
1964	July	Barbate	18	24

Table 24.--Sex ratio of *Sarda sarda* from the eastern tropical Atlantic.

(From Postel 1955a.)

Month	Males	Females	Ratio (Male:Female)
January	13	12	1:0.42
February	38	30	1:0.79
March	65	70	1:1.08
April	142	115	1:0.81
May	148	172	1:1.16
June	1	1	1:1
July	--	--	--
August	--	--	--
September	--	--	--
October	3	8	1:2.67
November	7	5	1:0.71
December	5	6	1:1.20
Total	422	419	1:0.99

Table 25.--Annual landings of Sarda sarda (thousands of metric tons).

(Data from FAO 1974.)

	1965	1966	1967	1968	1969	1970	1971	1972	1973
Eastern Atlantic									
North	2.7	2.7	1.6	0.8	2.1	1.9	0.8	6.1	1.5
Central	1.9	3.0	3.0	1.3	1.2	1.9	0.9	0.5	9.0
South	1.3	1.6	1.7	0.4	0.9	1.2	0.7	0.6	0.5
Total	5.9	7.3	6.3	2.5	4.2	5.0	2.4	7.2	11.0
Western Atlantic									
North	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
Central	0.3	0.4	0.5	0.8	0.8	0.7	1.0	1.2	1.8
South	1.5	2.0	4.6	3.8	5.4	7.6	6.1	5.7	4.0
Total	1.9	2.4	5.1	4.6	6.3	8.4	7.1	6.9	5.8
Mediterranean and Black Seas									
	26.9	22.1	41.1	25.3	55.2	10.6	22.9	21.9	22.0

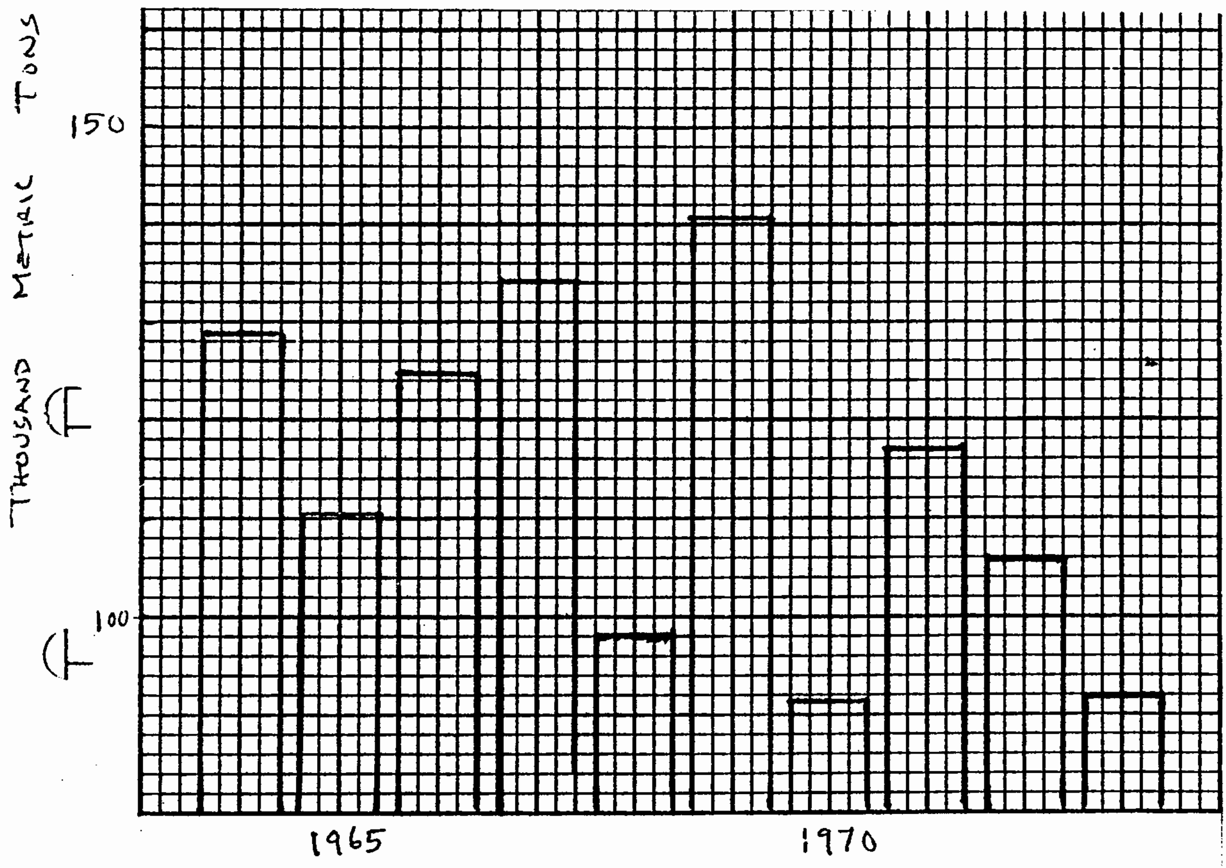


Figure 1.--Total world landings of bonito (Sarda spp.) 1964-73

(data from FAO 1970 and 1974).

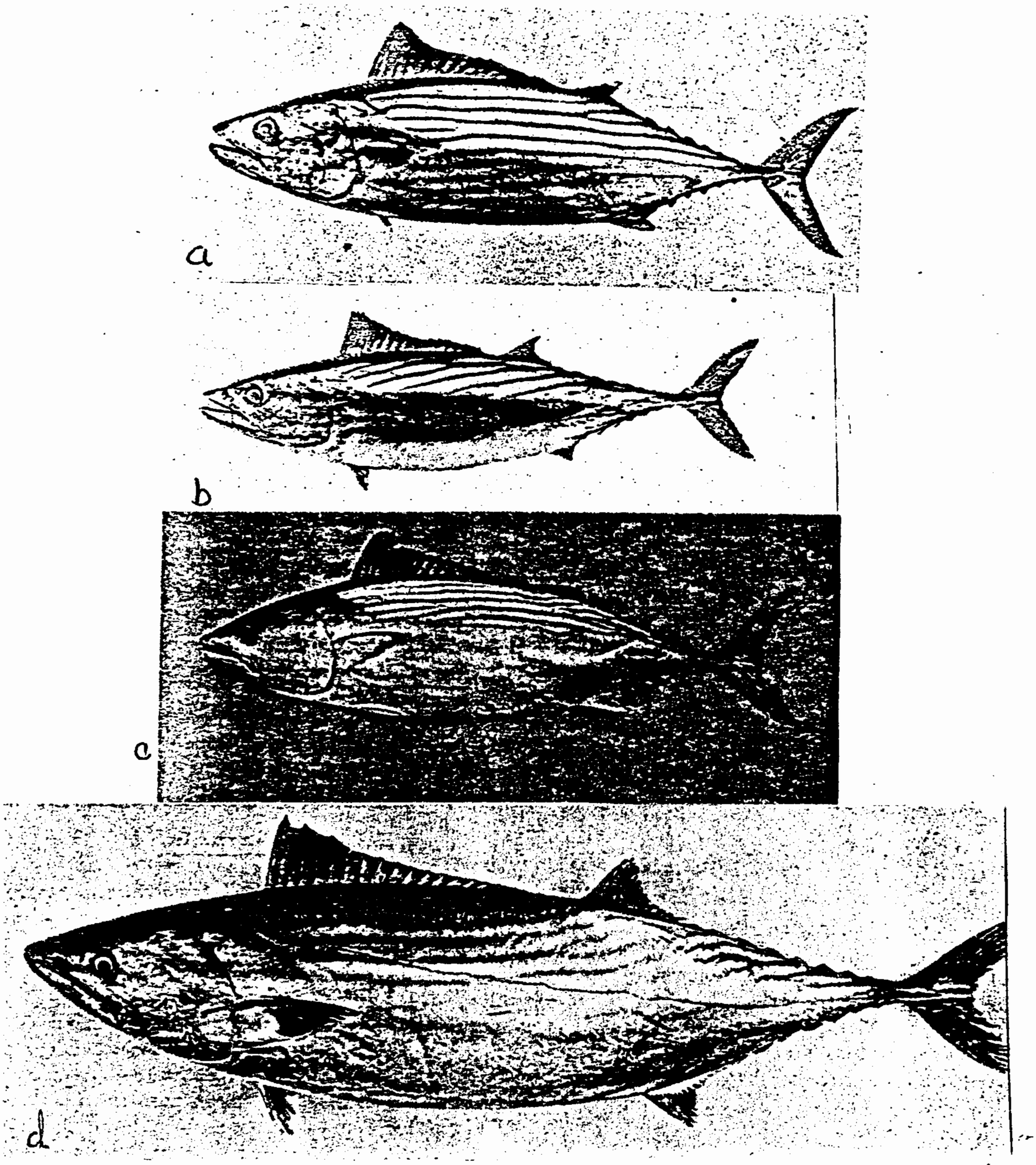


Figure 2.--The four species of Sarda: (a) Sarda australis (from Serventy 1941b); (b) Sarda chiliensis (from Frey 1971); (c) Sarda orientalis (from Kikawa and staff 1963); and (d) Sarda sarda (from Demir 1963).

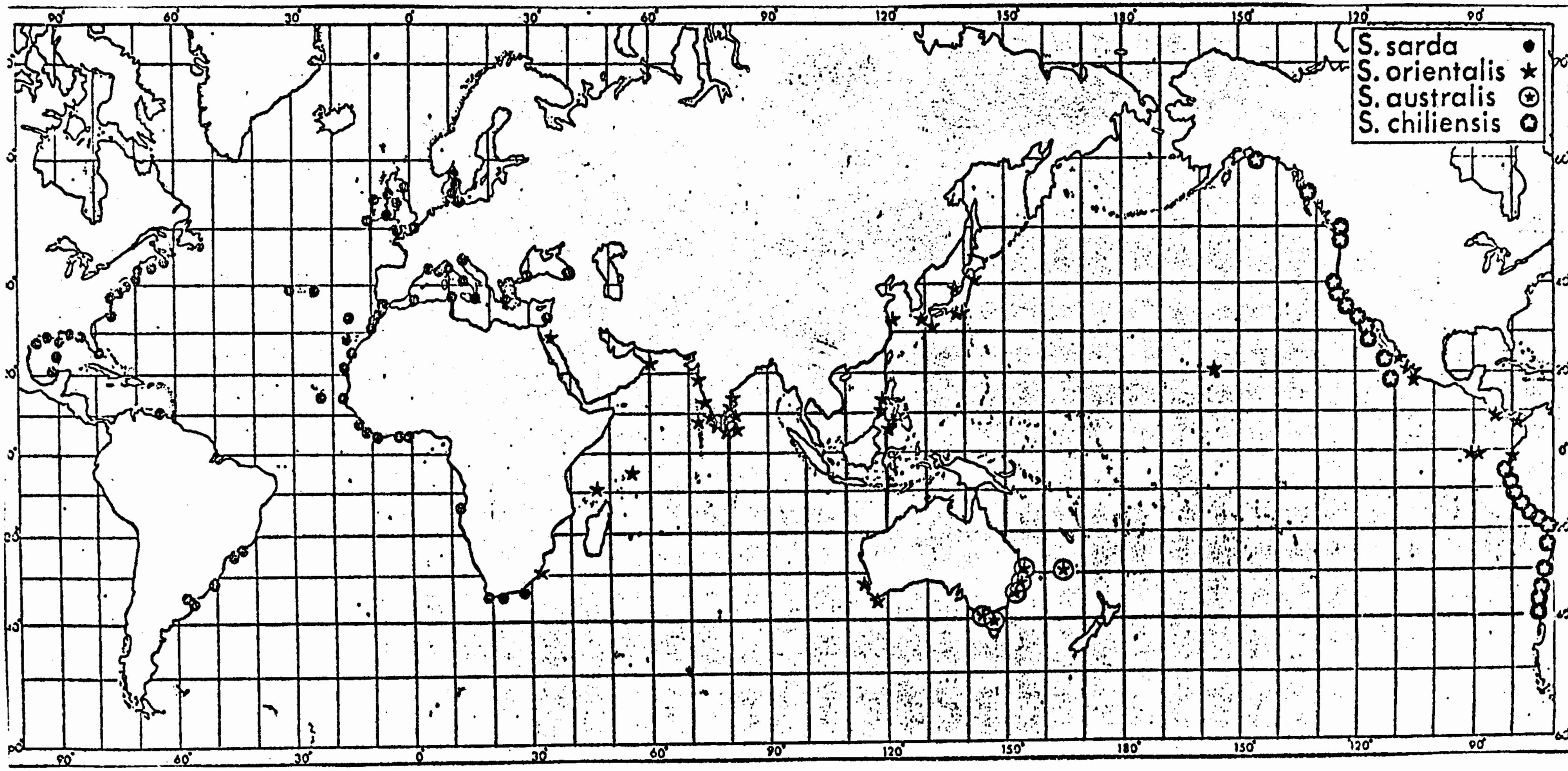


Figure 3.--Distribution of the four species of Sarda (from Collette and Chao 1975).

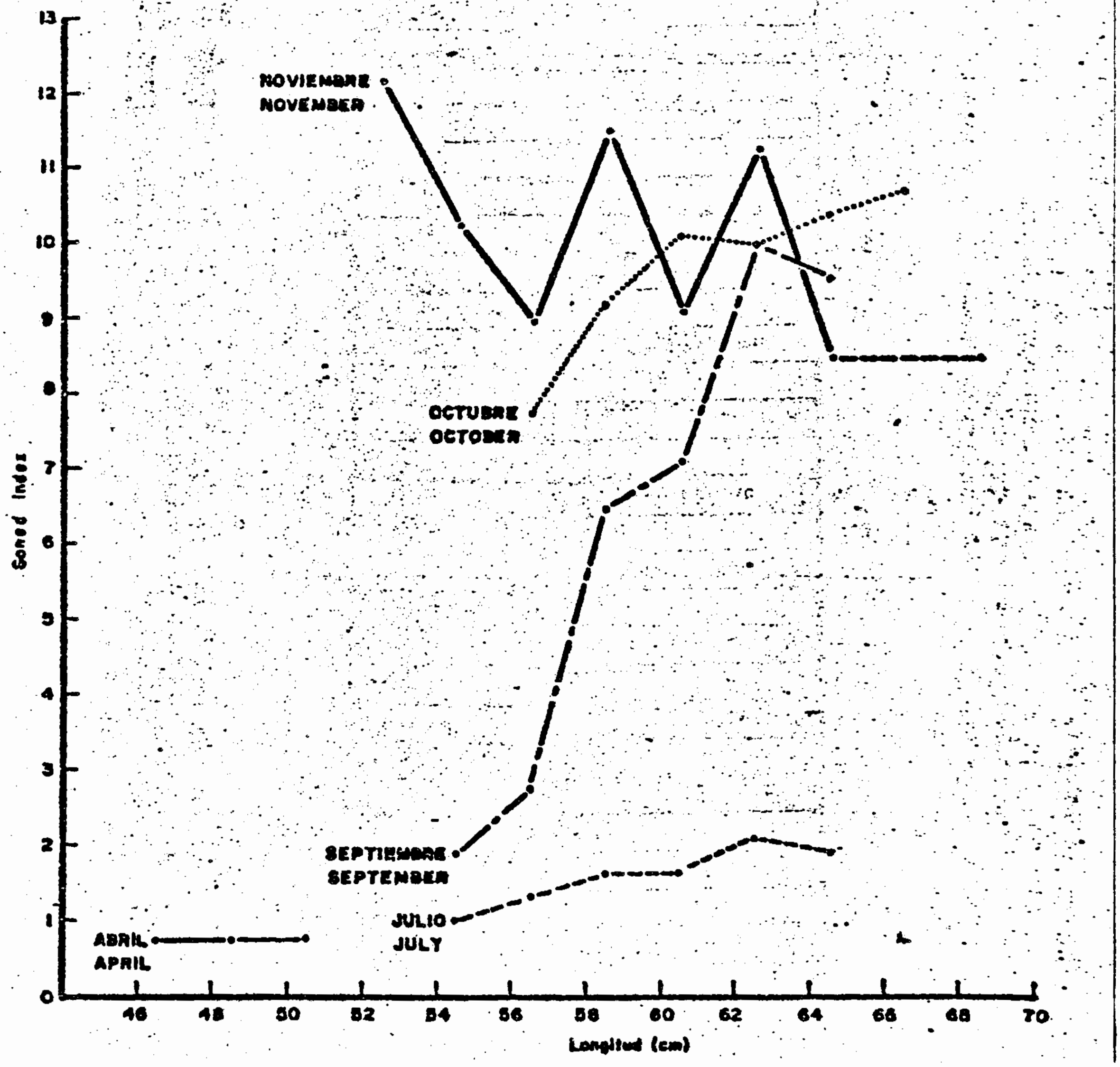


Figure 4.--Mean monthly gonad indices, by length class, of female bonito sampled from the commercial landings at Iquique, September 1968 to July 1969 (from Barrett 1971).

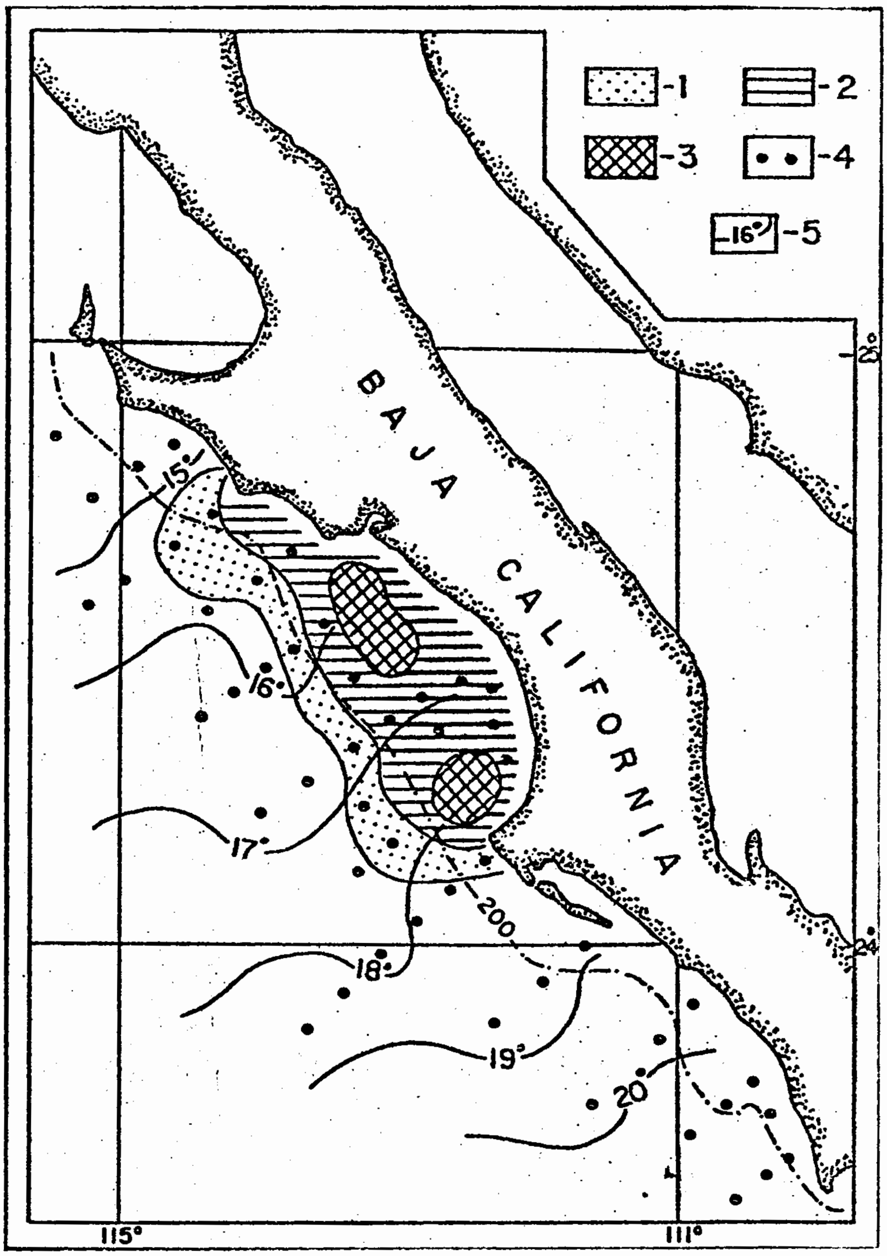


Figure 5.--Distribution of the bonito eggs off Baja California in the spring of 1966, based on tows with the ichthyoplankton net. 1--from 1 to 50; 2--from 51 to 500; 3--more than 500 in one tow of the egg net; 4--ichthyoplanktonic stations; 5--isotherms (from Sokolovskii 1971).

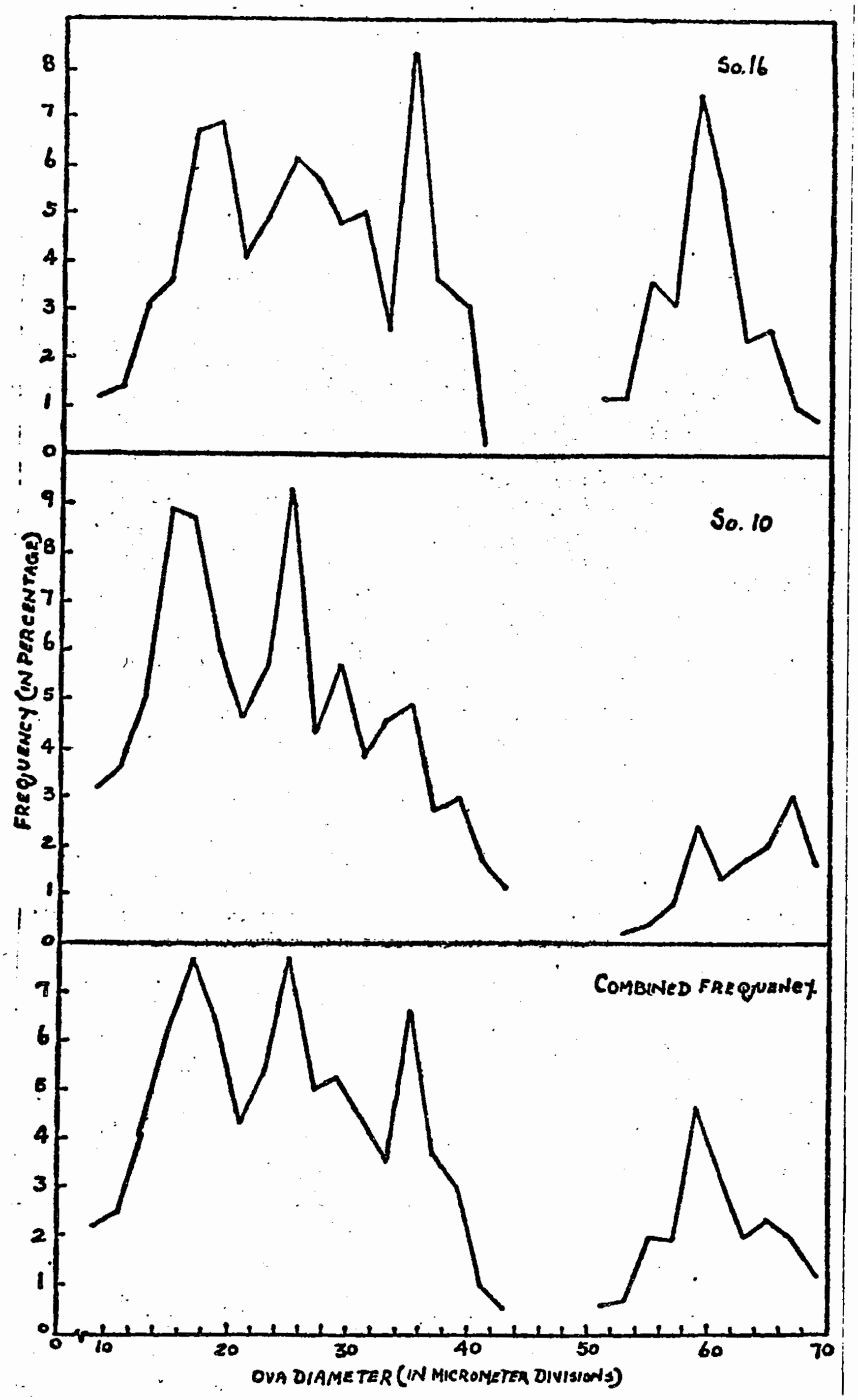


Figure 6.--Ova-diameter frequency polygons of ripe ovaries of the oriental bonito, Sarda orientalis (from Rao 1964).

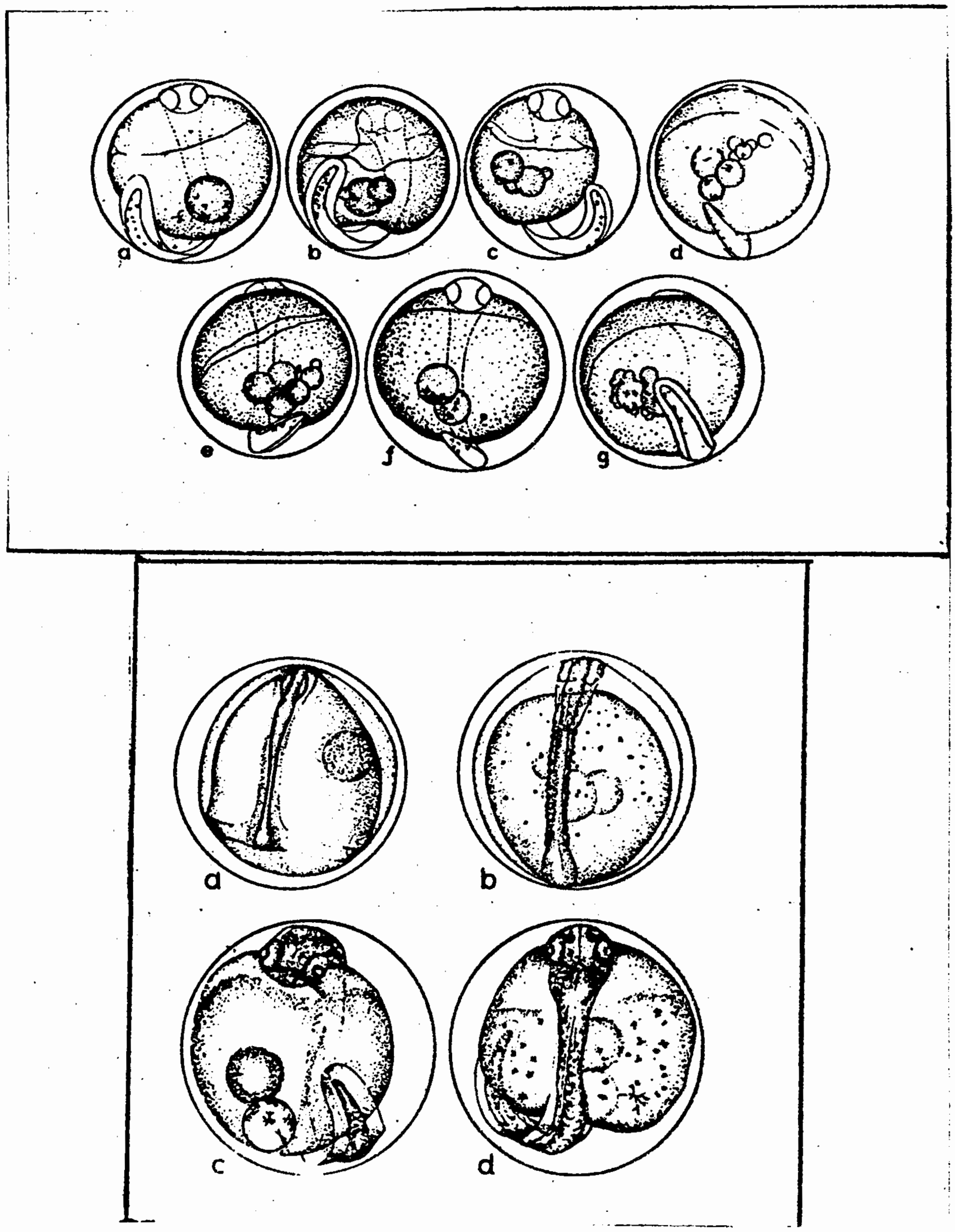


Figure 7.--The fertilized eggs of Sarda sarda at various developmental stages (from Demir and Demir 1960).

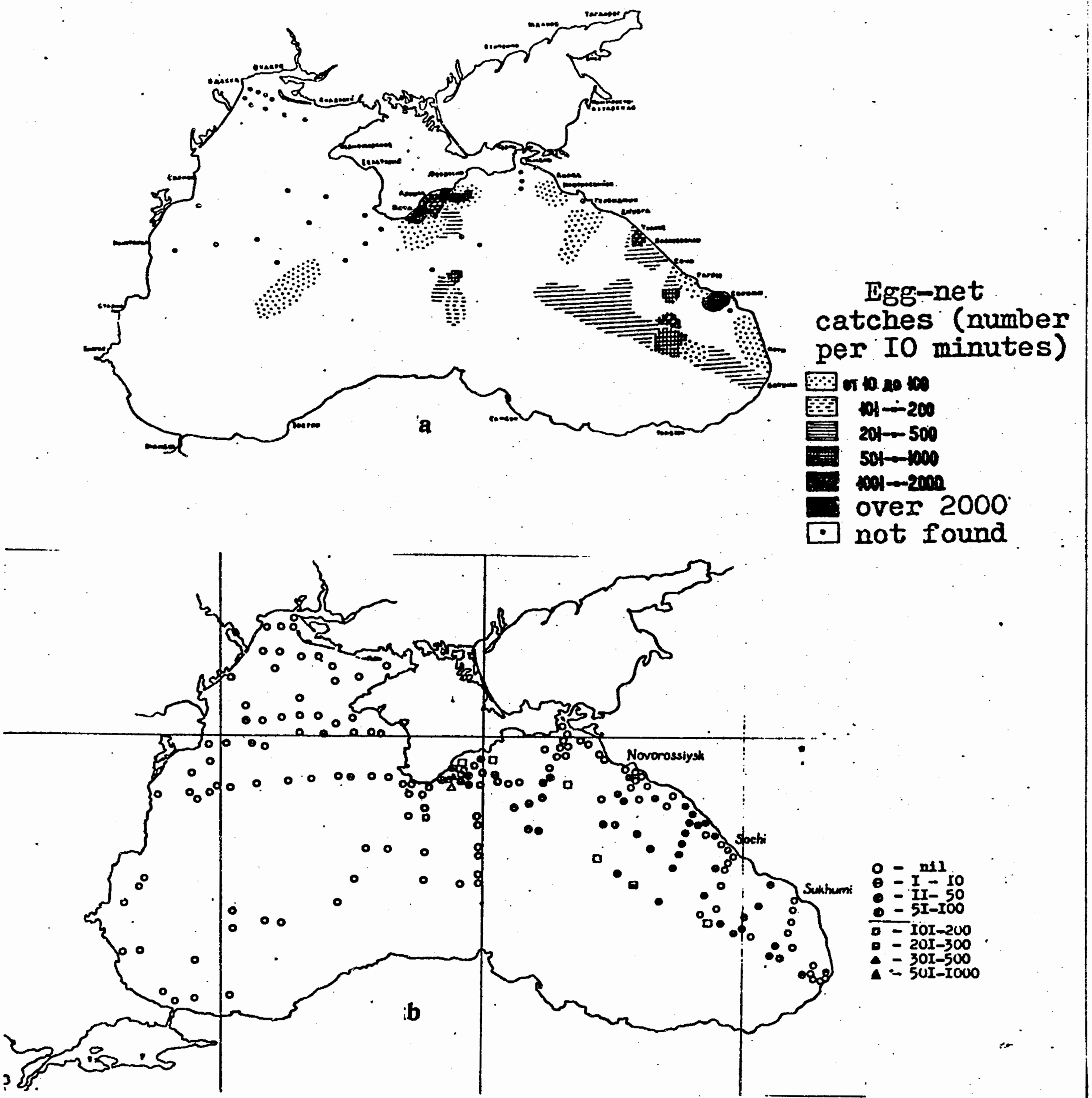


Figure 8.--Distribution of the fertilized eggs of Sarda sarda in the Black Sea, in June 1956(a) and June 1957 (b) (from Mayorova and Tkacheva 1959).

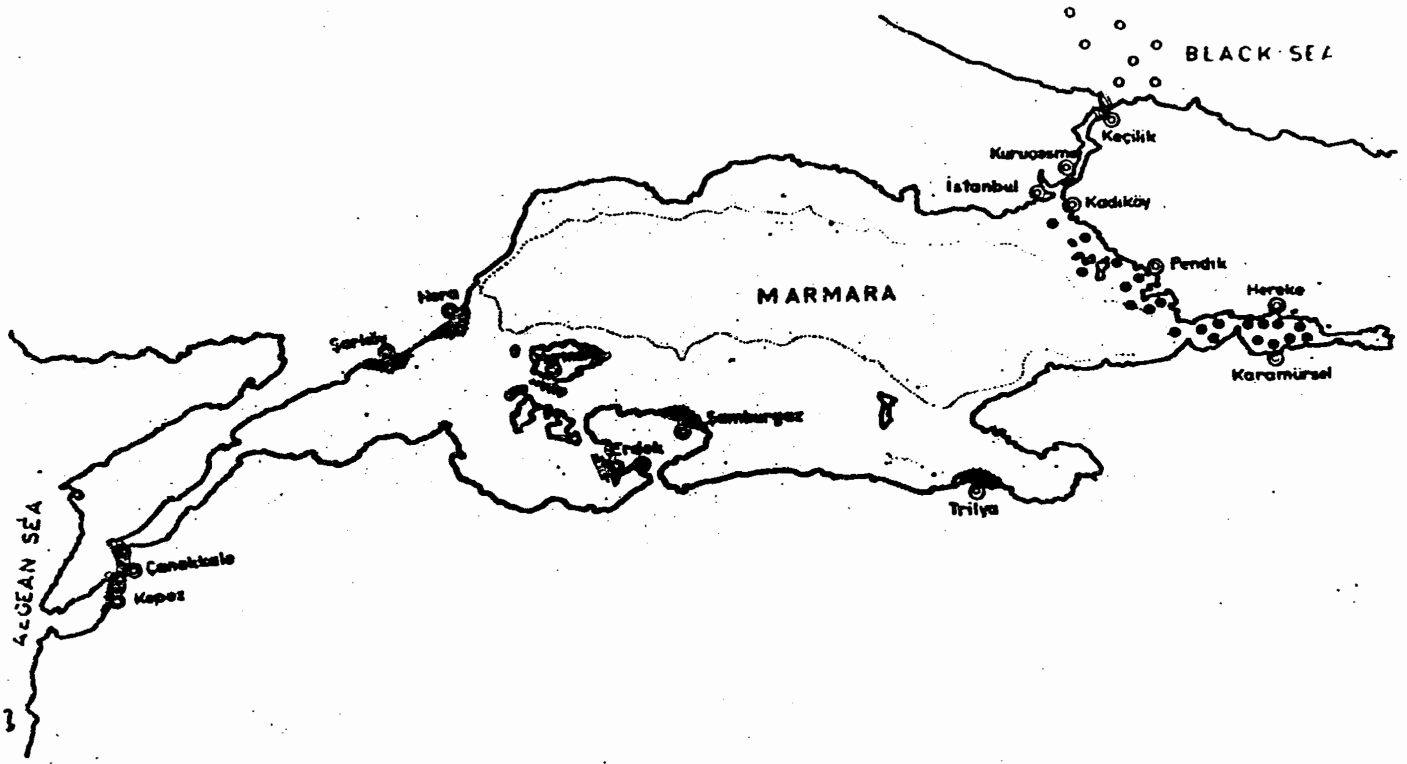


Figure 9.--Distribution of the fertilized eggs of <u>Sarda</u> <u>sarda</u> in the Sea of Marmara, June and July 1959 (from Demir 1963).

(o) Stations where no eggs occurred in mid-June plankton hauls.

(•) Stations where 100-200 eggs occurred in mid-June plankton hauls.

(◎) Locations where 6-14 cm long juveniles were captured in July.

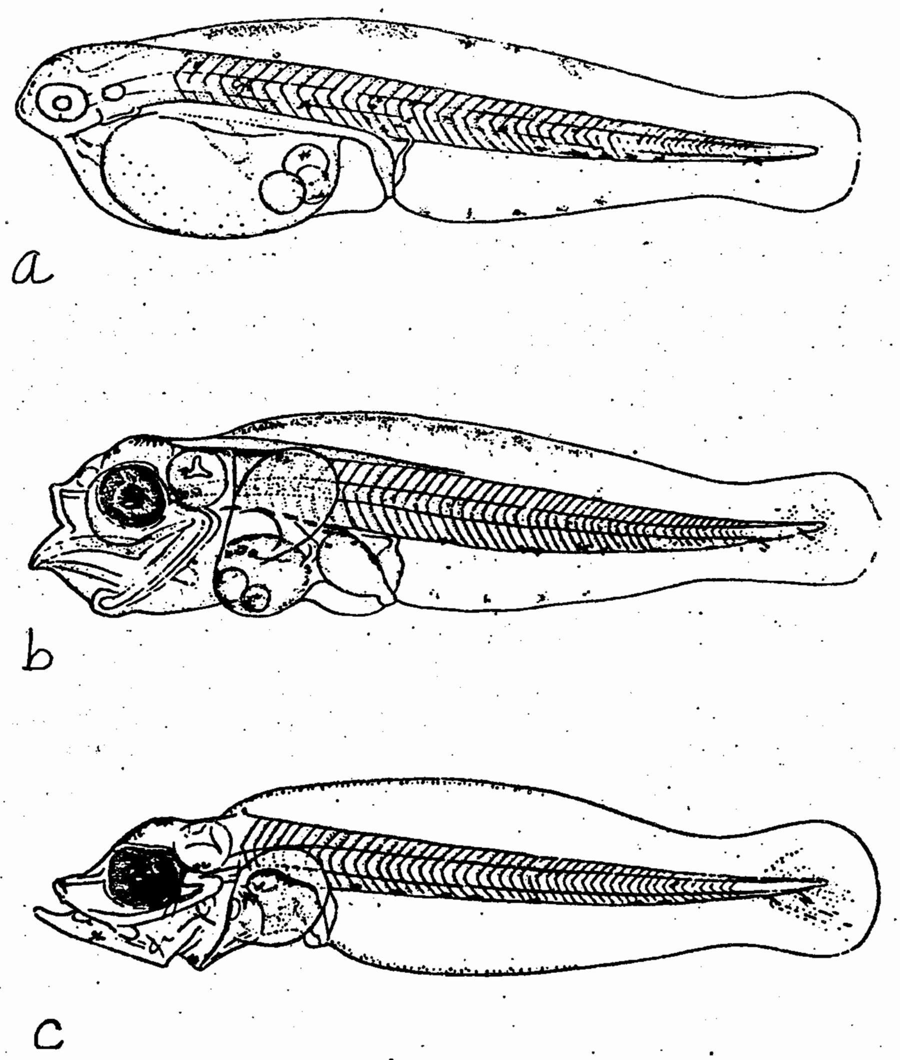


Figure 10.--Pre-larvae of Sarda sarda: (a) 4.32 mm long pre-larva (Fig. 309 of Padoa 1956); (b) 4.6 mm long pre-larva (Fig. 310 of Padoa 1956); (c) 4.20 mm long pre-larva (Fig. 311 of Padoa 1956).

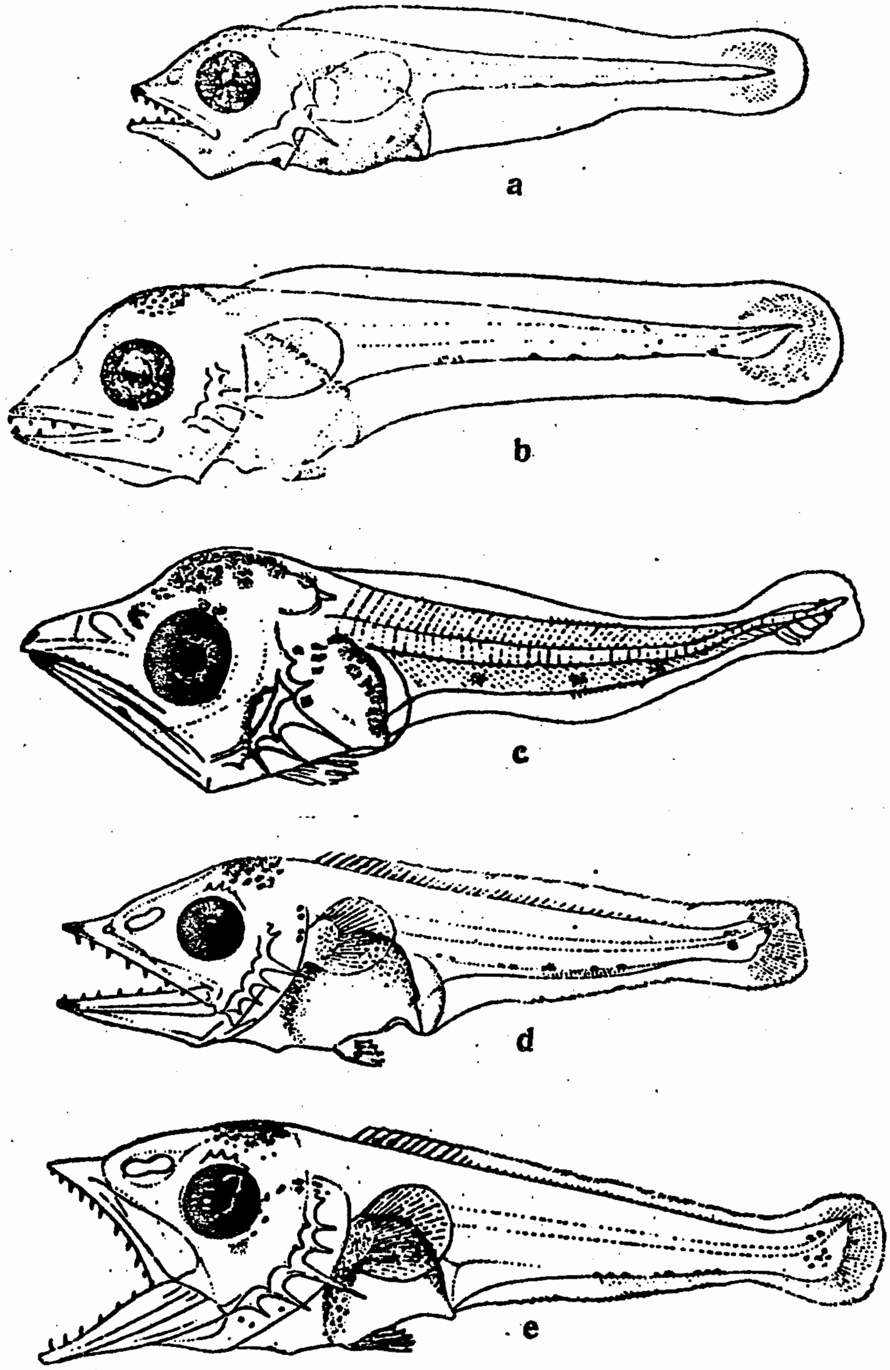


Figure 11.--The postlarvae of Sarda sarda

(a) 5.45 mm (from Vodianitski and Kazanova 1954)
(b) 6.95 mm (from Vodianitski and Kazanova 1954)
(c) 7.20 mm (from Ehrenbaum 1924)
(d) 9.59 mm (from Vodianitski and Kazanova 1954)
(e) 11.00 mm (from Vodianitski and Kazanova 1954)

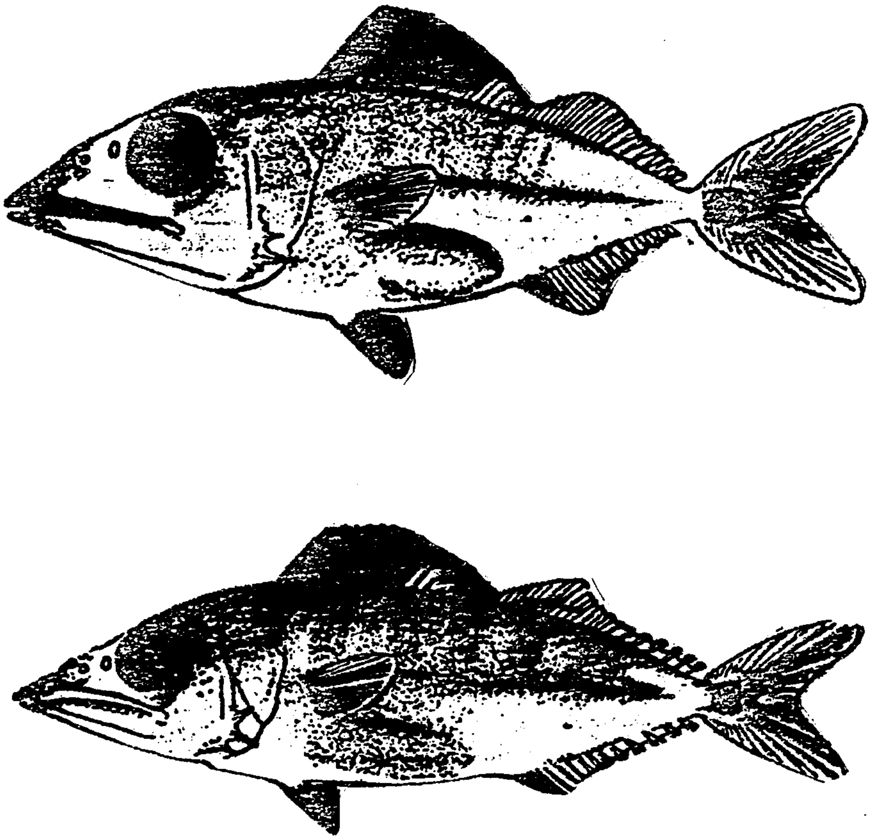
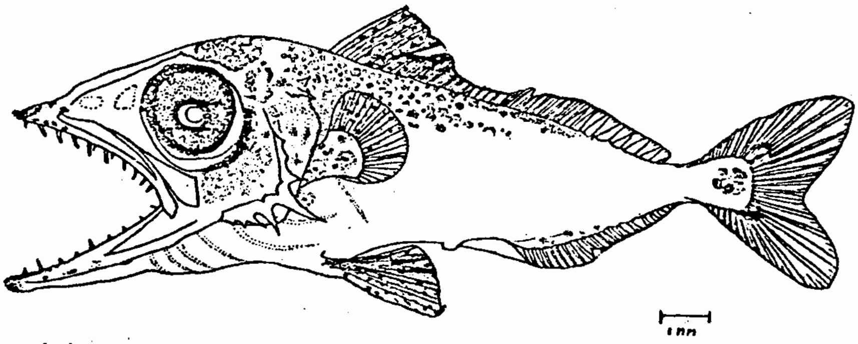
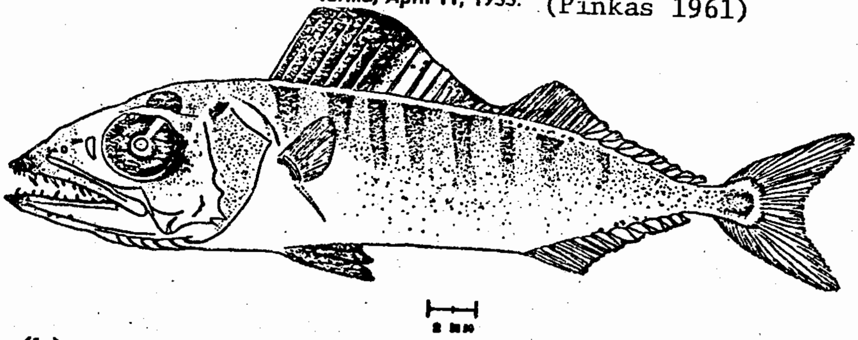


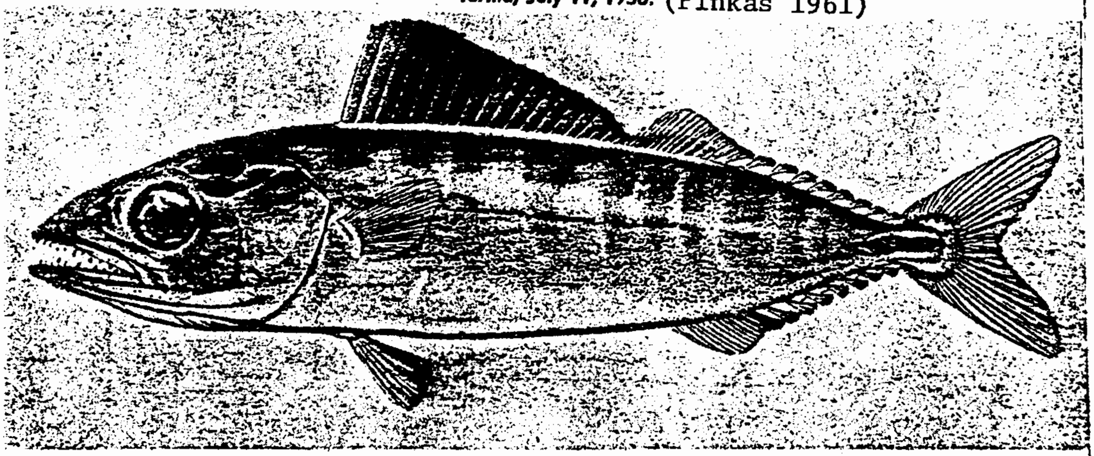
Figure 11.--Continued.



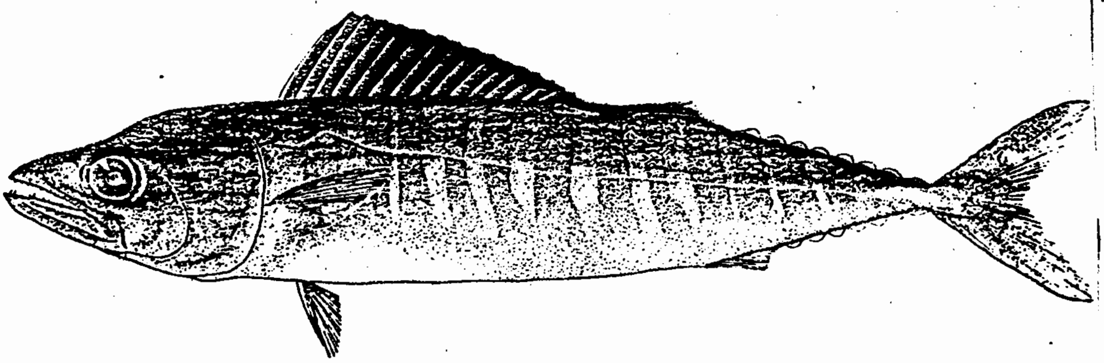
(a) *Sarda chiliensis* 16.7 mm. fork length dipnetted off Cape San Lucas, Baja California, April 11, 1955. (Pinkas 1961)



(b) *Sarda chiliensis* 33.0 mm. fork length dipnetted off Cape San Lucas, Baja California, July 11, 1956. (Pinkas 1961)



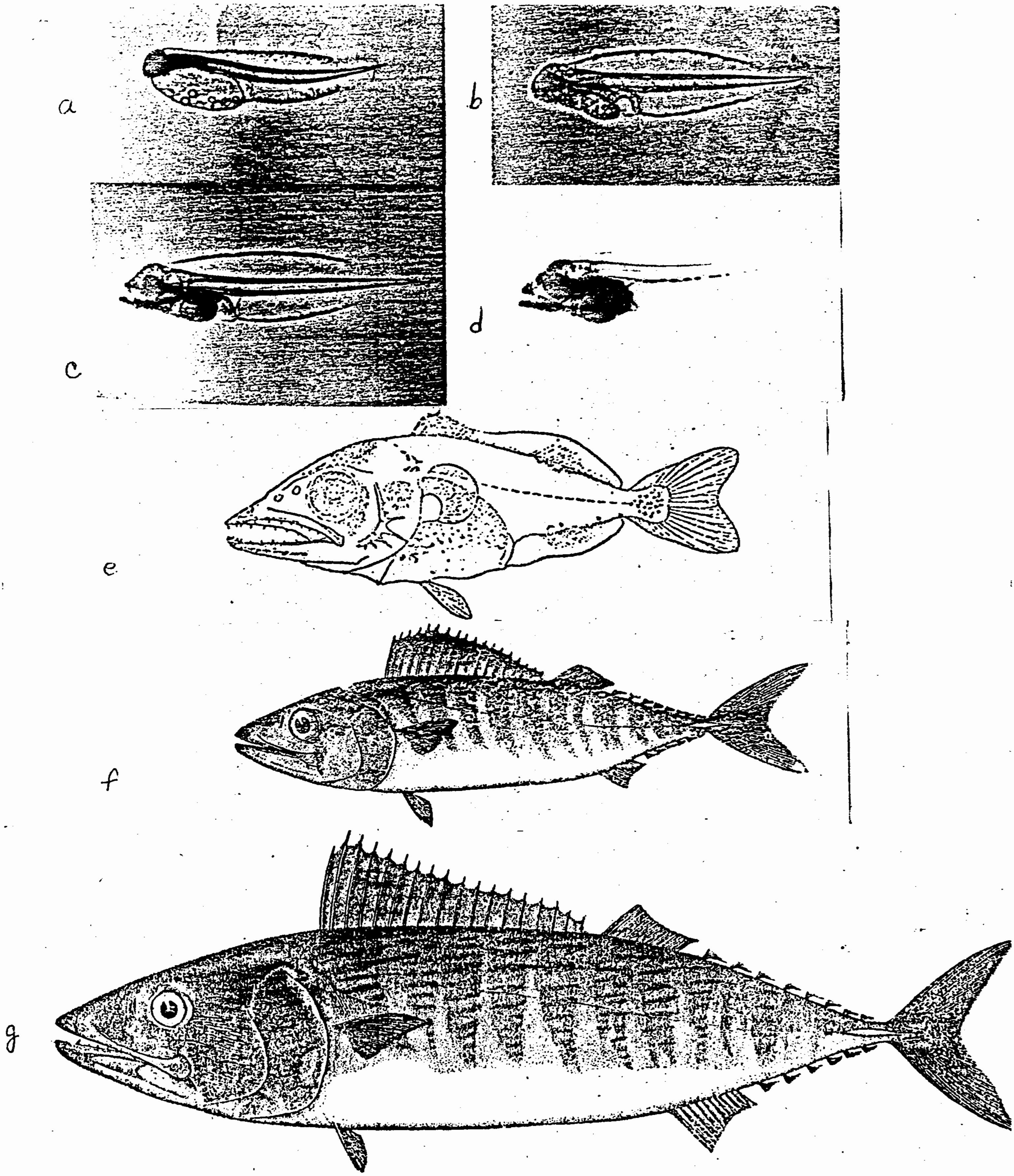
(c) A 42 mm. *Sarda chiliensis* caught on August 5, 1951, off Baja, California. (Klawe 1961b)



(d) A 160 mm. *Sarda chiliensis* caught on January 3, 1956, off northern Peru. (Klawe 1961b)

Figure 12.--Postlarval <u>Sarda</u> <u>chiliensis</u>.

Figure 13.--Larval and postlarva *Sarda orientalis*. (a) 4.2 mm long larva (from Harada et al. 1974); (b) 2-day-old larva (from Harada et al. 1974); (c) 5-day-old larva (from Harada et al. 1974); (d) 8-day-old larva (from Harada et al. 1974); (e) 11.56 mm long larva (from Gorbunova 1963); (f) 80.0 mm long postlarva (from Jones 1960); (g) 158.0 mm long postlarva (from Jones 1960).


a
b
c
d
e
f
g

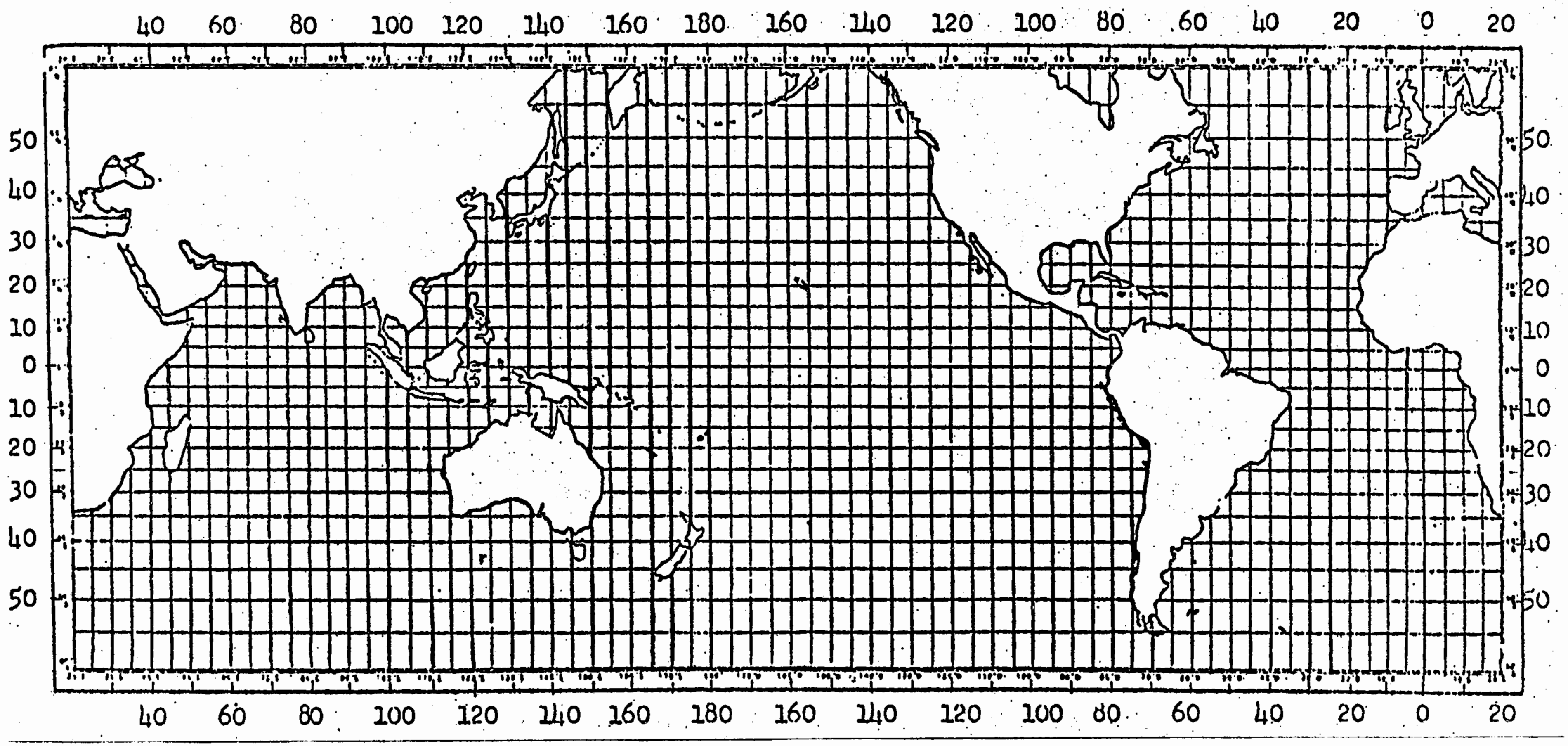


Figure 14.--Distribution of larval and juvenile <u>Sarda</u> spp. (Source: Kishinouye 1923; Ehrenbaum 1924; Yabe et al. 1953; Vodianitskii and Kazanova 1954; Padoa 1956; Klawe and Shimada 1959; Jones 1960; Klawe 1961a, 1961b; Mito 1961; Pinkas 1961; Demir 1963; Gorbunova 1963; Gorbunova and Salabarria 1967; and Duclerc et al. 1973.)

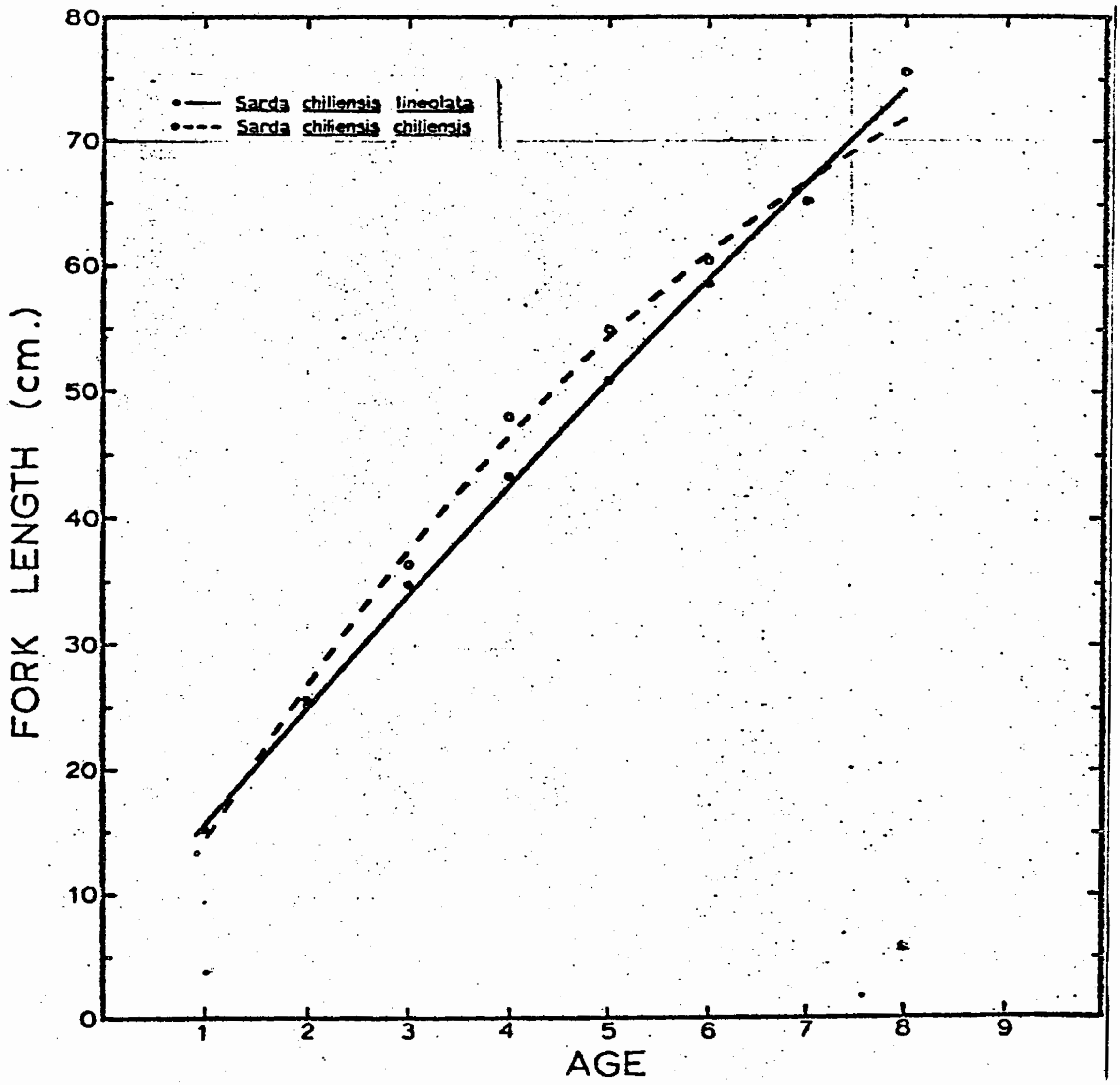


Figure 15.--Growth of <u>Sarda</u> <u>chiliensis</u> from southern California and Peru (from Kuo 1970).

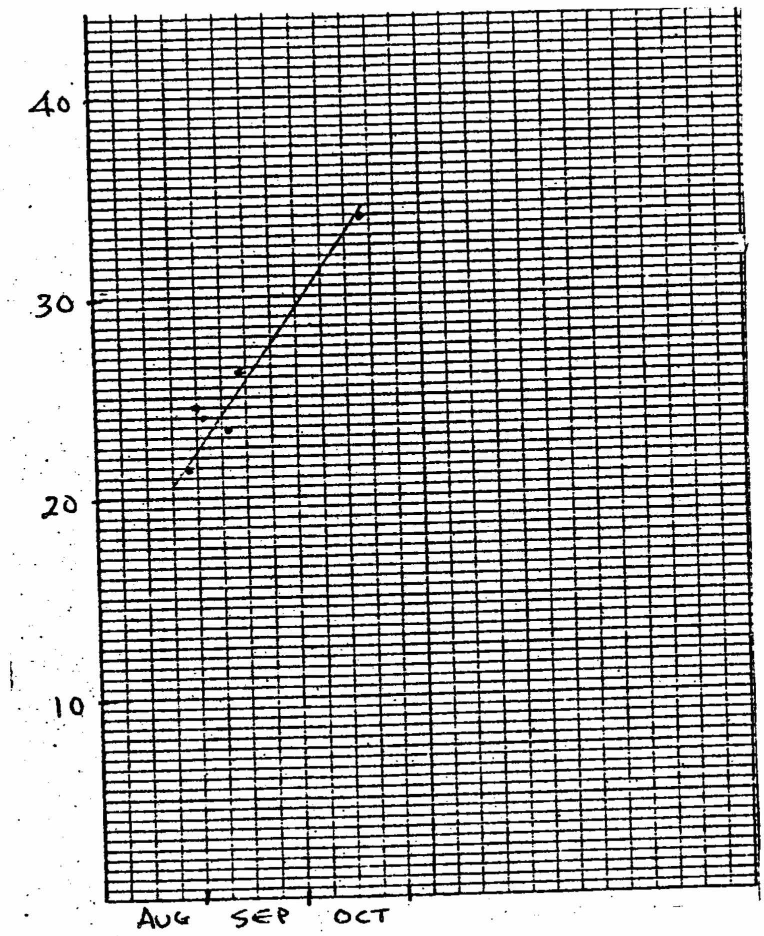


Figure 16.--Growth of juvenile Sarda orientalis (data from Yabe et al. 1953).

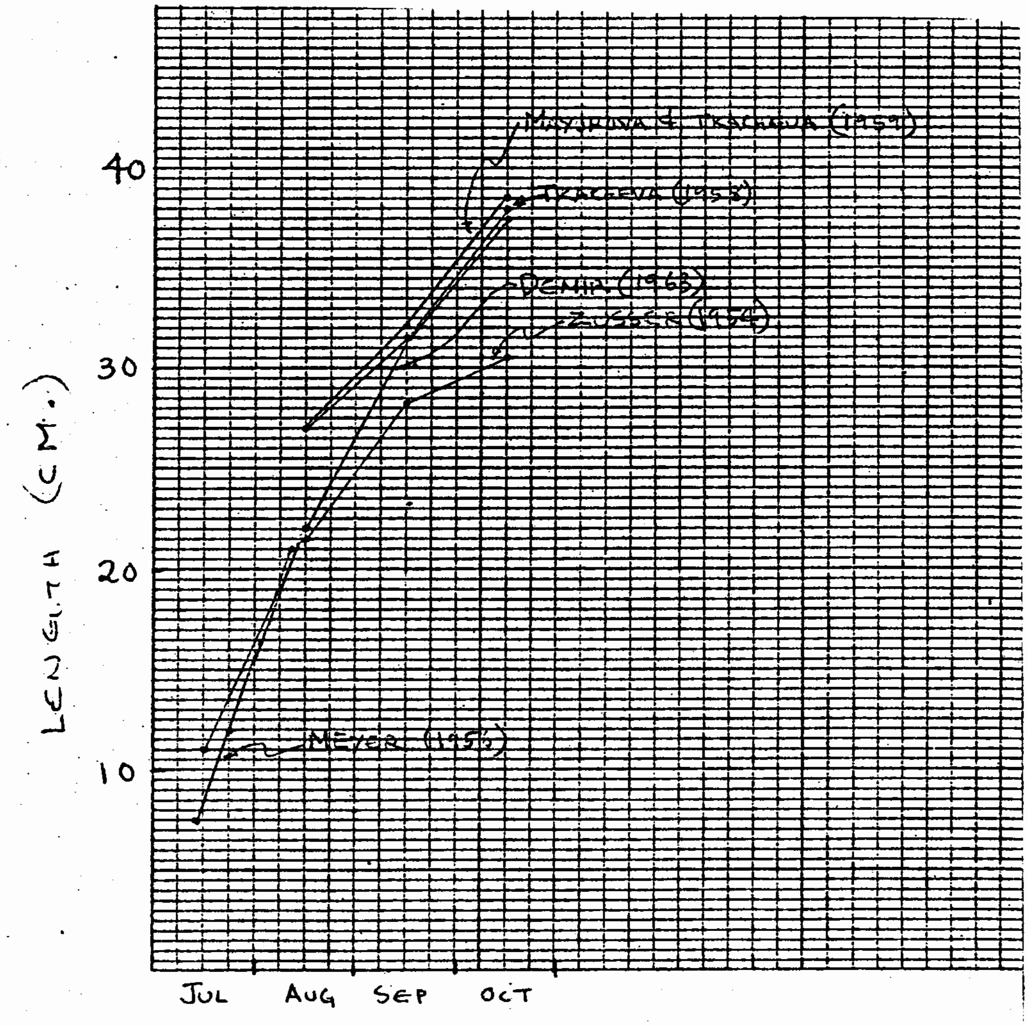


Figure 17.--Growth of juvenile Sarda sarda in the Black Sea.

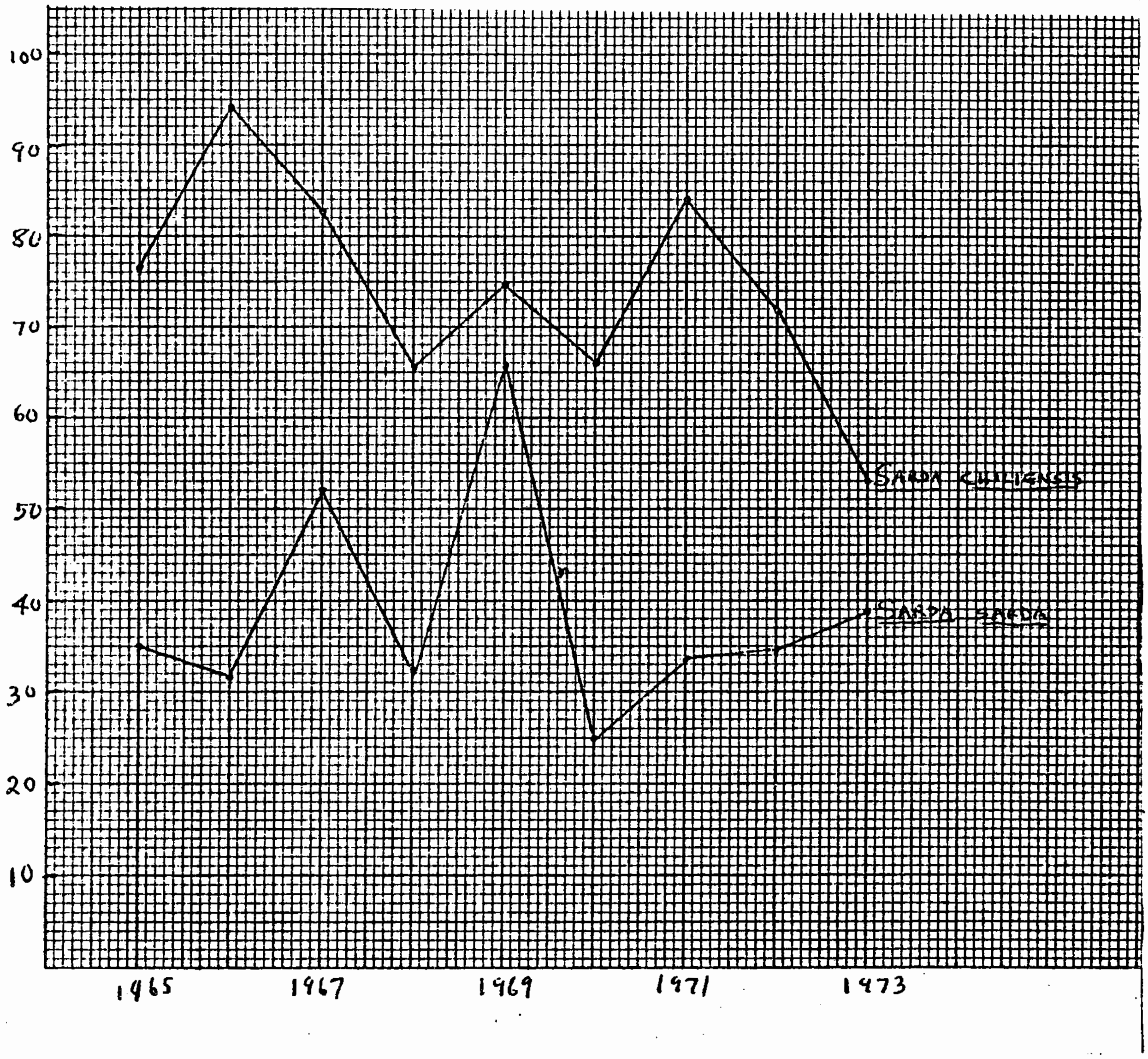


Figure 18.--Annual world landings of Sarda chiliensis and Sarda sarda, 1965-73 (data from FAO 1974).

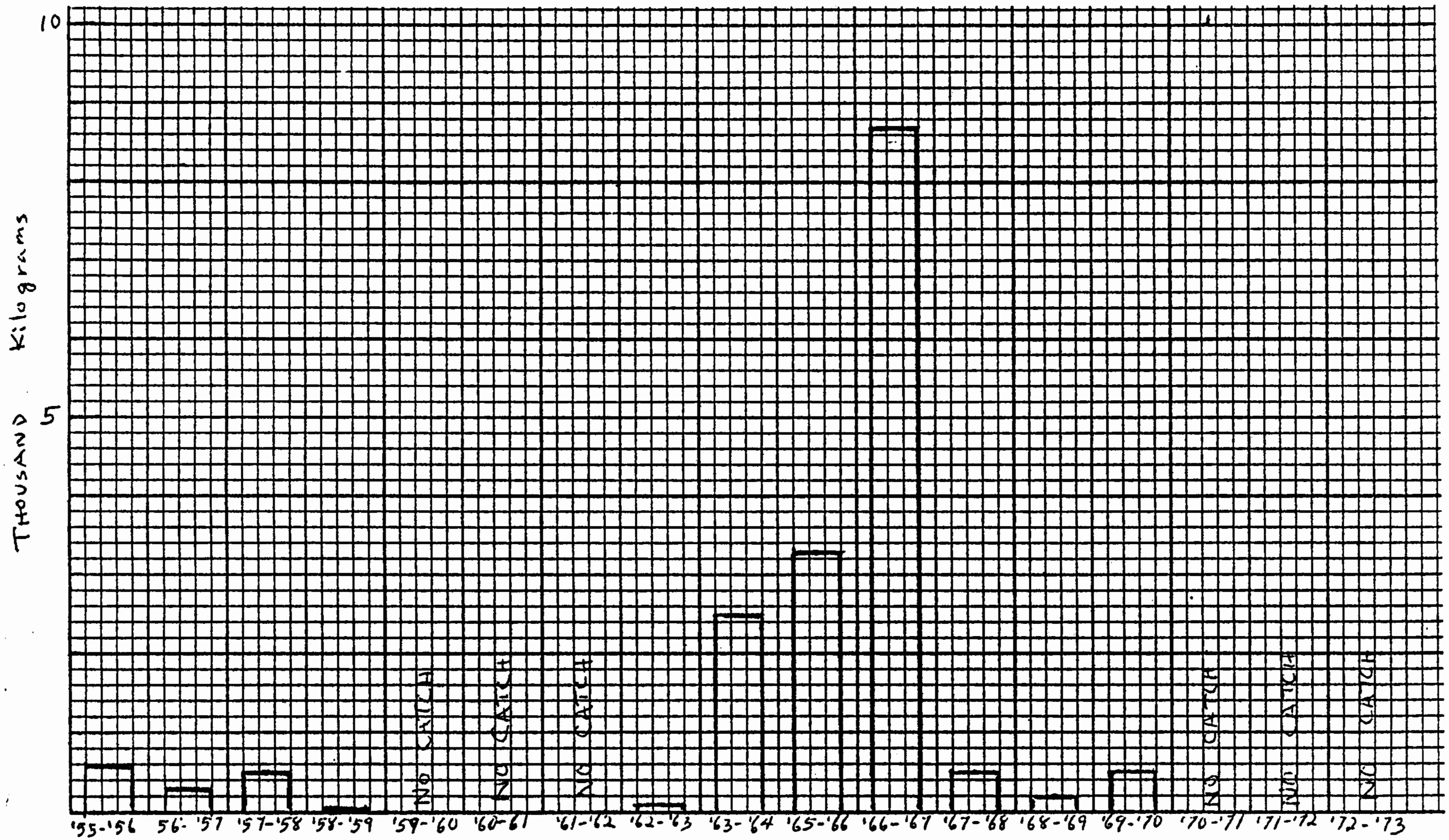


Figure 19.--Annual landings of <u>Sarda australis</u> in Australia.
(Data from Australia. Fisheries Branch, Department of Primary Industry 1957-74.)

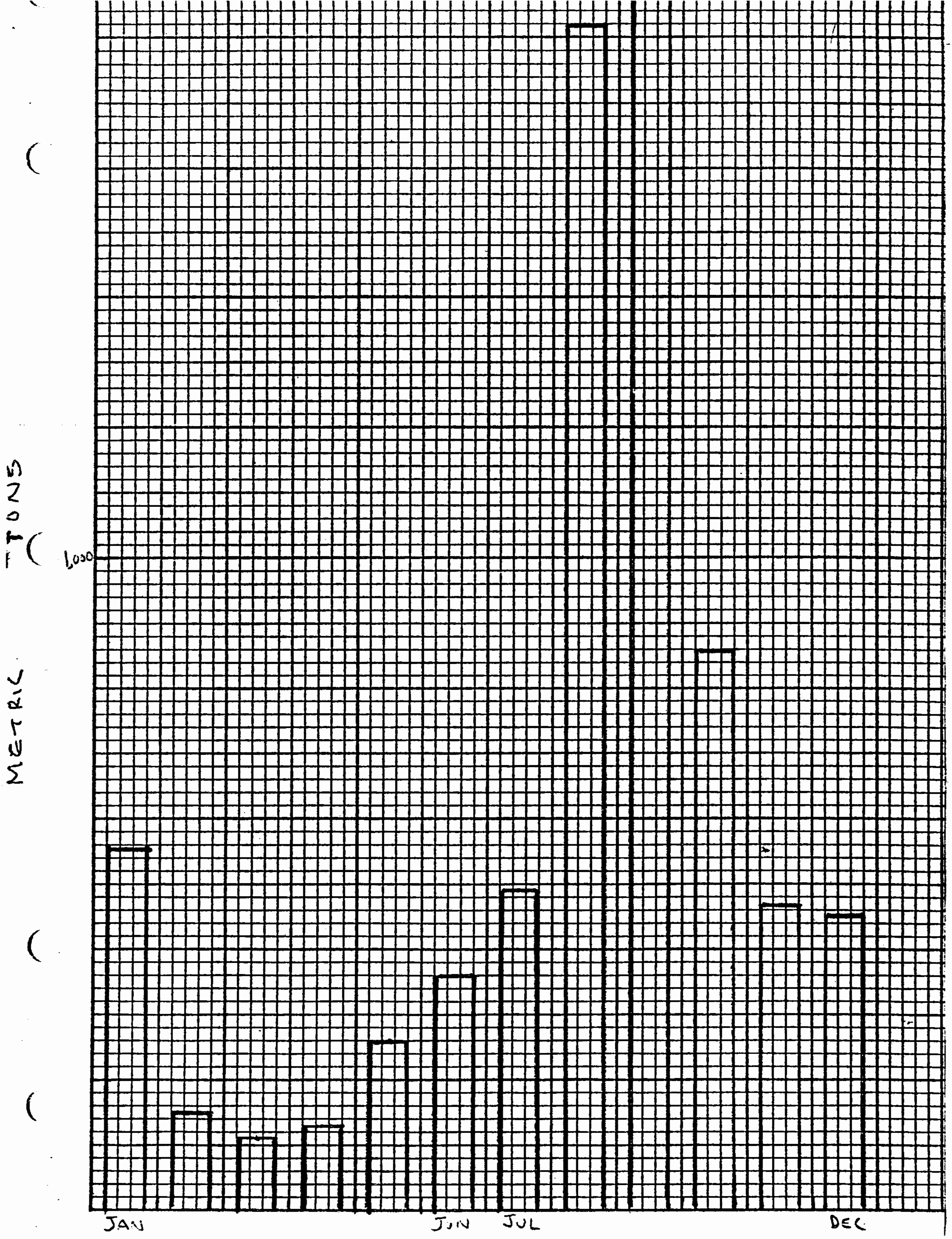


Figure 20.--Mean monthly landings of Sarda chiliensis in California (data from Oliphant and staff 1973).

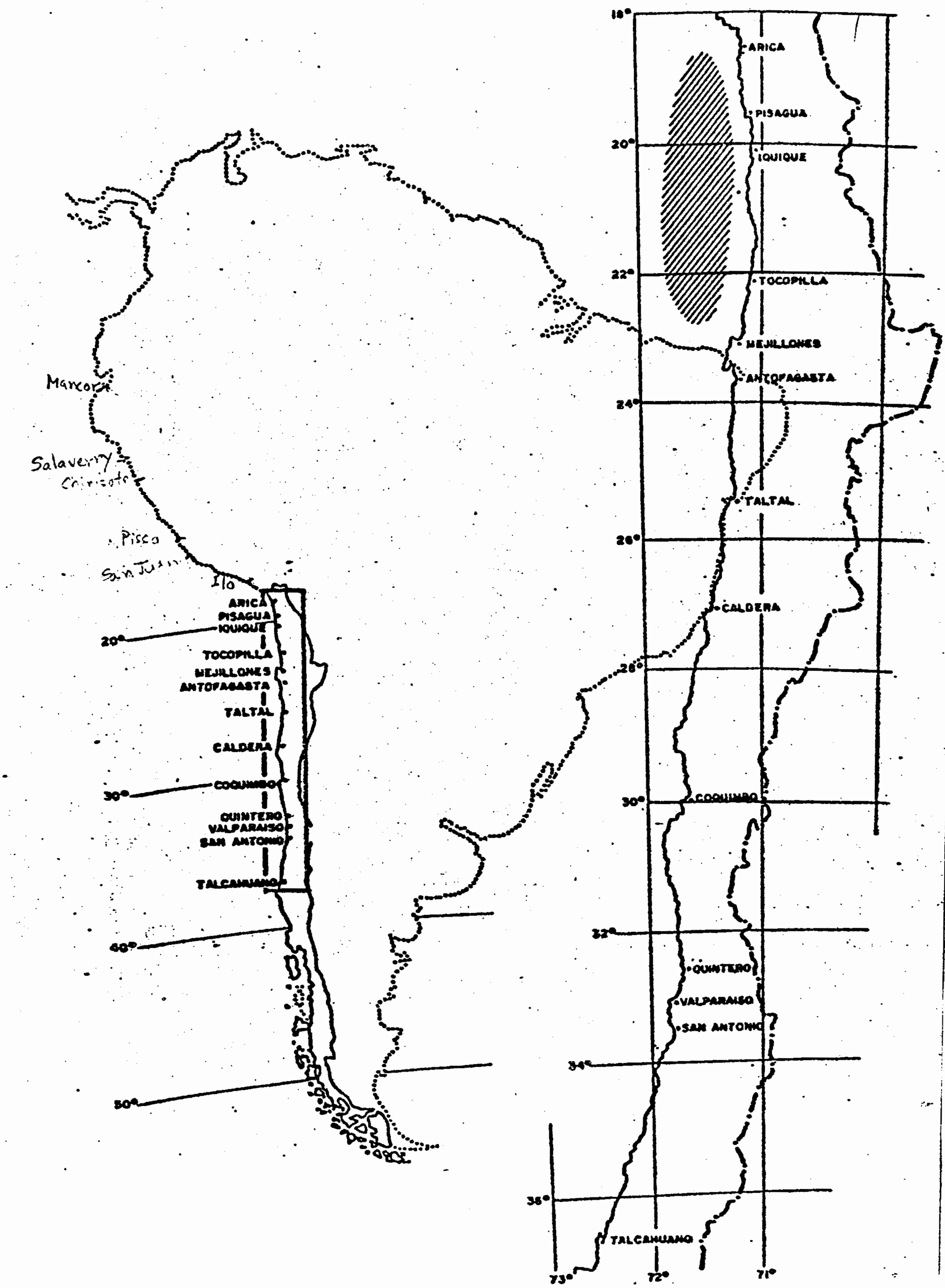


Figure 21.--The geographic extent of the Peruvian and Chilean fisheries for <u>Sarda chiliensis</u>.

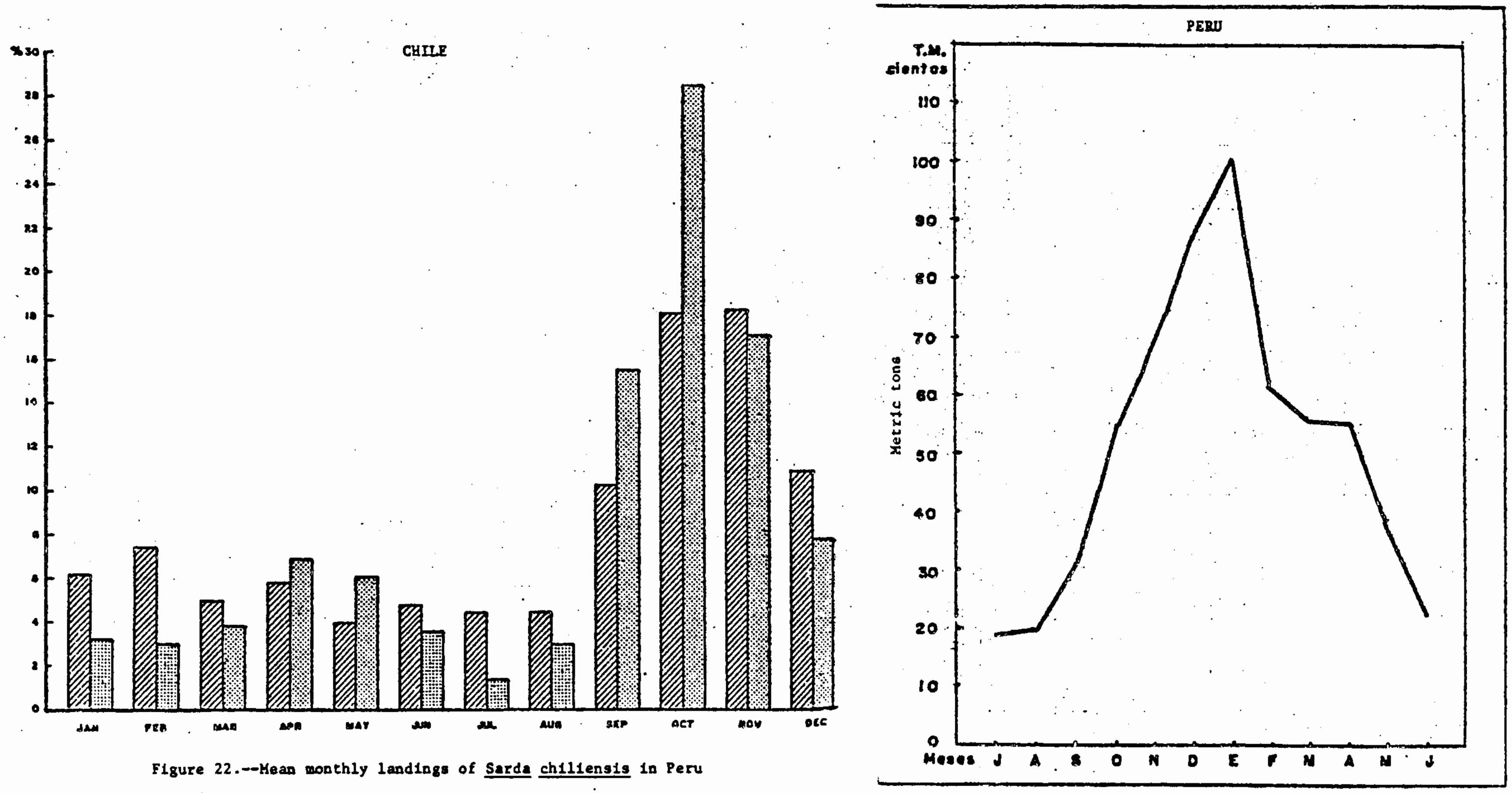


Figure 22.--Mean monthly landings of Sarda chiliensis in Peru (Ancieta 1963) and Chile (Barrett 1971).

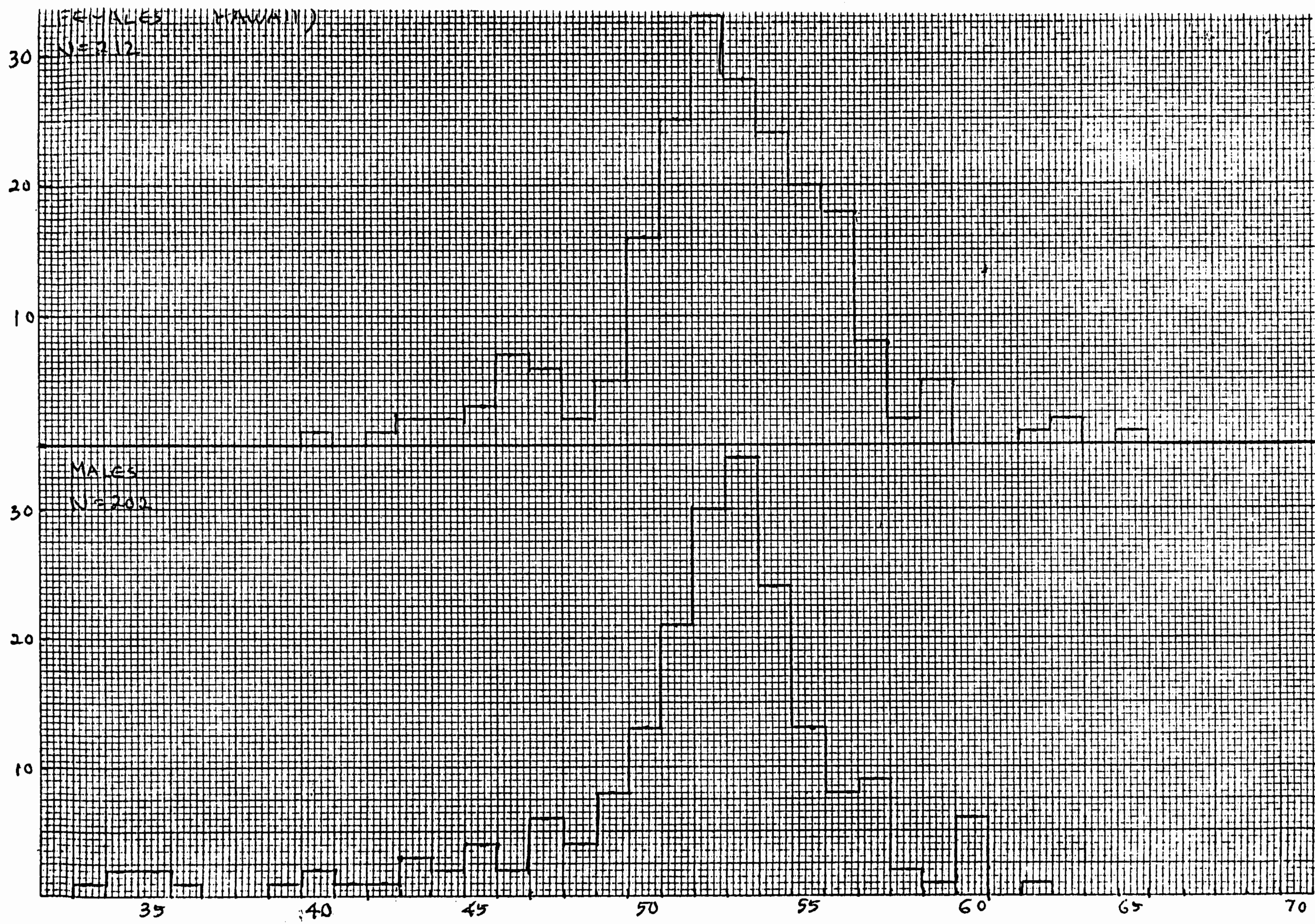


Figure 23.--Length-frequency distribution of *Sarda chiliensis* captured in the sport fishery in southern California. (Data kindly provided by Chin-Ming Kuo, Oceanic Institute, Makapuu Point, Waimanalo, Hawaii.)

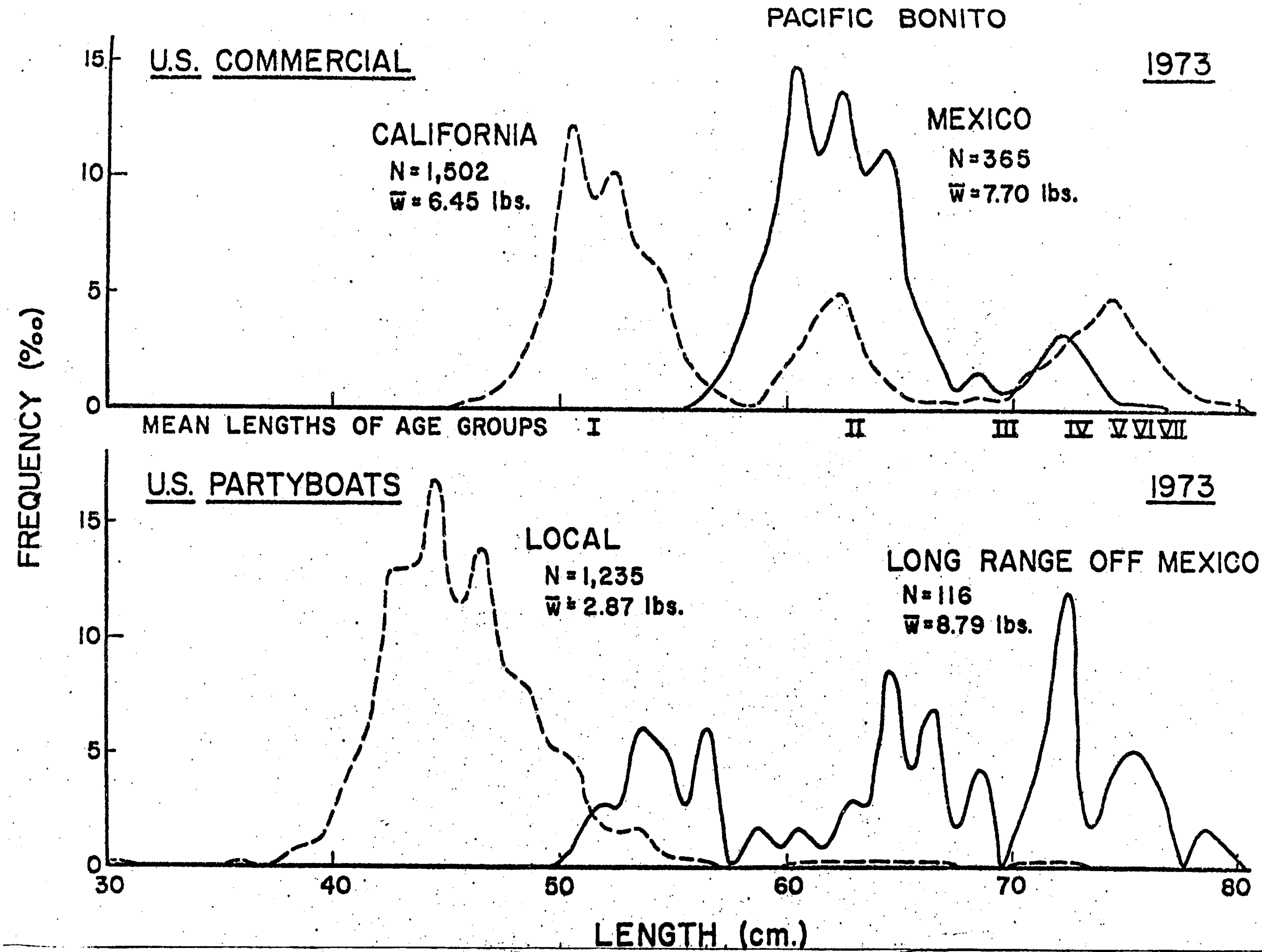


Figure 23a.--Length-frequency distribution of _Sarda chiliensis_ taken by the California commercial party boat fisheries (from McCall et al., see footnote 4).

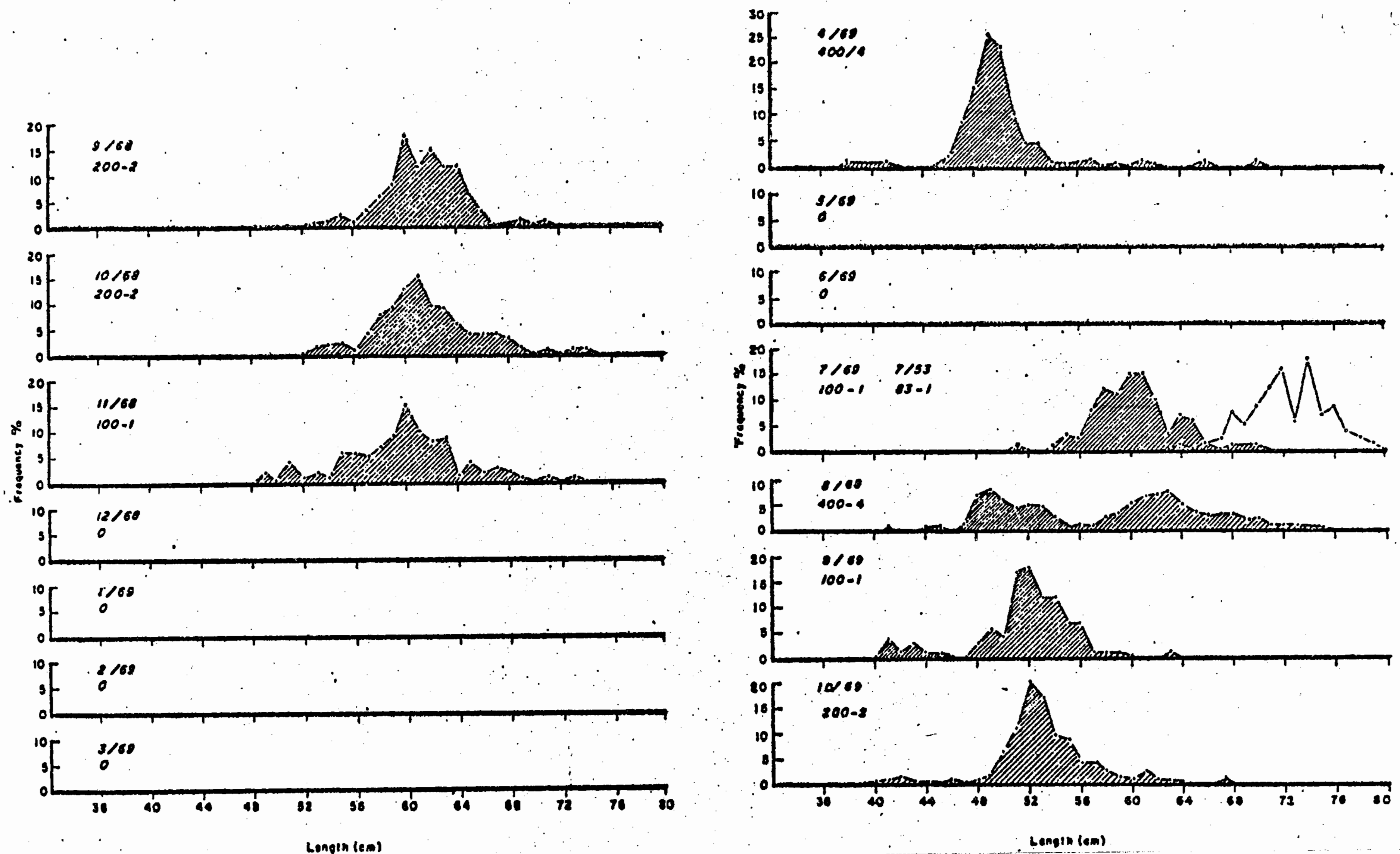


Figure 24.--Length-frequency distribution of bonitos sampled from the commercial landings at Iquique, Chile, September 1968 to October 1969. Numerals in upper left corner of each panel indicate the month and year, number of fish and number of samples. Unshaded distribution is from de Buen (1958). (From Barrett 1971.)

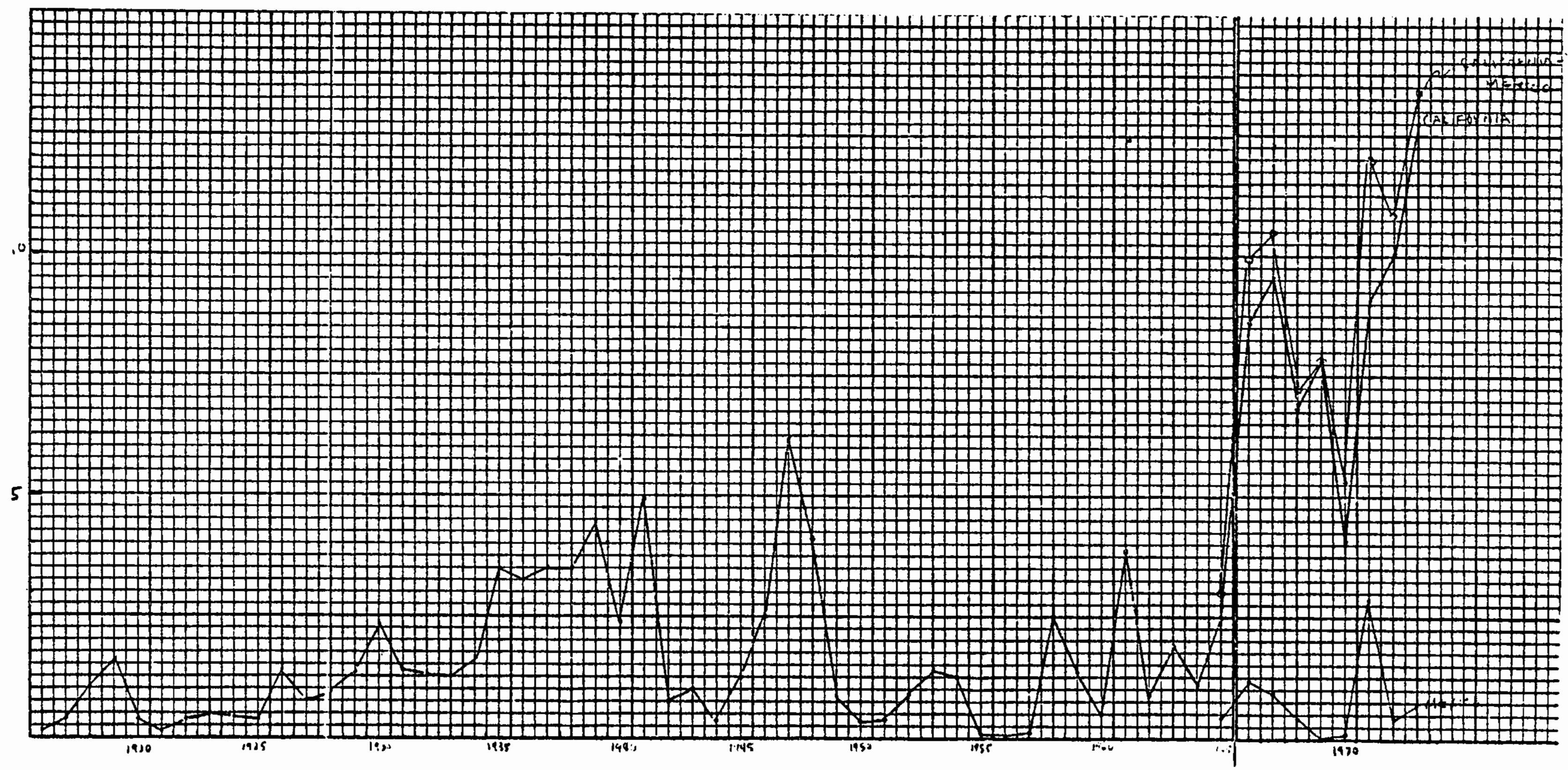


Figure 25.—California and Mexico landings of Sarda chiliensis (data from Bell 1971; Frey 1971; Oliphant and staff 1973; FAO (1974; and Pinkas 1974).

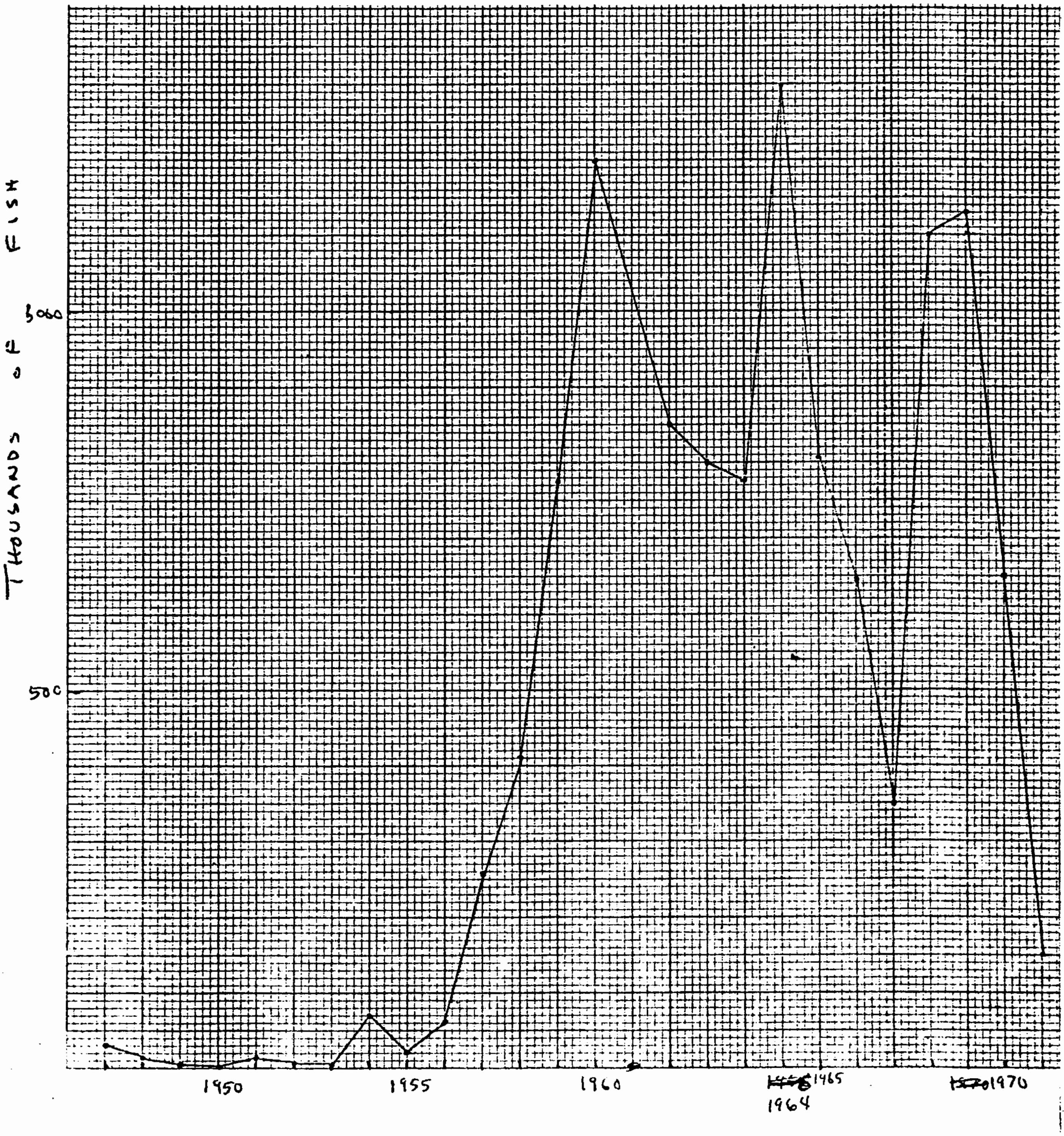


Figure 26.--Landings of Sarda chiliensis by the California party boat fleet. (Data from Frey 1971 and Oliphant and staff 1973.)

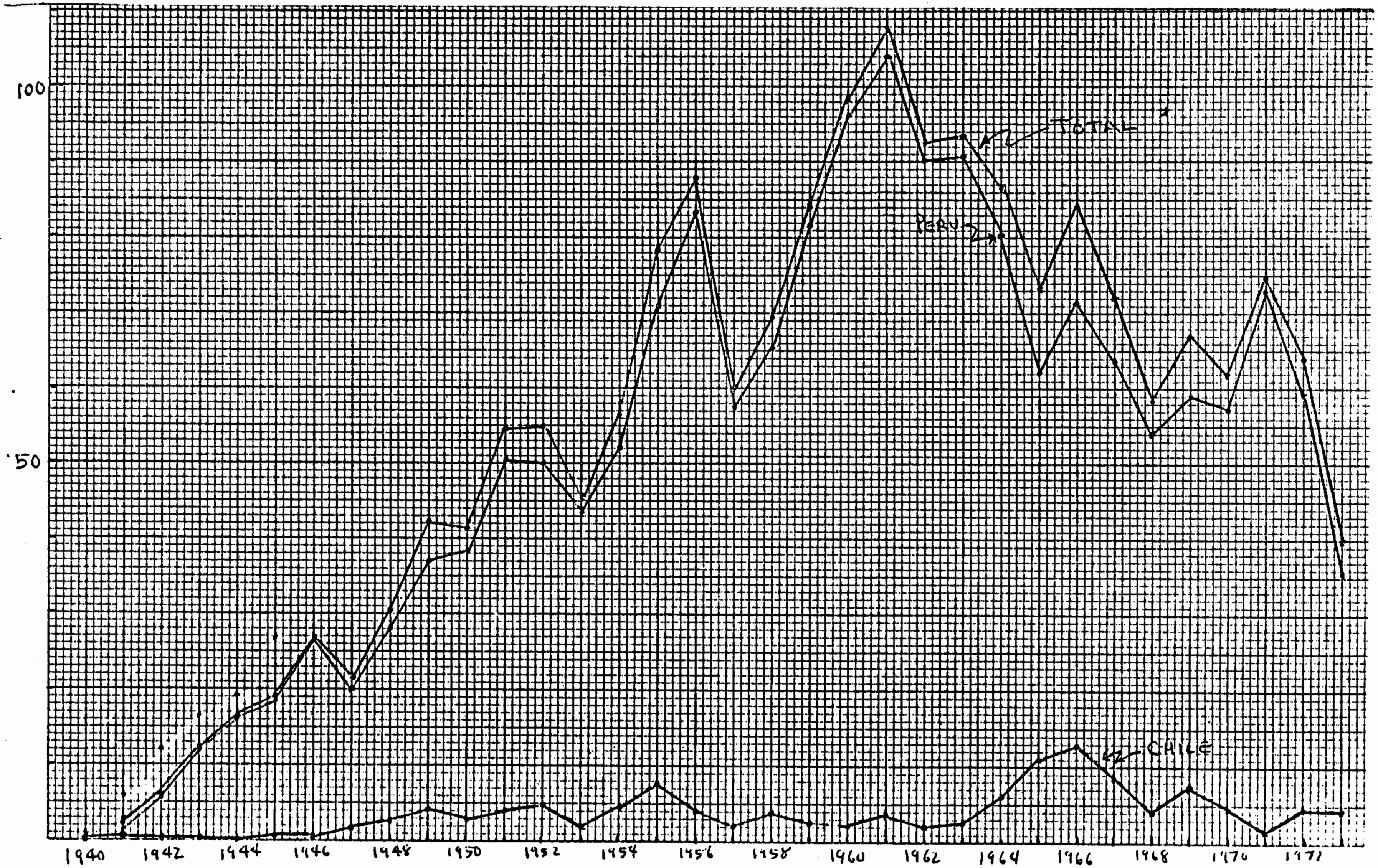


Figure 27.--Landings of <u>Sarda chiliensis</u> in Peru and Chile (data from Ancieta 1963; FAO 1965, 1974; and Barrett 1971.)

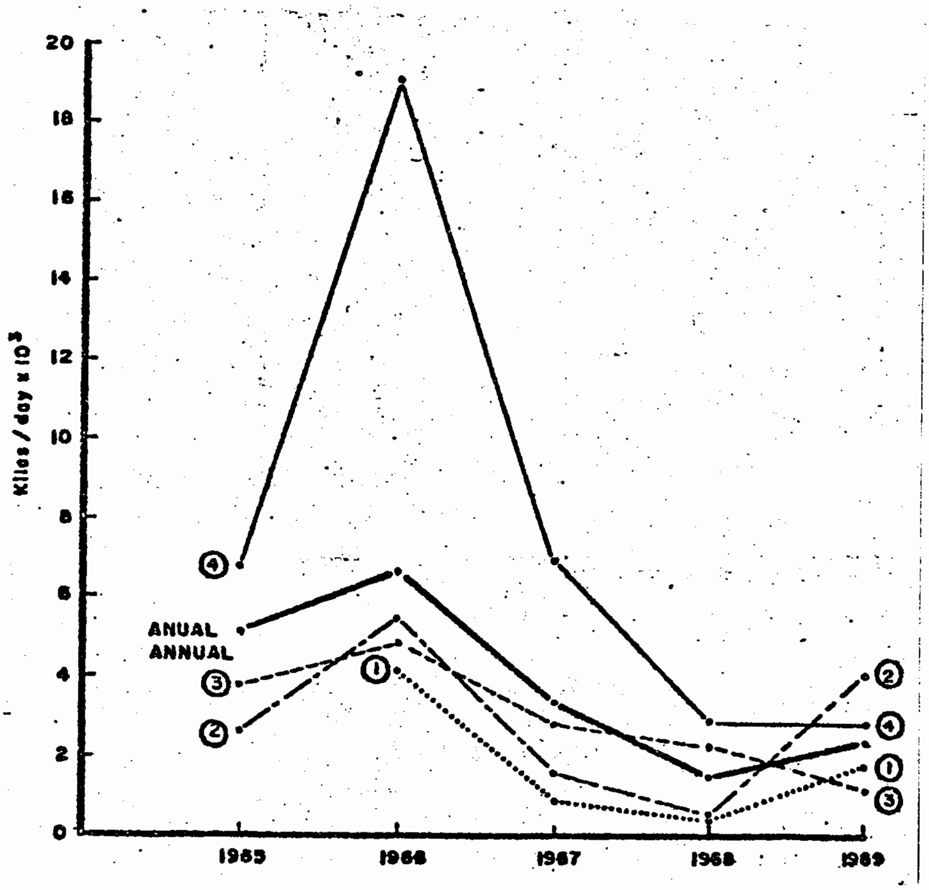


Figure 28.--Apparent abundance of bonito, for individual quarters and years, by years, from data for the bonito vessels (from Barrett 1971).

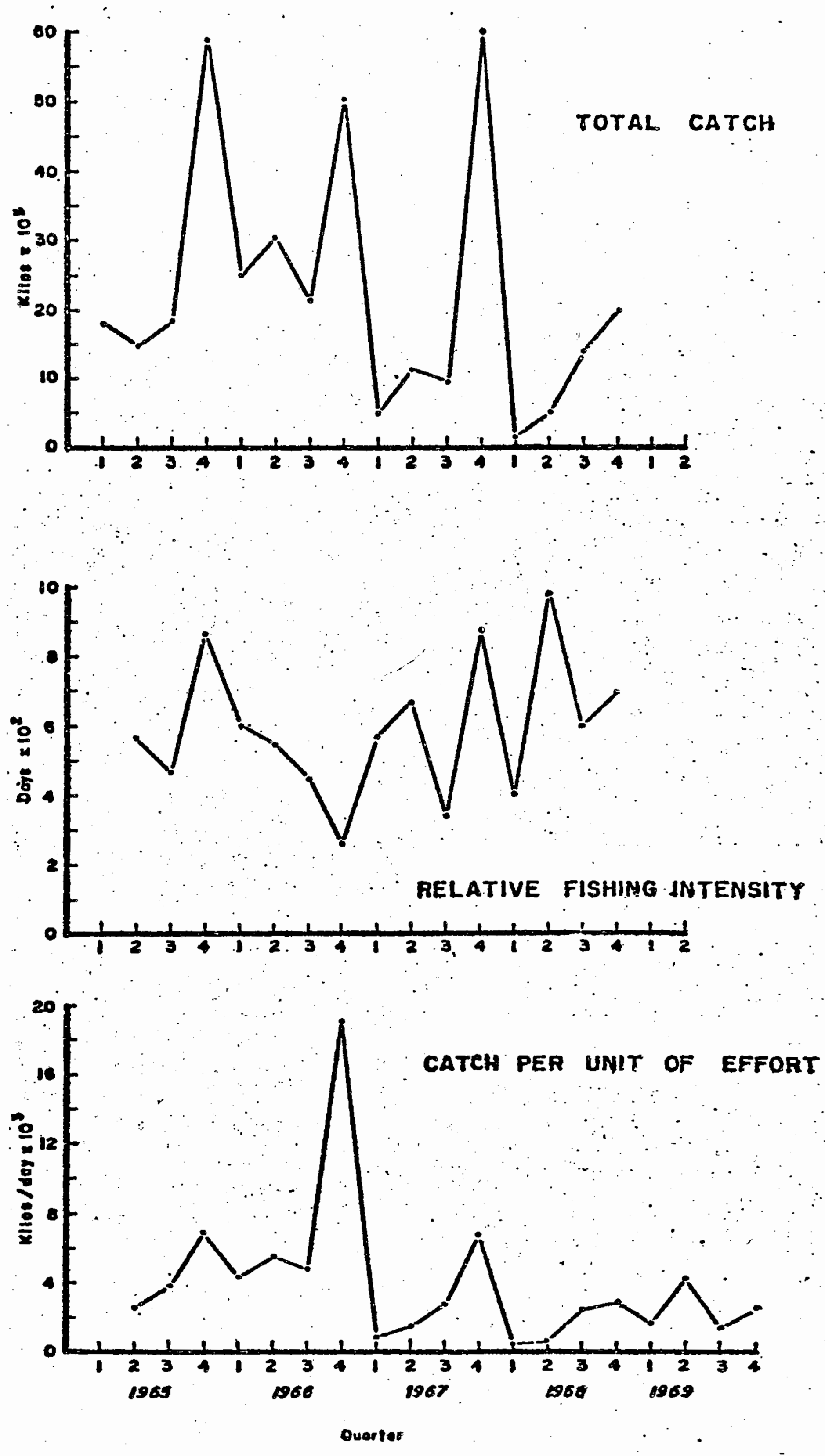


Figure 29.--Total catch, and relative fishing intensity and apparent abundance (from data for the bonito vessels) quarterly from 1965 to 1969. Relative fishing intensity for 1969 is not shown because data for total catch in 1969 were not available (from Barrett 1971).

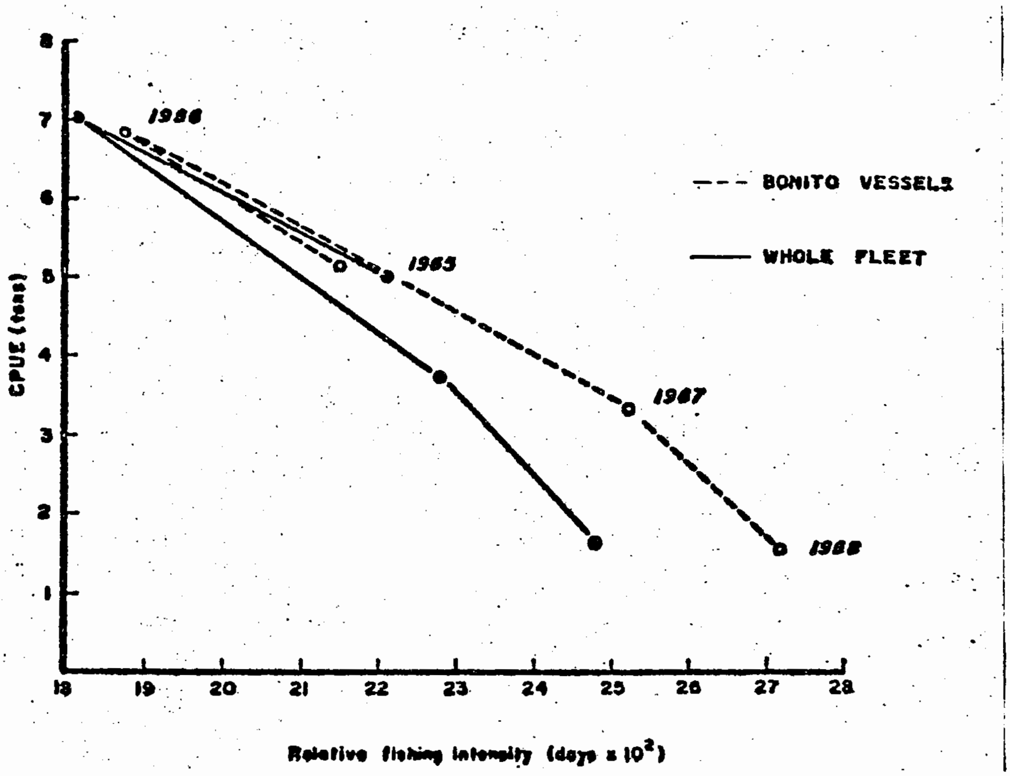


Figure 30.--Apparet abundance of bonito in relation to relative fishing intensity, from data for the bonito vessels only (dotted line) and for the fleet monitored by IFOP (Instituto de Fomento Pesquero) (solid line), 1965-68. (From Barrett 1971.)

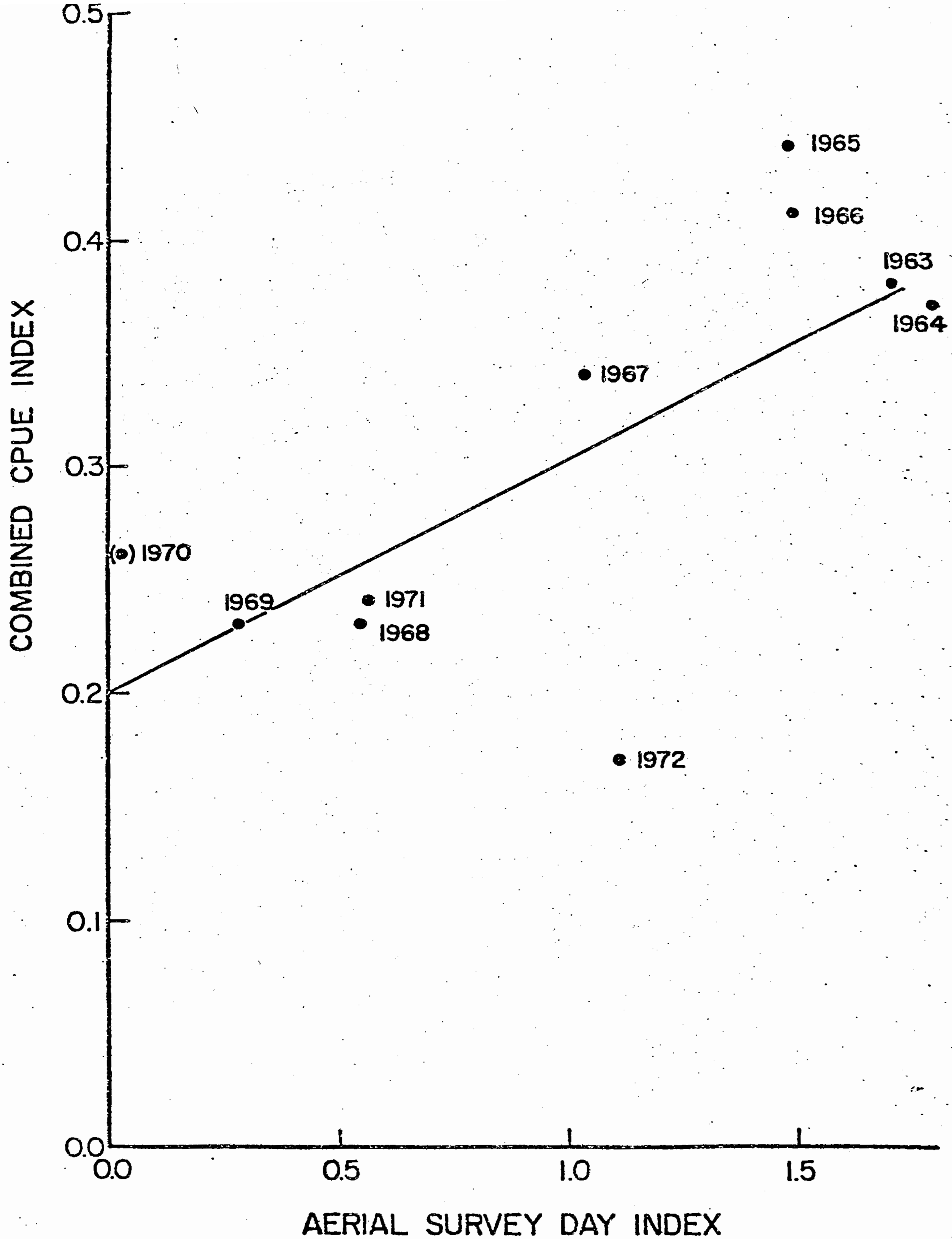


Figure 30a.--Regression of aerial survey day index against "combined" party boat CPUE index. (From McCall et al., see footnote 4.)

$$\left(\tfrac{1}{4}\,\mathrm{CPUE}_{i-1}e^{-1} + \tfrac{1}{2}\,\mathrm{CPUE}_{i-2}e^{-2} + \sum_{j=3}^{4} \mathrm{CPUE}_{i-j}e^{-j}\right)$$

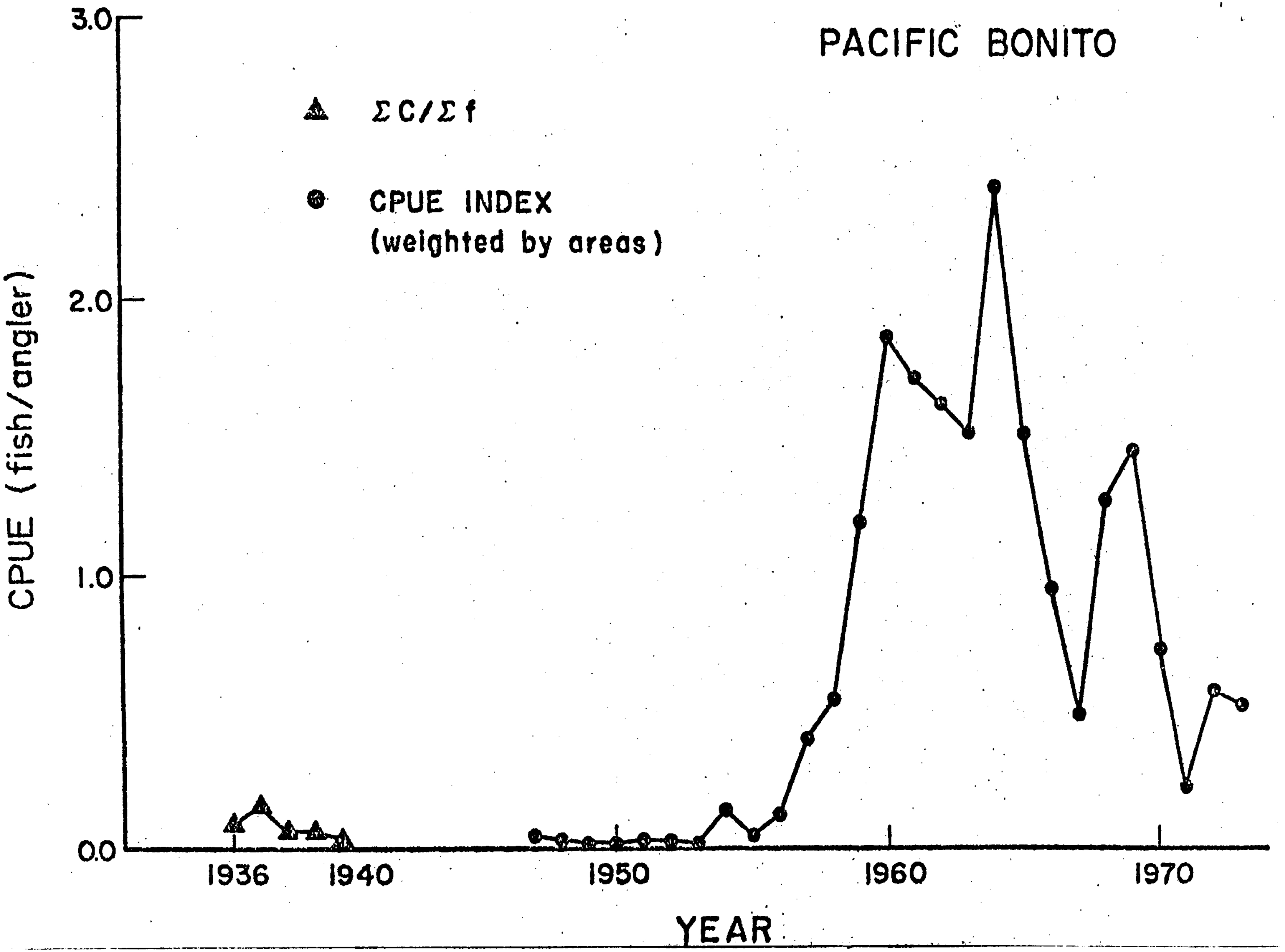


Figure 30b.--Party boat CPUE as an index of annual recruitment.
(From McCall et al., see footnote 4)

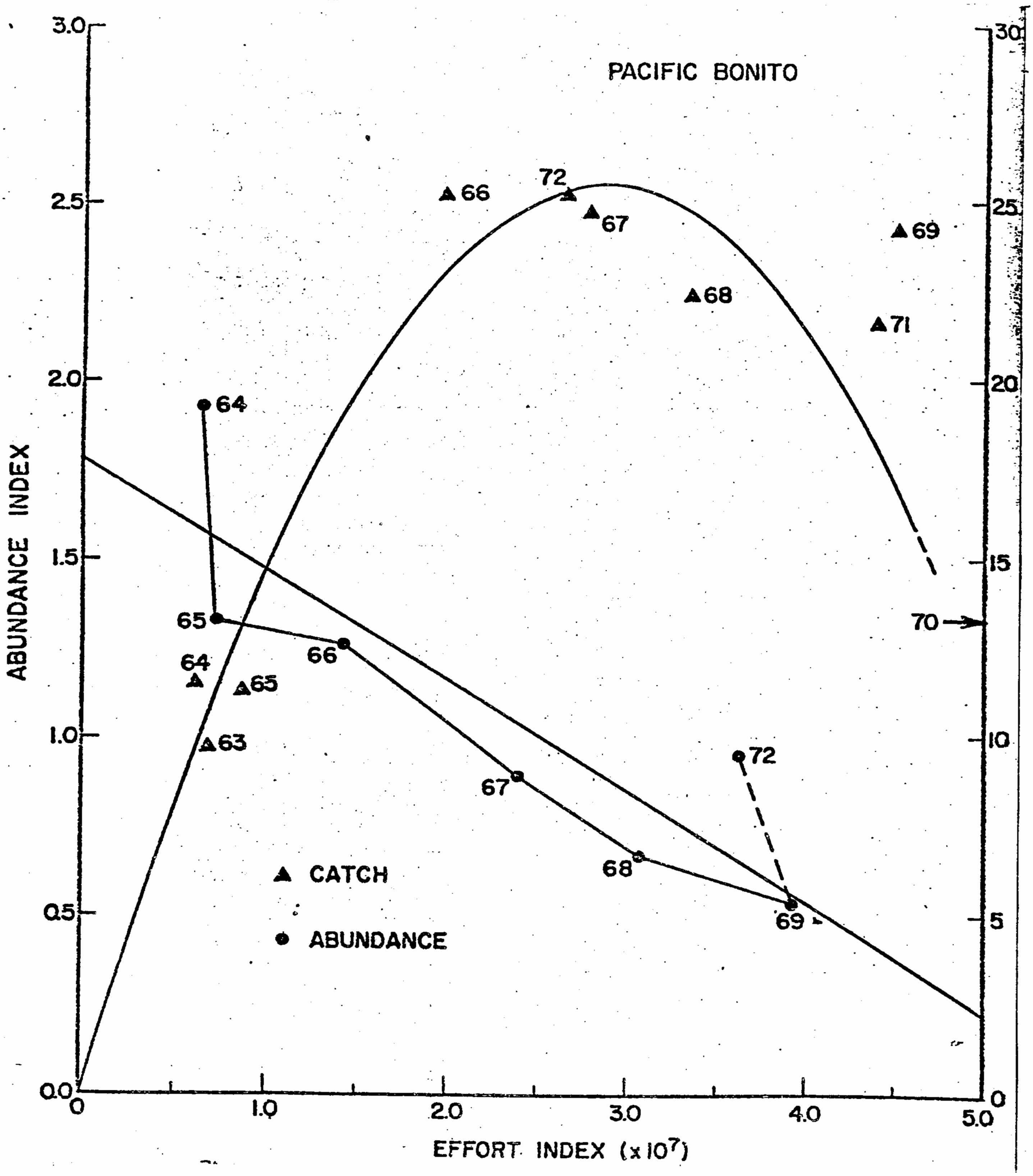
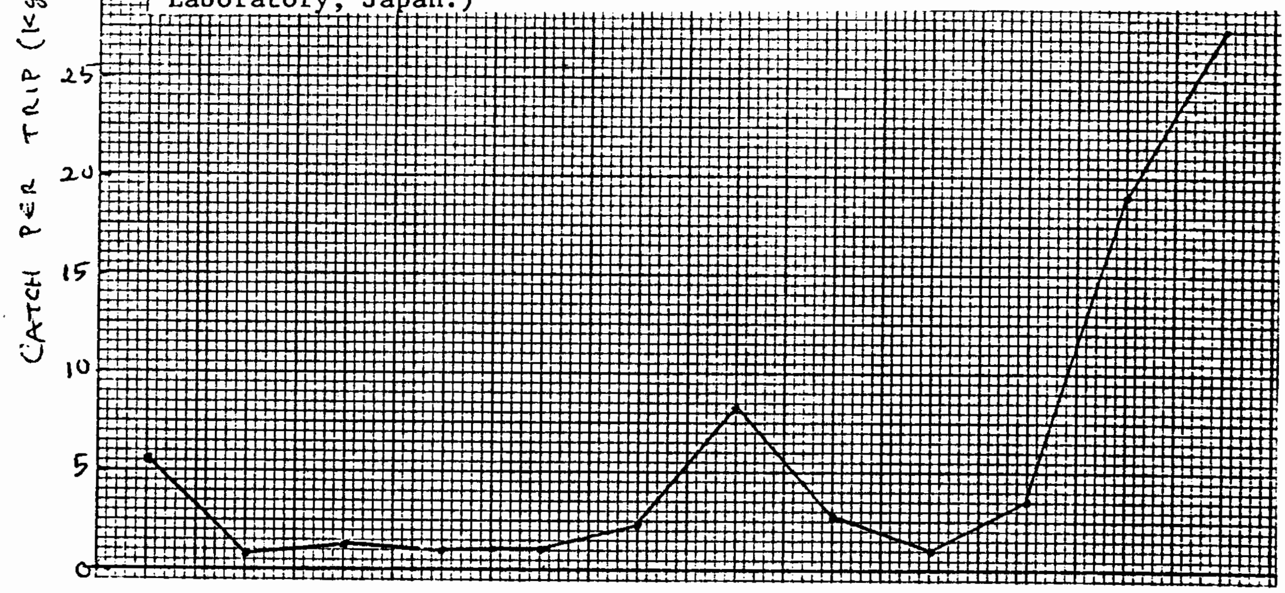


Figure 30c.--Pacific bonito equilibrium yield and abundance in California waters. (From McCall et al., see footnote 4.)

A.--Mean monthly catch per trip by trolling in the Aburatsu, southern Kyushu, Japan fishery for Sarda orientalis, 1970-73. (Data provided by Dr. S. Kikawa, Far Seas Fisheries Research Laboratory and Mr. T. Koto, Nansei Regional Fisheries Research Laboratory, Japan.)



B.--Mean monthly landings of Sarda orientalis at Tosashimizu and Muroto, Kochi, Japan by various fishing methods 1967-73. (Data provided by Dr. S. Kikawa, Far Seas Fisheries Research Laboratory and Mr. T. Koto, Nansei Regional Fisheries Research Laboratory, Japan.)

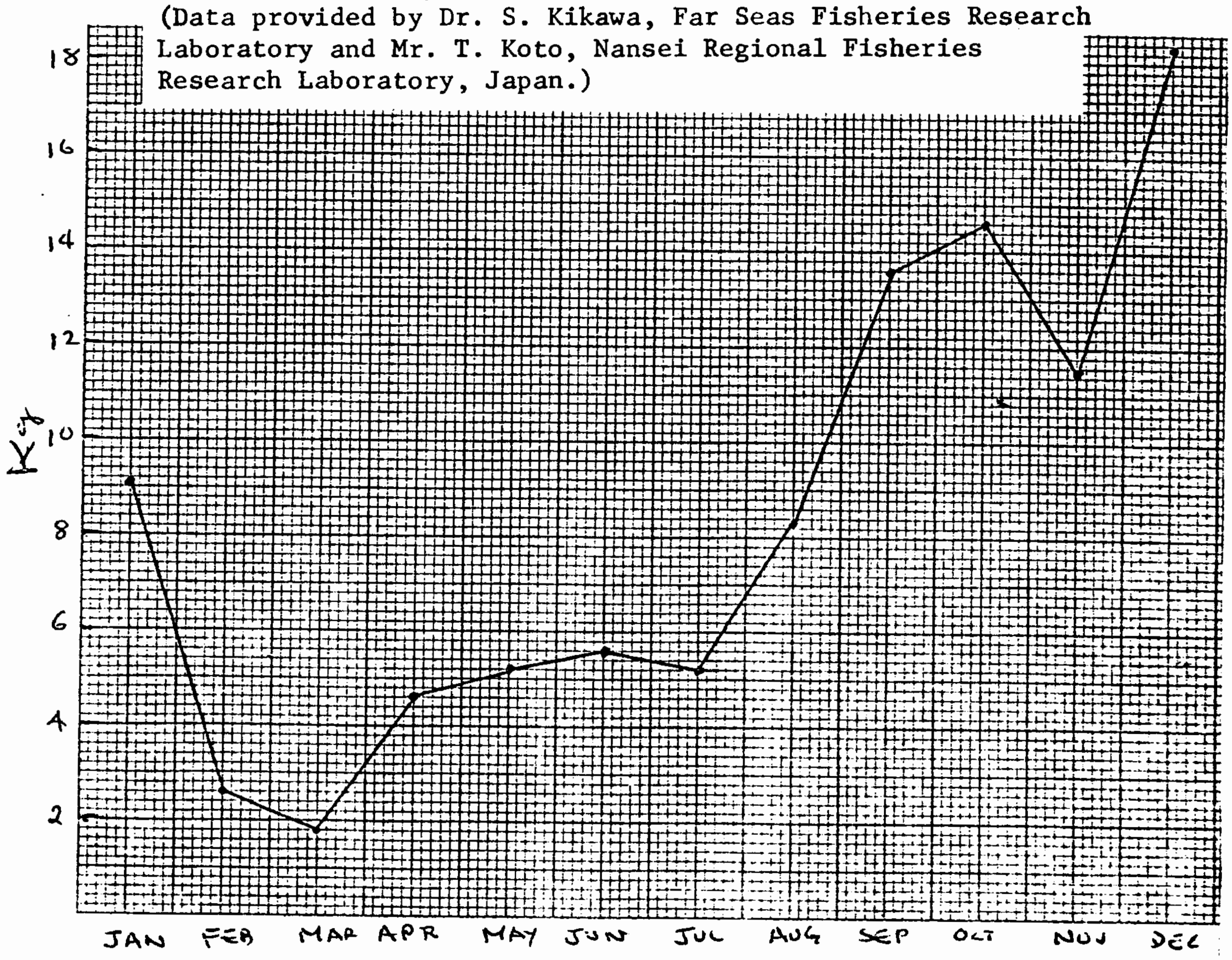


Figure 31.--Seasonal landings and catch rates of Sarda orientalis in southern Japan.

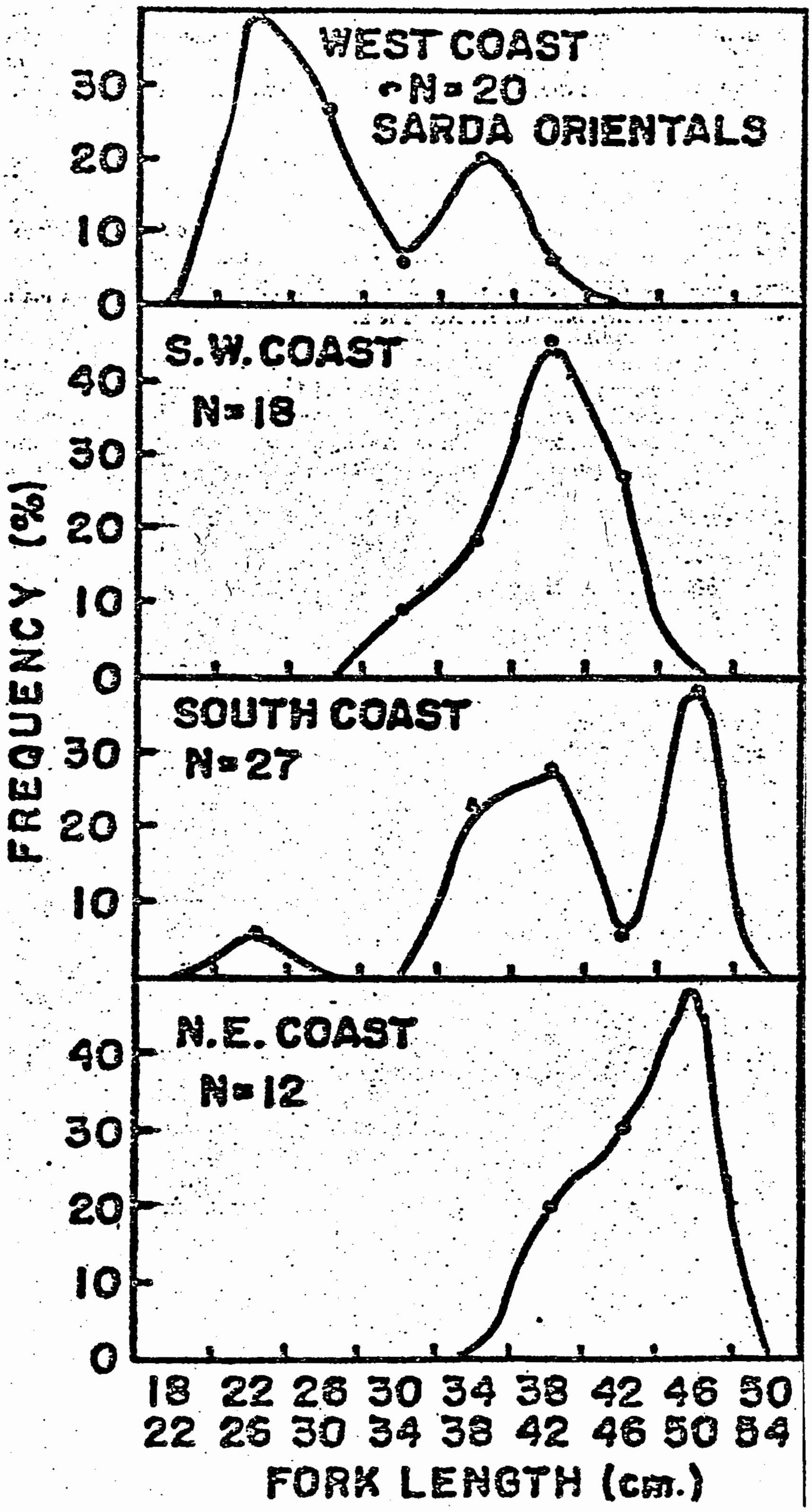
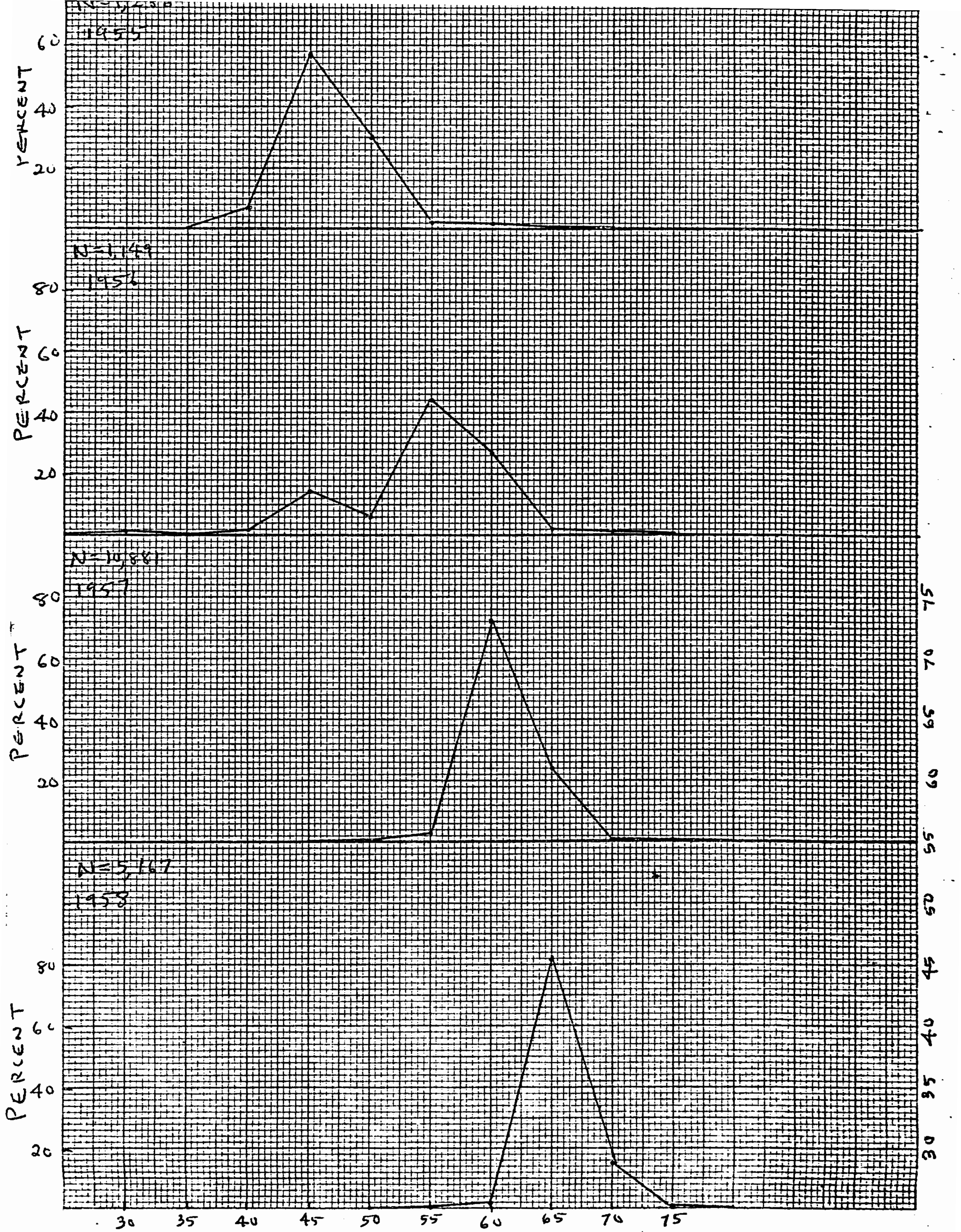


Figure 32.--Length-frequency distribution of Sarda orientalis around Sri Lanka (1967-68) (from Sivasubramaniam 1969).

Figure 33.--Length-frequency distribution of *Sarda sarda* in the Black Sea, spring 1955-58 (from Mayorova and Tkacheva 1959).


1955
PERCENT
60
40
20
N=1,149
1956
80
PERCENT
60
40
20
N=10,881
1957
80
PERCENT
60
40
20
N=5,167
1958
80
PERCENT
60
40
20
30
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40
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50
55
60
65
70
75

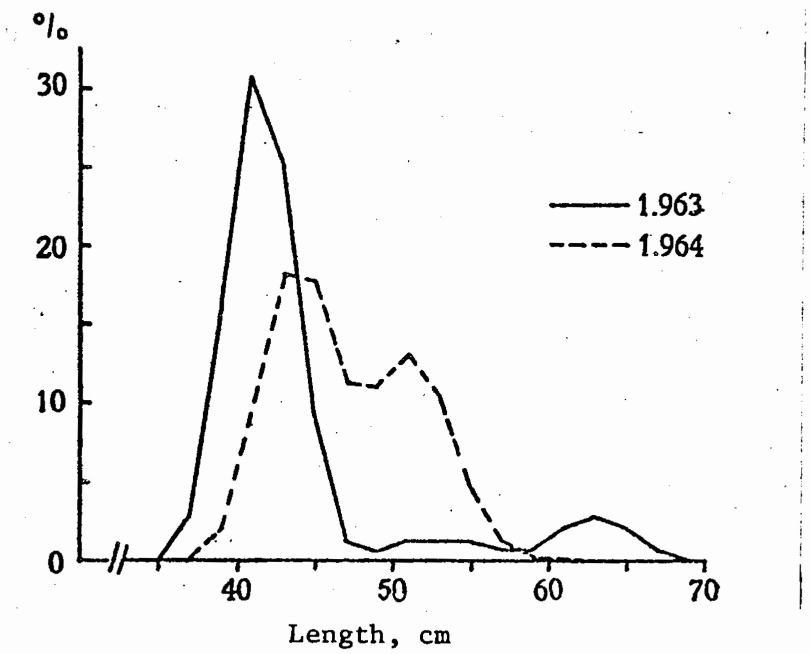

Figure 34.--Sarda sarda length-frequency distribution, Barbate and Tarifa, Spain. Data smoothed by formula $f_n = \frac{f_{n-1} + 2 f_n + f_{n+1}}{4}$ (from Rodriguez-Roda 1966).

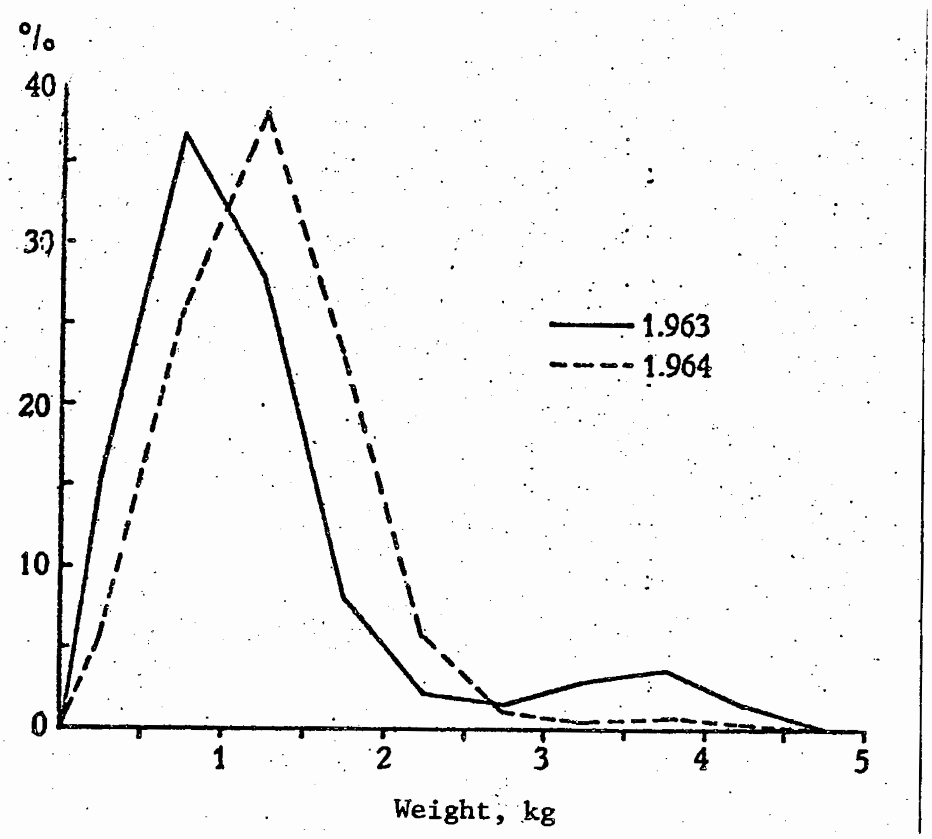

Figure 35.--Sarda sarda weight-frequency distribution, Barbate and Tarifa, Spain. Data smoothed by formula $f_n = \frac{f_{n-1} + 2 f_n + f_{n+1}}{4}$ (from Rodriguez-Roda 1966).

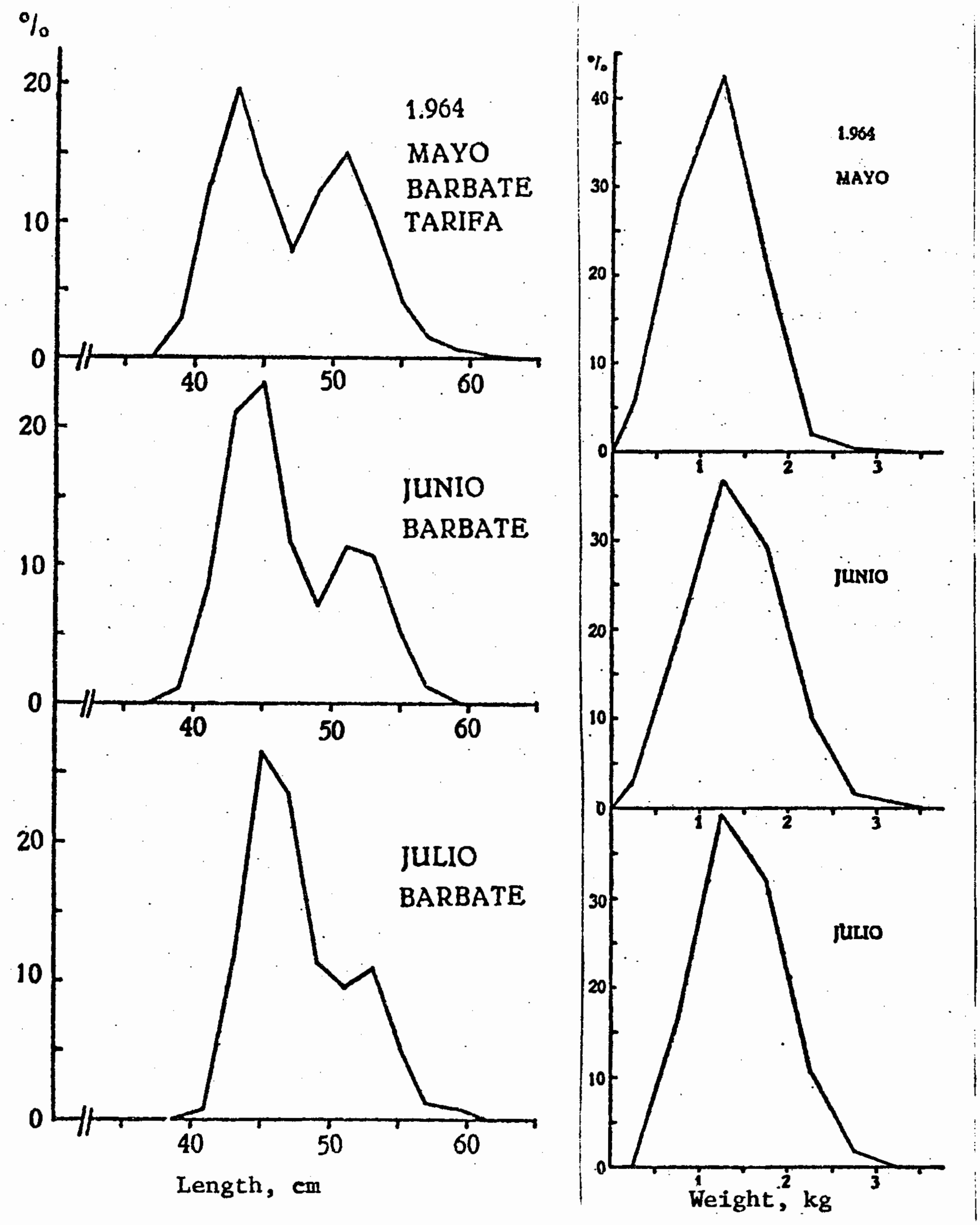

Figure 36.--Sarda sarda length (Barbate and Tarifa) and weight (Barbate) frequency distribution 1964 (from Rodriguez-Roda 1966).

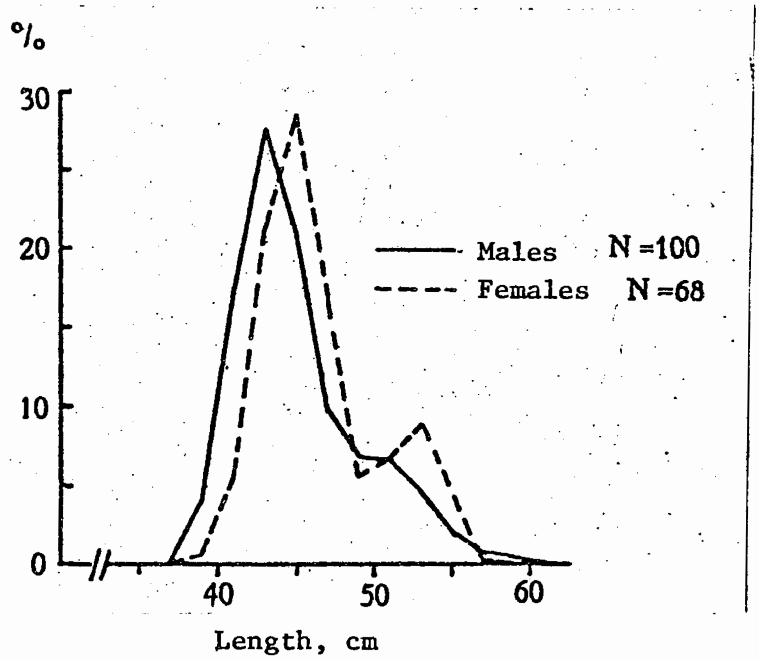

Figure 37.--Sarda sarda length-frequency distribution, Barbate and Tarifa, Spain, arranged by sex (from Rodriguez-Roda 1966).

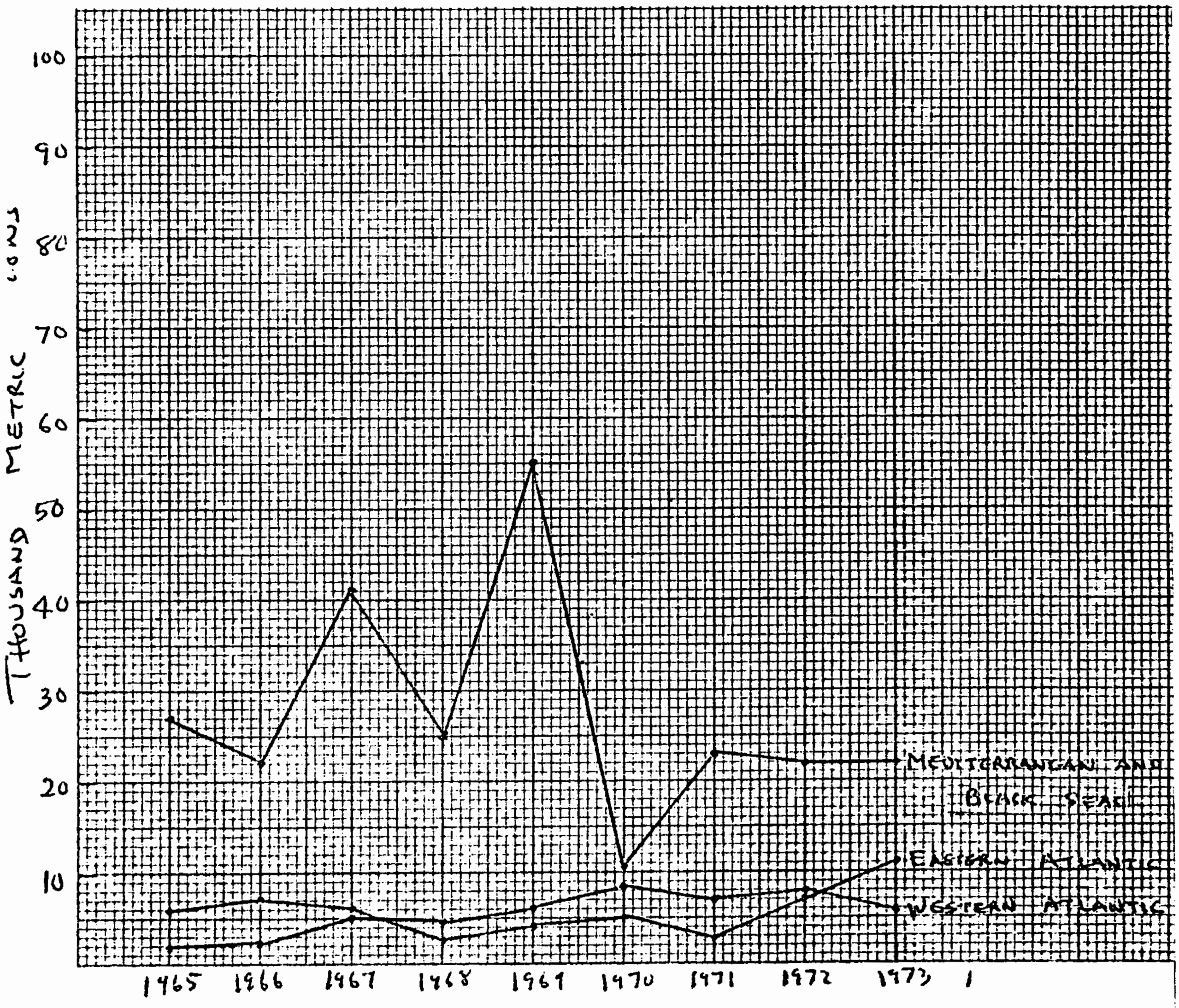

Figure 38.--Annual landings of Sarda sarda in the Atlantic and Mediterranean-Black Seas. (Data from FAO 1974.)

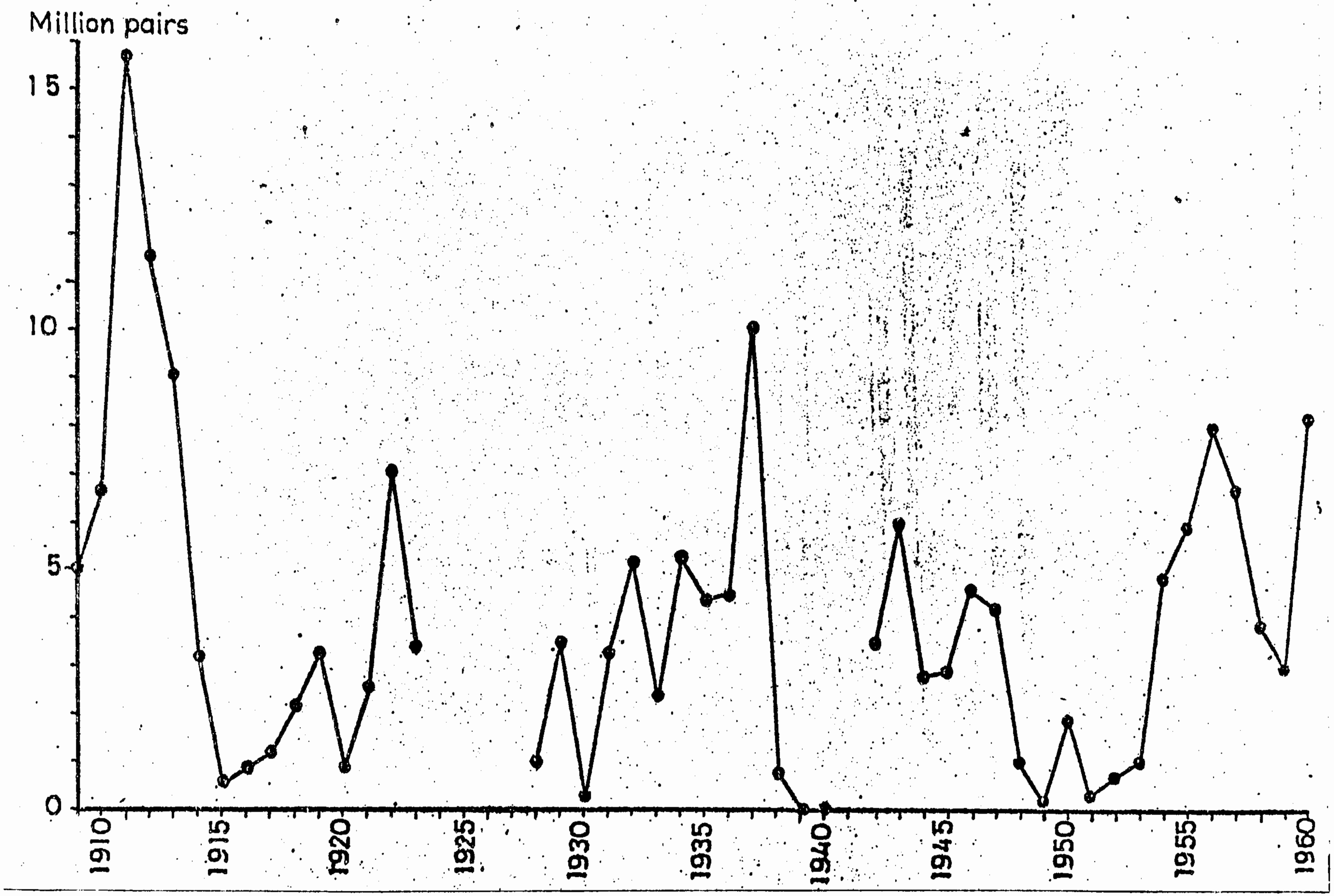

Figure 39.--The catches of <u>Sarda sarda</u> recorded at the Istanbul fish market, Turkey, 1909-60 (1 pair = 2 fishes). (From Demir 1963.)

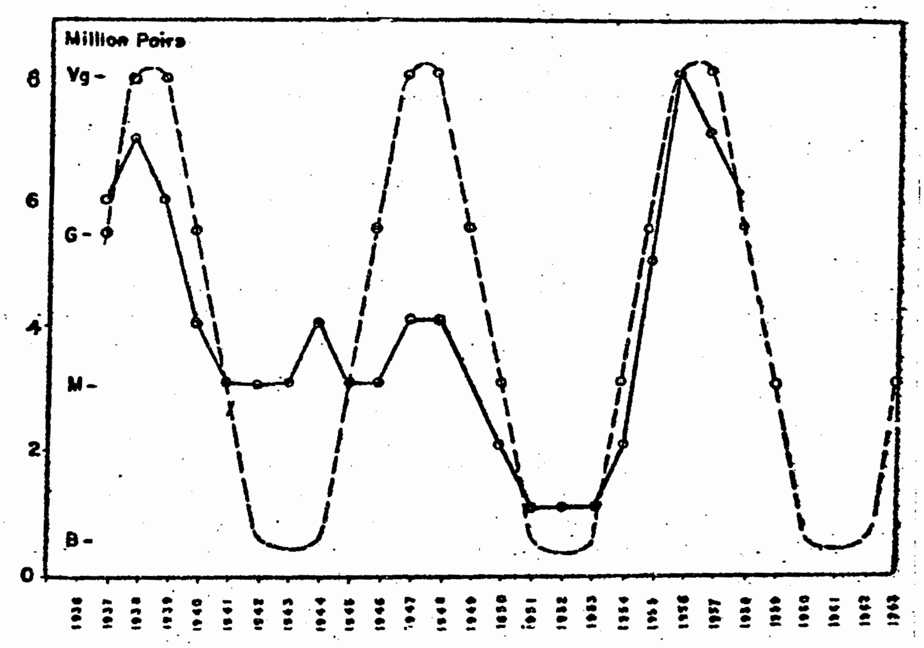

Figure 40.--Fluctuation pattern of Sarda sarda landed at the Istanbul fish market 1936-58. (From Artuz 1959.)

-----o----- *Hypothetical fluctuation curve*

——o—— *Smoothed values according to the formula* $v = \frac{a + 2b + c}{4}$

(Vg = very good; G = good; M = medium; B = bad; years).

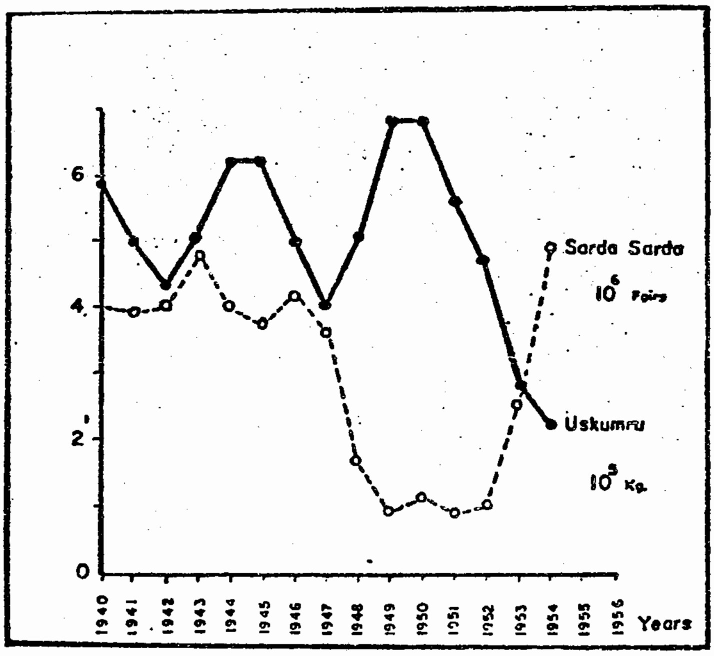

Figure 41.--Alternative occurrence of <u>Sarda sarda</u> and Uskumru, <u>Scomber Scomber</u> in Turkish waters during the period 1940-56. (From Artuz 1959.)