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Synopsis of Biological Data on Frigate Tuna, *Auxis thazard*, and Bullet Tuna, *A. rochei*

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417. Guide to the identification of genera of the fish Order Ophidiiformes with a tentative classification of the order. By Daniel M. Cohen and Jørgen G. Nielsen. December 1978, vii + 72 p., 103 figs., 2 tables.

NOAA Technical Report NMFS Circular 436

Synopsis of Biological Data on Frigate Tuna, *Auxis thazard*, and Bullet Tuna, *A. rochei*

Richard N. Uchida

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FAO Fisheries Synopsis No. 124

U.S. DEPARTMENT OF COMMERCE
Philip M. Klutznick, Secretary

National Oceanic and Atmospheric Administration
Richard A. Frank, Administrator

National Marine Fisheries Service
Terry L. Leitzell, Assistant Administrator for Fisheries

CONTENTS

*No information available.

Synopsis of Biological Data On Frigate Tuna, *Auxis thazard,* and Bullet Tuna, *A. rochei*

Richard N. Uchida[1]

ABSTRACT

This synopsis of biological and technical data on frigate tuna, *Auxis thazard*, and bullet tuna, *A. rochei*, includes information on identity, distribution, bionomics, life history, population, and exploitation. Over 200 published and unpublished reports, up to and including those published in 1978, are covered.

INTRODUCTION

Unlike a number of tuna species in the world's oceans which are heavily exploited and possibly are being harvested near the upper limit of rational utilization, frigate mackerels (or frigate and bullet tunas; see Klawe 1977), the most primitive genus of the higher tunas (tribe Thunnini), give every indication of being an underutilized fishery resource. In planning for the rational utilization of this resource, it is imperative to have on hand information concerning the biology of the species and estimates of present and potential catches. The purposes of this paper, therefore, are to update our current knowledge of the species by bringing together and abstracting all the available information on the biology and fisheries for frigate and bullet tunas and to review and evaluate in depth the results of past research, indicating in particular where conflicting evidence exists.

1 IDENTITY

1.1 Nomenclature

Auxis thazard (Lacepède) 1802
Auxis rochei (Risso) 1810

1.12 Synonymy

It it not possible at this time to assign all the various names that have appeared in the literature to either *thazard* or *rochei*. The following names are from Rosa (1950), de Beaufort and Chapman (1951), Collingnon (1960),[2] Williams (1963),[3] Idyll and de Sylva (1963), and Jones (1963) and are listed in chronological order.

Scomber thazard Lacepède 1802 (original description; off coast of New Guinea)
Scomber bisus Rafinesque 1810 (original description; Palermo)
Thynnus rocheanus Risso 1826 (original description; Nice)
Auxis taso Cuvier and Valenciennes 1831 (original description; New Guinea)
Auxis vulgaris Cuvier and Valenciennes 1831 (original description; Mediterranean)
Auxis tapeinosoma Bleeker 1854 (original description; Japan)
Auxis thynnoides Bleeker 1855 (original description; Ternate)
Auxis rochei. Günther 1860
Auxis thazard. Jordan and Evermann 1896
Auxis hira Kishinouye 1915 (original description; Japan)
Auxis maru Kishinouye 1915 (original description; Japan)
Auxis bisus. Cadenat 1950

1.2 Taxonomy

1.21 Affinities

Kingdom Animalia
Phylum Chordata
Subphylum Vertebrata
Superclass Gnathostomata
Class Osteichthyes
Subclass Actinopterygii
Division Teleostei
Cohort Acanthopterygii
Order Perciformes
Suborder Scombroidei
Family Scombridae
Subfamily Scombrinae
Tribe Tunnini
(*Thunnus, Katsuwonus, Euthynnus, Auxis*)

[1] Southwest Fisheries Center, National Marine Fisheries Service, NOAA, P.O. Box 3830, Honolulu, HI 96812.

[2] Collingnon, J. 1960. Report on *Auxis thazard* in the eastern Atlantic. [In Fr.] CCTA Symposium on Thunnidae, Dakar, 12-27 December 1960, 5 p. (Mimeogr.) (Engl. transl. available Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96812.)

[3] Williams, F. 1960. A symposium of existing knowledge on the fishes on the genus Auxis Cuvier, 1829 in the Indian Ocean. CCTA Symposium on Thunnidae, Dakar, 12-27 December 1960, 13 p. (Mimeogr.)

Genus *Auxis* Cuvier 1829 (type-species: *Scomber rochei* Risso) by subsequent selection by Gill (1862).

The description of the genus *Auxis* under "Les Scombres" first appeared in Cuvier's Règne Animal in 1829. From the time of Cuvier's work to the present, however, the genus *Auxis* has had several reclassifications. For example, in classifying the genus *Auxis*, Kishinouye (1915) first included it in the family Thunnidae. However, in a later work (1917), he placed Thunnidae and Katsuwonidae in a new order called Plecostei and placed the families Scombridae and Cybiidae in the order Teleostei. The genus *Thunnus* fell under Thunnidae and the genera *Katsuwonus*, *Euthynnus*, and *Auxis* came under Katsuwonidae (Kishinouye 1923). The primary characteristic subcutaneous blood vessels; a secondary characteristic of Plecostei was the presence of well-developed subcutaneous blood vessels; a secondary characteristic was the development of dark red lateral tissues in relation to the subcutaneous blood vessels.

Many scientists disagreed with Kishinouye's new order and its subdivision. Takahashi (1924) argued that Plecostei was established only on partial differences in the highly variable vascular system and cannot exist on an equal status with the other four orders of Teleostomi. Jordan (1923) and Herre (1953) placed the scombroid fishes in two families—Scombridae and Thunnidae. Fraser-Brunner (1950), on the other hand, rejected any division of the family Scombridae arguing that attempts to subdivide this family "have resulted in arrangements which are artificial and have left the classification in an uneasy, shifting state." de Sylva (1955), Collette and Gibbs (1963b), and most other recent workers recognize a single family Scombridae with various subdivisions. Collette and Chao (1975) placed *Auxis* in the tribe Thunnini of the subfamily Scombrinae.

The following description of the genus *Auxis* is from Jordan and Evermann (1905): "Body oblong, plump, most naked posteriorly, anteriorly covered with small scales, those of the pectoral region enlarged, forming a corselet; snout very short, conical, scarcely compressed; mouth rather small, the jaws equal; teeth very small, mostly in a single series, on the jaws only; tail very slender, depressed, with a rather large keel on each side; first dorsal short, separated from the second by a considerable interspace; second dorsal and anal small, each with 7 or 8 finlets; pectorals and ventrals small; no air-bladder; branchiostegals 7; pyloric coeca dentritical; gill-rakers very long and slender, numerous; vertebrae 39 in number, peculiarly modified . . . ."

Auxis is the most primitive genus among the higher tunas that have developed a prootic pit and a partial subcutaneous circulatory system (Collette and Gibbs 1963b). All the Thunnini, except *Auxis*, have a common cutaneous artery that divides into dorsal and ventral branches lateral to the aorta; in *Auxis*, however, the dorsal and ventral branches originate separately with the latter being very poorly developed (Collette 1978). The haemal spines of the thoracic vertebrae do not form a haemal arch and the first vertebra is not sutured to the cranium as in the higher members of Thunnini. Also, compared with *Euthynnus*, *Katsuwonus*, and *Thunnus*, *Auxis* lacks the frontoparietal fenestra, which is an additional pair of openings present in the cranium and has a lateral countercurrent system for heat exchange that is not as well developed phylogenetically (Collette 1978). All members of the tribe Thunnini have a swim bladder as juveniles; however, the bladder degenerate with growth in *Auxis*, *Euthynnus*, and *Katsuwonus*.

Several other characters distinguish members of the genus *Auxis*, the smallest of the higher tunas, from other scombrids (Collette and Gibbs 1963b; Fitch and Roedel 1963; Williams 1963). In *Auxis*, there is a single interpelvic process which is between and about as long as the pelvic fins. In other tunas, but not in other scombrids, the interpelvic process is bifurcate and much less than half the length of the pelvic fins (it is single but small in *Grammatorcynus* and *Gymnosarda*). The number of dorsal and anal finlets (seven or eight) distinguishes *Auxis* from *Scomber*, which has only five of each. *Auxis* can also be distinguished from *Rastrelliger* by the lack of a corselet and a body entirely covered with moderate-sized scales in the latter.

Species — *Auxis thazard* (Lacepède) 1802

The following description of *A. thazard* (Fig. 1, upper photo) is from Williams (1963). Major morphological features described under the genus are omitted from the account of the species.

"Depth 3.9 to 4.5, head 3.2 to 3.8 in standard length. Eye 5.0 to 5.85 in head, 1.25 to 1.66 in snout and 1.25 to 1.7 in the flatly rounded interorbital space. Snout 3.62 to 4 in head. Maxilla reaches to a point under the anterior half of the eye and is 3 in head. Single row of small pointed teeth in each jaw, none on palate. Jaws almost equal. First and second dorsal spines subequal, equal to snout and eye; following spines rapidly decreasing in size, eighth usually shorter than the pupil. Second dorsal fin very low, about three times its base distant from first dorsal; first ray of second dorsal about 5 in head. Anal similar to second dorsal, first ray about 5.2 in head. Pectorals short, roughly triangular, about 2 in head and shorter than postorbital; origin of pectoral before that of first dorsal. Pelvics thoracic, about 2.5 in head, origin somewhat behind that of pectorals. Caudal lunate, upper lobe about 1.8 in head. Body naked except for the corselet of scales anteriorly. Rear margin of the corselet runs from base of second dorsal to above end of pectoral; thence there is a posterior prolongation of the corselet along the lateral line; below the pectoral tips the corselet margin curves to above the pelvic base from where it turns posteriorly and finishes well behind the tips of the pelvics. The prolongation of the corselet along the lateral line tapers abruptly between first and second dorsal fins, and under the origin of the second dorsal is not more than 4 irregular scale rows wide. Scales large and imbricated above pectoral base. Gill rakers about 1.75 in length of gill filaments."

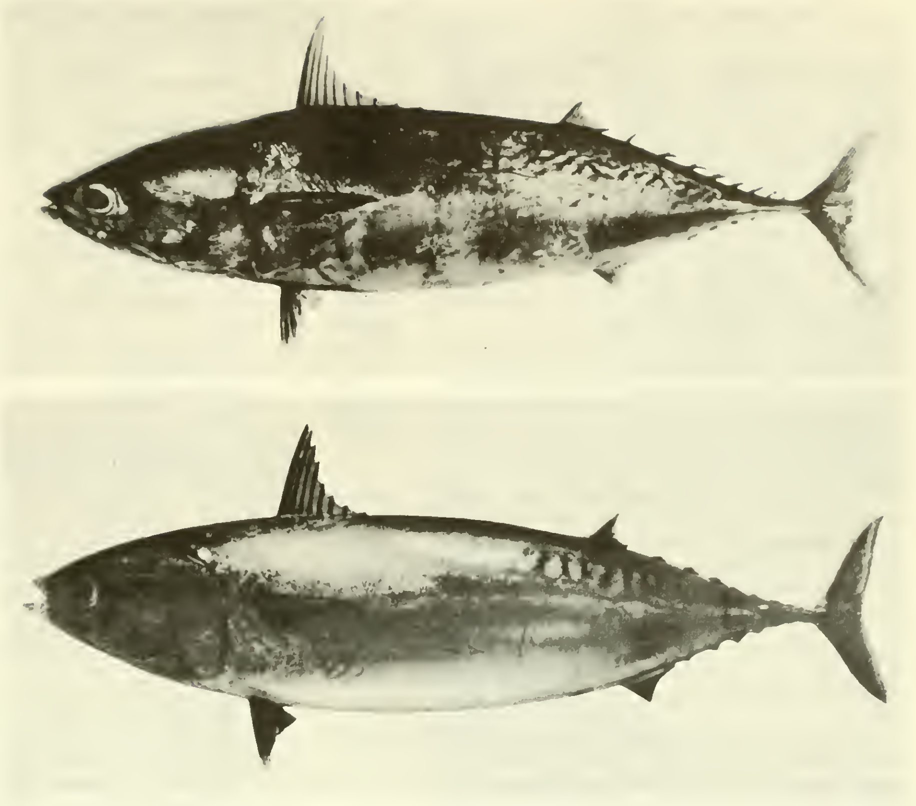


Figure 1.—*Auxis thazard* (upper photo) from the eastern Pacific, collected at Morgan Bank, Baja California, and *A. rochei* (lower photo) from near Santa Catalina Island, Calif. (Fitch and Roedel 1963)

Species – *Auxis rochei* (Risso) 1810

The description of *A. rochei* (Fig. 1, lower photo) is from Jones (1958), who originally referred to the specimen as *A. tapeinosoma.*

"Body robust, rounded, almost circular in cross-section. Dorsal outline moderately and evenly curved. Ventral outline evenly curved when fresh but slightly flattened abdominally after preservation in formalin.

"Height 5.38 in standard and 5.55 in furcal [= fork] length. Head 3.77 in standard and 3.88 in furcal length. Snout, pointed 3.9 in the head, longer than eye diameter. Eye 4.91 in the head, 1.27 in the snout, 1.27 in the almost flattened interorbital space. Mouth moderate, oblique, end of maxillary reaching vertical from anterior margin of eye. Jaws nearly equal, the lower jaw projecting almost imperceptibly beyond the upper. Teeth small, pointed in a single row on both jaws, none on palate. Branchiostegals 7. Gill rakers long and slender, 45 in first gill arch.

"Two dorsal fins separated by interspace slightly shorter than head length. First dorsal roughly triangular with 10 spines, anterior spine longest. Second dorsal small with 13 rays. Dorsal finlets 8. Anal fin small, with 2 spines, 11 rays. Anal finlets 7. Pectorals roughly triangular, reaching vertical from the base of first ray of first dorsal. Ventral thoracic, axillary scales equal in length to ventrals.

"Body naked except for the corselet of scales which taper gradually to 9-10 irregular scale rows at vertical through second dorsal and end as a narrow line at vertical below second dorsal finlet. Scales large and imbricated above pectoral base. Caudal peduncle slender with feebly developed lateral keels. Lateral line somewhat undulating and without a distinct arch."

1.22 Taxonomic status

A specimen of frigate tuna, collected by Commerson off New Guinea in 1768, was first described by Lacepède in 1802 as *Scomber thazard*. In 1810, Risso and Rafinesque, working independently, named the Mediterranean form *Scomber rochei* and *Scomber bisus*, respectively. Gill (1862) subsequently designated *rochei* as the type-species for *Auxis* Cuvier. Systematists generally followed Günther (1860) and Jordan and Gilbert (1882) in using Risso's *rochei* instead of Rafinesque's *bisus*, but no one has indicated which name was described first. Furthermore, the International Commission of Zoological Nomenclature has never ruled as to which name, *rochei* or *bisus*, is valid (Fitch and Roedel 1963).

Over the years, other names appeared in the literature. These include *Thynnus rocheanus* Risso, 1826 (Mediterranean), *A. vulgaris* Cuvier and Valenciennes, 1831 (Mediterranean), *A. taso* Cuvier and Valenciennes, 1831 (New Guinea), *A. tapeinosoma* Bleeker, 1854 (Japan), and *A. thynnoides* Bleeker, 1855 (Ternate). In 1915, Kishinouye described two additional names. The species he named *hira* had a short corselet which ended slightly posterior to the pectoral fin. The other he named *maru* had a long corselet which extended to the anal fin. Kishinouye stated that the *maru* is probably the same species as *thazard*, but could not say whether *thazard* corresponded to *hira* or *maru*. Furthermore, he believed that Bleeker's (1854) *tapeinosoma* could be *maru*, but the figure and description of this species were unclear and he was unable to make a positive identification. Therefore, Kishinouye described them as new species, *hira* and *maru*.

Fraser-Brunner (1950) disagreed with Kishinouye and recognized only a single, worldwide species, *thazard*, but others, such as Wade (1949), Cadenat (1950), and Jones (1958), recognized two species of *Auxis*. Wade (1949) used Bleeker's name *tapeinosoma* for a long-corseletted pacific form. Matsumoto (1959, 1960a), on the other hand, finding the nomenclature of the long-corseletted form confused, resurrected the name *thynnoides*. He argued that *tapeinosoma* of Wade (1949) and Herre and Herald (1951) appeared to be a misnomer because it is actually a short-corseletted form. Furthermore, Matsumoto regarded *hira* and *maru* of Kishinouye and *tapeinosoma* of Bleeker as synonyms of the short-corseletted, worldwide *thazard*.

1.23 Subspecies

None.

1.24 The standard common names, vernacular names

The standard common names and vernacular names of *A. thazard* were abstracted from the lists published in Fiedler (1945), Rosa (1950), Collingnon (1960—see footnote 2), FAO (1960, 1976), Idyll and de Sylva (1963), Uchida (1963), Williams (1963), Instituto del mar del Peru (1971[4]), Miyake and Hayasi (1972), Klawe (1977), and Roberts et al. (1977).

Country	*Common and vernacular names*
Algeria	Auxide, Scunno, Bisu, Melva, Melvara
Angola	Jedeu
Australia	Frigate mackerel, Leadenall
Brazil	Bonito cachorro
British Guiana	Frigate mackerel, Blowgoat
British West Indies	Frigate mackerel, Blowgoat, Roundbelly bonito
Canada	Frigate mackerel, Thazard
Denmark	Auxide
East Africa	Frigate mackerel, Sehewa (Kiswahili) also refers to *Euthynnus* and *Katsuwonus* sp.
Ecuador	Botellita
France	Auxide, Bonitou, Bounitou, Bounicou, Palamida, Auxide bise, Tazard, Bizet
French Morocco	Melva
French West Africa	Melva
Ghana	Okpopu, Odaabi, Poku-poku
Gold Coast	Frigate mackerel
Greece	Kopáni
Haiti	Maquereau
Hawaiian Islands	Frigate mackerel, Keokeo, Mexican skipjack
India	Frigate mackerel, Churai, Urulanchurai, Kutteli-churai (Tamil)
Israel	Tuna nanasit
Italy	Strumbo, Tambarello, Strombo, Scurmo, Tombarello, Tamburella, Tambarella, Sgionfetta, Tumbarel, Bisu, M'pisu, Pisantuni, Mazzita, Sangulu, Culariau, Sgamiru, Tunnacchiu, Biso
Ivory Coast	Boku-boku, Poku-poku, Bongu
Japan	
Auxis sp.	Sodagatsuwo
A. thazard = *A. hira*	Hirasôda, Hirasôdakatusuo, Hiramejika, Obosogatsuwo, Shibuwa, Soma, Suma, Oboso (Hirasohda, Hiragatsuo, and Hiramedika are variations in spelling of some of the above names)
Korea	Mul-chi-da-rae, Mul-chi, Mu-tae-daraeng, Mog-man-dung-i
Madeira	Chapouto
Malta Island	Tombrell, Mazzita, Tombitombi, Zgamirru
Mexico	Bonito

[4]Instituto del Mar del Peru. 1971. Report of the "Instituto del mer del Peru" and other institutes of fishery investigations from South America for the fourth session of the FAO panel of experts for the facilitation of tuna research. La Jolla, Calif., 8-13 November 1971, FIR:EPFTR/71/Inf. 12, 26 p. (Mimeogr.)

Morocco	Melva
New Zealand	Frigate tuna
Norway	Auxis
Papua New Guinea	Deho
Peru	Melva, Macarela
Phillipine Islands	Frigate mackerel, Tunungan, Manko, Mangko (Marinao, Samal, Visaya, and Tao Sug)
Portugal	Gayado, Judea, Serra, Cachorra, Bonito
Sarawak	Tongkol
Seychelles	Bonite folle
Somalia (Mijurtein coast)	Tubani (Somali)
South Africa	Frigate mackerel
Spain	Melva, Visol, Melvara, Bis, Bonito del Norte, Macaela
Spanish Morocco	Melva
Sri Lanka (Ceylon)	Frigate mackerel, Rogodwa (Sinhalese), Alagoduwa
Sweden	Auxide
Taiwan	Chien yu
Thailand	Pla O
Turkey	Gobene
Union of South Africa	Frigate mackerel, Boo hoo
Union of Soviet Socialist Republic	Auksida, Makrelevyi tunets
United Kingdom	Plain bonito
Unites States	Frigate mackerel, Bullet mackerel, Boo hoo, Frigate tuna
Venezuela	Cabaña negra
Yugoslāvia	Trupac, Tunjcic, Rumbac
International organization	
Food and Agriculture Organization of the United Nations (FAO)	Frigate tuna, Auxides, Melvas
International Commission for the Conservation of Atlantic Tunas (ICCAT)	Frigate tuna, Auxide, Melva

Jones (1963), Uchida (1963), Instituto del Mar del Peru (see footnote 4), FAO (1976), and Klawe (1977) provided the following common and vernacular names of *A. rochei* = *A. tapeinosoma* = *A. thynnoides* = *A. maru*.

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

To avoid confusion throughout the remainder of this paper, *A. rochei* will be used instead of *A. tapeinosoma, A. thynnoides,* or *A. maru* to describe the long-corseletted form. For the short-corseletted form, *A. thazard* will be used, but there is considerable confusion in the literature because several authors used *thazard* in the belief that there was only a single worldwide species of *Auxis* (Fraser-Brunner 1950; Rivas 1951). This usage must be translated into *Auxis* spp. where reference is made to the Pacific forms and into *A. rochei* in the Atlantic based on Fitch and Roedel's (1963) interpretation or *Auxis* spp. based on Richards and Randall's (1967) documentation of *A. thazard* in the Atlantic.

1.3 Morphology

1.31 External morphology

The fin ray counts, together with the gill raker and vertebral counts, are given for *A. thazard* and *A. rochei* in Tables 1 and 2, respectively. It should be noted that some investigators did not separate the two species of *Auxis* at the time the meristic counts were made and, therefore, their counts have not been included.

One of the sources of confusion in identifying *Auxis* to

Table 1.—Meristic characters of the short-corseletted frigate tuna, *Auxis thazard*, by various investigators.

	First dorsal fin	Second dorsal fin	Dorsal finlets	Anal fin	Anal finlets	Gill rakers	Vertebrae	Branchiostegals
Hawaii:								
Matsumoto (1960a)	XI	10-12	8	13	7	(9-10) + 1 + (28-31) = 39-42	20+19	—
Yoshida and Nakamura (1965)	—	—	—	—	—	(9-10) + 1 + (29-31) = 39-42	—	—
Japan:								
Kishinouye (1923)	X-XI	12	8	13	7	9+30	20+19	—
Philippines:								
Wade (1949)	X-XII	10-12	8	II, 8-11	7	(9-10) + 1 + (27-32) = 37-43	—	7
India:								
Jones (1958)	X	13	8	ii, 11	7	40	—	—

Table 2.—Meristic characters of the long-corseletted bullet tuna, *Auxis rochei*, by various investigators.

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

species stems from an overlap in the width of the corselet. Klawe (1963), lacking evidence to substantiate the presence of two distinct species of *Auxis* in the eastern Pacific, noted that there were intermediate forms of the short- and long-corseletted forms. Provisionally, he used *A. thazard* for frigate tuna from this region, but emphasized the possibility that as samples accumulate, there may be sufficient evidence to substantiate the presence of two separate species. From the Indian Ocean, a few large adults of *A. thazard* from the southwest coast of India were recognized as having a corselet that narrowed gradually somewhat as in *A. rochei* instead of one which tapered abruptly (Fig. 2) (Jones 1963).

In an attempt to unravel the confusion involving this genus, Fitch and Roedel (1963) examined numerous adult *Auxis*, mostly from the Pacific, but failed to find any significant morphometric differences among *A. thazard* from the western, central, and eastern Pacific (Table 3). Based on gill raker counts, they concluded that the eastern Pacific population seems to be separable from those in the central and western Pacific (Table 4). For adult *A. rochei*, Fitch and Roedel found apparent differences in body measurements among areas (Table 5) and in the average number of scale rows in the corselet. In an earlier study, Matsumoto (1960a) observed that the number of scale rows in the corselet increased with fish length. But Fitch and Roedel showed that in addition to the positive relationship between these two variables, there was also an increase in the average number of scale

Table 3.—Selected measurements of *Auxis thazard* from three geographical localities (Fitch and Roedel 1963).

	Western Pacific	Central Pacific	Eastern Pacific
Number of specimens	10	14	60
Ranges in standard length (mm)	200-402	248-384	263-392
Ranges in percent of standard length:			
Head	26.5-28.9	27.5-29.4	27.4-29.5
Eye	4.7-5.5	4.8-5.5	4.2-5.1
Snout	6.3-7.5	6.4-7.4	5.7-6.8
Pectoral length	12.2-14.2	13.1-14.9	12.7-14.6
Snout to first dorsal	30.6-33.2	32.3-33.6	31.8-34.5
Snout to second dorsal	61.5-66.2	62.6-66.9	64.6-69.0
Snout to anal	67.8-72.2	68.3-72.1	68.3-74.2
Depth	21.5-25.2	20.6-25.3	22.4-26.4
Width	14.6-17.2	15.1-19.5	16.7-20.2

rows for similar-sized fish from west to east. *Auxis rochei* in the western Atlantic had the fewest scale rows whereas those in the eastern Pacific had the most. And for *A. thazard*, Tortonese (1965) added that the Mediterranean forms have characters that are not entirely identical to those of the Indo-Pacific forms and suggested that geographical variations may be involved.

As a result of their study, Fitch and Roedel (1963) tentatively recognized two valid species—*A. thazard* and *A. rochei*. A summary of external and internal characters used by several investigators to differentiate the two species of *Auxis* is given in Table 6.

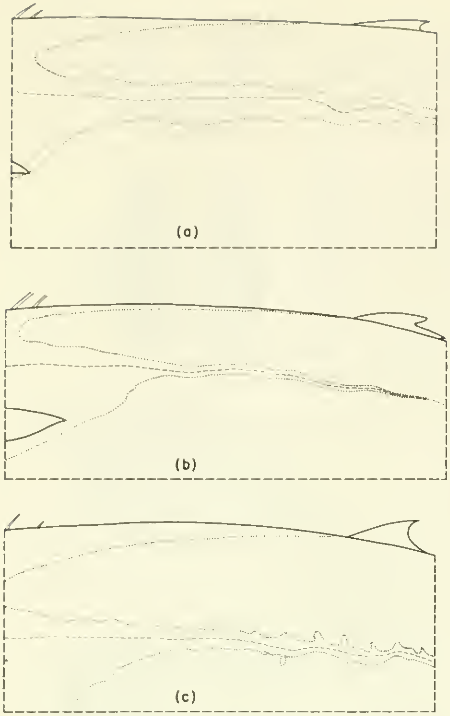


Figure 2.—Outlines of corselets drawn from actual specimens (Jones 1963). (a) *Auxis rochei*; (b) *A. thazard* - typical short-corseletted condition; (c) *A. thazard* - intermediate condition.

Among internal characters that have been a source of confusion is the gill raker count. Wade (1949) and Herre and Herald (1951) pointed out that *A. thazard* in the western Pacific normally have fewer gill rakers than *A. rochei*. And *A. thazard* taken in the eastern Pacific and the Indian Ocean also have counts that are definitely lower (Mead 1951; Jones 1963). Godsil (1954), on the other hand, reported that all the *A. thazard* taken off Baja California and the Galapagos Islands have high gill raker counts similar to those reported for *A. rochei* by Wade (1949) and Herre and Herald (1951). Matsumoto (1959), however, believed that the number of gill rakers, by itself, is not a reliable character in identifying the two species of *Auxis*. But Jones and Silas (1964) suggested that the gill raker counts could be useful; in case of doubtful identification from external characters, a combination of gill raker counts and corselet width should facilitate specific identity.

Jones and Silas (1964) have used body cross section as an aid to identification but Collette and Gibbs (1963a) have warned that this character is difficult to use (Fig. 3). Also suggested by Jones and Silas was the position of the visceral organs (Fig. 4). Godsil (1954) and Yoshida and Nakamura (1965) noted that other prominant differences between the two species occur in the skeletal structure. In *A. thazard*, the temporal crests diverge anteriorly so that they are not parallel to one another (Fig. 5) and the width of the skull is wider in relation to body length (Fig. 6). Yoshida and Nakamura also noted that the length of the anterior branch of the haemal processes was longer and touching on the preceding arch of the 24th to the 28th vertebrae in *A. thazard* (Fig. 7).

1.33 Protein specificity

Taniguchi and Nakamura (1970) examined muscle protein of *A. thazard* and *A. rochei* by the cellulose acetate electrophoretic method to determine whether specific divergence occurred between species. They found five components in the electropherograms of both species, but some components were not common to both. The genus *Auxis*, they concluded, contains two distinct species based on external and internal morphological characters although they are closely related.

To analyze muscle protein polymorphism in *Auxis* collected from the coastal region of Kochi Prefecture, Japan, Taniguchi and Konishi (1971) used starch-gel electrophoresis and detected differences in protein specificity between *A. thazard* and *A. rochei*. They concluded that whereas no individual variation could be recognized in electropherograms of 11 specimens of *A.*

Table 4.—Comparison of gill raker counts for 84 *Auxis thazard* from three geographical localities (Filch and Roedel 1963).

	Number of rakers on first arch														
	Upper limb					Center[1]	Lower limb								
Area	8	9	10	11	12	1	28	29	30	31	32	33	34	35	36
Western Pacific	1	7	1	1	—	10	1	1	5	2	1	—	—	—	—
Central Pacific	—	6	8	—	—	14		3	6	5	—	—	—	—	—
Eastern Pacific	—	4	31	24	1	60	—	—	1	5	11	14	19	9	1

	Total number of rakers									
Area	38	39	40	41	42	43	44	45	46	47
Western Pacific	2	—	4	2	1	1	—	—	—	—
Central Pacific	—	3	2	5	4	—	—	—	—	—
Eastern Pacific	—	—	—	1	5	8	13	15	11	7

[1]On all specimens the center raker has roots extending into both limbs.

Table 5.—Selected measurements of *Auxis rochei* from five geographic localities (Fitch and Roedel 1963).

	Western Atlantic	Eastern Atlantic	Western Pacific	Central Pacific	Eastern Pacific
Number of specimens	24	3	6	2	28
Ranges in standard length (mm)	277-347	368-398	206-250	272-277	253-352
Ranges in percent of standard length:					
Head	26.3-28.0	26.1-26.9	26.0-27.8	27.4-27.8	26.4-28.1
Eye	4.5-5.1	4.6	4.8-5.4	5.1	4.5-5.3
Snout	6.0-7.3	6.3-6.6	5.8-6.8	6.6-7.2	5.0-6.6
Pectoral length	12.0-14.0	12.2-12.7	11.7-13.2	13.1-13.7	12.2-13.9
Snout to first dorsal	30.7-33.3	30.7-31.9	30.4-32.5	31.3-32.5	30.7-33.0
Snout to second dorsal	63.3-67.8	66.4-68.6	64.0-65.8	65.1-66.8	65.4-68.3
Snout to anal	68.2-73.9	71.1-72.4	68.8-72.8	71.3-71.5	68.0-74.0
Depth	20.5-24.2	23.2-23.6	19.8-21.4	20.6-21.0	22.1-24.3
Width	14.7-18.1	17.9-20.6	13.3-16.1	14.7-15.2	16.4-18.9
Ranges in scale rows	6-9	7-10	[1]9-13	[1]11-15	13-28

[1]Matsumoto (1960a) gives 9-15 for 9 western Pacific specimens and 16-18 for 20 from the central Pacific. Fitch and Roedel's (1963) two central Pacific specimens were from Matsumoto's lot of 20.

Table 6.—Characters used by several investigators to differentiate *Auxis thazard* from *A. rochei* (Godsil 1954; Fitch and Roedel 1963; Jones and Silas 1964; Yoshida and Nakamura 1965).

Auxis thazard	*Auxis rochei*
1. Fifteen or more oblique to nearly horizontal dark wavy lines in bare area on each side of back.	Fifteen or more broad, nearly vertical dark bars on bare area on each side of back.
2. Corselet of scales running along lateral line is, at most, three rows wide where it passes beneath second dorsal.	Corselet with more than six rows of scales where it passes beneath second dorsal.
3. Pectoral fins extend beyond a vertical from anterior margin of patterned bare area on back.	Pectoral fins fail to reach vertical beneath the anterior end of the dorsal bare area.
4. Body compressed from side to side (Fig. 3).	Body more rounded and robust.
5. Shape of abdominal cavity more oval.	Shape of abdominal cavity dorsally compressed.
6. Right lobe of liver makes a complete loop crossing over midventral longitudinal axis (Fig. 4).	Right lobe of liver shows no looping and hepatic vein not in line with midventral longitudinal axis.
7. Stomach extends to slightly behind anal opening as does right lobe of liver.	Stomach is short with distal end not reaching anal opening and right lobe of liver extends backward but does not surpass a line drawn from origin of anal fin.
8. Caecal mass occupies less space, spleen is smaller, and left lobe of liver relatively long.	Caecal mass occupies more space, spleen is larger, and left lobe of liver relatively short.
9. Temporal crests diverge anteriorly and not parallel with each other (Fig. 5).	Temporal crests of skull parallel with each other and supraoccipital crest.
10. Skull wide relative to its length (Fig. 6).	Skull narrow relative to its length.
11. Anterior branch of haemal processes long and touching preceding haemal arches on 24th to 28th vertebrae (Fig. 7).	Anterior branch of haemal processes short, fragile, and separated from preceding haemal arches.

thazard, all 170 specimens of *A. rochei* fitted into one of three phenotypic protein patterns. They hypothesized that these three phenotypes are controlled by two codominant alleles. Furthermore, the distribution of the three phenotypes was independent of age and sex.

Almost all proteinases found in animal meat exhibit pH optima in the acid range; however, Makinodan and Ikeda (1969), studying fish muscle protease, concluded that there are actually two types of proteinases in fish muscle—one acting in the acid pH range and the other in the slightly alkaline range. They found that the former occurred in all fish tested whereas the latter was only in fishes with white flesh except the cod, *Gadus macrocephalus*. For red or slightly red-flesh fish such as albacore, *Thunnus alalunga*; bullet tuna, *A. rochei*; common mackerel, *Scomber japonicus*; sardine, *Sardinops melanosticta*; yellowtail, *Seriola quinqueradiata*; and horse mackerel, *Trachurus japonicus*, proteinase activity was either low or not present.

In attempts to find an easier and faster method of identifying larval and postlarval tunas, Matsumoto (1960b) experimented with paper chromatography, an important technique used to identify chemical compounds. On the assumption that the free amino acids in the muscle tissues of fishes are hereditary, Matsumoto attempted to separate adult *A. thazard* from *A. rochei* but encountered difficulty in distinguishing them; however, he was able to separate the two species from other tunas.

Sharp and Pirages (1978) inferred the phylogeny of several species in the four tribes of the subfamily Scombrinae, based on comparison of electrophoretic mobilities of several proteins. Calculating the percentage of protein bands that are shared and that show similarity between species pairs, they concluded that *Euthynnus lineatus* is more primitive than *A. thazard*. Placement of *A. thazard* above *E. lineatus* in the phylogeny is supported by the higher affinity of *Auxis* to both *Thunnus albacares* and *E. lineatus* than *E. lineatus* exhibits to any of the other Thunnini.

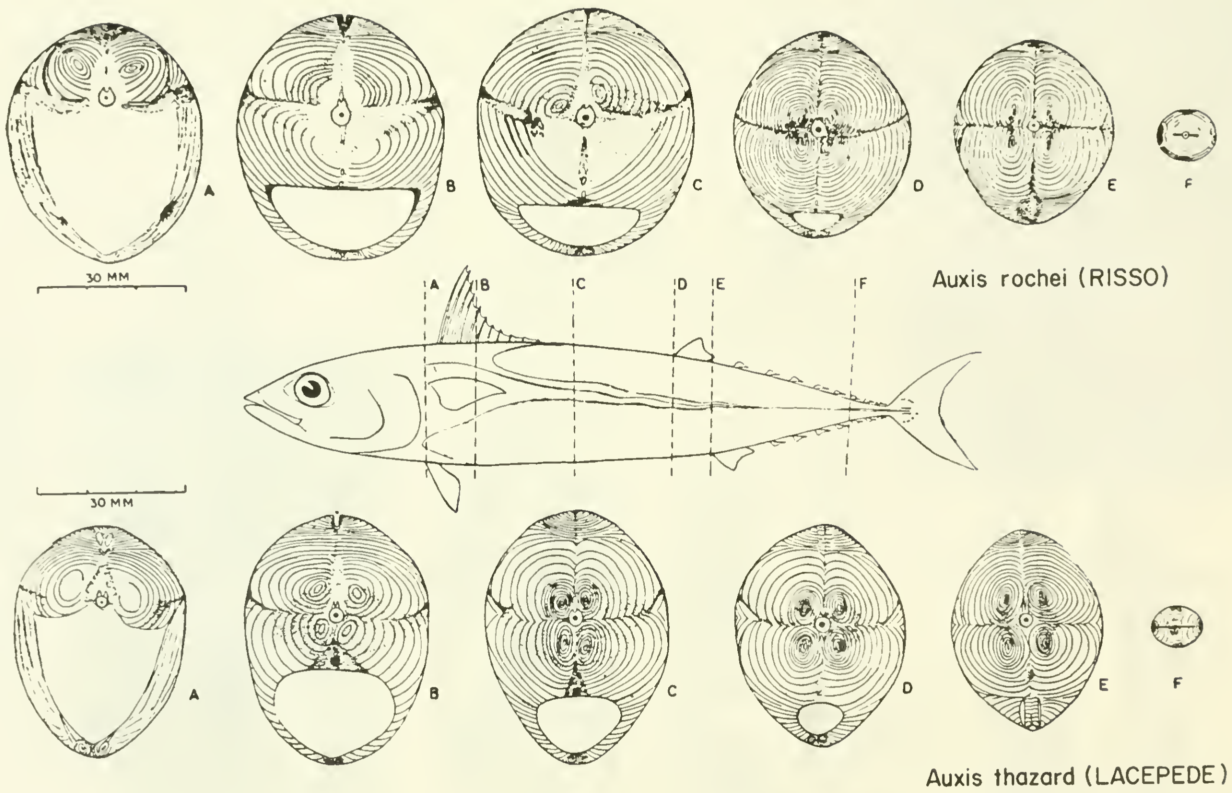


Figure 3.—Schematic drawing of *Auxis* (central figure) indicating locations from where six cross sections of the body were made in *A. rochei* and *A. thazard* and illustrating the differences in shape of the body and abdominal cavity (Jones and Silas 1964).

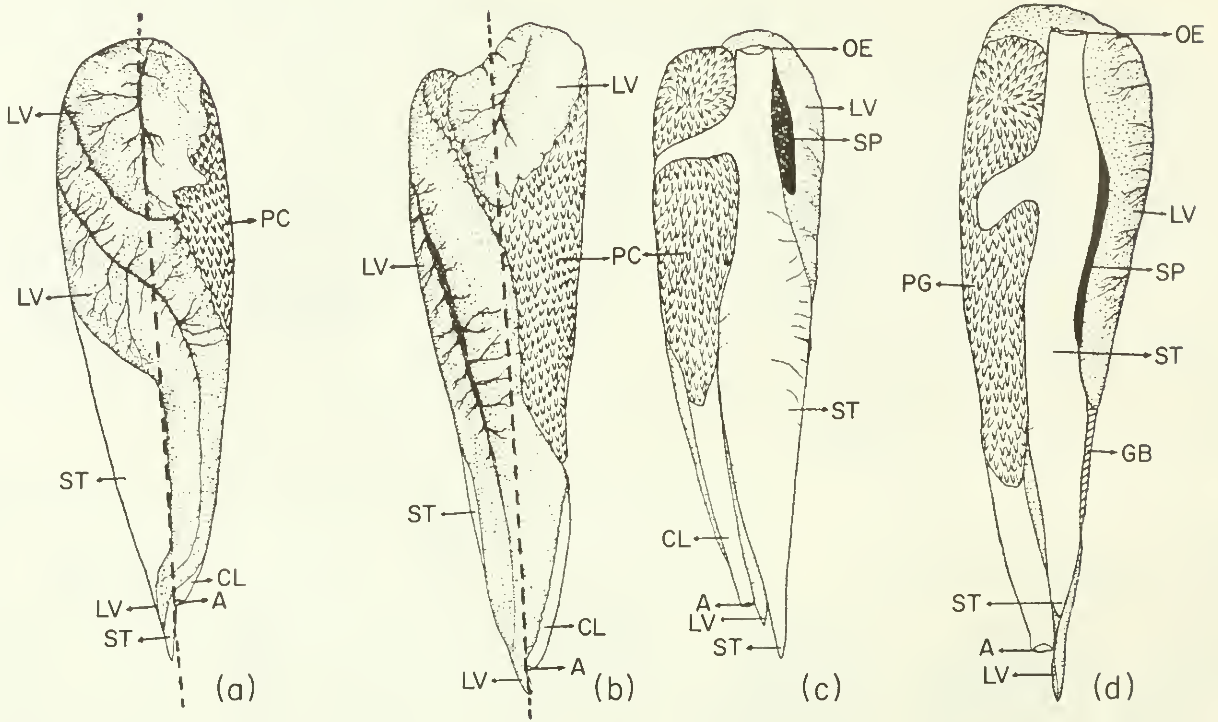


Figure 1.—Ventral and lateral views of viscera in situ in a 24.3 cm *Auxis thazard* (a, c) and a 25.5 cm *A. rochei* (b, d). A = anal opening; CL = colon; GB = gall bladder; LV = liver; OE = oesophageal end; PC = caecal mass; SP = spleen; and ST = stomach. (Jones and Silas 1961.)

Figure 5.—Dorsal view of skull of *Auxis rochei* (ca. 27 cm SL) on the left and *A. thazard* (ca. 30 cm SL) on the right. Note that the temporal crests of the *A. rochei* skull are parallel with each other and with the supraoccipital crest, whereas in *A. thazard* the temporal crests diverge anteriorly so that the three crests are not distinctly parallel (Yoshida and Nakamura 1965).

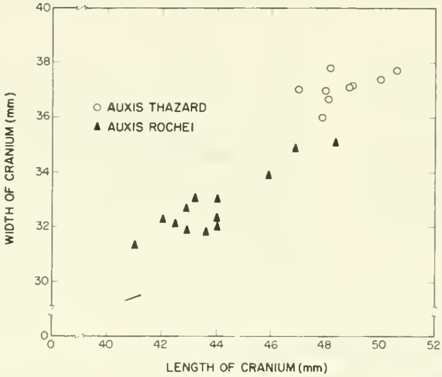


Figure 6.—Relation between the width and length of the cranium of *Auxis thazard* and *A. rochei*. Width: distance between widest points of pterotic processes; length: distance from anterior margin of vomer to concave ventral tip of aperature of myodome. (Yoshida and Nakamura 1965.)

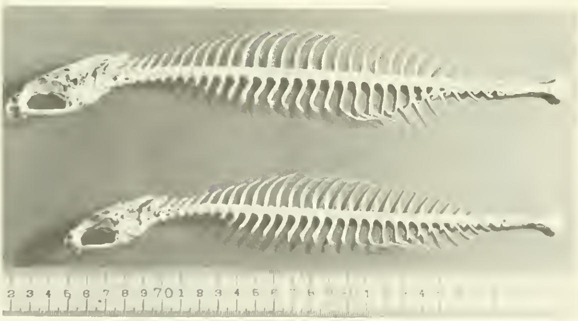


Figure 7.—Lateral view of skleton of *Auxis thazard* (top) and *A. rochei* (bottom). Note that in *A. thazard*, the anterior branch of the haemal processes are much longer than in *A. rochei* and that they are in contact with the preceding haemal arches on the 24th to the 28th vertebrae (Yoshida and Nakamura 1965).

2 DISTRIBUTION

2.1 Total area

The genus *Auxis* is distributed worldwide in tropical and subtropical waters.. The confusion surrounding the identification of the two species of *Auxis* is reflected in their reported distribution in the world's oceans. Fitch and Roedel (1963) concluded from their study that *A. rochei* was cosmopolitan in distribution whereas *A. thazard* was restricted to the Pacific. Collette and Gibbs (1963a) expressed uncertainty about the presence of both species of *Auxis* in the Atlantic but stated that both probably do occur there. Richards and Randall (1967) independently confirmed that adult *A. thazard* do occur in the Atlantic.

The distribution of *A. thazard* cannot be separated from that of *A. rochei* at the present time because of difficulties in the past in distinguishing one species from the other (Yabe et al. 1963). Therefore, the reported distribution in the literature for either *A. thazard* or *A. rochei* is questionable and needs to be critically reexamined. The following discussion takes into account the distribution of both species. Figure 8 shows the distribution of *Auxis* adults in relation to water and land areas.

In the Pacific Ocean, *Auxis* occur off the coast of the United States between Santa Catalina Island and San Clemente Island off California southward into the eastern tropical Pacific extending as far south as lat. 18°S (Radovich 1961; A. Ch. de Vildoso[5]). They have also been reported from the Hawaiian (Matsumoto 1960a) and Marquesas Islands (Nakamura and Matsumoto 1967). In the western Pacific, they occur off the coast of Japan as far north as Hokkaido, off Korea, off the coast of China mainland near southern Manchuria and Ningpo, around Formosa, and in waters surrounding the Ryukyu and Bonin Islands (Rosa 1950). Southward, *Auxis* have been reported from Samoa Islands and Papua New Guinea (Jordan and Seale 1906), the Philippine Islands (Herre 1953), along the eastern and southern coasts of Australia (Scott 1962; Laevastu and Rosa 1963; Whitley 1964), Tasmania (Lord 1927), and New Zealand (Roberts et al. 1977).

The usual latitudinal range reported for *Auxis* in the tropical and subtropical waters of the Atlantic Ocean is from lat. 45°N to 35°S (Collignon see footnote 2; Miyake and Hayasi 1972). In the eastern Atlantic, they occur infrequently as far north as Bergen, Norway, and the canal of Oslo Harbor (Rosa 1950) and in waters around the British Isles (Went 1955, 1956, 1958, 1967; Rae 1963; Went and Kennedy 1969; Wheeler and Blacker 1969). *Auxis* also occur in the Mediterranean and Black Seas. Southward, they are found in waters off the Republic of South Africa and offshore around Ascension and St. Helena Islands. In the western Atlantic, the northernmost occurrence of *Auxis* is off Barnstable, Mass., in the Gulf of Maine (Mather and Gibbs 1957). Southward in the western Atlantic, *Auxis* have been reported from the Gulf of Mexico, the Caribbean Sea, and the Atlan tic as far south as Mar del Plata, Argentina (López 1961).

In the eastern Indian Ocean, *Auxis* have been reported from the east coast of India and southward along the Indonesian Archipelago to Cape Leeuwin near the southern tip of Western Australia (Rosa 1950; Jones and Silas 1964; Nair et al. 1970). The western Indian Ocean distribution of *Auxis* extends from the west coast of India offshore to the Maldive and Laccadive Islands, the coast of Iraq in the Persian Gulf (Mahdi 1971), the Red Sea (Ben-Tuvia 1968), and from the Gulf of Aden southward to the coast of Natal in the Republic of South Africa (Williams 1963; Nair et al. 1970).

[5] A. Ch. de Vildoso, Instituto del Mar. Callao, Peru, pers. commun. December 1975.

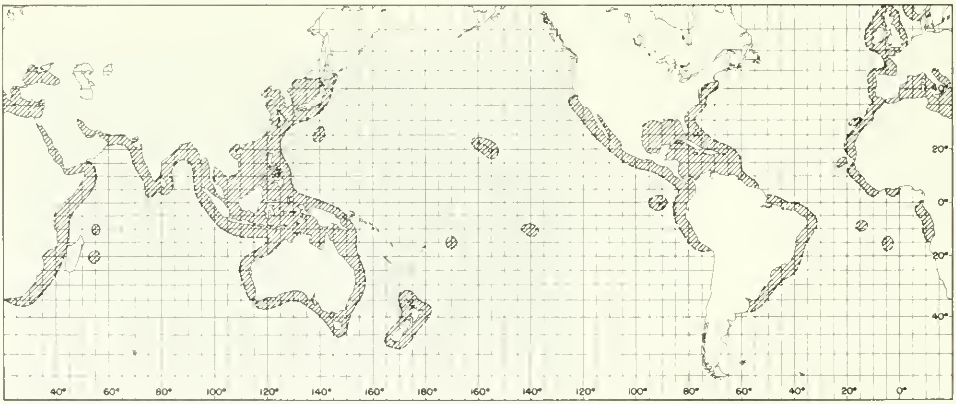


Figure 8.—The distribution of *Auxis* spp. adults in relation to water and land areas in the world's ocean.

2.2 Differential distribution

2.21 Spawn, larvae, and juveniles

The larvae of *Auxis*, like the eggs which precede them, are displaced from the area of spawning due to drift of the ocean currents (Matsumoto 1958, 1959). Except in a few areas where currents are swift, the actual displacement of eggs and larvae appears to be relatively insignificant.

Whereas the distribution of adult *Auxis* is usually associated with land masses, that of the larvae has been described as not only coastal but also oceanic. Figure 9 shows the localities of capture of *Auxis* larvae in the world's oceans. The actual differences in larval and adult distributions, however, may not be real. The adults are usually reported to occur in coastal waters because most of the fishing is done there. But plankton hauls conducted in waters far from land masses have shown that larval *Auxis* occur in oceanic as well as coastal waters. Matsumoto (1958, 1959) suggested that the localities where larvae of about 3 mm occur probably represent actual spawning sites; therefore, it can be expected that adult *Auxis* also occur in the oceanic regions of the world's oceans. Watanabe (1964), on the other hand, studying tuna and billfish stomach contents, concluded that *Auxis* are coastal dwellers.

The distribution of juvenile *Auxis*, 10-20 cm SL (standard length), agrees well with that of the larvae, especially near land masses, but in the oceanic regions the presence of juveniles have not been well documented (Fig. 10). Yabe et al. (1963) pointed out that the usual method of using a midwater trawl to collect juveniles has not been successful quantitatively; rather, more information can be obtained through examination of stomach contents of large tunas and billfishes.

That juvenile *Auxis* occur mostly in waters close to land masses is brought out in Table 7 which shows the number of juvenile *Auxis* taken by midwater trawl in Hawaiian waters. Higgins (1970) observed that in July-September 1967, the catch rate of juvenile *Auxis* reached 3.5 individuals/tow, the highest among all the

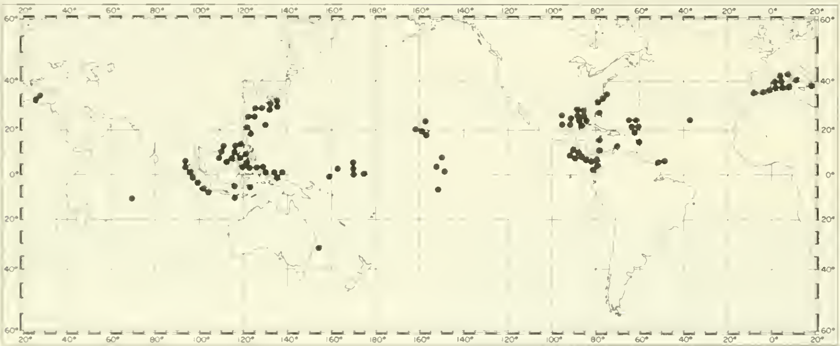


Figure 9.—Localities of capture of larval *Auxis* (Yabe et al. 1963).

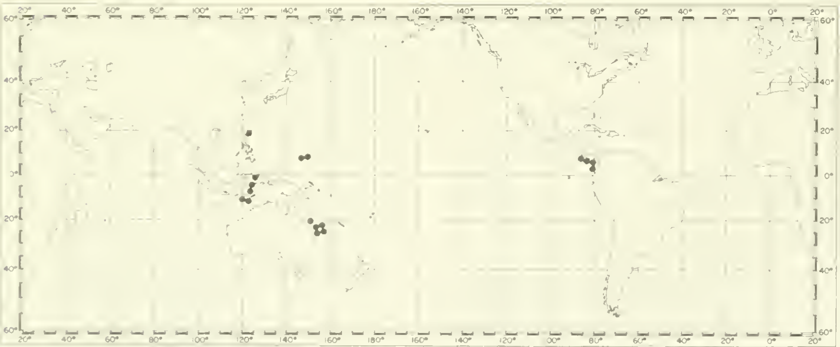


Figure 10.—Localities of capture of juvenile (10-20 cm SL) *Auxis* (Yabe et al. 1963).

Table 7.—Total number of juvenile *Auxis* and (in parentheses) the average number per tow collected by a 12 m wide by 8 m high midwater trawl during the day (1200-1800), night (2000-0200), and morning (0400-1000), RV *Townsend Cromwell* cruise 32, 12 July-25 September 1967. The trawl, fished at a depth of 100 m during deep hauls and 20 m during shallow hauls, was towed at a speed of 1.5 m/s (Higgins 1970).

Area and month	Number of tows	Frigate tuna		Total tunas	
Inshore Oahu:					
July	18	7	(0.4)	55	(3.0)
August	10	9	(0.9)	28	(2.8)
September	8	111	(13.9)	174	(21.8)
Total	36	127	(3.5)	257	(7.1)
Offshore Oahu:					
July	11	6	(0.5)	155	(14.1)
August	18	0		380	(21.2)
Total	29	6	(0.2)	535	(18.4)
Molokai[1]:					
August	2	0		1	(0.5)
Lanai[1]:					
September	4	0		0	
Hawaii:					
September	12	0		202	(16.8)
Grand total	83	133	(1.6)	995	(12.0)

[1]The duration of these tows was <6 h.

young tunas collected in inshore waters off the island of Oahu. Offshore, the catch rate dropped to 0.2 juvenile/tow.

2.22 Adults

Despite the argument that the distribution of *A. thazard* cannot be separated from that of *A. rochei* because of difficulties in distinguishing the two species, a study of stomach contents of tunas and billfishes indicated that there are conspicuous differences between the pattern of occurrence of these two species. Watanabe (1964) found that in the Banda Sea, specimens of *A. rochei* were found in the stomach contents more frequently than those of *A. thazard*, although both species occurred there. This pattern of occurrence reflected the difference in abundance of the two species in the Banda Sea. Off the Queensland coast in Australia, all the specimens collected from tuna and billfish stomachs were *A. rochei*.

2.3 Determinants of distribution changes

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

Temperature, it has been shown, is clearly a highly important variable in explaining the distribution of *Auxis* larvae. Klawe et al. (1970) observed that the optimum temperature of surface waters under which larval *Auxis* are found is between 27.0° and 27.9°C (Fig. 11). Their tolerance for temperature, however, is very wide. Richards and Simmons (1971) determined that *Auxis* larvae occur in waters with surface temperatures as low as 21.6°C and as high as 30.5°C, the widest range among any of the tuna larvae they studied.

The vertical distribution of larval *Auxis* has been reported to be limited to the layer above the thermocline. Comparing average catches of tuna (including *Auxis*) larvae for two types of plankton tows made in the eastern Pacific, Klawe (1963) found that the surface tows usually caught 9.2 times as many larvae as the deep tows. But comparison of catches made by surface and by 140 m oblique tows showed that the former caught an average of only 3.2 times as many larvae as the latter. In fact, the numbers of larvae caught in the simultaneous surface and oblique tows were significantly correlated. Klawe found that the relative number of tuna larvae taken in surface and oblique hauls approximates the ratio obtained from the depth of the oblique tow to the depth of the layer above the thermocline thus substantiating the conclusion earlier reached by others that larvae are limited to the layer above the thermocline.

Among other determinants of larval distribution that have been examined are salinity, plankton, and light conditions. Klawe et al. (1970) found no relationship between zooplankton volumes and larval catches; therefore, their findings are in agreement with those of Strasburg (1960) and Nakamura and Matsumoto (1967) who observed this phenomenon for tuna larvae in

Figure 11.—Average catches, log^{10} (number caught +1), of larval *Auxis* grouped according to surface temperatures at the time of capture (Klawe et al. 1970).

general. Salinity, likewise, showed no relationship with catches of larval *Auxis*, but Klawe et al. (1970) reasoned that this lack of relationship may be due to the narrow range of salinity encountered during the period that the study was made. Salinity, therefore, cannot be discounted as a factor affecting distribution. In fact, Richards and Simmons (1971) determined that larval *Auxis* were found in a relatively narrow salinity range from 33.2‰ to 35.4‰ compared to that of other tunas, with the exception of little tunny, *Euthynnus alletteratus*.

Concerning the effects of light intensity, Higgins (1970) observed that juvenile *Auxis* were more vulnerable to the midwater trawl at night than during daylight hours. Furthermore, they were more readily caught in shallower than in deeper tows, although the data suggested that they may occur as deep as 100 m. Strasburg (1960) reported that larval *Auxis* occur at the surface very infrequently during daylight hours but are often found there in large numbers at night. Noting that this pattern of an increase in catch at night could result from either net avoidance or vertical migration, Strasburg reasoned that if net avoidance only were involved, one would expect the catch to be essentially constant at night. The results of his study proved otherwise; therefore, he concluded that vertical migration appears to be the major factor causing the increase in surface catch at night. Contrarily, in a later study by Klawe et al. (1970), it was observed that larval *Auxis* show no significant diel movement in the water column. From a statistical test they conducted for time of day as well as for interaction between time of day and type of tow, Klawe et al. (1970) found no interaction between type of tow and time of day; therefore, they concluded that no vertical movement had occurred. They reasoned that any ability larval *Auxis* may have had to avoid the sampling gear was independent of time of day.

2.4 Hybridization

2.41 Hybrids; frequency of hybridication; species with which hybridization occurs; methods of hybridization

There has been considerable progress in studies on egg and larval development of tuna and tunalike fishes in recent years. Most impressive are the experiments by Japanese scientists on artificial fertilization of eggs and the subsequent rearing of the larvae. Among the tuna species that have been used in these experiments were yellowfin, skipjack, frigate, and bullet. In 1970, the Japan Fisheries Agency coordinated a 3-yr cooperative program to artificially fertilize and rear tunas (Ueyanagi et al. 1973). The experiments were conducted through the cooperative efforts of Tokai University, Kinki University, Shizuoka Prefectural Fisheries Experimental Station, Mie Prefectural Owase Fisheries Experimental Station, Nagasaki Prefectural Fisheries Experimental Station, and the Far Seas Fisheries Research Laboratory of the Japan Fisheries Agency.

Experiments conducted at Kinki University Fisheries Experimental Station (1974) involved cross-fertilization of *A. thazard* and *A. rochei*. The ripe eggs taken from *A. thazard* caught by set net at Kashino, Oshima, on 17 July 1973 at 0530 were fertilized and transported to the experimental station at Shirahama. At 1350 on the same day, there were about 35,120 viable eggs which averaged 0.86 mm in diameter and about 7,000 dead eggs. Twenty-five thousand viable eggs were placed in a 3-ton (3,000 liter) tank and 10,000 in a 1-ton (1,000 liter) tank. Water temperature in the tanks was about 26°C. Larvae started to emerge the next day, approximately 30 h after fertilization and all hatching was completed during the day. The larvae were kept in seawater with *Chlorella* which had a density of 400,000/cc. Aeration was also provided. Rotifers were added to the tank 2 days after hatching and marine plankton was added the next day. All the larvae in the 3-ton tank died after 6 days. In the 1-ton tank, although mortality was heavy, there were some survivors. At 14 days, the water was circulated, and at 18 days after hatching, artemia and eggs of frozen yellowtail, *Seriola quinqueradiata*, were used to supplement the marine plankton. Mortality continued and the last survivor, which attained a length of 4.8 cm and a weight of 0.907 g died after 31 days.

3 BIONOMICS AND LIFE HISTORY

3.1 Reproduction

3.11 Sexuality

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

3.12 Maturity

Studies of gonads of troll-caught fish from waters of Kaneohe Bay, Oahu, in the Hawaiian Islands indicate that frigate tuna are nearly mature at a size of about 35 cm (Tester and Nakamura 1957), but in Japanese waters, they have been reported to reach maturity at about 29 cm. Yasui (1975) investigated the use of liver weight as a possible index of sexual maturity. He plotted liver weight against body length of frigate tuna caught off the Izu Islands and off Mera, Shizuoka Prefecture, and observed a point of discontinuity at a body length of 29 cm. His data also showed that 97% of the fish <29 cm were caught after September whereas 95% of those larger than that were caught before August. The reproductive index, according to Yasui, was highest in July.

Observing that almost all fish >29 cm had high reproductive indices, Yasui hypothesized that liver weight is related to oogenesis and that it can be used as an indicator of sexual maturity.

In the Spanish trap net fishery located in and around the Strait of Gibraltar, the size of *A. rochei* at first spawning is 35 cm for the females and 36.5 cm for the males (Rodríguez-Roda 1966). Rodríguez-Roda classified the testes and ovaries according to the developmental stages as follows:

I	Immature	IV	Prespawning
II	Maturing	V	Spawning
III	Ripening	VI	Spent

Rodríguez-Roda noted that in May, a large proportion of the males and females were in stage III. In June-August some showed development in stage IV, but by September about one-third of the males and one-fourth of the females sampled had gonads that appeared to be spent (Table 8). Rodríguez-Roda noted that gonad classification based on gross characteristics such as he used could lead to misleading conclusions; however, he indicated that the relative gonad weight (gonad weight in relation to body weight) tended to confirm his conclusions.

Table 8.—Percentages of male and female *Auxis rochei* from the Spanish trap net fishery classified as I - immature, II - maturing, III - ripening, IV - prespawning, V - spawning, and VI - spent in May-September in 1958, 1961, 1963, and 1964 combined (Rodriguez-Roda 1966).

	Males							Females						
Month	I	II	III	IV	V	VI	*N*	I	II	III	IV	V	VI	*N*
May	—	8.57	88.57	1.43	—	1.43	70	—	12.86	75.71	—	—	11.43	62
June	—	2.94	79.41	17.65	—	—	34	—	6.06	69.70	24.24	—	—	33
July	—	—	90.00	10.00	—	—	30	—	20.00	80.00	—	—	—	20
August	—	2.74	97.26	—	—	—	73	—	1.35	94.59	2.70	—	1.35	74
September	20.00	14.29	25.71	5.71	1.48	32.86	70	32.61	17.89	15.22	8.70	—	26.09	46
							277							235

3.13 Mating

No information is available on the mating habits of *Auxis* but, in general, it is believed that scombrids release their sexual products directly into the water without pairing of the male and female. The mechanism which triggers the reproductive activity, i.e., spawning and fertilization, is still unknown.

3.14 Fertilization

Fertilization is external.

3.15 Gonads

The gonads of *Auxis* are paired, elongate organs suspended from the dorsal wall of the body cavity by lengthwise mesenteries. Rao (1964) described the ovaries of *A. thazard* in "spawn-ripe" condition as pinkish-pale yellow organs. Two samples of ovaries coming from fish measuring 41.6 and 44.2 cm weighed 52 and 125 g, respectively. According to Rao, the smaller of the two fish may "have been captured while in the act of spawning since most of the ripe ova were already lost by the time it was examined."

3.16 Spawning

Earlier, it was pointed out that although the planktonic eggs and larvae of *Auxis* become displaced from the area of spawning due to ocean currents, the displacement is insignificant. Therefore, localities where larvae of 3 mm or less occur probably represent actual spawning sites.

In the eastern tropical Pacific, *Auxis* larvae are the most abundant among all the scombrid larvae collected. Ahlstrom (1971) identified 1,563 out of 1,919 scombrid larvae in the EASTROPAC collection as *Auxis* spp. Based on this information and the distribution of the catches of larval *Auxis*, Klawe (1963) observed that off Baja California, spawning occurred in coastal waters whereas to the south it appeared to be in more oceanic waters away from continents or islands. The most northerly area of spawning appeared to be near Cedros Island and at the head of the Gulf of California. To the south, Klawe found the limit of spawning to be off Point Santa Elena in Ecuador. He delimited the general area of occurrence by drawing a straight line from Point Santa Elena to the intersection of lat. 10°N and long. 116°W and from there to Cedros Island off Baja California.

In the extreme eastern Pacific, *A. thazard* spawn throughout the year, although in the northern region, it may be restricted (Figs. 12, 13). This phenomenon of seasonal spawning in the northern region of the eastern Pacific may be similarly reflected in the most southern region, but data are inadequate to confirm this. Data from collections made off Cape Blanco indicated that *Auxis* spawn off Costa Rica throughout the year but peak spawning occurs in December-April (Table 9). Klawe et al. (1970), however, observed that the period of peak spawning of *A. thazard* may vary, because their data suggested that larvae were more abundant in August-November with a peak in October (Fig. 14). They suggested that differences in spawning peak between their samples and those examined earlier by Klawe (1963) may be due to differences in sampling locations within the general area, to environmental changes, or other unknown causes.

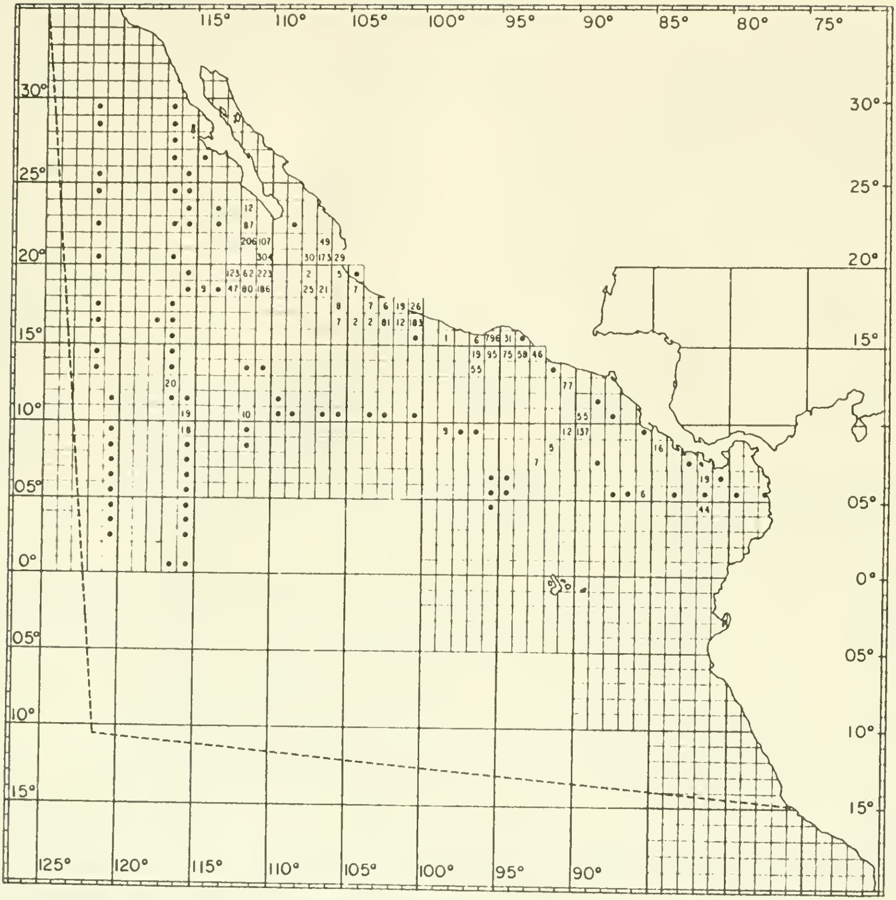


Figure 12.—Relative abundance (number of larvae per 1,000 m³ of water strained at the surface) of *Auxis* in May-October, based on plankton collections made in the eastern tropical Pacific. Dashed lines enclose area under investigation by Inter-American Tropical Tuna Commission in 1952-59; black dots indicate positions of plankton hauls with zero catches. (Klawe 1963.)

Table 9.—Average number of *Auxis* larvae caught per hour during different months off Cape Blanco, Costa Rica, with a 1 m (silk or nylon) net towed at 1.0 m/x (Klawe 1963).

Month capture	Number of larvae	Month of capture	Number of larvae
January	7.6	July	0.2
February	1.0	August	0.9
March	21.7	September	3.5
April	18.3	October	0.1
May	3.8	November	1.3
June	0.5	December	6.0

From the central Pacific, there is evidence that *Auxis* spawn not only in waters around the Hawaiian Islands but also to the west and south of these islands. The presence of small larvae of 3 mm or less in plankton samples indicated that spawning probably occurred in these waters just a few days prior to sampling (Table 10) (Matsumoto 1958; Strasburg 1959). Further evidence of spawning has been reported by Yoshida and Nakamura (1965), who observed that among the fish landed from schools of *A. thazard* and *A. rochei* fished by pole and line off Kaena Point, Oahu, milt was flowing from the vent of males of both species. The females, however, showed no signs of free-flowing eggs even after pressure was applied to the abdomen externally. Subsequent examination revealed that the females had ovaries that were flaccid, translucent, and grayish such as those usually seen in spent females of yellowfin tuna (June 1953).

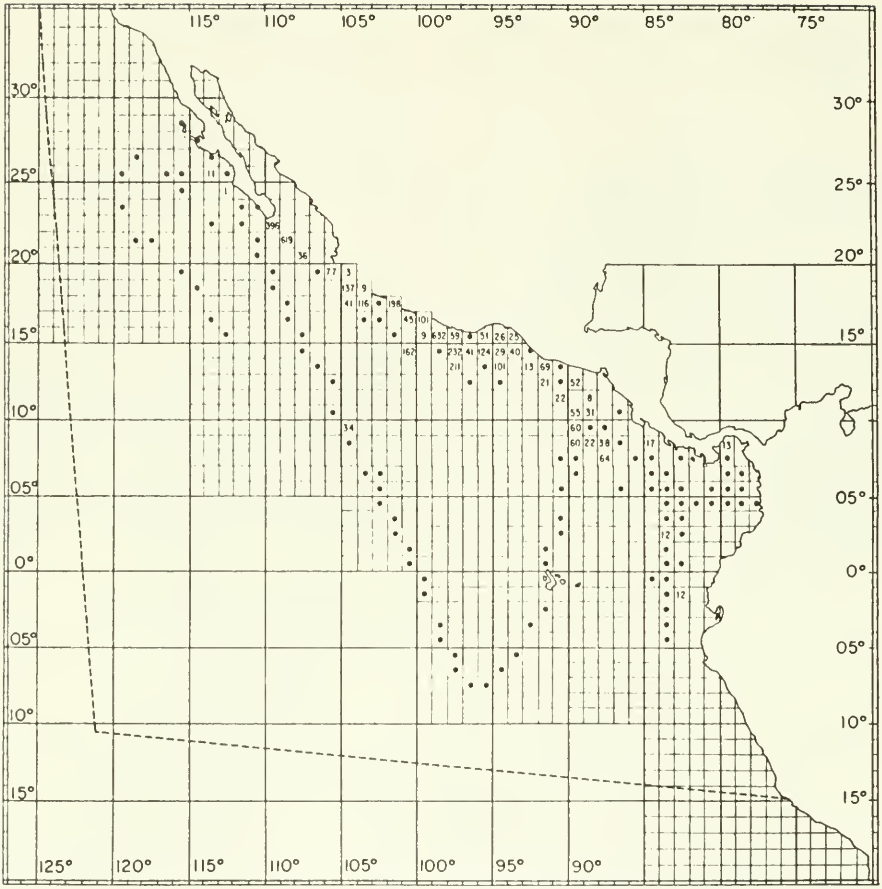


Figure 13.—Relative abundance (number of larvae per 1,000 m³ of water strained at the surface) of *Auxis* in November-April, based on plankton collections made in the eastern tropical Pacific. Dashed lines enclose area under investigation by Inter-American Tropical Tuna Commission in 1952-59; black dots indicate positions of plankton hauls with zero catches. (Klawe 1963.)

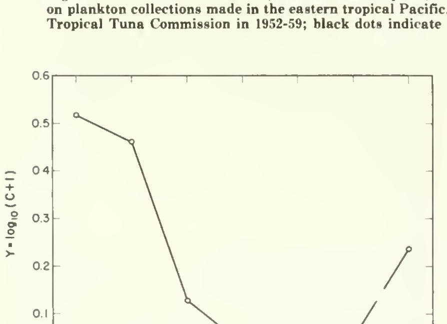


Figure 14.—Average monthly catches, $\log_{10}$ (number caught + 1), of larva *Auxis* during cruises in October-February, April, and August to the entrance of the Gulf of California (Klawe et al. 1970).

Auxis have also been reported to spawn in waters around the Marquesas Islands (Nakamura and Matsumoto 1967). From samples of tuna larvae collected at the diel variability station (station occupied for 24-h periods), Nakamura and Matsumoto found that skipjack tuna, *Katsuwonus pelamis*, larvae were most numerous followed by *Auxis* larvae. Because currents around the Marquesas Islands are suspected to be weak, *Auxis* larvae as well as those of other tunas could not have drifted very far from the spawning site; therefore,

Table 10.—Number and size range of larval *Auxis thazard* (3 mm or less) collected in 1-h horizontal hauls (three 1 m nets towed simultaneously at different depths) and 30-min oblique hauls (surface to 200 m) by the RV *Hugh M. Smith* in Hawaiian and equatorial waters (Matsumoto 1958).

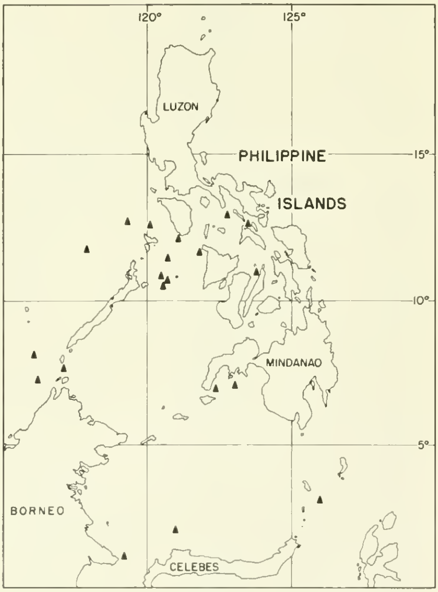
Cruise and station number	Date	Time tow started	Depth of haul (m)	Number of larvae	Size range (mm)
Hawaiian waters:					
Cruise 6:					
No. 1A	25 Aug. 1950	1405	0, 50, 150	1	3.6
No. 7	27 Aug. 1950	1853	0, 50, 150	1	6.2
No. 8	28 Aug. 1950	0507	0, 100, 200	4	2.5-8.2
No. 10	24 Aug. 1950	2239	0, 150, 300	10	2.7-3.7
No. 11	25 Aug. 1950	0500	0, 50, 150	2	7.02, 8.1
No. 13	24 Aug. 1950	0528	0, 50, 150	12	3.0-5.2
Total				30	2.5-8.2
Equatorial waters:					
Cruise 5:					
No. 21	9 July 1950	0143	0-200	2	2.6
No. 51	5 Aug. 1950	2300	0-200	2	4.2, 5.5
Cruise 14:					
No. 26	1 Feb. 1952	1920	0-200	1	3.6
No. 29	19 Feb. 1952	2008	0-200	1	3.1
Cruise 15:					
No. 3	29 May 1952	0315	0-200	1	7.2
Cruise 18:					
No. 31	9 Nov. 1952	2329	0-200	1	4.0
Total				8	2.6-7.2

it is reasonable to assume that *Auxis* spawning occurs throughout Marquesan waters.

The western Pacific also has a number of probable spawning areas. Figure 15 shows the locations where larval and postlarval *Auxis* (4.2-11.6 mm) were captured in plankton tows in Philippine waters. Wade (1951) noted that *Auxis* larvae were most abundant in January-March whereas they were scarce the remainder of the year. Furthermore, by examining the time of capture of juvenile *Auxis* in fish traps and nets close to shore, Wade determined that small juveniles first appear on the market in late November, become abundant in January-February, then become scarce so that after May there were none. From these observations, he concluded that adult *Auxis* spawn in protected, more or less shallow areas, fairly close to land, that the main spawning season is during the winter months, and that scattered spawning takes place the remainder of the year.

Other western Pacific spawning sites include waters around Australia and Japan and the Celebes and South China Seas. The Tasman Sea off Sydney, Australia, where larval *Auxis* (sizes not given) have been captured, is reported to be a possible spawning site (Fig. 16). Spawning also appears to be of significant intensity in the Gulf of Tonkin (Gorbunova 1965b). Whitley (1964) reported that larval and juvenile *Auxis* are common in the Tasman Sea. Two types of *Auxis* larvae were identified from the collection made by the *Dana* Expedition in 1929 (Matsumoto 1959, append. table 2); these specimens probably represent *A. thazard* and *A. rochei*. According to Whitley (1964), similar specimens were washed up on Collaroy Beach in August-September 1958. The presence of larval and juvenile *Auxis* in waters of the Tasman Sea would indicate that adult *Auxis* also spawn in this region of the Pacific.

Figure 15.—Localities of capture of larval and postlarval *Auxis* in Philippine waters (wade 1951).



In Japanese waters, *A. rochei* with ripening gonads are caught in April-June, whereas those with ripe and

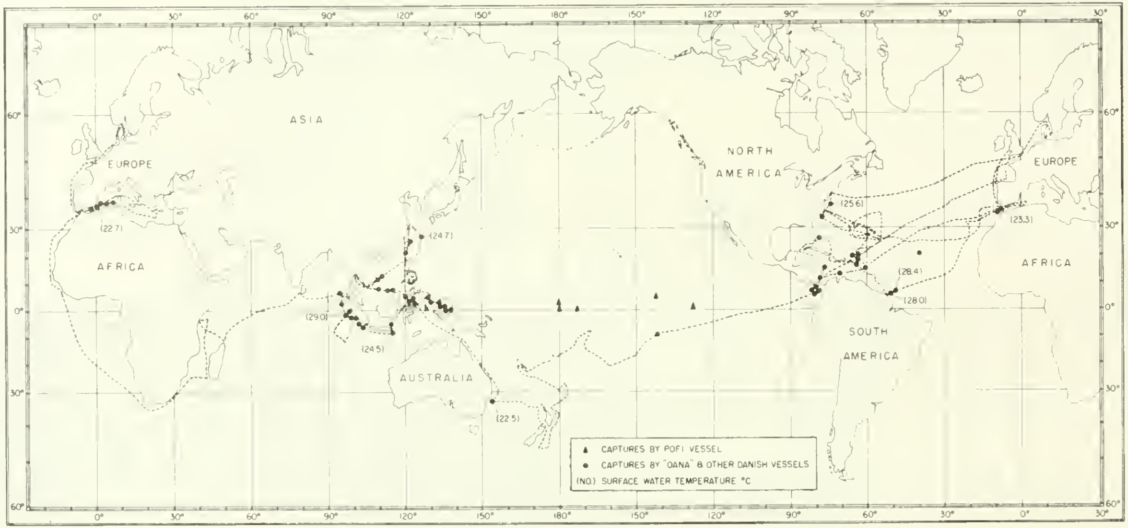


Figure 16.—Localities of capture of *Auxis* larvae by the *Dana* and Pacific Oceanic Fishery Investigations research vessels Matsumoto 1959).

spent gonads were taken in June-July and July-August, respectively (Suzuki and Morio 1957). This was confirmed by Hamada, Morita, Ishida, and Takezawa (1973), who examined the gonad condition factors of *A. rochei* caught in waters off Kochi Prefecture and suggested that spawning took place in late June. They also examined the gonad condition of *A. rochei* taken off Taiwan in June-July and found that the gonad index was very high indicating perhaps that spawning was imminent. Concerning the larvae, Yabe and Ueyanagi (1962) collected those of *A. rochei* from May through July near Japan whereas Yokota et al. (1961) obtained larval *A. rochei*, measuring 3-5 mm TL (total length), from south of Shikoku and Kyushu in June-August but most were taken in July. Farther south, however, in the Celebes and South China Seas, larval *A. rochei* were collected predominantly during January and February (Yabe and Ueyanagi 1962).

It has also been established that *Auxis* spawn in the Indian Ocean (Bogorov and Rass 1961) and that spawning extends for at least 8 months from August to April; however, there is no information on their spawning activity for the rest of the year. Among the tuna larvae collected by the *Dana* Expedition from south of the equator between lat. 3° and 24°S at long. 50°E, Jones and Kumaran (1963) found 131 larval *A. thazard*, indicating that this species spawned in this area in December-January. North of the equator in the Laccadive Sea, they also found larval *A. thazard* in the samples indicating a spawning period in January-April, slightly later in the year than in the south. Rao (1964) added that among samples of *A. thazard* he collected from commercial landings, the percentage of maturing and mature ovaries was highest in March. In August and September, the majority of the fishes examined were actually in spawning condition and some individuals completely spent. Samples obtained subsequently in November contained only spent fish.

Although evidence indicates that *A. thazard* spawn in the Indian Ocean, present data concerning spawning of *A. rochei* are still too meager to draw definite conclusions. Jones and Kumaran (1963) found 20 larval *A. rochei* in the *Dana* collection from the Indian Ocean. All were collected in December-January from three locations between Madagascar and the African coast. Matsumoto (1959), who examined the collection made by the *Dana* from the eastern Indian Ocean southwest of the Sunda Archipelago in August-November, recognized the presence of two types of *Auxis* larvae. Gorbunova (1963) confirmed Matsumoto's observations, reporting that two types of *Auxis* larvae were distinguished in the Soviet collection made in the Indian Ocean. From the information available, Jones and Kumaran (1963) hypothesized that low latitudinal areas of the eastern Indian Ocean southwest of the Sunda Archipelago and the western Indian Ocean between Madagascar and the coast of Africa are possible spawning grounds of *A. rochei*. Gorbunova (1965a, 1965c) collected *A. thazard* larvae of 5-11 mm in February and March in the Bay of Bengal.

In the Atlantic Ocean, tuna larvae have been collected off the west coast of Africa, mainly in the region of Dakar at the western tip of Africa, and off Takoradi in the Gulf of Guinea (Kazanova 1962; Richards 1969). Among the various species of larval tuna and tunalike fishes collected, those identified as *Auxis* were most numerous. Kazanova had at his disposal a series of *Auxis* larvae some as small as 3 mm. Furthermore, in addition to larvae identified as *A. thazard*, there were others which were similar to *A. thazard* but differing in some characteristics. Kazanova referred to them as the second of the two groups (Type II of Matsumoto 1959) of *Auxis* larvae. Therefore, it can be inferred that these regions of the Atlantic are also spawning grounds of the two species of *Auxis*.

Certain areas in the Mediterranean Sea have also been suggested as possible spawning sites of *Auxis* sp. Ehrenbaum (1924) reported *Auxis* spawning from July to September in the Mediterranean. Off Greece, spawning of *Auxis* was also reported to occur from June to September and in the Gulf of Catania (Sicily) in June and July (Belloc 1954). Declerc et al. (1973) reported capturing recently hatched larvae of *Auxis* in waters surrounding the Balearic Islands, located off the Mediterranean Spanish coast. In August-September 1971, 140 larval *Auxis* were captured by the RV *Ichthys* and in June-July 1972, an additional 52 *Auxis* larvae were taken. According to the authors, larval *Auxis* was the most abundant among the tuna larvae captured which included *Thunnus thynnus*, *T. alalunga*, and *Sarda* sp. The presence of the planktonic stages of all these tuna species in the plankton-net catches provided evidence that these species spawned in waters near the Balearic Islands.

The waters around Tunisia have yielded *Auxis* in a mature state, and this bit of evidence has led Postel (1964) to believe that spawning probably takes place in Tunisian waters. Postel examined the gonads of *Auxis* caught in madragues (traps) off Tunisia, found them mature, and concluded that spawning occurs in June-August. For *Auxis* that were taken off Algeria, Postel also determined that they spawn there probably in August. Off the northwestern coast of Africa, Cape Verde Islands and Dakar have been mentioned as spawning sites of *Auxis* (Frade and Postel 1955; Kazanova 1962). Gorbunova (1965c) reported capturing about 600 *Auxis* larvae at one station in the Gulf of Aden.

In the western Atlantic, the Gulf of Mexico appears to be a large spawning ground for *Auxis*. Hayasi (1972) reported collecting tuna larvae identified as yellowfin, bigeye, skipjack, and *Auxis* in gulf waters (Fig. 17). Klawe and Shimada (1959), who collected juvenile *Auxis* in March-April and in June-August from a large number of stations spread widely over the Gulf of Mexico, stated that the north central gulf region is definitely a spawning locality for this species. The area southeast of the Mississippi River Delta is another possible spawning site because most of the larvae were captured there, but Klawe and Shimada pointed out that the collection

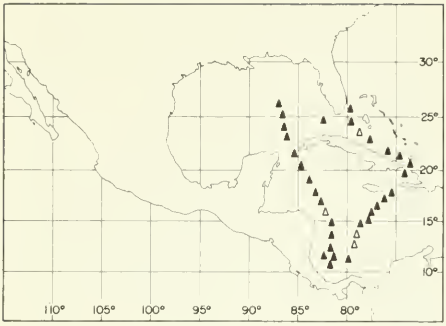


Figure 17.—Plankton stations occupied during cruises of the RV *Shoyo Maru* in 1969-70. Solid triangles represent stations at which *Auxis* larvae were collected. (Hayasi 1972.)

may reflect sampling intensity rather than actual distribution of young *Auxis*. In waters adjacent to the gulf extending from Cape Hatteras to Cuba and particularly in the Strait of Florida, larval *Auxis* have shown up in collections made in February-March (Tibbo and Beckett 1972) and in May-June and in August (Klawe 1961) indicating the possibility that spawning occurred during these months in this region.

3.17 Spawn

The eggs of *Auxis* are pelagic. Rao (1964), who examined ovaries of *A. thazard* from the Indian Ocean, observed that ripe eggs flowed freely out of the ovaries when slight pressure was applied on the abdomen. Fresh ripe eggs were perfectly spherical, had a colorless homogeneous yolk mass, and had an average diameter of 0.97 mm (range of 0.88-1.09 mm). Preserved eggs were somewhat translucent and had an average diameter of 0.86 mm (range 0.78-0.98 mm). Each ripe egg contained a fairly large, spherical, single oil globule which averaged 0.22 mm (range 0.21-0.22 mm) in diameter.

Like other scombrids, female *Auxis* do not extrude all their ripe eggs during spawning. Microscopic examination by Yoshida and Nakamura (1965) of ovaries from eight *A. thazard* and five *A. rochei* caught in Hawaiian waters revealed that both species had eggs in various stages of resorption. One specimen of *A. thazard* still contained residual eggs in the lumen; their diameters varied between 0.75 and 1.30 mm and averaged 1.08 mm. No free residual eggs were found in *A. rochei*. Concerning primordial eggs, two size groups—one ranging from 0.07 to 0.10 mm and the other from 0.17 to 0.22 mm in diameter—were noted in ovaries of *A. thazard*. In *A. rochei*, there was only one group of primordial eggs ranging from 0.07 to 0.08 mm in diameter.

The development of eggs and larvae of *Auxis* has been described for the two species from the Atlantic and Pacific Oceans. Mayo (1973) successfully hatched eggs of two species of *Auxis* collected from the Straits of Florida and described the growth, behavior, ecology, and development of the larvae. In the Pacific, artificial fertilization of eggs and subsequent rearing of larvae were conducted by Japanese scientists and their results have been briefly discussed in section 2.41. Harada, Murata, and Miyashita (1973) and Ueyanagi et al. (1973) published the results of these tuna-rearing experiments in which fish in advanced stages of sexual maturity were used. Of three conventional fishing methods attempted, only purse seining proved effective in capturing mature yellowfin and skipjack tunas and set nets for collecting mature *Auxis*.

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

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

Auxis thazard

Mature eggs of *A. thazard* caught at Mera, Shizuoka Prefecture, were collected, fertilized, and successfully hatched on five occasions between 15 July and 15 August 1971 (Ueyanagi et al. 1973). Larval rearing was most successful on the first trial when survival lasted up to 10 days. Newly hatched larvae emerged 25 h after fertilization and measured 2.59 mm TL. Heavy mortality usually occurred 4-5 days after hatching.

At Kushimoto, Wakayama Prefecture, mature eggs were collected, fertilized, and transported to the Marine Laboratory of Kinki University on three occasions in 1972 (Harada, Murata, and Miyashita 1973; Ueyanagi et al. 1973). The spherical, fertilized eggs were buoyant and varied from 0.93 to 0.98 mm in diameter (Fig. 18). Emerging 34-62 h after fertilization at temperature ranging between 21.4° and 23.5°C, the newly hatched larvae measured from 3.26 to 3.60 mm TL. On the third day after hatching, the larvae were fed rotifers, which were replaced by marine plankton, mainly copepods, on the seventh day. Twenty days after hatching, the larvae were fed several types of fish flesh. The larvae were placed in various-sized aquaria to determine the effects of tank capacity on growth and survival; the investigators found that growth was rapid in the 0.5-ton (500 liter) aquarium during the first 30 days after which time the rate slowed appreciably (Table 11, Fig. 19). Maximum survival was 36 days. Larvae reared in aquaria which had capacities of 3 tons (3,000 liters) and 70 tons

Figure 18.—Various stages of development of egg and larvae of *Auxis thazard* (Harada, Murata, and Miyashita 1973).

(70,000 liters) grew faster than those reared in the 0.5-ton aquarium, reaching a length of 12 cm in 33 days (Table 12, Fig. 19). Growth decreased significantly after that and the last larvae died on the 41st day.

Auxis rochei

In 1972, the collection and fertilization of eggs from mature *A. rochei* succeeded in seven trials at Mera,

Table 11.—Measurements on *Auxis thazard* larvae reared in a small (500 liter) aquarium (Harada, Murata, and Miyashita 1973).

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

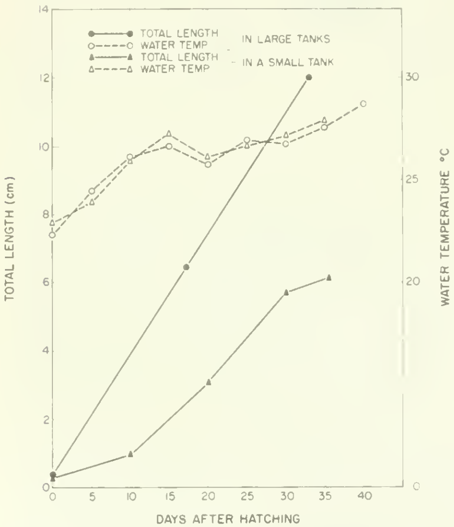


Figure 19.—Growth curves of *Auxis thazard* larvae reared in two large (3,000 and 70,000 liter) and one small (500 liter) aquaria. Length measurements are based on a single fish. (Harada, Murata, and Miyashita 1973.)

Table 12.—Measurements on *Auxis thazard* larvae reared in two large (3,000 and 70,000 liter) aquaria (Harada, Murata, and Miyashita 1973).

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

Shizuoka Prefecture (Ueyanagi et al. 1973). In one experiment, the larvae, which were fed rotifers, copepods, larvae of sea bream and goby, chopped bivalve meat, and chopped fish flesh, survived up to 67 days after fertilization.

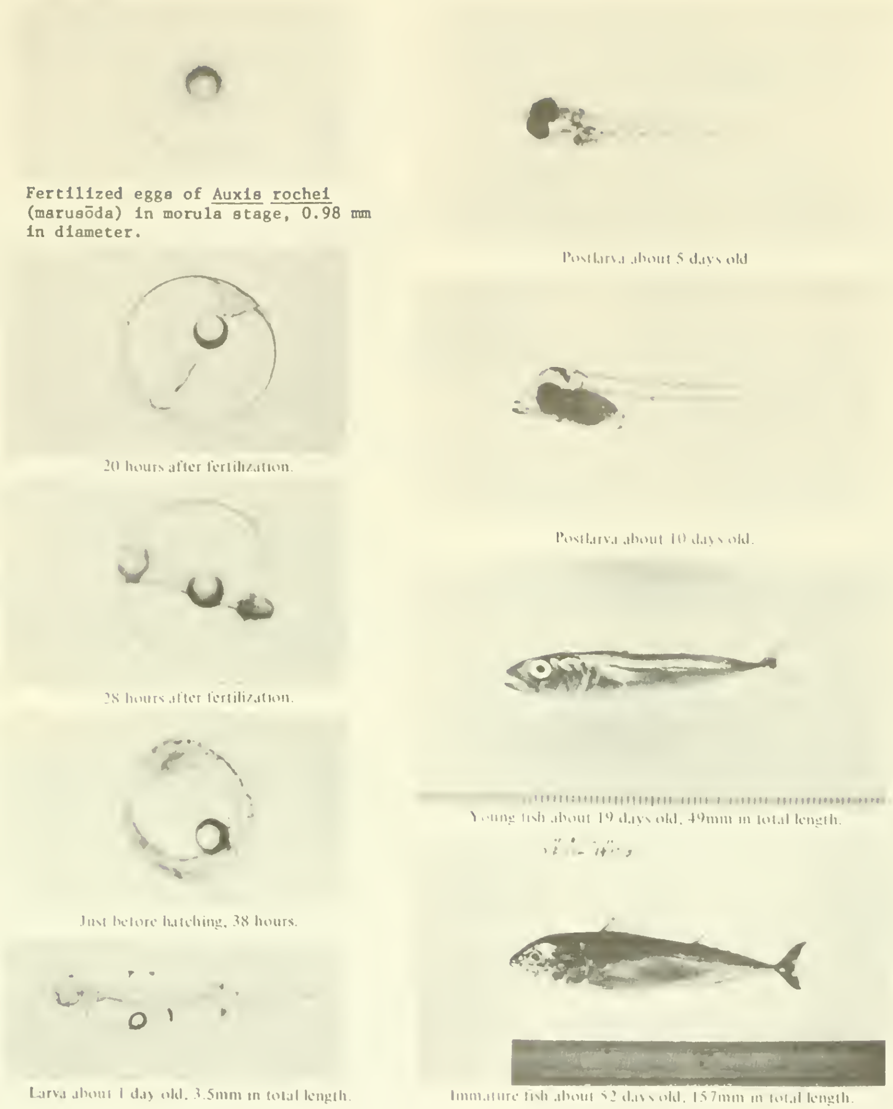
In other rearing trials of *A. rochei* conducted at the Shirahama Fisheries Laboratory of Kinki University, Wakayama Prefecture, in June 1972, about 40,000 eggs were collected from mature females caught in a trap net near Oshima Island by Cape Shionomisaki, fertilized, and transported to the laboratory (Harada, Murata, and Furutani 1973). The buoyant, spherical fertilized eggs, which measured between 0.97 and 0.99 mm in diameter (Fig. 20), hatched 38-52 h later at temperatures ranging from 21.4° to 23.5°C. The newly hatched larvae ranged from 3.3 to 3.6 mm TL. Fed the same diet as that given larvae of *A. thazard* as previously described and confined in one small 0.5-ton aquarium and two large aquaria of 3- and 30-ton (30,000 liter) capacities, the larvae of *A. rochei*, like those of *A. thazard*, grew faster in the large aquaria than in the small aquarium (Tables 13, 14; Fig. 21).

Table 13.—Measurements on *Auxis rochei* larvae reared in a small (500 liter) aquarium (Harada, Murata, and Furutani 1973).

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

Table 14.—Measurements on *Auxis rochei* larvae reared in two large (3,000 and 30,000 liter) aquaria (Harada, Murata, and Furutani 1973).

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



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

20 hours after fertilization.

28 hours after fertilization.

Just before hatching, 38 hours.

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

Postlarva about 5 days old

Postlarva about 10 days old.

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

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

Figure 20.—Various stages of development of egg and larva of *Auxis rochei* (Harada, Murata, and Furutani 1973).

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

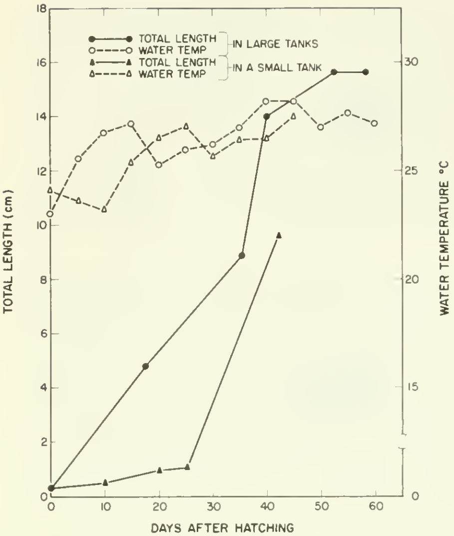


Figure 21.—Growth curves of *Auxis rochei* larvae reared in two large (3,000 and 30,000 liter) and one small (500 liter) aquaria. Length measurements are based on a single fish. (Harada, Murata, and Furutani 1973.)

a 3-ton aquarium and at age 2 days were fed rotifers and marine plankton. By age 18 days, the larvae were 3 cm long. From the 24th day, the larvae were fed minced fish flesh, and they grew rapidly, reaching 5-6 cm by the 27th day; however, heavy mortality reduced the number of larvae to 36. By the 35th day, the survivors were 7.7-7.9 cm long. Only one larva survived for 50 days. The Japanese investigators observed that this rate of growth was slower than in previous experiments and believed that it was due to lack of fish larvae as food. They emphasized, however, that the experiments succeeded in artificially producing "seedlings" of *A. rochei* which were several centimeters in length.

In general, then, these experiments on frigate and bullet tunas have shown that:

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

3.2 Preadult phase

3.21 Embryonic phase

See section 3.17 above.

3.22 Larval phase

Studies of anatomical development of larval *Auxis* show that gross nucleation of the central nervous system of young *Auxis* (3.6-23.0 mm SL) is similar to young *Thunnus albacares* but heavier than in *Katsuwonus pelamis, T. obesus, T. thynnus, T. alalunga, T. atlanticus,* and *Euthynnus alletteratus* (Richards and Dove 1971). Using sectioned organs and tissues, Richards and Dove determined that the swim bladder in *katsuwonus* and *Auxis,* which, among scombrids is similar in the very early stages of development, starts to degenerate when the larvae reach the size of 9 mm, and is nearly completely degenerated in specimens 24 mm long at which time only the gas gland remains. Richards and Dove also determined that in *Auxis* the kidney is short until the larvae reach 11 mm after which it lengthens significantly and that the postcardinal vein is larger in *Auxis* and *Euthynnus* than in other species.

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

Key to the larvae of tunas from the western Pacific[6]

a_1 Melanophores visible on the forebrain
- b_1 One conspicuous melanophore present on the caudal peduncle. No chromatophores on the isthmus or directly anterior to the anus.
  .... skipjack tuna, *Katsuwonus pelamis*
- b_2 There is a dotted line of melanophores along the midlateral line on the posterior part of the body. Chromatophores appear on the isthmus and directly anterior to the anus.
  .... kawakawa, *Euthynnus affinis*

a_2 No melanophores visible on the forebrain.
- c_1 Melanophores appear on the sides of the body.
  - d_1 Chromatophores appear on the isthmus and directly anterior to the anus. Melanophores appear as dotted lines along the middorsal, midlateral, and midventral lines of the caudal region (usually in three lines).
    .... frigate and bullet tunas, *Auxis* spp.
  - d_2 Chromatophores do not appear on the

[6] Applicable to larvae under about 8 mm TL.

isthmus nor directly anterior to the anus.

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

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

........bluefin tuna, *Thunnus thynnus*

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

..... long-tailed tuna, *Thunnus tonggol*

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

..........*bigeye tuna, Thunnus obesus*

c_2 No melanophores appear on the sides of the body.

h_1 Chromatophores appear at tip of lower jaw. In the profile of the head, the center of the eye is clearly located higher than the tip of the snout.

.....yellowfin tuna, *Thunnus albacares*

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

.... albacore, *Thunnus alalunga*

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

Additional observations on the morphology of larval *Auxis* showed that the snout is shorter than in other tuna and tunalike larvae of comparable size (Jones 1963). Jones also noted that larval *Auxis* has 39 myotomes, a large chromatophore at the symphysis of the pectoral girdle, and that fin ray development is later than in other tuna and tunalike larvae. Jones and Kumaran (1964) added that compared with larval *Euthynnus affinis,* larval *Auxis* exhibits later development of the first dorsal fin and has relatively few chromatophores on the first dorsal fin membrane, and its fin membrane is relatively narrow.

The variations in pigmentation among larval *Auxis* has been used as a basis for separating the larvae into two possible types. Matsumoto (1959), who described the morphology of larval and postlarval *Auxis* on a worldwide basis, pointed out the possibility that this variation may well be due to the presence of two species of frigate tuna; therefore, he provided two separate descriptions calling them Type I and Type II, as shown in Figure 22.

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

Subsequently, Type I larvae, which are stouter than Type II, were provisionally identified as *A. thazard* and Type II, which are relatively elongate, were identified as *A. rochei* (Jones 1963). Further observations revealed that compared to *A. thazard*, larval *A. rochei* has a relatively shallow body, shows later development of the spinous dorsal, and has less intense pigmentation on the caudal peduncle (Jones 1963; Gorbunova 1969). A later study confirmed Jones' observation; Yabe and Ueyanagi (1962) published the results of a study on larval tuna in which they positively identified specimens of *A. rochei.*

A controversy over the identification of larval *Auxis* erupted in 1963 when Jones (1963) questioned the results obtained by Mito (1961), who described the egg and larval development of *Auxis* (Fig. 23). Jones pointed out that because *A. rochei* is the most common frigate mackerel in Japanese waters, the eggs and larval stages described by Mito may be this species; but he also noted that there were striking differences between larvae described by Mito and those described by Matsumoto (1959) and Jones (1961). These differences, he believed, should be explained by Mito. The breakthrough in artificial rearing accomplished by the Japanese should make it possible to compare specimens of artificially reared larvae and those obtaind from net tows and night lighting to obtain positive identification.

3.23 Adolescent phase

Juvenile *Auxis* can be distinguished from other tunas by certain morphological features (Schaefer and Marr 1948; Wade 1949; Mead 1951; Matsumoto 1962). They can be distinguished from other tunas by the wide gap between the first and second dorsal fins and the virtually colorless appearance of the first dorsal. Compared to *Katsuwonus,* however, the first dorsals are somewhat similar, both having a lightly pigmented or colorless fin.

Figure 22.—*Auxis* larvae Type I, 7.05 mm (A) and Type II, 7.2 mm (B) (Matsumoto 1959).

Katsuwonus, nevertheless, possess more pigment in the first dorsal, which is also more or less brown or tan distally, whereas in *Auxis*, a few scattered chromatophores are found along several of the anterior rays in the distal portion of the first dorsal. Compared with *Euthynnus*, *Auxis* are rounder in cross section, relatively less compressed laterally, and the length of the head and the caudal region shorter in comparison to total length. Juvenile *Auxis* also possess a black spot at the isthmus which is seen only in one other genus, *Euthynnus*. In young *Euthynnus*, however, the first and second dorsals are continuous. The large interspace between the dorsals, the low ray count of the first dorsal, and the absence of an elaborate "trellis" of the vertebrae also help to separate *Auxis* from *Euthynnus* and *Katsuwonus*.

The pattern of pigmentation is also a good identifying character. Schaefer and Marr (1948) wrote "In the smaller specimens the prominent areas of pigmentation are on the upper and lower jaws, above the snout, around the postero-ventral margin of the orbit, on the upper operculum, between the orbits, along the mid-line of the body, along the bases of the dorsal and anal fins including the finlets, and around the posterior end of the urostyle. Large chromatophores in the peritoneum show through the body wall along the upper half of the body cavity. None of the fins or finlets bears pigment spots, with the exception of the first dorsal. The first dorsal bears a few scattered chromatophores, largely distributed along the spines."

Several features of the axial skeleton also are useful in separating the juveniles of partially digested tunas. Potthoff and Richards (1970), who studied regurgitated food of terns and noddies from the Dry Tortugas, Fla., observed that damaged or partly digested *Auxis* and those <30 mm could easily be separated from *Euthynnus* if judged on fin position and gill raker counts. Potthoff and Richards revealed that extreme care must be used to examine *Auxis* specimens because the spines of the first dorsal in some juveniles are subcutaneous and come to the surface in the fin interspace. Furthermore, they noted that the number of gill rakers is evenly distributed over the range for *Auxis* whereas they are more normally distributed in other species. Counts were as follows: 19 in 38% of the ceratobranchials, 20 in 25%, 21 in 25%, and 22 in 12%. Potthoff and Richards suggested that this kind of distribution may be attributable to the presence of two types of *Auxis* and their intermediates.

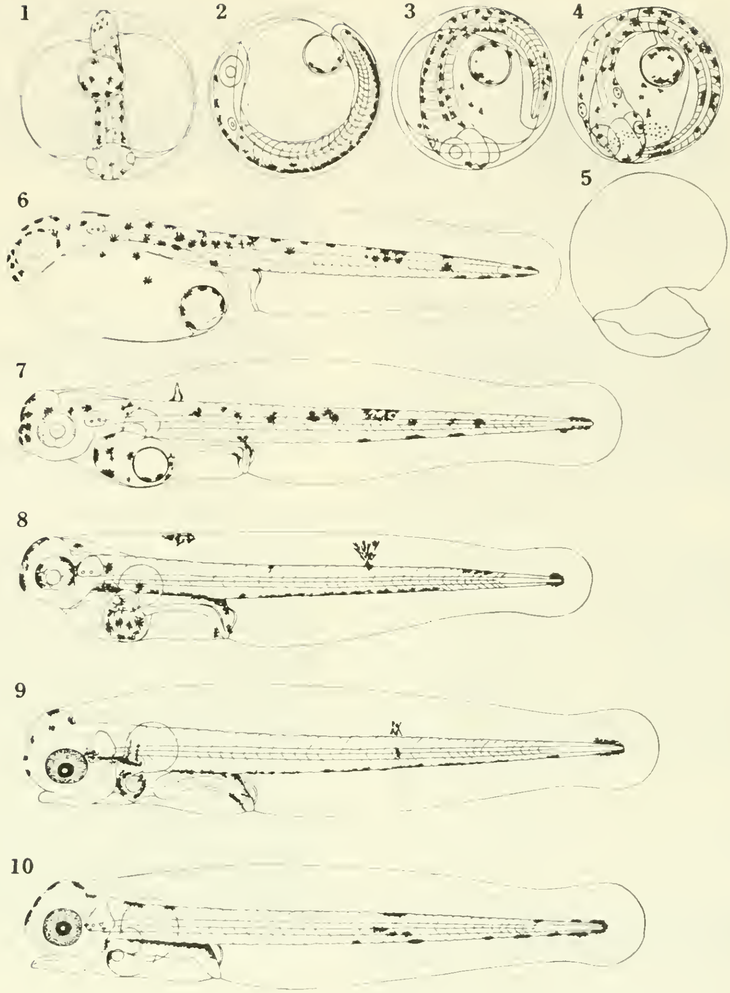


Figure 23.—Various stages of development of egg and larvae of *Auxis* (Mito 1961); 1) Pelagic egg, 7½ h after collecting, 1.04 mm in diameter, oil lobule 0.26 mm; 2) 29-myotome stage, 9½ h after; 3) 10½ h after; 4) 14½ hr after, shortly before hatching (24°-27°C); 5) empty egg capsule; 6) larva just hatched, 2.70 mm TL, myotomes 11 + 32 = 43; 7) larva 16½ h after hatching, 3.68 mm TL, myotomes 9 + 31 = 40; 8) larva 30 h after, 3.58 mm TL, myotomes 9 + 31 = 40; 9) larva 42½ h after, 3.92 mm TL, myotomes 9 + 32 = 41; 10) larva 55 h after, 3.75 mm TL, myotomes 8 + 31 = 39.

In addition to the gill raker counts (38-43 for *A. thazard* and 43-49 for *A. rochei*), the form of the free parapophyses is a useful feature of the axial skeleton for separating *Auxis* to species. Watanabe (1964) determined that in *A. thazard*, the free parapophyses are long, extend downward and almost touch the haemal spine of the preceding vertebra whereas in *A. rochei* they are short. This difference in length of the parapophyses is particularly evident on specimens of 111 mm or more (Figs. 24, 25).

Four other characters used by Watanabe (1964) include: 1) the number of the vertebra on which the first free parapophysis occurs, 2) the number of the vertebra on which the first inferior foramen occurs, 3) the ratio of the length of the caudal to the precaudal vertebra, and 4) the ratio of the body height at the origin of the anal

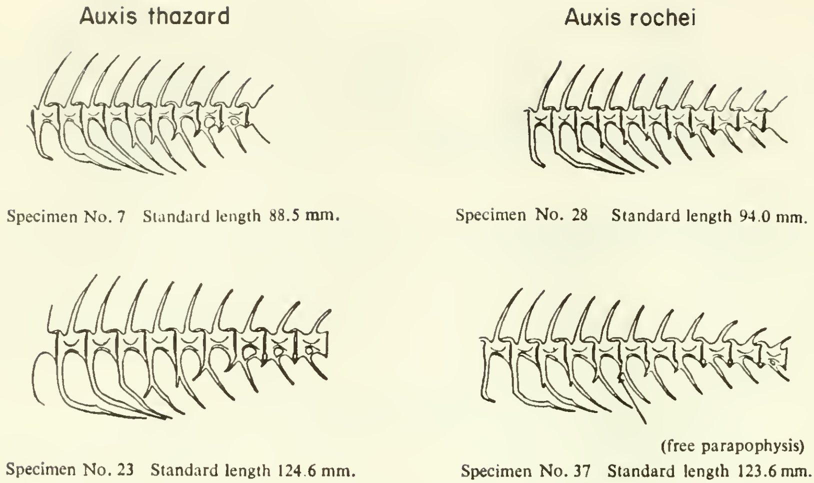


Figure 24.—Caudal vertebrae of *Auxis thazard* (left) and *A. rochei* (Watanabe 1964).

fin to the distance between the origin of the first and second dorsal fins. Watanabe found that in *A. thazard*, the first free parapophysis occurred most frequently on the 23d vertebra, whereas in *A. rochei*, it was on the 21st or 22d vertebra on 80% of the specimens; however, there were some in which it occurred on the 23d vertebra. Furthermore, the inferior foramen in young specimens occurs on the 27th or 28th vertebra in *A. thazard* and usually on the 29th and 30th vertebra in *A. rochei.* Watanabe also observed that the ratio of the length of the caudal to the precaudal vertebra for young specimens was 0.973 or less in *A. rochei* and 0.985 or more for *A. thazard.* This character also changes as growth occurs; therefore, the stage of growth needs to be considered in making a diagnosis. Figure 26 shows a plot of the ratios—body height at the origin of the anal fin to the distance between the origins of the first and second dorsal fins—on standard lengths and except for a single specimen which showed an intermediate value, those for *A. thazard* tend to be higher than for *A. rochei.*

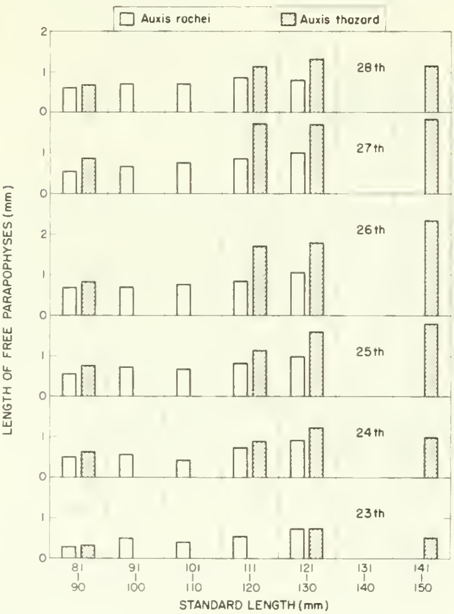


Figure 25.—Comparison of the length of the free parapophyses of the caudal vertebrae between *Auxis thazard* and *A. rochei* (Watanabe 1964).

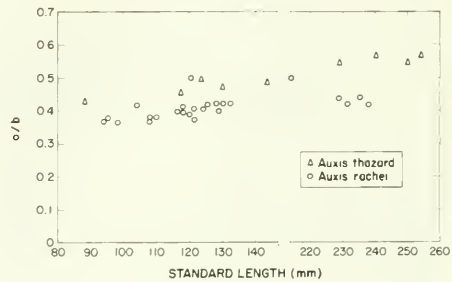


Figure 26.—Comparison of the value (a/b) between individuals of *Auxis thazard* and *A. rochei* (Watanabe 1964). (a = Body height at anal origin; b = length of first dorsal to second dorsal origin.)

Table 15.—Standard length and gill raker counts of juvenile *Auxis thazard* and *A. rochei* (Wade 1949).

Species	Standard length (mm)	Gill raker count
Auxis thazard	21.8	[1]4 + 1 + 18 = 23
	22.6	10 + 1 + 30 = 41
	26.0	7 + 1 + 29 = 37
	26.0	10 + 1 + 31 = 42
	43.5	10 + 1 + 29 = 40
	44.0	8 + 1 + 29 = 38
	46.0	8 + 1 + 30 = 39
	47.0	9 + 1 + 29 = 39
	47.0	9 + 1 + 29 = 39
	48.0	9 + 1 + 29 = 39
	49.0	8 + 1 + 30 = 39
	55.0	9 + 1 + 29 = 39
Auxis rochei	32.0	10 + 1 + 35 = 46
	42.0	11 + 1 + 34 = 46
	48.0	10 + 1 + 34 = 45
	51.5	10 + 1 + 35 = 46
	58.5	10 + 1 + 34 = 45
	61.0	10 + 1 + 34 = 45
	75.0	10 + 1 + 36 = 47

[1]Low count possibly due to the small size of the specimen and the undeveloped gill rakers.

Some investigators believe that the separation of juvenile *Auxis* into either *A. thazard* or *A. rochei* could be accomplished by gill raker counts alone (Table 15). In small specimens, errors in gill raker counts are possible, but in specimens 25-30 mm SL, no difficulty should be experienced (Wade 1949). Schaefer and Marr (1948), however, observed that in a 21 mm specimen, the gill rakers are very tiny projections and are difficult to count. The rakers are first apparent near the angle of the arch, but as the fish increases in size, those that are near the angle of the arch increase in length and new rakers are added distally on each arm. Schaefer and Marr judged by counts on specimens of various sizes that the full complement of rakers on *A. thazard* is attained at about 50 mm TL, but Klawe and Shimada (1959), who plotted the total gill raker counts against corresponding total lengths, found that the full complement is attained at sizes 40 mm or larger (Fig. 27). And Wade (1949) reported that in *A. rochei*, the full complement of gill rakers can be found in juveniles as small as 32 mm.

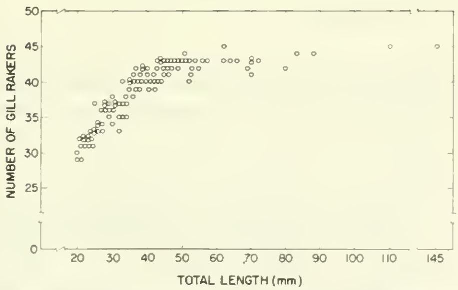


Figure 27.—Gil raker counts of young *Auxis thazard* plotted against total length (Klawe and Shimada 1959).

Noting that their specimens differed in some respects from observations made by Starks (1910) and Kishinouye (1923), Schaefer and Marr (1948) suggested that some of the specimens they examined may be juveniles of an undescribed species. Wade (1949), on the other hand, suggested that Schaefer and Marr examined juveniles of two species of *Auxis*. Schaefer and Marr's specimens, 42, 48, and 68 mm TL, had gill raker counts of 39, 41, and 42, respectively; these counts fall within the limits for *A. thazard*. Two other specimens—52 and 54 mm—had gill raker counts of 48 and 47, respectively, well within the limits of the gill raker counts for *A. rochei*.

Juveniles of *A. thazard* collected in Indian waters have also been misidentified as those of *A. rochei*. Originally, Jones (1961) examined 26 juvenile specimens collected from Vizhingam on the west coast of India and called them *A. rochei* (Table 16). In a later paper, Jones (1963) pointed out that on reexamining the material, specimens measuring 44.0-132.0 mm in length cannot be definitely assigned to *A. rochei*; rather, they could more correctly be assigned to *A. thazard*. He concluded that the remaining juveniles, from 181.0 to 209.8 mm were most likely *A. rochei*.

Juvenile *Auxis* are presumed to be relatively abundant in the world's oceans. One published report, based on the examination of juvenile tunas collected by midwater trawling in Hawaiian waters, indicated that the relative abundance of juvenile tunas is highest for skipjack tuna, reaching 7.0 juveniles/tow during the summer followed by yellowfin tuna, which was estimated at 2.2 individuals/tow (Higgins 1970). The catch rates were 1.6 individuals/tow for *Auxis* and below 1.0 individuals/tow for bigeye tuna, *Thunnus obesus*; albacore; and kawakawa, *Euthynnus affinis*.

3.3 Adult phase

3.32 Hardiness

The literature contains no direct evidence in reference to the hardiness of *Auxis*. Kishinouye (1923) observed that the salinity preference of scombroid fishes differs widely for different species. *Auxis* are sometimes seen in littoral waters of low density and apparently show no ill effect.

3.33 Competitors

Auxis compete against other tunas and tunalike fishes during all stages of their lives. Food studies indicate that most of the organisms consumed by *Auxis* also constitute part of the diet of other tuna and tunalike fishes; therefore, many species compete with them for food.

Species that have been mentioned specifically as possible competitors of *Auxis* in Japanese waters are given, by type of gear, in Table 17. In Hawaiian waters, Gosline and Brock (1960) observed that sometimes *Auxis* and kawakawa are caught in the pole-and-line fishery from mixed schools indicating that these two species are com-

Table 16.—Measurements of Indian Ocean juvenile *Auxis thazard* (specimen Nos. 1-12, 14) and *A. rochei* (specimen Nos. 17, 19-26) in millimeters and the gill raker counts in the upper and lower limbs (Jones 1961).

Specimen No.	Date	Standard length	Head	Snout	Eye	Maxilla	Maximum depth	Snout to dorsal	Snout to anal	Longest dorsal spine length	Gill raker count
1	?	44.0	13.0	4.0	3.5	5.4	8.5	15.0	30.0	4.6	—
2	29 May 1958	46.7	13.8	4.4	3.4	5.7	8.2	16.2	33.2	5.8	7 + 20
3	29 May 1958	46.8	14.0	4.1	3.2	5.5	8.6	16.3	33.9	5.0	7 + 20
4	?	48.0	13.9	4.4	3.5	5.8	8.4	16.2	33.6	5.8	8 + 22
5	26 March 1959	49.2	15.1	4.4	3.3	6.1	8.9	17.3	35.7	5.2	8 + 21
6	26 March 1959	61.7	17.4	5.7	3.9	7.0	11.2	21.0	42.3	6.2	8 + 22
7	26 March 1959	67.0	19.2	6.2	4.0	8.0	12.0	23.0	46.2	7.5	8 + 23
8	?	69.2	18.8	5.9	4.1	7.5	12.8	22.5	47.2	7.3	8 + 26
9	26 March 1959	79.5	22.0	6.3	4.5	8.1	14.7	26.1	55.0	8.0	9 + 31
10	30 Sept. 1958	125.0	33.0	9.8	6.1	12.0	22.0	38.5	85.0	12.6	9 + 31
11	?	126.1	33.7	10.1	7.0	13.0	21.8	38.8	87.0	14.0	—
12	30 Sept. 1958	128.5	33.8	10.2	6.3	12.8	23.0	41.0	89.2	13.7	10 + 31
14	30 Sept. 1958	132.0	35.0	10.4	6.4	12.9	23.3	41.0	89.4	14.8	10 + 30
17	30 Sept. 1958	181.0	48.0	13.5	9.0	15.7	34.0	55.3	131.1	16.5	10 + 36
19	30 Sept. 1958	183.0	49.0	11.8	11.0	16.5	36.0	51.2	128.0	20.0	11 + 35
20	30 Sept. 1958	185.3	46.7	11.9	9.0	15.3	33.8	57.0	131.5	16.8	11 + 35
21	30 Sept. 1958	187.5	49.0	12.0	10.0	16.5	36.9	59.5	131.9	19.9	10 + 34
22	3 Oct. 1958	189.0	49.0	12.4	9.0	15.5	36.9	59.7	134.0	18.7	11 + 34
23	3 Oct. 1958	191.0	50.1	12.8	9.2	16.0	36.2	59.5	134.5	19.5	10 + 35
24	3 Oct. 1958	196.0	51.5	13.2	10.2	17.2	36.0	62.5	142.0	19.2	10 + 36
25	3 Oct. 1958	205.2	51.5	12.5	9.2	16.0	38.0	61.0	139.5	20.2	11 + 34
26	3 Oct. 1958	209.8	55.8	14.0	10.5	17.2	41.0	65.6	150.2	22.2	10 + 36

Table 17.—Various fish species usually taken with frigate and bullet tunas and presumably in competition with them, by type of gear (Yokota et al. 1961).

	Pole and line	Troll	Long line	Set or fixed net
Albacore, *Thunnus alalunga*	x			
Bigeye tuna, *Thunnus obesus*	x	x		x
Bluefin tuna, *Thunnus thynnus*	x	x	x	x
Indo-Pacific bonito, *Sarda orientalis*		x		x
Kawakawa, *Euthynnus affinis*		x		x
Mahimahi, *Coryphaena hippurus*		x		
Sailfish, *Istiophorus orientalis*		x	x	
Scad, *Decopterus moruadsi*				x
Skipjack tuna, *Katsuwonus pelamis*	x	x	x	x
Japanese Spanish mackerel, *Scomberomorus niphonius*				x
Spotted mackerel, *Scomber australasicus*	x	x	x	x
Striped marlin, *Makaira mitsukurii*			x	
Swordfish, *Xiphias gladius*		x	x	
Yellowfin tuna, *Thunnus albacores*	x	x	x	
Yellowtail, *Seriola oureovittata* and *S. purpurascens*				x

peting for available food. Competitors of *Auxis* in African waters include yellowfin tuna, bluefin tuna, albacore, and bigeye tuna (de Jager et al. 1963). Other possible competitors mentioned by de Jager et al. are listed below.

Blue shark, *Prionace glauca*
Mako shark, *Isurus oxyrinchus*
Brown shark, *Carcharhinus obscurus*
Thresher shark, *Alopias vulpinus*
Moonfish, *Lampris regius*
Angelfish, *Brama raii*
Mackerel, *Scomber japonicus*
Lancetfish, *Alepisaurus ferox*
Stockfish, *Merluccius capensis*
Snoek, *Thyrsites atun*
Yellowtail, *Seriola lalandii*
Skipjack tuna, *Katsuwonus pelamis*
Gannet, *Morus capensis*
Cormorant, *Phalacrocorax capensis*
Cape penguin, *Spheniscus demersus*
Wandering albatross, *Diomedia exulans*
Cape fur seal, *Arctocephalus pusillus*
Sperm whale, *Physeter catodon*
Sei whale, *Balaenoptera borealis*

In Indian waters, *A. rochei* and *A. thazard*, and other competitors such as *Megalaspos cordyla*, *Stromateus niger*, and *E. affinis* are frequently caught together in gill nets (Jones 1963). In the hook-and-line fishery, Jones observed that *A. rochei*, carangids, seerfishes, thunnids, and perches (includes lethrinids, lutjanids, and serranids) all appear in the catches.

3.34 Predators

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

Tunas

Albacore, *Thunnus alalunga* (Kishinouye 1917, Japan; de Jager et al. 1963, South Africa; Dragovich 1969, Atlantic; Matthews et al. 1977, North Atlantic)

Bigeye tuna, *T. obesus* (Kishinouye 1917; King and Ikehara 1956, central Pacific; Yokota et al. 1961, Japan; de Jager et al. 1963; Watanabe 1964, Japan)

Bluefin tuna, *T. thynnus* (Yokota et al. 1961; de Jager et al. 1963; Matthews et al. 1977)

Kawakawa, *Euthynnus affinis* (Ronquillo 1954; Philippine Islands)

Little tunny, *E. alletteratus* (Dragovich 1969)

Skipjack tuna, *Katsuwonus pelamis* (Kishinouye 1917, 1923, Japan; Ronquillo 1954; Yokota et al. 1961; Batts 1972, North Carolina)

Yellowfin tuna, *T. albacares* (Kishinouye 1917; Nakamura 1936, Celebes Sea; Mead 1951, eastern tropical Pacific; Ronquillo 1954; King and Ikehara 1956; Yokota et al. 1961; Alverson 1963, eastern tropical Pacific; de Jager et al. 1963; Watanabe 1964; Dragovich 1969; Matthews et al. 1977)

Billfishes

Black marlin, *Makaira indica* (Nakamura 1942, Taiwan; Watanabe 1964)

Atlantic blue marlin, *M. nigricans* (Krumholz and de Sylva 1958, Bahamas; Erdman 1962, Puerto Rico)

Indo-Pacific sailfish, *Istiophorus platypterus* (Jones 1958, India; Idyll and de Sylva 1963, western Atlantic)

Striped marlin, *Tetrapturus audax* (Royce 1957, central Pacific)

White marlin, *T. albidus* (Idyll and de Sylva 1963; Davies and Bortone 1976, northeast Gulf of Mexico)

Other Species

Barracuda, *Sphyraena* sp. (Idyll and de Sylva 1963)

Lancetfish, *Alepisaurus* sp. (Matthews et al. 1977)

Mahimahi, *Coryphaena hippurus* (Ronquillo 1954; Idyll and de Sylva 1963; Rose and Hassler 1974, North Carolina)

Porpoise, *Stenella* sp. (Perrin et al. 1973, eastern tropical Pacific)

Thresher shark, *Alopias vulpinus* (Whitley 1964, Australia)

Tiger flathead, *Neoplatycephalus richardsoni* (Whitley 1964)

Wahoo, *Acanthocybium solandri* (Idyll and de Sylva 1963)

Perhaps because of their abundance, *Auxis* are considered forage elements which occupy an important position in the food chain. In the eastern Pacific, *A. thazard* are of no commercial importance but they contribute to the tropical skipjack and yellowfin tuna fishery indirectly, because they constitute a significant part of the food of adult yellowfin tuna. In the western Pacific, *Auxis*, because of their distribution and abundance close to land masses, form a relatively high proportion of the forage of tunas and billfishes that are similarly distributed (Watanable 1964).

The size of *Auxis* consumed by large predators varies considerably. Klawe (1963) noted that specimens of *A. thazard* found in the stomachs of skipjack tuna, yellowfin tuna, and kawakawa varied from 60 to 125 mm, but Watanabe (1964) has shown that *Auxis* up to 320 mm may fall prey to large tunas and billfishes (Table 18). In the Atlantic, Krumholz and de Sylva (1958) reported that *Auxis* ranging in size from 200 to 250 mm have been recovered from stomachs of blue marlin caught near Bimini in the Bahamas.

Table 18.—Size-frequency distribution of *Auxis* found in the stomachs of tunas and marlins (Watanabe 1964).

		Body length (cm)																									
Area	Period	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
A	Jan 1955	7	14	25	28	17	15	6	8	4	1		1	1													
B	Feb 1953							—	—	—	—			—	8	1	2	8	—	14	1	—					
C	Nov–Dec 1956	—	7	—	18	1	7		1	1		—	1							—	—			—	—		—
D	Dec 1951–Mar. 1952	—	—	—	—	—	—	—	—	—		—	—	—					1	1	—	2	1				

A - Banda Sea, north of Timor Island, Indonesia.
B - Sawu [Saru] Sea, south of Flores Island, Indonesia.
C - Off the coast of Queensland, Australia.
D - Off the southern coast of Shikoku, Japan.

3.35 Parasites, diseases, injuries, and abnormalities

Table 19, extracted from MacCallum and MacCallum (1916), Linton (1940), Manter (1940, 1947, 1954), Vervoort (1965), Lewis (1967), Pillai (1967), Silas (1967a), Silas and Ummerkutty (1967), and Mamaev (1968), lists the monogenetic and digenetic trematodes, cestodes, and copepods that are parasitic on *Auxis*.

Table 19.—Monogenetic and digenetic trematodes, cestodes, and parasitic copepods on *Auxis* (MacCallum and MacCallum 1916; Linton 1940; Manter 1940, 1947, 1951; Vervoort 1965; Lewis 1967; Pillai 1967; Silas 1967a; Silas and Ummerkutty 1967; Mamaev 1968).

Type of parasite	Family	Species
Monogenetic trematode	Hexostomatidae	*Hexostoma auxidi*
Digenetic trematode	Bucephalidae	*Rhipidocotyle capitatum*
	Fellodistomidae	*Tergestia laticollis*
	Didymozoidae	*Didymozoon auxis*
		Phacelotrema claviforme
		Opepherotremo planum
		Coloсyntotremo auxis
	Gorgoderidae	*Phyllodistomum lonceo*
Cestode	Dasyrhynchidae	*Callitetrarhynchus gracilis*
Parasitic copepod	Caligidae	*Caligus macarovi*
		C. productus
		C. auxisi
	Bomolochidae	*Bomolochus mycterobius*

3.4 Nutrition and growth

3.41 Feeding

Observations on the feeding habits of larval *A. rochei* indicate that they are particulate feeders. Yokota et al. (1961) observed that larval *A. rochei* between 3.0 and 5.4 mm in length consumed nauplii ranging in size from 0.10 to 10.30 mm and copepodites of about 0.55 mm.

Auxis have been observed to use their caudal fin to hold their position in swift currents to capture drifting food and to migrate away from swift currents in search for food. They seek food not only by sight but also by using their lateral line sensory system (Imamura 1949; Uchihashi 1953).

The maximum size of fish eaten and also the total weight of food consumed by different sizes of *A. rochei* caught in the pole-and-line and set net fisheries have been discussed by Morita (1972). For the relationship between length of prey and body length of the predator, he calculated the following formula:

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

where X = length of predator in centimeters
Y = length of prey in centimeters.

The curvilinear relationship can be seen in Figure 28.

The linear regression describing the relationship between weight of stomach contents and body length is shown in Figure 29. The equation is as follows:

$$Y = 2.33X - 40.78$$

where X = length of *A. rochei*
Y = weight of the stomach contents in grams.

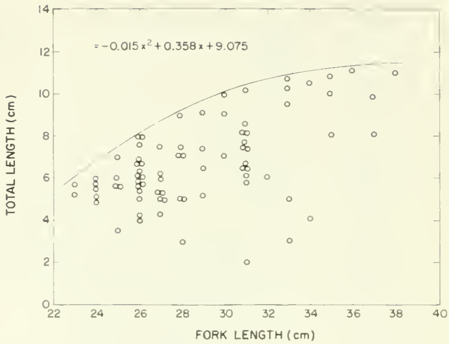


Figure 28.—Relationship between fork length of *Auxis rochei* and total length of prey consumed, off Japan (Morita 1972).

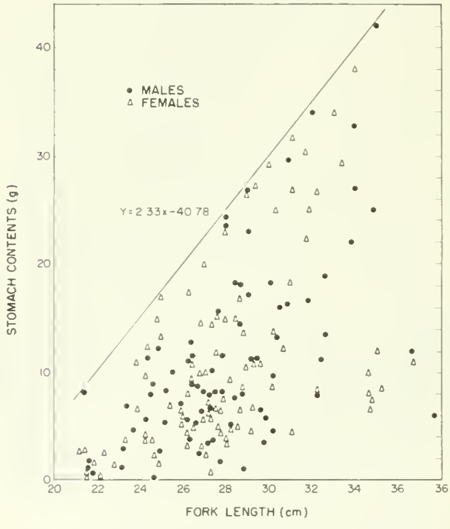


Figure 29.—Relationship between fork length of *Auxis rochei* and weight of stomach contents, off Japan (Morita 1972).

The selection of food organisms above a minimum size apparently is determined by the magnitude of gill raker gaps among mackerels, tunas, and dolphins. Magnuson and Heitz (1971), who calculated mean gill raker gaps of 0.74 mm for *A. thazard* and 0.51 mm for *A. rochei*, concluded that among scombrids *Auxis* and *Katsuwonus* have small gill raker gaps. The filtering areas of the two species of *Auxis*, which measured 570 mm² for *A. thazard* and 55 mm² for *A. rochei*, were intermediate when compared to other scombrids. Magnuson and Heitz suggested that gill raker gap and the maximum distensibility of the esophagus would set limits on the size of food eaten. Usually, however, selectivity in feeding among scombrids is masked because of the diversity of food organisms in the size range consumed by them.

Competition for food appears to be of fundamental importance in inducing young scombrids to feed (Clemens 1956). In the eastern Pacific, juvenile *Auxis* kept in shipboard aquaria learned to eat unnatural food that was offered them by watching other species—mahimahi, *Coryphaena* sp.; jacks, *Caranx* sp.; pompano, *Trachinotus* sp.; threadfins, *Polydactylus* sp.; and pomacentrids, *Chromis* sp.—splashing and moving about the tank swiftly and striking voraciously at everything in sight (Clemens 1956). The food offered included live planktonic organisms, ground flesh of anchoveta, *Cetengralis mysticetus*, yellowfin tuna, skipjack tuna, and mahimahi, particles of coagulated fish blood, and mahimahi eggs.

3.42 Food

Planktonic crustaceans and fishes constitute a large part of the diet of juvenile *Auxis*. In Japanese waters, juvenile *A. rochei*, which were recovered from the stomachs of yellowfin and skipjack tunas, had larval copepods and decapods in their stomachs (Kishinouye 1924).

Auxis feed on a large variety of fishes, crustaceans, and molluscs. In *Auxis* captured in Hawaiian waters, fishes comprised the greatest volume with crustaceans next in rank (Tester and Nakamura 1957). Those captured in Japanese waters fed on plankton as well as a wide variety of herringlike fishes such as silverside, *Atherina* sp.; anchovy, *Stolephorus* sp.; small round herring, *Spratelloides* sp.; and immature *Engraulis* sp. (Kishinouye 1923). Okada (1955) observed that *A. rochei* fed on small pelagic organisms, anchovies, silversides, and other small fishes. Of *A. rochei* taken in Australian waters, Whitley (1964) found the stomach crammed with anchovies and young mullet.

Auxis also feed on their own young. Yokota et al. (1961) examined *A. thazard* caught by trolling in Japanese waters in June 1959 and discovered that their diet included young *Auxis* as well as skipjack tuna. Other items in their diet included jack mackerel, *Trachurus japonicus*; flyingfishes, Exocoetidae; filefishes, Monacanthidae; *Mene maculata*; round herring, *Spratelloides japonicus*; anchovy; and squids (Table 20).

Troll-caught *A. rochei* consumed anchovy as the principal food and other items only infrequently whereas those taken in set nets fed predominantly on jack mackerel with anchovy next in importance (Yokota et al, 1961). Spotted mackerel, *Scomber australasicus*, and lizardfish, *Saurida undosquamis*, were also found in fair numbers in stomachs of fish caught by set net but were usually absent in stomachs of fish taken by trolling (Table 21).

In Indian waters, Thomas and Kumaran (1963) and Kumaran (1964), reporting on the stomach contents of 11 juvenile *A. thazard* (49-132 mm), observed that in small individuals <75 mm, fishes constituted 88% and crustaceans 12% by volume with squids entirely absent (Fig. 30). In individuals >75 mm, fishes formed 39% and Crustacea 42% by volume. Squids occurred very infrequently. *Anchoviella* sp. and *Leiognathus* sp. were the

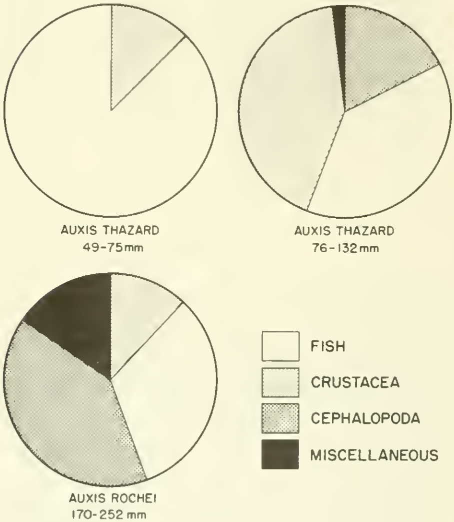


Figure 30.—Diagrams illustrating the composition, by volume, of the stomach contents of *Auxis thazard* and *A. Rochei* caught in the Indian Ocean (Thomas and Kumaran 1963).

Table 20.—The number of identifiable orgamisms found in stomachs of 30 *Auxis thazard* caught by trolling gear in Japanese waters (Tokara fishing ground), June 1959 (Yokota et al. 1961).

Prey	No.	Prey	No.	Prey	No.
Skipjack tuna	9	Flyingfishes	1	Kibinago[1]	8
Frigate tuna	1	Filefishes	1	Squid	6
Jack mackerel	2	Ginkagami[2]	1	Anchovy	147

[1]Kibinago — *Spratelloides japonicus* (Houttuyn).
[2]Ginkagami — *Mene maculata* (Bloch).

Table 21.—The stomach contents of *Auxis rochei* caught by trolling gear and set net in Japanese waters. 1958-61 (Yokota et al. 1961).

Date	Fishing ground	Number	Spotted mackerel	Jack mackerel	Saury	Nezumi gisu[1]	Kurotachi kamasu[2]	Sagi-fue	Lizard-fish	Hata-aji[4]	Matouishi-mochi[5]	Mishima-okoze[6]	Squid	Anchovy
Trolling line:														
Dec. 1958	Kumanonada	187				2	2				1			4
Jan. 1959	Kumanonada	137				1	1							36
Feb. 1959	Kumanonada	175								1		2		38
Mar. 1959	Kumanonada	105	4		1		2		1					1
Dec. 1960	Kumanonada	30												243
Jan. 1961	Kumanonada	9						1						
Mar. 1961	Kumanonada	29											4	2
Apr. 1961	Kumanonada	17		6									3	25
Set or fixed net:														
Apr 1961	Tanegashima	30	37	995					26					459

[1]Nezumi gisu - *Gonorhynchus abbreviatus* Temminck and Schlegel.
[2]Kurotachi kamasu - *Acinacea notha* Bory and St. Vincent.
[3]Sagifue - *Macrorhamphosus scolopax* (Linné).
[4]Hataaji - *Elephenor macropus* (Bellotti).
[5]Matouishimochi - *Apogonichthys carinatus* (Cuvier and Valenciennes).
[6]Mishimaokoze - *Gnathagnus elongatus* (Temminck and Schlegel).

most common among the fish species consumed. Among 31 preadult *A. rochei* (170-252 mm), fishes constituted 42% by volume and were found in 80% of the samples (Fig. 31). Those that were important were *Sardinella* spp., *Anchoviella* sp., *Leiognathus* sp., and carangids (Table 22). Crustaceans were next in importance accounting for 24% by volume and found in 77% of the samples. Rabindra Nath (1962) reported that among the most common crustaceans consumed by *Auxis* in Indian waters were *Rhopolophthalmus* sp., *Hyperia bengalensis, Oxycephalus clausi, Pseudophausia latifrons, Acetes erythreus,* and *Squilla* larvae. Cephalopods formed 22% of the food consumed (Kumaran 1964), but pteropods were relatively unimportant in the diet (Rabindra Nath 1962). Kumaran (1964) also noted that larval stomatopods and *Lucifer* constituted a major portion of the diet of some specimens captured near Quilandy on the west coast of India. Other items of food occasionally seen were chaetognaths, *Halobates*, and polychaetes.

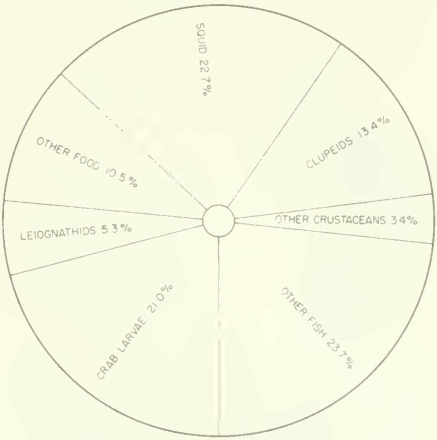


Figure 31.—Percentages, by volume, of the types of food consumed by preadult specimens of *Auxis rochei* in the Indian Ocean (Kumaran 1964).

Table 22.—List of food items of preadult specimens of *Auxis rochei* from the Indian Ocean (Kumaran 1964).

Food items	Number of food organisms	Percentage of prevalence	Percentage by volume
Polychaeta	14	3.2	1.2
Crustacea:	(142)	(77.4)	(24.4)
Amphipods	8	16.1	0.9
Mysis stage of prawn	8	12.9	0.9
Megalopa larvae	118	38.7	21.0
Alima larvae	5	12.9	0.9
Unidentified crustaceans	3	6.4	0.6
Insecta:			
Halobates	2	3.2	0.6
Chaetognatha:			
Sagitta spp.	580	3.2	8.7
Cephalopoda:			
Sepioteuthis sp.	7	16.1	22.7
Vertebrata (Pisces):	(78)	(80.6)	(42.3)
Sardinella spp.	5	9.7	3.5
Clupeid larvae	8	6.4	2.9
Anchoviella commersonii	3	6.4	2.3
Anchoviella tri	7	12.9	4.7
Hemirhamphus sp.	3	6.4	2.7
Sphyraena sp.	2	3.2	2.3
Caranx sp.	3	9.7	1.8
Carangid larvae	22	9.7	2.1
Leiognathus sp.	8	16.1	5.3
Unidentified fish and larvae	17	25.5	14.5

3.43 Growth rate

Observations on postlarval growth indicate that captive *Auxis* grow faster than *Euthynnus lineatus* (Clemens 1956). Of five postlarval *Auxis* placed in an aquarium for observation, three died several hours later from injuries received in handling. Of the two remaining *Auxis*, one measuring 20 mm TL grew to 40 mm in 6 days; the larger 30 mm specimen reached 46 mm during the same period.

The rate of growth of *A. rochei* estimated from modal progression of length-frequency data appears to be rather slow compared to that observed in larvae that were hatched from artificially fertilized eggs. Hotta (1955), who used monthly length-frequency histograms to estimate the growth of *A. rochei* caught in the northeastern sea off the Pacific coast of Japan, constructed a growth curve depicting body lengths at ages 0-IV. From the curve, shown in Figure 32, it appears that *A. rochei* reach about 17 cm 1 yr after hatching. But Harada, Murata, and Furutani (1973) observed that larvae of *A. rochei* under the best condition grew to 15.7 cm in 52 days (Fig. 21).

In addition to growth rates, the condition factor has been calculated for *A. thazard*. The condition factor (K), which expresses the relative well-being of the fish,

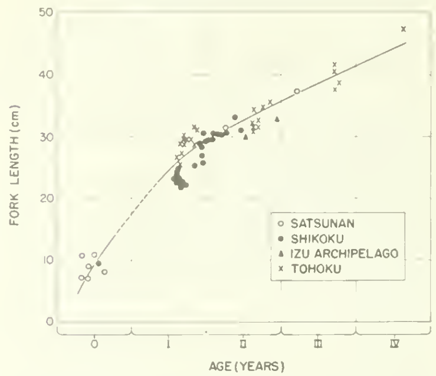


Figure 32.—Growth curve of *Auxis rochei* based on specimens from four localities in Japan (Hotta 1955).

increases with age because older fish tend to gain proportionately more in weight than in length. The formula for K is

$$K = \frac{aW}{L^3}$$

in which a = constant
W = weight in grams
L = standard length in millimeters (Rounsefell and Everhart 1953).

At La Linea, Spain, the average values of the condition factor for each length group of *A. rochei* were usually larger for males than for females (Rodríguez-Roda 1966). Furthermore, the values of K decreased from May to August, but increased in September which coincided with the spawning period. Comparison of K among the size groups showed no significant differences.

Ishida (1971), who also calculated condition factor of *Auxis* caught off Japan, found that of the two species, *A. thazard* caught at Mikomoto and Shionomisaki had higher indices than *A. rochei*. Between areas, however, there appeared to be no appreciable difference.

The length-weight relationship has been described for *A. thazard* and *A. rochei* caught in the world's oceans. The expression for the relationship is

$$W = aL^b$$

in which W = weight in grams
L = length in centimeters
a and b = constants.

Table 23 gives the constant for the expression of the predictive length-weight relationship calculated by Ishida (1971) for both species of *Auxis* and by Yasui (1975) for *A. rochei* caught in Japanese waters, by Lenarz (1974) for *A. rochei* captured in the Atlantic Ocean, by Rodríguez-Roda (1966) for *A. rochei* caught in Spanish waters near the Strait of Gibraltar, and by Sivasubramaniam (1966) for both species caught around Sri Lanka in the Indian Ocean. Figure 33 depicts the length-weight curves constructed by Rodríguez-Roda (1966) and Yasui (1975). For *A. rochei* caught in Spanish waters, Rodríguez-Roda has also provided the average and calculated weights for the length groups studied (Table 24).

The maximum size reported is 66 cm for *A. rochei* in the eastern Atlantic Ocean (Collignon see footnote 2).

Table 24.—Length groups, average weights, and calculated average weights of *Auxis rochei* caught at Barbate, Tarifa, and La Linea, Spain, in 1958, 1961, 1963, and 1974 combined (Rodriguez-Roda 1966).

Size intervals (cm)	N	Average weight (kg)	Calculated average weight (kg)
34-34.5	2	0.635	0.654
35-35.5	10	0.709	0.715
36-36.5	26	0.782	0.780
37-37.5	58	0.864	0.849
38-38.5	97	0.947	0.922
39-39.5	115	1.010	0.999
40-40.5	117	1.089	1.080
41-41.5	88	1.169	1.166
42-42.5	89	1.250	1.256
43-43.5	97	1.339	1.351
44-44.5	34	1.428	1.450
45-45.5	11	1.551	1.555
Total	744		

3.44 Metabolism

In *A. rochei*, a correlation has been found between sexual maturity and the amount of iron, copper, and zinc in various body tissues (Suzuki and Morio 1957). Suzuki and Morio showed that in the liver, the iron content decreases progressively with maturation, is at a minimum when the gonads become ripe and then increases significantly when the gonads are spent (Fig. 34a). The contents of copper and zinc show a similar tendency to decrease with maturation but minimums are reached at a stage when egg formation is still continuing in the ovaries (Fig. 34b, c). Suzuki and Morio also observed a negative correlation between the fat content of the liver and the amount of iron and copper (Fig. 34d). The relationship, however, is not consistent; it tends to break down in fish that have gonads approaching the ripe stage. Concerning molybdenum and nickel in the tissues of *A. rochei*, Morio and Suzuki (1959) determined that the former occurs in highest concentration in the liver whereas the latter shows up highest in the pyloric caeca. Further analysis indicated that the

Table 23.—Constants calculated by various investigators for the expression of the predictive length-weight relationship of *Auxis thazard* and *A. rochei*.

Area	Investigators	*Auxis thazard* N	*a*	*b*	*Auxis rochei* N	*a*	*b*
Japan:							
	Yasui (1975)	—	—		NA[1]	1.549 × 10	3.65705
Mikomoto	Ishida (1971)	NA	6.05 × 10	3.300	NA[1]	4.13 × 10	3.384
Shionomisaki	Ishida (1971)	NA	7.70 × 10	2.509	NA	4.64 × 10	3.362
Atlantic	Lenarz (1974)	—		—	50	2.80 × 10	4.13514
Spain	Rodriguez-Roda (1966)	—	—	—	744	1.00538 × 10	3.129871
Sri Lanka	Sivasubramaniam (1966)	160	1.780×10^{-4}	3.3338	28	2.598×10^{-6}	4.6315

[1] Not available in the paper.

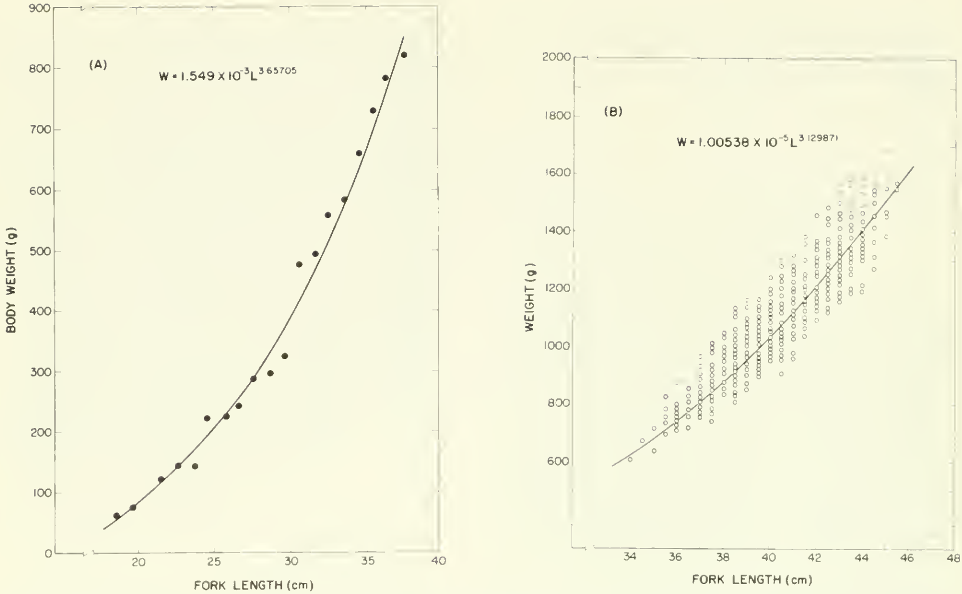


Figure 33.—Length-weight relationship of *Auxis rochei* caught in (A) Japanese waters (Yasui 1975) and in (B) Mediterranean waters (Rodriguez-Roda 1966).

contents of molybdenum and nickel in the liver show no relationship to sexual maturity, rate of growth, and area of catch.

The blood of Pacific *A. rochei* has been tested and found to be relatively high in hemoglobin concentration (Klawe et al. 1963). Barrett and Williams (1965) showed that compared with other scombrids, the mean level found for *A. rochei* was among the highest, reaching 19.2 g/100 ml and varying from 16.5 to 22.8 g/100 ml. Blood smears of *A. thazard* caught in Puerto Rican waters showed a blood count of 1 large hemoblast, 1 small hemoblast, 1 large lymphocyte, 30 small lymphocytes, 45 thrombocytes, and 22 granulocytes (neutrophils) (Saunders 1966). Mature erythrocytes from *A. thazard* blood averaged 10 μ in length and 7.5 μ in width.

3.5 Behavior

3.51 Migrations and local movements

Not much is known about the migration of *Auxis* in the world's oceans. Most of what is known comes from results of studies conducted in Japanese waters. Hotta (1955), after examining the fluctuations in landings of *A. rochei* along the coast of Japan in 1952, determined their seasonal movement up and down the coast of Japan. He observed that they occur in the Satsunan Sea region and off Shikoku early in the year, but as the year progresses, larger catches are made farther north and by June they are landed in the Izu Archipelago region (Fig. 35). The schools reach their most northern point around Hokkaido in September, then move southward until in December they appear to be concentrated mostly off the Izu Archipelago and Shikoku.

Detailed studies of long-distance movement of *A. rochei* in Japanese waters showed that fish caught, tagged, and released in August, September, and November had a general tendency to move southward (Table 25, Fig. 36). Yamashige (1974) determined from his tagging studies that within the population of *A. rochei* off Japan, differential migration occurs according to size. The large influx of small fish into the fishery, as shown by the length-frequency distribution (Fig. 37), is the consequence of small fish moving south before the movement of large fish begins.

Short-distance movement of tagged *A. rochei* in Japanese waters shows that they tend to move southward late in the year although some northward movement is also seen, but early in the year there is a definite northward movement (Table 25) (Morita 1972; Hamada, Ishida, Morita, Takezawa, Okabayashi, and Ishii 1973; Hamada et al. 1974).

3.52 Schooling

The schooling instinct, according to a number of sources, is very strong and orderly in *Auxis*. Jones (1963) noted that the tendency of *A. rochei* to form large

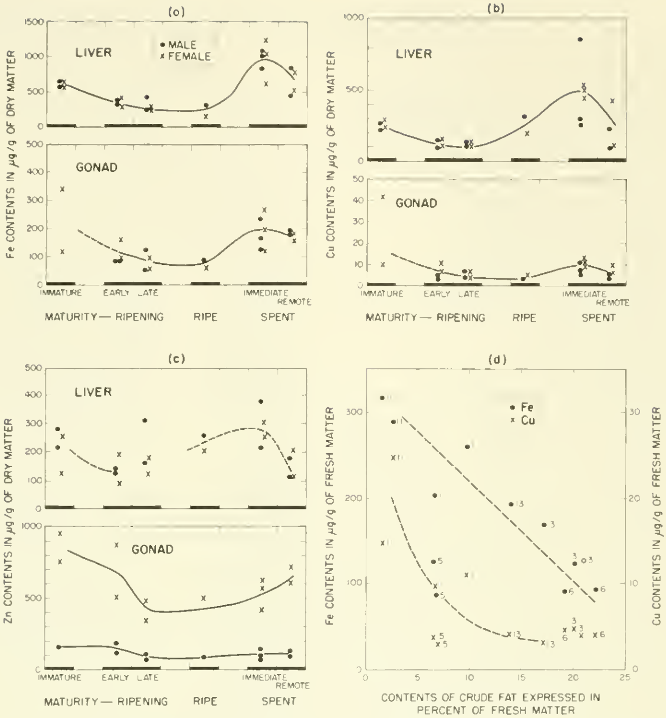


Figure 34.—Correlation between stage of maturation and contents of: (a) iron, (b) copper, (c) zinc in the liver and gonad, and (d) the relationship between the amounts of crude fat and of iron and copper in the liver, *Auxis rochei* (Suzuki and Morio 1947).

schools is strong not only among the adults but also among juveniles. Data collected during fishing operations suggest that individuals tend to school by size because those caught are more or less of the same length. The fish scatter when disturbed but soon school again. In Japanese waters, *A. thazard,* which usually school near the surface during morning and evening and also during periods of cloudy weather, do not form large schools (Imamura 1949). But the formation of dense schools appears to be quite common in other areas; for example, Nakamura (1938) reported that dense schools of *Auxis* migrate into coastal waters of Taiwan during certain times of the year and Serventy (1941) observed schools composed of hundreds of *Auxis* in southwestern Australia in the summer. In East African waters, Wheeler and Ommanney (1953) observed schools composed of 100 to 1,000 fish whereas Serventy described those around the Seychelles as "large" but gave no estimate of the numbers involved.

Schools of *A. thazard* are known to mix with those of *A. rochei,* other tunas, and tunalike fishes. In Hawaiian waters, *Auxis* are occasionally found mixed with schools of kawakawa (Gosline and Brock 1960), and both *A. thazard* and *A rochei* have been reported captured from one school (Matsumoto 1960a). Similar observations were made by Kishinouye (1915) of *Auxis* in Japanese waters and by Jones (pers. commun. with Matsumoto in 1959) of those that occur in Indian waters. Imamura (1949) observed that *A. thazard* in Japanese waters are also found occasionally mixed with skipjack tuna.

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

3.53 Responses to stimuli

The importance of light in relation to the diurnal activity of tunas has been discussed by Whitney (1969). Experimental work on the activity of various tunas in captivity showed that captive *A. rochei* is negatively

Table 25.—Partial data on release and recovery of ***Auxis rochei*** in the 1965 and 1970-72 fishing
Hamada et al.

Date of release	Area of release	Location of release	Number of fish released	Fork length at release (cm)	Tag numbers	Number recap-tured
1965						
26 Aug.		36°02'N, 141°02'E				
15 Sept		34°38'N, 138°58'E				
22 Sept.		34°41'N, 139°27'E				
25 Sept		33°29'N, 135°58'E				
7 Nov		33°25'N, 135°49'E				
1970						
5 Sept	Tosa-wan	Off Yatabezaki	299	19-21		1
13-15 Sept.		Off Ito	691	20-23		1
				28-29		2
						3
						1
						2
16-17 Sept		Off Shimada	2,327	21-31		7
						5
[illegible] Sept	Kumanonada	Hamashima	207	21		
[illegible] Sept	Kumanonada	Off Owase	319	27		1
[illegible]9 Sept		Off Hamashima				
[illegible] Nov	Tosa wan	Off Susaki	40	25.4		2
						3
1971						
21 Mar	Ashizuri	Ashizurimisaki SW, 10 nmi	60	23-28		1
						1
9 Nov	Ashizuri	Ashizurimisaki SSE, 10 nmi	307	24		2
						3
1972						
26-27 Mar	Satsunan	Yukushima S, 10 15 nmi	409	25.8		11
11 June	Off Ashiz[illegible]	32°36.7'N, 132°54.9'E to	89	29	1-100	0
		32°36.7'N 132°49.4'E	99	29	101-200	
			100	29	201-300	
			100	29	401-500	
			16	29	801-820	
[illegible] Aug	Tosa wan	Sus[illegible]ki 0.5 nmi	400	21	1401-1800	3
			30	21	106-209	
[illegible] Sept		34°59'N, 139°09'E				
[illegible] Sept	Sa[illegible] [illegible]hern Kyushu	K[illegible]tan[illegible]saki, [illegible] nmi	5	23	1901-2000	0
18 Sept	Koshiki Islands	Kami-Koshikishima	53	24	1340-1360	0
					1600-1620	
					1901-2000	
19 Sept	Satsunan	Bono-misaki	2	24	1955-1956	0

phototactic (Inoue et al. 1970). Experiments on spectral sensitivity and color vision have determined that *A. thazard* is probably color blind (Tamura et al. 1972). Niwa et al. (1975) also determined that *A. thazard*, together with skipjack tuna, seem to have only one cone pigment with its maximum wave length at around 497 nmi in the classical position for rod sensitivity. They concluded that the position of the sensitivity maximum at such a short wave length undoubtedly is due to adaptation to oceanic behavioral life, because wave lengths which most effectively penetrate clear oceanic water varies between 480 and 500 nmi.

Nakamura and Magnuson (1965) observed opercular and orbital black spots on live *A. thazard* and *A. rochei* that were maintained in captivity in shoreside tanks. They concluded that although the function of the opercular spots, if any, is not obvious, the orbital spot may reduce the amount of light reflected up into the eye from the ventral rim of the orbit.

seasons off Japan (adapted from Morita 1972; Hamada, Ishida, Morita, Takezawa, Okabayashi, and Ishii 1973; 1974; Yamashige 1974).

Date of recapture	Location of recapture	Fishing method	Tag number	Recapture Length (cm)	Recapture Weight (g)	Release and recapture Days	Release and recapture Distance (km)
1965							
20 Sept.	Uchiura-wan, Numazu, Shizuoka Pref.					25	
18 Sept.	Katsuura, Chiba Pref.					3	
28 Nov.	Asagawa, 5 nmi, Tokushima Pref.					67	
17 Oct.	Off Susaki, Kochi Pref.					22	
3 Dec.	Ashizuri SW, 12 nmi					26	
1970							
14 Sept.	Off Hiraiwa, Hyuga-shi				20.7	9	408
15 Sept.	Uchiura-wan, Shizuoka Pref.	Purse seine				2	130
26 Oct.	Ashizurimisaki NE, 1.5 nmi	Pole and line				13	704
9 Nov.	Ashizurimisaki SSW, 4.5 nmi	Pole and line				26	704
18 Sept.	Off Shimoda	Purse seine				2	
23 Sept.	Off Tateyama, Chiba Pref.	Purse seine				7	93
2 Oct.	Off Ose, Numazu-shi	Purse seine				16	83
4 Oct.	Uchiura-wan, Shizuoka Pref.	Purse seine				18	93
Not available	Off Shimoda-machi						
2 Oct.	Off Mie Pref.	Purse seine				12	6
26 Oct.	Off Shimoda, Shizuoka Pref.					27	
4 Dec.	Off Ashizurimisaki	Pole and line				9	89
18 Dec.	Off Ashizurimisaki	Pole and line		25	160	23	89
1971							
22 Mar.	Ashizurimisaki SSE, 6 nmi	Pole and line				1	
22 Nov.	Ashizurimisaki S, 18 nmi	Pole and line				11	
23 Nov.	Ashizurimisaki SSE, 8.5 nmi	Pole and line				12	
30 Nov.	Off Ashizurimisaki, 8 nmi	Pole and line				21	
1972							
10-11 Apr.	Off southern Yakushima	Pole and line				15	
1 Sept.	Nakadosa-machi	Set net	1417				
	Kaminokae		1650				
	Yatabe		1716				
13 Sept.	Off Esaki, Wakayama Pref.					10	

4 POPULATION

4.1 Structure

4.11 Sex ratio

The analysis of catches of *A. rochei* in April-December 1971 from waters off Kochi and Tohoku Prefectures, Japan, and off Taiwan indicates an inequality in sex ratio. Individual samples show significant deviation from a 1:1 ratio, e.g., the set net catches from Shiina, Japan, on 13 December had a ratio of two males to nine females. On the other extreme, the pole-and-line catch made off Taiwan on 19 June had a male to female ratio of 7:5 (Hamada, Morita, Ishida, and Takezawa 1973).

Off Sri Lanka, the number of males and females in the catches of *A. thazard* showed no noticeable difference from a 1:1 ratio except in one area (Sivasubramanium 1973). Along the southwest coast of the island, the

KAN (8.27 POUNDS)	METRIC TONS
x < 1,000	< 3.75
2 1,000 — 3,000	3.75 — 11.25
3 3,000 — 10,000	11.25 — 37.51
4 10,000 — 35,000	37.51 — 131.29
5 35,000 - 105,000	131.29 — 393.88
6 105,000 - 350,000	393.88 - 1,312.94
7 > 350,000	> 1,312.95

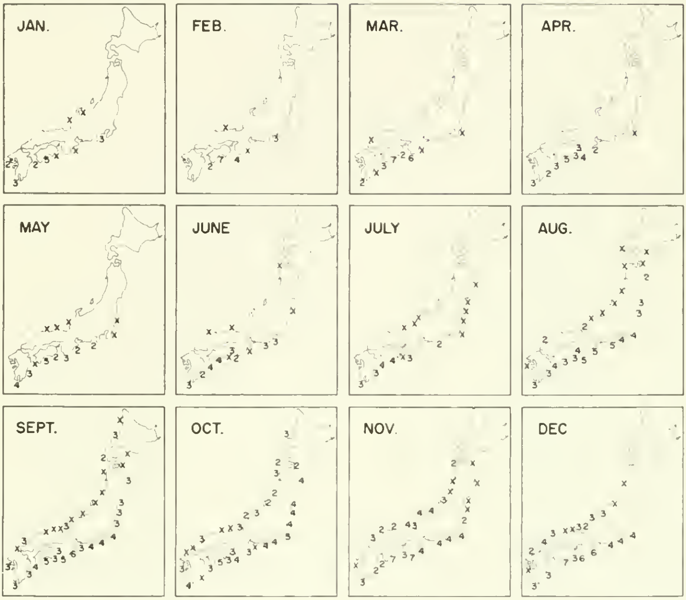


Figure 35.—Landings of *Auxis rochei* off Japan, by month, in 1952 (Hotta 1955).

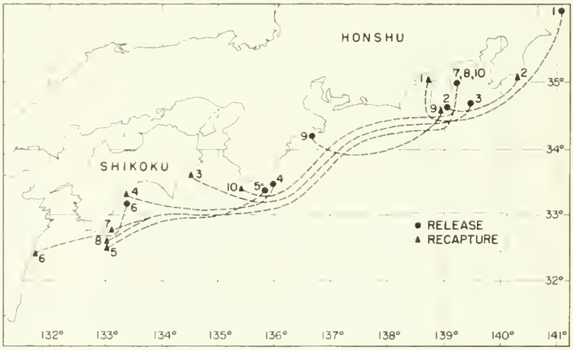


Figure 36.—Long distance movement of *Auxis rochei* tagged in August, September, and November (Yamashige 1974).

catches showed a slight predominance of females during periods of southwest monsoons; the male to female ratio reached 1:1.5 during this period.

For *A. rochei* caught in Spanish waters, Rodríguez-Roda (1966) also tested the ratios of males to females in the catches at Barbate, Tarifa, and La Linea, particularly for those months where a ratio of 1:1 was in doubt. The results showed no significant departures from a 1:1 ratio except at La Linea where in September 1961, significantly more males were taken in the traps.

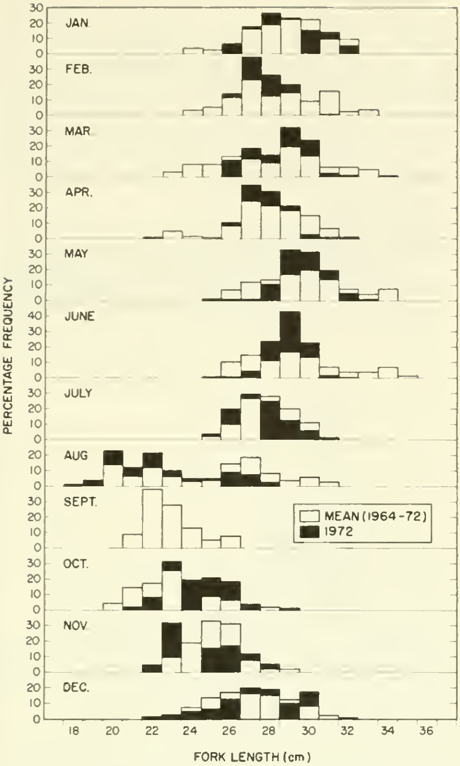


Figure 37.—Percentage length-frequency distributions, by month, of *Auxis* spp. taken in Japanese waters (Yamashige 1974).

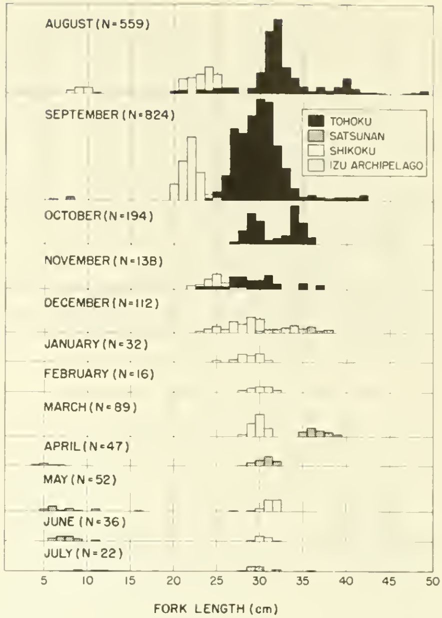


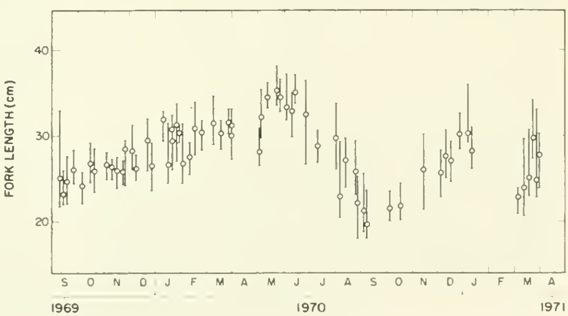
Figure 38.—Length-frequency distribution of *Auxis rochei* caught near Japan (Hotta 1955).

4.13 Size composition

Although the size of *A. rochei* in the Japanese commercial catch varies widely from 4 to 50 cm, the bulk of the catch usually falls between 20 and 35 cm (Fig. 38) (Hotta 1955; Yokota et al. 1961). Furthermore, the average size of the fish varies considerably from month to month. Hotta (1955), Ishida (1972a), and Morita (1972) observed that the average size was usually smallest in August or September after which it increased gradually until early June of the following year then decreased sharply (Fig. 39).

In addition to the monthly variation in average size, there is also a large variation in the size range from month to month. Hamada, Morita, Ishida, and Takezawa (1973), who examined lengths of *A. rochei* caught in waters off Kochi Prefecture in Shikoku (north-

Figure 39.—Mean and range of fork lengths, by months, of *Auxis rochei* caught off Kochi Prefecture, Japan (Morita 1972).



eastern), off Tohoku Prefecture, and off Taiwan, determined that the size range was usually narrowest among fish caught in October-November whereas it varied widely among the fish caught in May-June (Fig. 40).

Comparison of size data collected in Japan with those from the Philippines shows that the former's commercial catch constitutes smaller fish than the latter's. The size of *Auxis* taken by the purse seiners *Royal Venture* and *Southward Ho* in the Philippines, shown in Figure 41, ranged from about 25 to 55 cm with the majority of the fish in the 40-45 cm range.

Data from the Indian Ocean show that the size of *Auxis* in the commercial catch also varies widely. Silas (1969) showed that *A. thazard* taken by drift net ranged from about 20 to 51 cm, but a large proportion of the catch fell between 38 and 43 cm (Fig. 42). Silas also showed that compared with *A. thazard*, *A. rochei* are much smaller, ranging from about 19 to 29 cm and the mode at about 20 to 21 cm. The purse seine apparently catches *Auxis* of more uniform sizes. Figure 43 shows that *A. thazard* caught by purse seine in Indian waters had a relatively wide range from about 32 to 46 cm, but a large proportion of the fish fell between 40 and 42 cm (Silas 1969).

Off Sri Lanka, *A. rochei* appearing in the commercial catch are relatively small and their sizes vary from 16 to 34 cm; however, most are between 22 and 30 cm. *Auxis thazard*, on the other hand, are much larger and range from 20 to 58 cm, but a large proportion of them falls between 22 and 40 cm (Sivasubramaniam 1968). Separat-

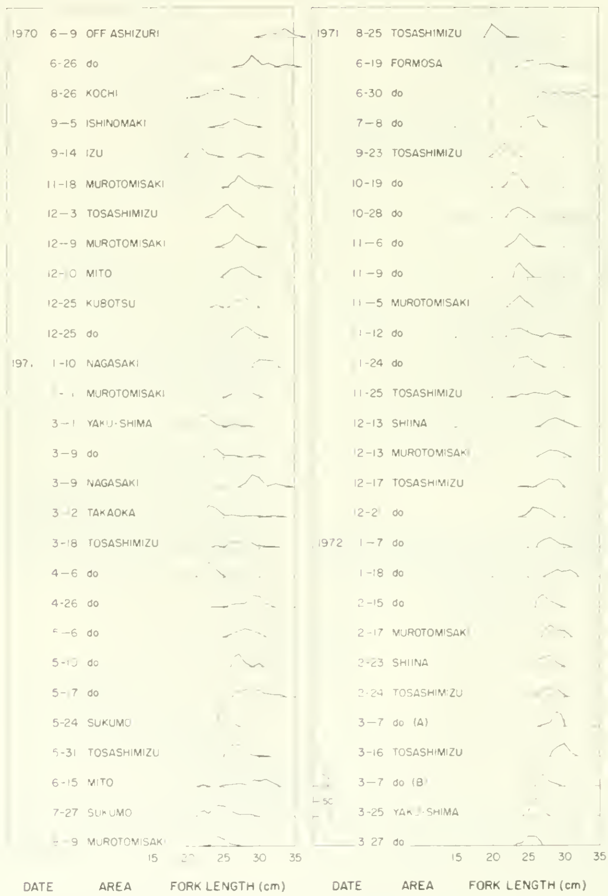


Figure 40.—Percentage frequency distribution of lengths of *Auxis rochei*, by date and area of capture, Japan (Hamada, Morita, Ishida, and Takezawa 1973).

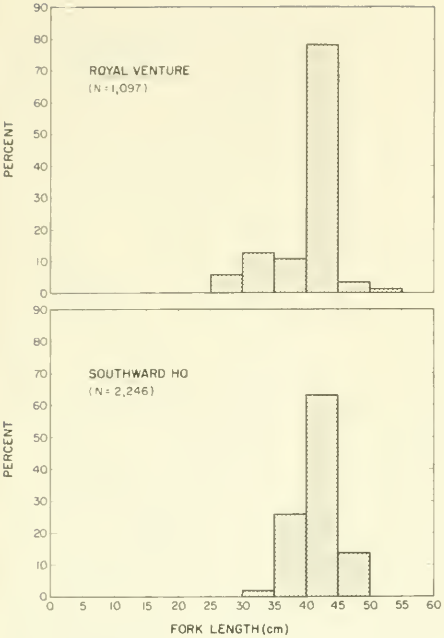


Figure 41.—Length-frequency distribution of *Auxis* sp. caught by the *Royal Venture* and *Southward Ho*, in Philippine waters, April-May 1975 (Rosenberg et al. see text footnote 9).

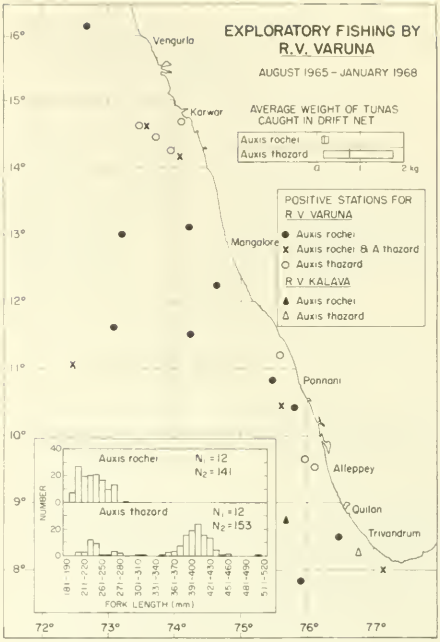


Figure 42.—Location of exploratory drift-net catches by the RV *Varuna* off southwestern India, and the length-frequency distribution and average weights of *Auxis thazard* and *A. rochei* in the catches (Silas 1969). (N_1 = number of fishing operations; N_2 = number of specimens.)

ing catches of *A. thazard* by type of gear, Sivasubramaniam also discovered that the size data from fish caught by beach seine were biased. Because large *A. thazard* present in the population were usually caught by other gear, the size of fish taken by the beach seines was not representative of the population of *A. thazard* in the area (Fig. 44). Most often, medium-sized fish, varying from about 28 to 44 cm were taken by this gear. The bulk of the catch, however, consisted of fish in the 32-36 cm length group.

Trolling gear is effective in taking small tunas such as *Auxis* as well as larger ones. Sivasubramaniam (1973) observed that although trolling gear samples a very wide size range of fish, it is particularly effective for *A. rochei* in the 28-32 cm length group, a group for which none of the other gears used has been effective. The smallest bullet tuna were usually taken in waters around Beruwala or further south (Sivasubramaniam 1965). Compared with size groups in the pole-and-line fishery, which captured mainly fish in the 44-46 cm and 48-50 cm size groups, Sri Lanka's troll fishery exploited the smaller ones—26-28 cm, 32-34 cm, and 36-38 cm.

The sizes of Atlantic *Auxis* do not depart appreciably from those in the Pacific and Indian Oceans. Figures 45 and 46 show the percentage frequency distribution of lengths of *A. rochei* caught in various years at the Barbate, La Linea, and Tarifa trap net operations in Spain. Rodríguez-Roda (1966) reported finding two size groups in the Barbate and Tarifa samples—one around 38.5-39.5 cm—and the other at about 45 cm—and hypothesized that these two groups may possibly correspond to two age groups. Furthermore, he noted that at La Linea, the smaller group was at 40.5 cm and the larger at 42.5 cm. This led him to suspect that two distinct populations of *A. rochei* may be involved in the catches at these localities. Rodrigues-Roda found no significant sex-related differences in the length-frequency distributions.

4.2 Abundance and density

4.21 Average abundance

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

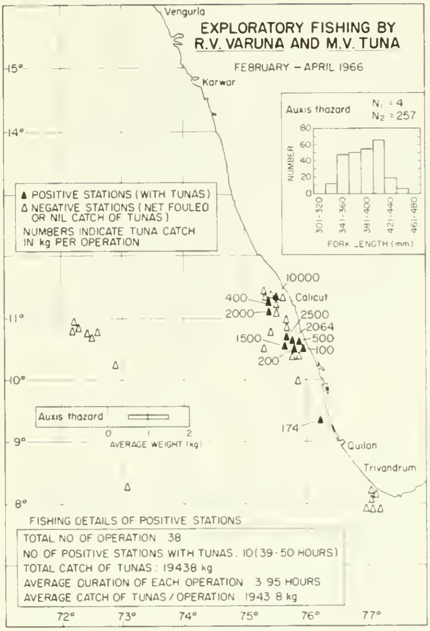
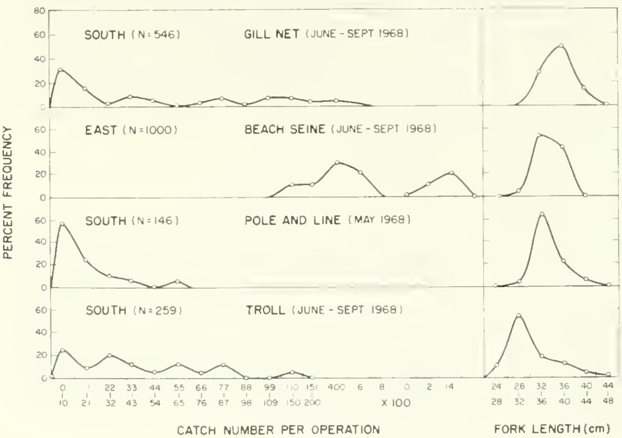


Figure 43.—Location of exploratory purse seine sets and catches for tunas by the RV *Varuna* and MV *Tuna* off southwestern India and the Laccadive Sea, and the length-frequency distribution and average weight of *Auxis thazard* in the catches (Silas 1969). (N_1 = number of fishing operations; N_2 = number of specimens.

Figure 44.—The percentage frequencies of the number of *Auxis thazard* caught per operation, by type of gear, and of the fork lengths of the catches made off the southern and eastern coasts of Sri Lanka (Sivasubramaniam 1968).



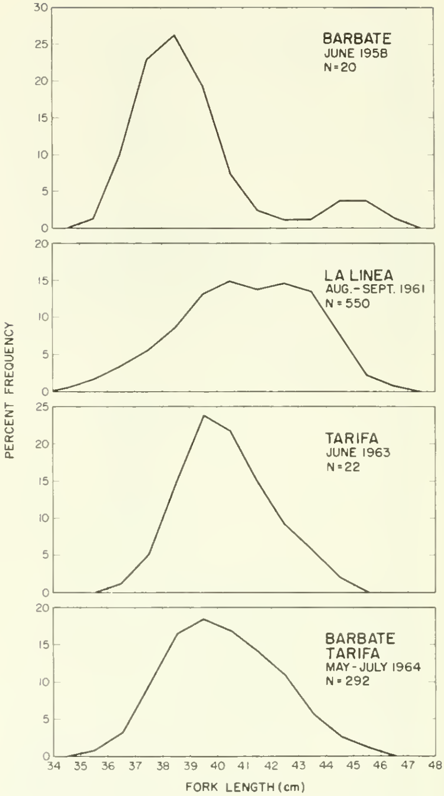


Figure 45.—Length-frequency distributions of *Auxis rochei* caught by traps at Barbate, Tarifa, and La Linea, by month and year (1961, 1963, 1964) (Rodriguez-Roda 1966).

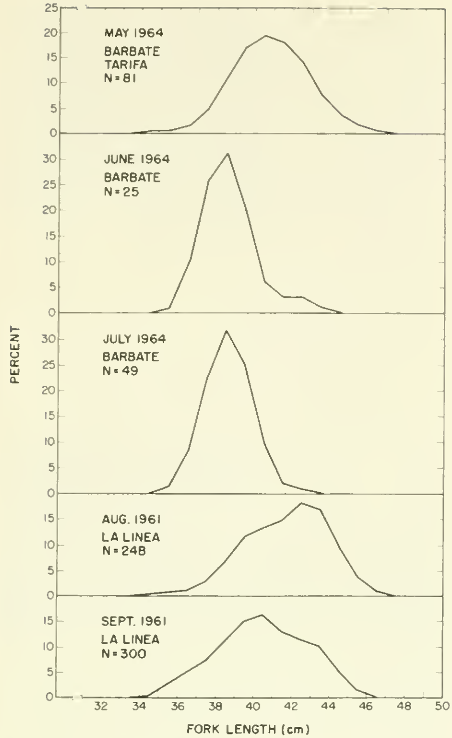


Figure 46.—Length-frequency distribution of *Auxis rochei* caught by traps at Barbate, Tarifa, and La Linea, by month and year (1961, 1964) (Rodriguez-Roda 1966).

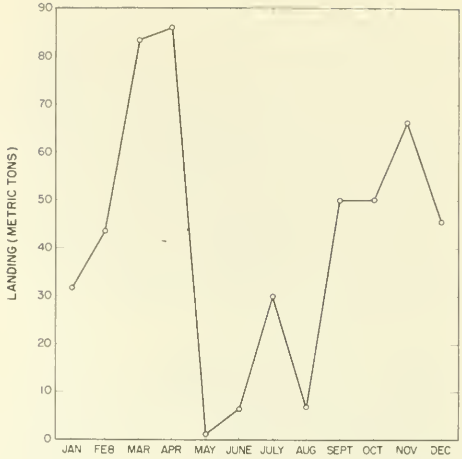


Figure 47.—Landings of *Auxis* spp. per day in the fishery off Ashizurimisaki, Japan, calculated from data collected from October 1964 to June 1967 and combined by months (Ishida 1972a).

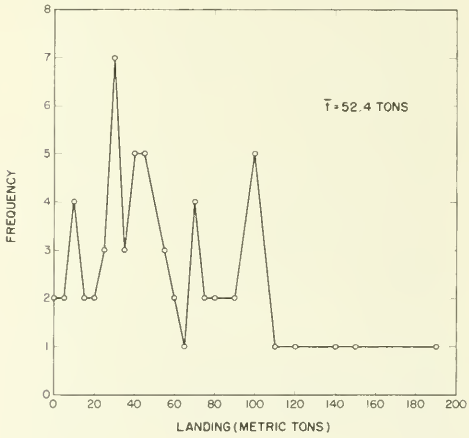


Figure 48.—Frequency distribution of landings per day in the fishery for *Auxis* spp. off Ashizurimisaki, Japan (Ishida 1972a).

Taking a vessel-day as a unit of fishing effort, Ishida (1972a) calculated the monthly landings per day and found that this index fluctuated in a similar fashion as the number of vessels in operation per day (Fig. 47). Ishida also constructed a frequency distribution of the landings per day and found that the primary mode fell at 30 t/day (t = metric tons) (Fig. 48). The annual mean was 52.4 t/day but the seasonal mean, presumably calculated from selected data on landings per day for the peak months, reached 56.5 t/day. A plot of landings per day on number of vessels operating per day showed that an increase in fishing intensity was usually accompanied by a similar increase in catch per day.

Off the coasts of Sri Lanka, *Auxis* are distributed in all waters surrounding the island but their densities vary widely (Sivasubramaniam 1973). Using the number of fish caught per standard trolling unit (a vessel with a fixed number of lines) per day, Sivasubramaniam found that *A. thazard* was most abundant along the southwest coast as catch rates reached 21.7 fish/boat-day. Almost equally high were the catch rates along the southern coast which peaked at 21.3 fish/boat-day. Fish appeared to be fewer along the east and west coasts with catch rates of 18.9 and 14.3 fish/boat-day, respectively. The lowest catch rate occurred off the north coast with only 4.2 fish/boat-day. For *A. rochei*, the variation in catch rates followed a similar pattern. Sivasubramaniam (1973) estimated that usually a fishing vessel will encounter two to three mixed schools per day in waters around Sri Lanka.

4.3 Natality and recruitment

4.31 Reproduction rates

An *A. thazard* of moderate size (44.2 cm) produces about 280,000 eggs/spawning and about 1.37 million eggs are extruded over the entire spawning season (Rao 1964). From *Auxis* caught in drift nets in Indian waters, Silas (1969) also estimated their fecundity and concluded that *A. thazard* ($n = 9$) spawn from 197,000 to 1,056 million eggs and average 601,000 eggs/spawning; for *A. rochei* ($n = 4$), he found fewer eggs per spawning. Silas estimated that females spawn from 31,000 to 103,000 eggs and average 52,000 eggs/spawning.

4.33 Recruitment

Off Sri Lanka, major recruitment to the exploitable stock of *A. thazard* occurs annually along the south and southwest coasts between March and August (Sivasubramaniam 1973). There is also evidence that sporadic recruitment occurs during the rest of the year. Off the east coast, recruitment has been observed in July-September, but no clear trend in recruitment has been found in catches along the north coast. For *A. rochei*, Sivasubramaniam conjectured that recruitment probably takes place at about the same time as that for *A. thazard*. Therefore, the exploitation of new recruits starts around the middle of the year then shifts to large size classes until the following year's recruitment.

The time of recruitment influences the annual production of *Auxis* in Sri Lanka (Sivasubramaniam 1973). When recruitment occurs during the southwest monsoon, the schools that enter the fishery are available at a time when the relative abundance of skipjack tuna, yellowfin tuna, and kawakawa is low and frigate and bullet tunas are fished until the beginning of the northeast monsoon. But when recruitment occurs late in the year, the fishing effort expended on these two species is less intense because of the presence of more desirable species such as skipjack and yellowfin tunas. Thus, fishing emphasis shifts from trolling to pole and line, longline, and drift netting. November-March marks the peak fishing season for the skipjack tuna pole-and-line fishery in the south and southwest coasts of Sri Lanka. It is at this time that large *Auxis* (40-50 cm), usually mixed with skipjack and yellowfin tunas, show up frequently in the catch.

4.4 Mortality and morbidity

4.42 Factors causing or affecting mortalty

An instance of natural mass mortality of larval *Auxis* in Hawaiian waters has been reported by Strasburg (1959). Noting the presence of two distinct conditions of larval *Auxis* in the preserved plankton samples collected in the vicinity of Lanai (an island in the Hawaiian chain), Strasburg hypothesized that these conditions represented fish that were alive and dead just prior to capture. In a simple experiment, he placed several fresh, dead specimens in dishes of seawater and allowed them to decompose. Other fresh, dead specimens were preserved in Formalin. The results showed that fresh preserved specimens were clean cut and normal in appearance whereas dead, deteriorated specimens were imperfect. Strasburg concluded that large numbers of larval *Auxis* in the samples were dead before capture, but no cause of death could be isolated. One possible cause of death is the passage of the larvae through an area of marked temperature discontinuity in the surface layer.

5 EXPLOITATION

5.1 Fishing equipment

5.11 Gears

Pole and line is the most commonly used gear to catch *Auxis*. In Japan, pole-and-line gear designed exclusively for fishing *A. rochei* differs from that used for skipjack tuna fishing. According to Yasui[7] the pole-and-line gear for bullet tuna consists of a bamboo pole, nylon monofilament, trolling board, and jig, and is attached at the butt end of a tag line to the vessel so that the entire gear is "trolled" at a speed of 2-3 nmi/h while searching for bullet tuna schools (Fig. 49). Two to three fishermen manage the "trolled" poles at the stern. When a fish

[7] M. Yasui, Shizuoka Prefectural Fisheries Experimental Station, Shizuoka, Japan, pers. commun. December 1975.

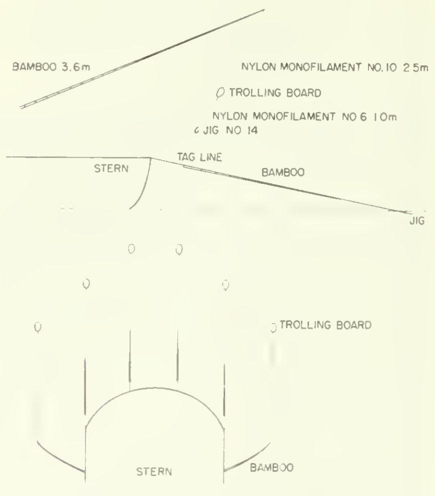


Figure 49.—Diagram of the pole-and-line gear used and the method of fishing in the fishery for *Auxis* spp. in Japanese water (Ishida 1971).

strikes the lure, the fisherman pulls on the tag line, retrieves the pole, and flips the hooked fish aboard. A mixture of dead, salted "shirasu" (larval fish) and boiled noodles (somen) is chummed over the side while the boat circles the school counterclockwise, thus keeping the boat close to the dead shirasu and boiled noodles which are pushed toward the school by the rotation of the propeller. When biting is fast, the poles are no longer "trolled"; rather, each fisherman grasps one pole and flips the hooked fish aboard.

The use of other commercial gear depends on availability of *Auxis* and the efficiency of the gear. Among them are trolling line, handline, small-scale longline, and a wide assortment of nets including traps (set net, pound net), gill or drift nets, bag net, ring net, beach seine, otter trawl, and purse seine. In some countries where these gears are in use, *Auxis* are not the principal species sought by the fishermen; rather, they are caught when other species of tuna such as yellowfin, bluefin, and skipjack tunas either become unavailable or are relatively low in abundance. Some of these gears are discussed in the section that follows.

In the Philippines, purse seines appear to be effective in taking *Auxis*. To accelerate commercial development of pelagic fisheries, chartered commercial purse seiners, and research and survey boats under the South China Sea Fisheries Development and Coordinating Programme have been doing exploratory fishing including the detection and estimation of the abundance of the pelagic resources. Rosenberg and Simpson,[8] reporting on voyage 3 of the purse seiners *Royal Venture* and *Southward Ho*, stated that during the period when both worked the southeasterly portion of Moro Gulf, some of the floating logs seen had good signs of tuna. About 26,000 kg of "*Tulingan*" (probably *Auxis*) and kawakawa were landed, composing roughly 21% of the landings of the two seiners. Rosenberg and Simpson noted that large quantities of kawakawa and *Auxis* are consumed fresh in the Philippines, but there is no market for them when frozen.

The total landings of tuna by the two seiners after voyage 4 reached 31,000 kg of which *Auxis* represented about 11%. *Southward Ho* usually caught less *Auxis* than the *Royal Venture* because the former used a slightly larger mesh in the bunt section of the seine (Rosenberg et al.[9]). The result was that *Auxis*, which are smaller than either skipjack or yellowfin tunas, tended to gill and had to be discarded.

In Indian waters, *A. rochei* occasionally occur in very large schools close to shore and large quantities are usually taken by beach seines (Jones and Silas 1964). Silas (1967b) reported that *Auxis* are very rare in the multiple troll catches made along the Tinnevelly coast in the Gulf of Mannar but are caught in small numbers together with skipjack tuna on pole-and-line and troll gear in the Laccadive Islands.

India, like the Philippines, has also been active in upgrading her tuna fishing capability. In January 1962, the Indo-Norwegian Project made the RV *Varuna* available to the Central Marine Fisheries Research Institute of India for exploratory fishing and oceanographic surveys in the Indian Ocean (Silas 1969). Two types of gear—drift net and purse seine—were used. Each unit of nylon drift net was 25.85 m long and 6.10 m wide. Five mesh sizes were used—2.5, 5.5, 10.0, 12.5, and 17.0 cm. The smaller mesh sizes captured juvenile pelagic fishes whereas the larger meshes captured *A. thazard* and *A. rochei* in both the continental shelf and oceanic areas. Figure 42 shows the number of drift net sets, the number of specimens collected, the average weight, and the length-frequency distribution of *Auxis* in the tuna catch.

Initial attempts at exploratory purse seining in the Laccadive Sea by the RV *Varuna* were unsuccessful, but subsequent attempts by the MV *Tuna* were reasonably successful (Silas 1969). The purse seine used in the exploratory work was 540 m long and 67 m wide with a mesh size of 10 cm. Out of 38 purse seine sets, made with a net 540 m long, 67 m wide, and mesh size of 10 cm, 10 were successful and the maximum catch exceeded 10 t in one instance. The catch was composed mainly of schools of *E. affinis* and *A. thazard*. Figure 43 shows the locations of the purse seine sets, catch per set, and sizes caught. Silas noted that the average weight of *A. rochei* was only 0.168 kg compared with an average of 0.750 kg for *A. thazard*. Of these early attempts at tuna purse seining in Indian waters, Silas remarked that they were not highly successful because the sinking rate of the net was too slow thus allowing the schools to escape. Also, he noted that the crew lacked experience in purse seining, but the failures, he felt, should not deter further attempts at purse seining.

In Sri Lanka, five types of gear are used to exploit tuna—longline, pole and line, trolling line, drift net, and beach seine. The longline is used for large, deep-swimming tunas and will not be discussed here. The remaining four are used in varying degrees to catch *Auxis*.

The beach seine is not a selective gear for *Auxis*; therefore, the catch by this gear is insignificant (Sivasubramaniam 1965, 1973). Beach seining, requiring about 30 men to conduct successfully, is possible in places like Tangalle, Udapu, and Trincomalee, because schools of *Auxis* occasionally migrate close (within 0.9 km) to shore.

The most important method of capturing *Auxis* off Sri Lanka, however, is by trolling. The gear is adapted from salmon trolling gear and is unlike the standard tuna trolling gear used extensively by Japanese and United States fishermen (Sivasubramaniam 1965). Consisting of three mainlines each with 30 branch lines which end in jigs, the trolling gear is well suited for Sri Lanka's waters because of the denseness of the schools of *Auxis*

[8]Rosenberg, K. J., and A. C. Simpson. 1975. Pelagic fisheries development - Trip reports, chartered purse seine vessels. (Trip reports of chartered purse seine vessels *Royal Venture* and *Southward Ho*, covering Voyage 3, 9 February to 26 March 1975.) South China Sea Fish. Dev. Coord. Programme, Manila, June 1975. SCS/75/WP/10, 28 p.

[9]Rosenberg, K. J., A. C. Simpson, and C. M. Renwick. 1975. Pelagic fisheries development—Trip reports, chartered purse seine vessels. (Trip reports of chartered purse seine vessels *Royal Venture* and *Southward Ho*, covering Voyage 4, 9 April to 24 May 1975.) South China Dev. Coord. Programme, Manila, June 1975. SCS/75/WP12, 36 p.

and kawakawa (Sivasubramaniam 1973). Trolling, usually limited to 3-5 h in the morning when *Auxis* schools are at the surface, is effective during periods of monsoon when the water is turbid. The gear was formerly operated from "orus" (outrigger canoes with sail), but catches were poor because of difficulty in maneuvering the vessel. Nowadays, 3.5-gross ton motorized boats, manned by crews of at least three fishermen, are used and their efficiency have made them popular for fishing the various species of tunas. Trolling contributes over 50% of the total *Auxis* production.

Pole-and-line fishing boats in Sri Lanka concentrate primarily on skipjack tuna but also catch significant quantities of other tunas including kawakawa, yellowfin tuna, and *Auxis* (Fig. 50). Sivasubramaniam (1965) pointed out that Sri Lanka's pole-and-line boats operate gear similar to that used by fishermen of Minicoy, Laccadive, and Maldive Islands. The boats, manned by at least five fishermen, carry live bait in cane baskets that are partially submerged alongside the craft. Wooden spades are used for spraying water. Originally, pole-and-line fishing was restricted to waters off the southwest coast of the island, but mechanization of the boats has expanded this type of fishing to the east coast. Like other pole-and-line fisheries operating in the Indian Ocean, however, the availability of live bait has limited the popularity of this fishing method.

Although pole-and-line fishing is effective for skipjack tuna, it is not equally effective for *Auxis* (Sivasubramaniam 1973). The reason is that *Auxis* respond poorly to chumming probably because the live bait used are usually larger than the most common food items in their stomachs. Furthermore, this type of fishing is not effective during periods of southwest monsoon, because water turbidity makes baiting difficult.

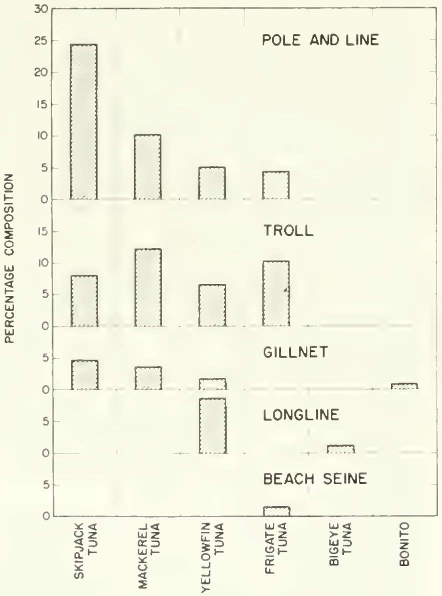


Figure 50.—Percentage composition of tuna species caught by various types of gear from the coastal waters of Sri Lanka (Sivasubramaniam 1965).

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

Drift nets are operated around the entire island of Sri Lanka (Sivasubramaniam 1973). A 3.5-gross ton boat usually carried 15 pieces of netting whereas as 11-gross ton boat carried 60 pieces. With mesh sizes varying from 10.2 to 14.0 cm, the synthetic drift net has proven effective for skipjack and large kawakawa. For *Auxis*, however, fish <30 cm in length are too small to be enmeshed. The catch of *Auxis*, therefore, amounts to only about 18 kg/day for a 3.5-gross ton boat and about 54 kg/day for an 11-gross ton boat. *Auxis rochei*, being smaller, are very rare in drift net catches. *Auxis* are usually taken by drift net from about September to March.

5.12 Boats

As with gear, a wide variety of fishing boats, ranging from modern high-seas purse seiners and pole-and-line boats to primitive sailing crafts, is used in fishing for *Auxis*.

In Japanese waters, the pole-and-line boats that are engaged in the *Auxis* fishery are small, usually <15 gross tons (Ishida 1972a). These boats are smaller than the usual pole-and-line boats of >30 gross tons which fish in the coastal waters and high seas for surface schools of tunas such as skipjack tuna, yellowfin tuna, and albacore. Japanese pole-and-line boats that fish in the Atlantic for yellowfin and skipjack tunas and occasionally for *Auxis* and bigeye tuna vary from 151 to 239 gross tons, whereas the seiners, both single and double boats, range from 50 up to >400 gross tons (Borgstrom 1964; Hayasi 1973, 1974).

Among the more primitive types of crafts used in *Auxis* fishing are dugout canoes and catamarans (Silas 1967b). In the Maldive Islands, for example, sailing boats called vadu dhony, which are about 6.1 m long and 1.8 m wide, and fish three to four baited trolling lines, are used as trollers (Sivasubramaniam[10]). Slightly larger sailing crafts, called the mas dhony, are used in pole-and-line fishing; they vary in length from 10.7 to 12.2 m, have a beam of about 3.4 m and a draft of nearly 0.8 m. The Maldivian boats are constructed of coconut wood, beautifully streamlined, and keeled for windward sailing. Compartments for carrying live bait have continuous water circulation through holes along the bottom. The fishermen fish at the stern atop a U-shaped removable wooden platform.

[10]K. Sivasubramaniam, UNDP-Sri Lanka Skipjack Fishery Development Project, FAO, Colombo, Sri Lanka, pers. commun. August 1975.

In 1972, the Maldivian fishing fleet had an estimated 5,100 fishing boats which included 2,980 trollers and 2,100 pole-and-line tuna boats operating within a 46 km radius of the islands. Skipjack tuna, yellowfin tuna, kawakawa, and *Auxis* are the main species caught by the pole-and-line boats. Hiebert and Alverson (1971) pointed out that one of the factors hindering the development of the Maldivian tuna fishery is the limited access of the boats to more distant fishing grounds. Lack of refrigeration also precludes long trips; therefore, the tuna boats leave port for the fishing grounds at about 0300 and return late in the evening. The introduction of motorized, refrigerated boats can probably increase the present fish catch 3-4 times.

In waters around Sri Lanka, trolling gear was formerly operated from "orus" or outrigger canoes with sails. Nowadays, however, 3- to 5-gross ton motorized boats, manned by a crew of at least three fishermen, are used (Sivasubramaniam 1973). In the Canary Islands where *Auxis* are landed along with other species of tuna, there are large boats (average 400 gross tons), which have refrigerated holds and carry about 20 men, and smaller, artisanal fishing boats (average 10 gross tons), which are crewed by 4-5 fishermen, are about 12 m long and have open decks and bait tanks. Propelled by engines that vary in size from 50 to 120 hp, these small boats usually engage in pole-and-line and occasionally purse seine fishing.

Off Angola, yellowfin and skipjack tunas are the principal species caught by the small, pole-and-line boats, but *Auxis* are also landed in smaller quantities (De Campos Rosado 1972). These boats, which operate within a narrow strip about 75 km wide and 370 km long along the coast, vary in size from 12 to 20 m long. The Cuban pole-and-line fishery, which lands small amounts of *Auxis*, operates motorized sailing boats, which have been described as modified sloops with a gaff-rigged mainsail and usually with a flying jib (Rawlings 1953; Wise and Jones 1971).

5.2 Fishing areas

5.21 General geographic distribution

Almost all the *Auxis* caught in the Japan Sea are *A. rochei* (Okachi 1958). Percentagewise, Okachi determined that of the fishing areas established for *Auxis* in Japanese waters, the South Pacific region had 62% of the catch, the middle Pacific region 22%, and the Japan Sea and East China Sea regions combined only 12%. Catches from west Japan Sea and East China Sea regions were usually similar whereas catches from the north Japan Sea region were smaller than either one.

In other areas of the world, *Auxis* are usually caught as incidental species. In the Pacific, for example, *Auxis* are caught incidentally in waters around Taiwan, the Philippines, Thailand, West Malaysia, Hawaii, and Australia (Serventy 1941; Gosline and Brock 1960; Kume 1973; Philippine Bureau of Fisheries 1973). Small numbers of *Auxis* are also taken in the Indian Ocean. Jones (1967) reported that *Auxis* are captured along the coasts of India and in waters surrounding the Maldive Islands (Sivasubramaniam footnote 10). According to Sivasubramaniam (1973), *Auxis* are caught in waters around Sri Lanka on a commercial scale throughout the year in the south and southwest coast of Sri Lanka.

In the Mediterranean region, the waters around Cyprus, Greece, Italy, Malta, Morocco, Spain, and Yugoslavia are fishing grounds for *Auxis*. Spanish trapnet fishermen land commercial quantities of *Auxis* at Barbate on the Atlantic Spanish coast near the Strait of Gibralter, at Tarifa in the middle of the Strait, and at La Linea on the Mediterranean Spanish coast near the entrance of the Strait. Some fishing is also carried on around the Canary Islands (Bas 1967; Cendrero and Garcia-Cabrera 1972).

Auxis are taken in Moroccan waters mostly by trap fishermen. Traps located at Larache and at Cape Spartel are set primarily to catch bluefin tuna that make their spawning migration toward the Mediterranean Sea along the Moroccan coast in April-July. Traps at M'diq in the Mediterranean also capture tuna as they exit after spawning. In traps located along the Atlantic Moroccan coast, *Auxis* account for only 3% of the tuna landed, but in those situated along the Mediterranean Moroccan coast, they represent 98% of the tuna catch (Lamboeuf 1972).

Around Portugal, the tuna fishing grounds are along the north and west coasts where small pole-and-line vessels operate. Other grounds fished by Portuguese fishermen are located off the islands of Azores and Madeira where small- to medium-sized pole-and-line vessels operate, and off Angola (De Campos Rosado 1972; Dias and Barraca 1972). Catches of little tunny, bonito, and *Auxis* represent roughly 60% of the total tuna landings from Angola.

Off Ghana, in the Gulf of Guinea, there is another fishing ground for *Auxis*. Although most of the tuna landings at Tema are made by foreign longline, pole-and-line, and purse seine vessels, Ghana's canoes and motorized fishing crafts also account for some of the landings of tuna and tunalike fishes (Di Palma 1968).

In the western Atlantic, *Auxis* were previously taken along the east coast of the United States. Pound nets fished along the Middle Atlantic States during the 1940's and early 1950's frequently caught *Auxis* along with bluefin tuna, little tunny, and bonito (Anderson et al. 1953). Southward, the waters around Cuba, off Venezuela, and off Brazil also yield small quantities of *Auxis*.

5.22 Geographic ranges

See section 5.21.

5.23 Depth ranges

Adult *A. thazard* has been reported to distribute themselves vertically from the surface down to a depth of about 45 m (Kishinouye 1923).

5.3 Fishing seasons

5.31 General pattern of seasons

The average monthly landings of *Auxis* at Tosashimizu (Kochi Prefecture), at Hachijo (Izu Archipelago), and at Mera (Shizuoka Prefecture) are shown in Figure 51. At Tosashimizu, where a pole-and-line fishery operates, *Auxis* are caught throughout the year, but peak fishing usually extends from October through May (Yasui 1975). During the remainder of the year (June-September), some of the pole-and-line boats concentrate on other species; therefore, there is a reduction in fishing effort for *Auxis*.

In the region of the South China Sea, the fishing season for *Auxis* varies considerably. For example, in the Philippines, the fishing season varies for different parts of the island group beginning at any time between November and January and extending into May (Philippine Bureau of Fisheries 1973). In Thailand and West Malaysia, however, the landings of *Auxis*, *Euthynnus affinis*, and *Thunnus tonggol* are usually better during the latter half of the year (Kume 1973).

Fishing for *A. thazard* in Indian waters begins about August and extends to about December (Nair et al. 1970). Sivasubramaniam (1973), who examined the seasonal and annual variations in the catches of frigate tuna from waters surrounding Sri Lanka, observed that in the south and southwest coasts, *A. thazard* are caught throughout the year but in the east and north coasts, they are caught primarily in June-September and lesser amounts in March-April.

In the Maldives, catches of *Auxis*, combined with that of kawakawa, peak at least twice a year (Hiebert and Alverson 1971). In 1965, for example, combined catches of *Auxis* and kawakawa in the Maldives peaked in January at 1.2 million fish, declined sharply in February-May to <0.6 million, then fluctuated irregularly until September after which the catch rose to a second minor peak in November before declining again in December.

At Barbate, Spain, *A. rochei* appear in the trap catches in May-July with the heaviest catches occurring in the first 2 months. About 53% of the catch is composed of *A. rochei* and the remainder consists of little tunny and bonito (Rodríguez-Roda 1966). At Tarifa, bullet tuna constitute 95% of the trap catches and average 67.1 t annually. Here, the trap fishery is active in May-June. The traps at La Linea make the largest catches of small tunas with *A. rochei* accounting for 97% of the catches. The fishing season extends from August to October but most of the catches are made in the first 2 months.

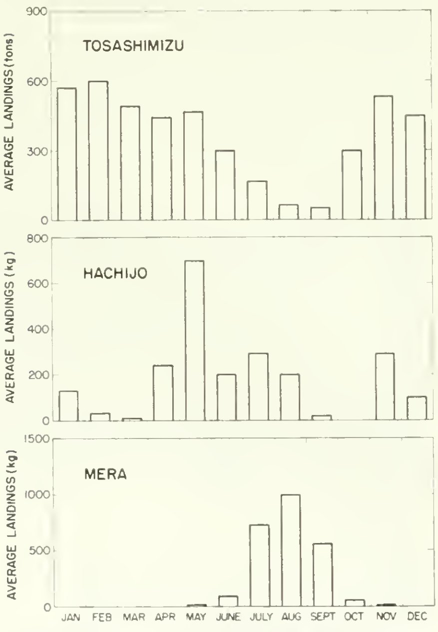


Figure 51.—Landings of *Auxis* spp. average by month from catches made between January 1969 to December 1976 at Tosashimizu, between January 1969 and October 1974 at Hachijo, and between January 1967 and December 1974 at Mera, Japan (Yasui 1975).

5.32 Dates of beginning, peak, and end of season

See section 5.31.

5.33 Variation in date or duration of season

At Tosashimizu, Japan, where a pole-and-line fishery for *A. rochei* operates, severe fluctuations in the monthly landings usually occur in October-December whereas landings are stable in January-March (Yasui 1975). Yasui examined the relationship between sea-surface temperature and monthly landings and found that in years of good fishing, there was a complex distribution of surface temperature with 28°C water very close to shore (Fig. 52A), whereas in years of poor fishing the warm water was displaced farther offshore (Fig. 52B). He concluded that the location of the 28°C isotherm in July-September significantly influenced fishing conditions in subsequent months. Temperature, it appeared, affects the concentration of bullet tuna schools, i.e., their availability to the boats and the length of their stay on the fishing grounds.

Monthly landings at Mera, where the fish are taken by nets, show that peak fishing occurs in July-September (Fig. 51). Yasui (1975) noted that in this fishery, the large, mature fish with high reproductive index are usually taken in June and that progressively smaller fish are taken in subsequent months. The proportion of immature fish in the catch increased in July-August and by September all fish were immature. Yasui concluded from these findings that the catch of *Auxis* at Mera is in-

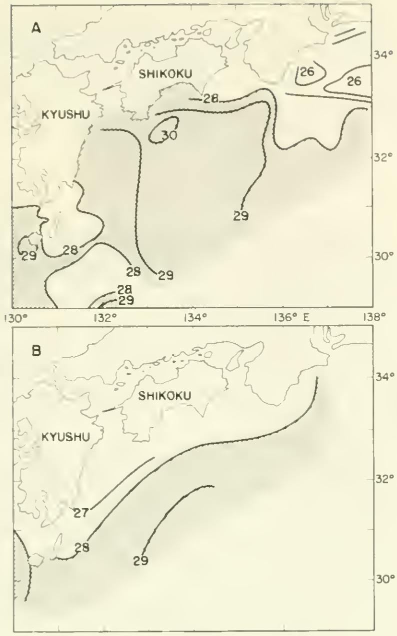


Figure 52.—Distribution of surface temperatures in July-September in years of good (A) and poor (B) fishing for *Auxis rochei* at Tosashimizu, Kochi Prefecture, Japan (Yasui 1975).

fluenced to a large extent by a seasonal in-migration of fish from the west and south.

At Hachijo, where *Auxis* are landed by surface trollers, catches are made throughout the year except in October (Fig. 51). Yasui (1975) observed that there are two seasons for *Auxis* at Hachijo—one in April-August and another in November-January. The appearance of *Auxis* in April-May at Hachijo coincides with the end of the gill net fishery for flyingfish, which are preyed on by *Auxis*. Yasui also noted that sexually mature fish appear in the catches in April-May followed by larger, older fish in July.

At Ashizurimisaki in Kochi Prefecture, Ishida (1972b) noted considerable fluctuations in landings of *Auxis*. To determine the possibility of predicting the degree of success of a fishing season, Ishida, using data for 1952-67., obtained the following:

C_j = catch in October-March in year j
C_{j+1} = catch in October-March in year $j + 1$
ΔC_{j+1} = difference between C_j and C_{j+1}.

Plotting C_j against ΔC_{j+1}, Ishida found that when C_j was small, ΔC_{j+1} tended to be positive and vice versa. Ishida also noted that larger catches of *Auxis* tended to be associated with cooler temperatures. Yamashige (1974), on the other hand, found a positive relatonship between catches of *A. rochei* in August-July and the difference in the mean surface temperature between August and October of a given year, and he described the relationship between these two variables as follows:

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

where Y = catch, in 1,000 t, from August (n year) to July ($n + 1$ year)
t_8 = mean surface temperature in August at Ashizurimisaki (°C).
t_{10} = mean surface temperature in October at Ashizurimisaki (°C).

In Sri Lanka, the mechanization of fishing boats made fishing possible even during periods of monsoons and has been primarily responsible for a shift in the fishing season. Originally, Williams (1963) reported that the main fishing season for *Auxis* in Sri Lanka extended from October or November to May. Sivasubramaniam (1973), however, found that Williams defined the fishing season by examining catches made during the northeast and intermonsoons when beach seines are usually in operation. Excellent fishing occurs in all fishing areas around Sri Lanka particularly during the end of the southwest monsoon. Sivasubramaniam observed that this period is associated with heavy recruitment and vulnerability of the recruits to trolling gear. The result is that the number of fish caught per day rises abruptly, but the net tonnage landed. does not rise proportionately.

5.4 Fishing operation and results

5.41 Effort and intensity

In the *Auxis* fishery off Ashizurimisaki in Kochi Prefecture, Japan, fishing intensity (the number of small, 3-gross ton pole-and-line boats operating per day) varies widely from as few as 10 to as many as 260 boats/day (Ishida 1972a). Fishing intensity usually peaks once in March and again in November to about 200 boats/day. During the balance of the fishing season, which extends usually from October to May, however, the average number operating is about 170 boats/day.

5.42 Selectivity

Although pole-and-line fishing is effective for skipjack and yellowfin tunas, it is not equally effective for *Auxis*. Sivasubramaniam (1973) observed that in Sri Lanka, *Auxis* respond poorly to chumming probably because the live bait used is larger than the most common food items in their stomachs.

The drift net, which is in operation around the entire island of Sri Lanka, is also ineffective at times particularly for *Auxis* <30 cm. It is, however, effective for skipjack and large kawakawa. Catches of *Auxis* by drift nets, therefore, amount to only about 18 kg/day for a 3.5-

gross ton boat and about 54 kg/day for an 11-gross ton boat. *Auxis rochei*, being smaller, are very rare in drift net catches.

5.43 Catches

Total catches of frigate and bullet tunas by various countries in the Atlantic (including the Mediterranean Sea), Pacific, and Indian Oceans in 1953-76 are given in Table 26. By far, the total catch in the Pacific was the largest among the three oceans, averaging 40,700 t annually. The Atlantic and Indian Ocean catches, on the other hand, averaged about 13.8 t in each ocean or about a third of the Pacific catch.

In the Report of the Ad Hoc Committee Meeting of Specialists to Review the Biology and Status of Stocks of Small Tunas, it was pointed out that the catches of *Auxis* reported by the various countries do not truly reflect the abundance of the two species in the world's ocean. For example, purse seine fishermen avoid catching *Auxis* because they are a nuisance as many become gilled in the net and require considerable time and manpower to remove. Furthermore, the catches of *Auxis* by tuna seiners are often discarded at sea. Other difficulties noted with *Auxis* catch statistics are that artisanal catches are usually not fully reported and that there is confusion and inclusion of *Auxis* with other species.

Pacifc Ocean

Japan lands, by far, more *Auxis* than any other country and is, in fact, the only country that has a well-established commercial fishery. In 1953-76, the catch of *Auxis* averaged 24,300 t, varying from 14,900 t in 1975 to 48,300 t in 1963 (Table 26).

In Taiwan, the catches of frigate and bullet tunas in 1961-73 varied between 600 and 1,200 t and averaged 1,000 t (Table 26). Perhaps it should be pointed out that there is a discrepancy in the catch statistics for frigate

Table 26.—Estimated catches of *Auxis* sp. by countries, 1953-76 (in units of 1,000 metric tons). (Data compiled from FAO 1959, 1964, 1969, 1974, 1977; Lamboeuf 1972; Miyake and Tibbo[1]; Miyake et al.[2]; Sivasubramaniam[3]; Hagborg.[4]) — = data not available; 0.0 = magnitude negligible or insignificant.

	Atlantic Ocean (including Mediterranean Sea)												Pacific Ocean				Indian Ocean						
Year	Angola	Cyprus	Ghana	Greece[5]	Italy	Japan (Overseas operation)	Malta	Morocco[6]	Spain[7]	United States	Venezuela[8]	Yugoslavia	China mainland	Japan	Philippine Islands	Taiwan	Bangladesh	India[9]	Maldive Islands	Pakistan	Reunion Island	Sri Lanka	Tanzania
1953	6.4	—	—	0.8	—	—	—	4.0	2.0	—	1.2	—	—	15.6	—	—	—	—	—	—	—	—	—
1954	7.3	—	—	0.6	—	—	—	1.4	4.0	—	1.3	0.1	—	20.6	—	—	—	—	—	—	—	—	—
1955	5.2	—	—	1.2	—	—	—	4.0	4.8	—	1.3	0.2	—	23.4	—	—	—	—	—	—	—	—	—
1956	1.8	—	—	0.9	—	—	—	2.4	3.4	—	1.1	0.1	—	25.9	—	—	—	—	—	—	—	—	—
1957	1.1	—	—	0.5	—	—	—	2.5	5.4	—	1.0	—	—	20.4	—	—	—	—	—	—	—	—	—
1958	2.5	—	—	0.7	0.4	—	—	3.0	10.0	—	1.2	0.1	—	23.3	—	—	—	—	—	—	—	—	—
1959	1.9	—	—	0.7	0.7	—	—	1.0	3.8	—	1.7	0.1	—	19.9	—	—	—	—	—	—	—	—	—
1960	1.9	—	—	—	0.6	—	—	1.8	5.2	—	1.3	0.0	—	15.8	—	—	—	—	—	—	—	—	—
1961	2.7	—	—	—	1.0	—	—	0.2	3.4	—	0.8	0.0	—	18.2	—	0.7	—	—	—	—	—	—	—
1962	1.6	—	—	—	0.7	—	—	0.6	4.4	—	1.0	0.0	—	21.1	—	0.8	—	—	—	—	—	—	—
1963	1.3	—	—	—	0.8	—	—	1.6	3.1	—	1.0	0.0	—	48.3	—	0.6	—	—	—	—	—	—	—
1964	0.9	—	—	0.6	0.5	—	—	1.5	2.5	—	1.4	0.0	5.3	26.9	9.1	1.1	0.8	2.4	1.5	1.1	—	4.0	—
1965	1.7	0.0	2.0	0.7	0.7	0.9	0.0	1.8	2.5	—	1.8	0.0	4.8	29.8	12.4	0.8	0.4	2.0	2.5	1.2	—	4.5	—
1966	1.4	0.0	2.0	0.5	0.9	0.4	0.0	0.8	2.3	—	1.4	0.0	4.0	29.3	16.4	1.2	0.3	2.0	3.0	1.5	—	4.5	—
1967	1.2	0.0	2.0	0.6	1.2	0.6	0.0	1.2	3.5	—	1.1	0.0	4.4	28.7	10.5	0.8	0.1	1.7	3.0	1.3	—	5.0	—
1968	0.6	0.0	1.8	0.5	1.2	1.6	0.0	0.9	1.7	—	0.4	0.0	3.2	21.0	19.5	0.4	0.1	2.3	3.0	1.3	—	5.0	—
1969	0.8	0.0	3.0	—	1.1	3.2	0.0	0.6	2.0	—	0.4	0.1	3.2	24.1	14.8	0.4	0.2	1.9	3.0	1.0	—	5.5	—
1970	0.5	0.0	3.0	—	1.1	3.1	0.0	1.0	2.2	—	0.7	0.0	2.4	25.9	9.6	0.7	0.7	7.9	1.7	5.5	0.1	5.0	—
1971	1.1	0.0	2.7	—	1.6	—	0.0	0.3	3.8	—	0.5	0.0	2.6	20.1	9.9	0.5	0.7	0.2	1.8	5.6	0.2	3.2	0.4
1972	1.6	0.0	5.3	—	1.7	0.0	0.0	0.5	1.9	—	0.6	0.0	—	31.1	10.6	0.6	0.5	0.2	3.1	4.9	0.2	4.1	0.6
1973	1.1	0.0	2.3	—	1.2	1.2	0.0	1.6	1.9	—	0.7	0.0	—	33.5	13.0	0.7	—	0.2	6.2	5.4	—	3.8	—
1974	1.5	0.0	6.3	—	1.3	0.5	0.0	0.5	0.6	0.0	0.9	0.0	—	26.2	5.0	—	—	—	5.9	—	—	—	—
1975	0.5	0.0	6.0	—	0.9	0.0	0.0	0.1	0.5	0.0	1.0	0.0	—	14.9	7.6	—	—	—	3.9	—	—	—	—
1976	0.5	0.0	4.3	—	0.9	0.0	0.0	0.4	0.5	0.0	1.2	0.0	—	20.2	14.0	—	—	—	2.7	—	—	—	—
Mean	2.0	0.0	3.4	0.7	1.0	1.2	0.0	1.4	3.1	0.0	1.0	0.0	3.7	24.3	11.7	1.0	0.4	2.1	3.2	2.9	0.2	4.5	0.5

[1]Miyake, M. P., and C. G. Tibbo (compilers. 1972. Statistical bulletin. International Commission for the Conservation of Atlantic Tuna ST/Total/72/2-10-11. [No pagination.]

[2]See text footnote 12.

[3]See text footnote 11.

[4]D. W. Hagborg, Fishery Resources & Environment Division, Food and Agriculture Organization of the United Nations, Rome, Italy, pers. commun. February 1975.

[5]Includes bluefin tuna.

[6]Includes Atlantic bonito.

[7]Includes catches from Ceuta in 1954-58.

[8]Includes Atlantic bonito in 1965-67.

[9]Probably includes several other species of tuna and tunalike fishes in 1964-70.

and bullet tunas from Taiwan for 1961-68. Examination of the catch statistics from Taiwan for 1958-63 (FAO 1964) showed catches to be rather high. In 1961-63, for example, they were as follows:

Year	*Catch (1,000 metric tons)*
1961	11.9
1962	18.2
1963	15.1

But in FAO (1967), the frigate and bullet tuna catches in 1961-63 were given as follows:

Year	*Catch (1,000 metric tons)*
1961	0.7
1962	0.8
1963	0.6

Further research into the method of compiling catch statistics indicated that data from FAO (1964) included other species under frigate and bullet tunas. Kume (1973) revealed that Taiwan uses a categroy called "bonito" in which are included *Auxis* as well as kawakawa and perhaps other small tunas. Kume gave the "bonito" catch for 1970 as 15,500 t but estimated that of this total, only 778 t or roughly 5% were *Auxis*. Furthermore, the frigate and bullet tuna catches in 1961-63, as given in FAO (1967), amounts to only 4-6% of the catches as given in FAO (1964). Therefore, it can be presumed that roughly 5% of the catches of frigate and bullet tunas in Taiwan, as given in FAO (1964), are actually of this species with the remainder constituting catches of other small tunas.

Southward, in the South China Sea region, the Philippines, Sabah, Sarawak, Thailand, and West Malaysia also harvest *Auxis*. In the Philippines, catches of *Auxis* in 1964-76 varied from 5,000 t in 1974 to 19,500 t in 1968 and averaged 11,700 t (Table 26). The Thailand landings of *Auxis*, *Euthynnus affinis*, and *Thunnus tonggol* are combined and called "bonito" or "pla o" locally in the catch statistics (Kume 1973). In 1971, Thai and Chinese seiners landed 5,090 t or 78% of the 6,548 t of "bonito" reportedly caught in Thailand. In West Malaysia, landings of *Auxis* are also combined with those of *E. affinis* and *T. tonggol*. The 1958-71 production of these three species combined varied between 789 t in 1959 and 5,578 t in 1967 and averaged 3,131 t annually. Table 26 shows that the catches of *Auxis* from China mainland varied from 2,400 to 5,300 t in 1964-71 and averaged 3,700 t.

Indian Ocean

In addition to *E. affinis* and *T. Tonggol*, which are the two most common tuna species landed from Indian waters, small numbers of *Auxis* are also captured in the tuna fishery along the coast of India (Jones 1967). Of the two species, *A. thazard* are more common whereas *A. rochei* are rarely seen in the commercial catch. Thomas (1967) reported that *Auxis* are taken in the Laccadive Islands, but catches are usually recorded in the category, "other fishes," which includes *E. affinis*, *Acanthocybium solandri*, *Istiophorus gladius*, *Elagatis bipinnulatus*, *Caranx* sp., *Chorinemus* sp., and sharks. Sivasubramaniam[11] estimated that *Auxis* catches in India account for about 5% of the tuna and tunalike catches. It is also apparent from the data that the west coast of India usually yields *Auxis* catches that are about 5 times more than those from the east coast. In 1964-73, India's *Auxis* catches varied between 200 and 7,900 t and averaged 2,100 t annually (Table 26).

The tuna fishery in the Maldives is carried out by sailing boats; therefore, fluctuations in the catches are associated with various environmental conditions such as wind direction and velocity and ocean surface currents. In 1964-76, the catches of *Auxis* from the Maldives fluctuated between 1,500 t in 1964 and 6,200 t in 1973 and averaged 3,200 t annually (Table 26.) There are, however, serious discrepancies in the catch statistics. For 1970 and 1971, for example, Sivasubramaniam (see footnote 11) gave the catch of *Auxis* from the Maldives as 1,700 and 1,800 t, respectively. Data from a tuna canning plant project, however, indicate catches of 3,094 t in 1970 and 26,871 t in 1971. Based on landings in 1965-69 and in 1972-73, it appears that the 1971 catch of 26,871 t is unreasonably high. Furthermore, FAO (1974) estimated the 1970 frigate and bullet tuna catch to be 20,000 t and the 1971 catch as 26,900 t, also unreasonably high; therefore, until these discrepancies can be resolved, data from Sivasubramaniam (see footnote 11) will be accepted provisionally.

In waters around Sri Lanka, *Auxis* are caught on a commercial scale from all the main fishing grounds (Sivasubramaniam 1973). Being the smallest member of the tuna and tunalike fishes, *Auxis* contribute only 15-20% to the total catch, by weight, but are the most abundant of all the tuna varieties in the waters around Sri Lanka. Sivasubramaniam reported that although both species appear in the commercial catches, *A. thazard* contributes 92% and *A. rochei* 8% to the total annual production. In 1964-73, Sri Lanka's production of frigate and bullet tunas ranged between 3,200 and 5,500 t and averaged 4,500 t annually (Table 26). Percentagewise, they constituted more than a third of the catch of tuna and tunalike fishes from Sri Lanka in 1964-67. The proportion fell to about a fourth in 1968-69, one fifth in 1970, and has been about one-sixth of the total production since 1971.

Other countries that harvest *Auxis* in the Indian Ocean include Bangladesh, Pakistan, Reunion Island, and Tanzania. Table 26 shows that in 1964-72, *Auxis* catches in Bangladesh fluctuated between 100 and 800 t and averaged 400 t. In Pakistan, catches in 1964-73

[11] Sivasubramaniam, K. 1974. More recent information on the tuna fishery in Sri Lanka, India and the Maldive Islands. Indo-Pacific Fishery Council/Indian Ocean Fishery Commission Ad Hoc Working Group, Nantes, France, 16-18 September 1974. (IPFC/IOFC/WPU4/12, 4 p.

varied from 1,000 to 5,600 t and averaged 2,900 t annually. Catches from the Reunion Island, recorded for 1970-72, are relatively small, varying between 100 and 200 t and an annual average of about 200 t. Tanzania landed 400 t in 1971 and 600 t in 1972 and averaged 500 t for these 2 years.

Atlantic Ocean

In the Atlantic, Spain, which annually lands about 3,500 t of *Auxis*, exploits mackerel, *Scomber scombrus*; bluefin tuna; bonito, *Sarda sarda*; and occasionally albacore along the Mediterranian Spanish coast (Bas 1967). Mackerel are caught by ring net and trawl; bluefin tuna, bonito, and *Auxis* are caught occasionally by very large ring nets. The annual production of *Auxis* by large ring nets is small, ranging between 274 and 2,500 t. The most important gear is the trap. At Barbate, *A. rochei* appear in the traps in May-July and catches average 15.6 t but larger catches usually occur in May-June (Rodríguez-Roda 1966). Little tunny and bonito are also taken at Barbate, but *A. rochei* predominate, accounting for about 53% of the production. The traps at La Linea make the largest catches of these small tunas with *A. rochei* constituting about 97% of the catches (216 t). At Tarifa, 95% of the catch is *A. rochei* and production averages about 67.1 t. The annual catches of *A. rochei* by traps throughout Spain vary widely. Catches at Barbate in some years are very low and fall below 2,000 fish/yr but in other years they may be very high. Table 26 gives the annual production of *Auxis* in Spain and Table 27 gives a partial breakdown of the catches by type of gear. In 1953-76, the annual landings varied from 500 to 10,000 t and averaged 3,100 t (Rodríguez-Roda 1966, 1967).

Auxis are taken in Moroccan waters mostly by trap fishermen, but surface gear is also employed (Table 27). Lamboeuf (1972) stated that both bait boats and seiners operate as a team in fishing. The bait boat, which is usually an old, low tonnage sardine boat converted to carry bait, chums fish to the surface and keeps them there long enough for the seiner to set the net around the school. Lacking such a bait boat frequently results in an unsuccessful purse seine set. Along the Atlantic Moroccan coast, boats landed 69% of the *Auxis* whereas traps contributed less than half or 31% (Lamboeuf 1973). Along the Mediterranean Moroccan coast, however, traps contributed 91% of the *Auxis* landed with the remaining 9% produced by boats. In 1953-76, the annual catches of *Auxis* fluctuated between 100 and 4,000 t and averaged 1,400 t (Table 26). *Auxis* landings in Morocco rose from about 15% to 20% of the total tuna landings in 1963-65, fell to about 12% in 1966, then rose steadily to about 27% of the total catch in 1969 (Lamboeuf 1972). The change in the relative importance of *Auxis* in the total tuna landings resulted from a very sharp decline in bluefin tuna landings in Morocco. It should be noted that slight discrepancies exist in the catch data for *Auxis*; only 200 t in Table 26 versus a 1969 catch of 588 t, according to Lamboeuf (1972).

In Portugal, traps, which are the principal tuna-fishing gear, are usually fished off the southern coast whereas pole-and-line boats operate along the north and west coasts and off the islands of Azores and Madeira (Dias and Barraca 1972). In the Portuguese overseas province of Angola where the yield of tuna is much higher, the fishery is carried on by small, pole-and-line boats (De

Table 27.—Annual catches of *Auxis* (in units of 1,000 metric tons) in the Atlantic Ocean, by country and type of gear, 1960-74[1]

	Type of gear	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
Total		9.0	8.1	8.3	7.9	6.8	9.3	7.1	9.2	9.5	11.0	12.3	10.7	12.8	9.3	(10.7)
By type of gear																
Total surface		4.2	2.8	4.3	4.3	2.6	5.1	3.4	5.8	4.7	5.5	6.2	1.1	1.5	5.9	(8.5)
Bait boats		—	—	—	1.3	0.9	2.6	1.8	1.8	2.2	4.0	3.1	0.2	0.2	1.2	(0.5)
Purse seiners		—	—	—	—	—	—	—	0.4	1.3	0.2	0.7	0.8	1.2	1.8	—
Unspecified		4.2	2.8	4.3	3.0	1.7	2.5	1.6	3.6	1.2	1.3	2.4	0.1	0.1	2.9	(8.0)
Total traps		1.0	0.8	0.7	1.8	2.3	1.7	1.4	1.1	1.4	0.9	1.1	0.7	1.1	0.3	(0.9)
Total unclassified		3.8	4.5	3.3	1.8	1.9	2.5	2.3	2.3	3.4	4.6	5.0	8.9	10.2	3.1	(1.3)
By country																
Ghana	Purse seine	—	—	—	—	—	—	—	—	—	—	—	—	—	1.6	—
	Unclassified	—	—	—	—	—	—	—	—	1.8	3.0	3.0	2.7	5.3	—	6.3
Japan	Purse seine	—	—	—	—	—	—	—	0.4	1.3	0.2	0.7	0.7	1.2	0.2	0.0
	Bait boat	—	—	—	—	—	0.9	0.4	0.6	1.6	3.2	3.1	—	0.0	1.2	0.5
Morocco[2]	Traps	1.8	0.2	0.6	1.2	1.4	1.2	0.6	0.6	0.8	0.1	0.5	0.2	0.4	0.3	0.4
	Surface gear	—	—	—	0.5	0.1	0.5	0.1	0.6	0.1	0.1	0.5	0.1	0.1	1.3	0.1
Portugal (Angola)	Traps	—	—	—	—	—	—	—	—	—	—	0.3	0.4	0.4	—	—
	Bait boat	1.9	2.7	1.6	1.3	0.9	1.7	1.4	1.2	0.6	0.8	0.0	0.2	0.2	—	—
	Unclassified (surface) gear	—	—	—	—	—	—	—	—	—	—	0.2	0.5	1.0	1.6	1.6
Spain[3]	Traps	1.0	0.8	0.7	0.6	0.9	0.5	0.8	0.5	0.6	0.8	0.3	0.1	0.3	—	0.5
	Unclassified	4.2	2.6	3.7	2.5	1.6	2.0	1.5	3.0	1.1	1.2	1.9	3.6	1.6	1.9	—
	Purse seine	—	—	—	—	—	—	—	—	—	—	—	0 1	—	—	—

[1]Data for 1960-62 from Miyake and Tibbo (see footnote 1 in Table 26); for 1963-73 from Miyake et al. (see text footnote 13); for 1974 from Miyake (personal communication with R. S. Shomura, Southwest Fish. Cent., Natl. Mar. Fish. Serv., Honolulu, HI 96812).

[2]Catch in 1960 includes bonito.

[3]Catches in 1960 and 1961 include a small amount of little tunny.

Campos Rosado 1972). Landings of *Auxis* from Angola in 1953-76 varied from 500 to 7,300 t and averaged 2,000 t (Table 26).

Ghana's modern fishing fleet and industry, which developed only since the early 1960's, are probably the best among African nations (Di Palma 1968). Di Palma observed that confusion exists in the catch statistics on mackerels and scads because some boats do not differentiate between the various species. For example, several species may be reported together including mackerel, *Scomber japonicus*, various species of horse mackerels of the family Carangidae, *Auxis*, and mackerel scad, *Decapterus rhoncus*. Miyake et al.[12] reported that Ghana's landings of *Auxis* by unclassified gear varied between 1,800 and 5,300 t and averaged 3,160 t in 1968-72. In 1965-76, Ghana's annual catch of *Auxis* varied from 1,600 to 6,300 t and averaged 3,400 t (Table 26).

Japan's resurgence as a fishing power after World War II was not restricted to the Pacific and Indian Oceans. Japanese tuna longliners first made their appearance in the Atlantic in 1957 and by 1961 at least 60 vessels were fishing there for yellowfin tuna and albacore (Borgstrom 1964). In 1962, the Japanese placed pole-and-line fishing boats of 239 gross tons each in Ghana to fish for surface schools of tuna. Yellowfin and skipjack tunas are the main species landed by these Japanese bait boats but *Auxis* and bigeye tuna are also taken in limited quantities (Shomura 1966; Hayasi 1973). Three or four Japanese purse seiners and five to seven pole-and-line (14 in 1972) boats operated in the Atlantic Ocean in 1962-63 and in 1967-72.

Tema, with excellent shore facilities, including cold storage, serves as a base for Japanese purse seiners, pole-and-line boats, and longliners (Di Palma 1968). *Auxis* as well as yellowfin, skipjack, and bigeye tunas are caught along the coast of Africa and in coastal waters of the offshore islands in the eastern Atlantic.

In 1967-73, Japanese seiners landed from 177 to 1,256 t of *Auxis* and averaged 670 t annually (Hayasi 1973, 1974). The proportion of the purse seine tuna catch consisting of *Auxis*, however, was small varying from 3% to 15% in 1969-72.

Auxis catches by Japanese pole-and-line boats also fluctuated widely in 1967-70 varying between 675 and 3,200 t and averaging 1,375 t annually (Hayasi 1973, 1974). The proportion of the pole-and-line tuna catch which constitutes *Auxis* varied widely from an insignificant part of the total pole-and-line tuna landings in 1972 to nearly one-third in the 1969 catch.

Japanese boats fish not only in the eastern but also in the western Atlantic Ocean. The Caribbean region is an important fishing ground for tuna and tunalike fishes including *Auxis*. Wise and Jones (1971) pointed out that the catches of several species of tunas and related fishes occurring in the Caribbean region are shared by several countries. Japan lands about two-thirds, Cuba and Venezuela each take about one-tenth, and the remaining countries, each with <2,000 t annually, land the balance of the catch. Among the species landed, yellowfin tuna is the most important, contributing slightly over a third of the total landings. Second most important is the "bonitos" but this category includes few true bonitos and is made up largely of skipjack tuna and blackfin tuna, *Thunnus atlanticus*, with small amounts of other species such as little tunny and *Auxis*. Bigeye tuna is third in importance followed by bluefin tuna and albacore. The total landings of *Auxis* by all Japanese fishing boats operating in the Atlantic varied from 400 to 3,200 t and averaged 1,200 t (Table 26).

In Venezuela, scombrids of commercial interest are *Sarda sarda*, *Auxis*, *Scomberomorus maculatus* (= *S. brasiliensis*), *S. cavalla*, and *Scomber japonicus* (Griffiths 1971). The catches of *Sarda* and *Auxis*, primarily by baited hooks ("cordel") and gill nets along eastern Venezuela, are grouped in the official statistics into "cabañas." Unfortunately, the proportion of each species in this category is unknown. Griffiths noted that the proportions may be variable among the fishing areas and also with time. "Cabañas" are usually sold fresh locally or salted and sometimes canned as "tuna" or "bonito." In 1953-76, the landings of *Auxis* fluctuated between 400 and 1,800 t and averaged 1,000 t (Table 26).

A number of other countries, given in Table 26, lists *Auxis* as among the species they land. Cyprus, Malta, and Yugoslavia are among them but their landings appear to be insignificant. Greece also lands *Auxis*, but its annual catches are small and appear to be erratic, varying from 500 to 1,200 t and averaging 700 t. Italy's landings are also quite small fluctuating between 400 and 1,700 t and averaging 1,000 t annually.

[12] Miyake, M. P., A. De Boisset, and J. Manning (compilers). 1974. Statistical bulletin. International Commission for the Conservation of Atlantic Tunas, Vol. 4. ST/Total/74/2 - 13-15 Rev. [No pagination.]

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